

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**GRAPPLING WITH COMPLEXITY:
FINDING THE CORE PROBLEMS BEHIND
AIRCRAFT ACCIDENTS**

A thesis presented in partial fulfilment of the requirements for the degree of
Doctor of Philosophy in Aviation

at Massey University, Palmerston North, New Zealand

Dmitri Victorovitch Zotov

2006

Abstract

The purpose of accident investigation is the discovery of causal factors, so that they may be remedied, in order to avert the recurrence of accidents (ICAO, 1994). However, experience has shown that the present intuitive methods of analysis do not always achieve this aim. Investigation failure may come about because of failure to discover causal factors, or to devise effective remedies, or to persuade those in a position to act of the need to do so.

Each of these types of failure can be made less likely by the use of formal analytical methods which can show whether information gathering has been incomplete, and point to the sources of additional information that may be needed. A formal analysis can be examined by formal logical tests. Also, the use of formal change mechanisms can not only devise changes likely to be effective, but can present these changes in such a way that the case for them is compelling.

Formal methods currently available are concerned with *what* happened, and *why* it happened. To produce generic remedies which might avert future accidents of similar type, some formal change mechanism is needed. The Theory of Constraints has become widely adopted in business as a way of replacing undesirable effects with desired outcomes. The Theory of Constraints has not previously been used for safety investigation, and a principal object of this thesis is to see whether it can usefully be employed in this area.

It is demonstrated that the use of formal methodology can bring to light factors which were overlooked during an official accident investigation, and can 'tell the story' in a more coherent manner than is possible with present methods. The recommendations derived from the formal analysis are shown to be generic in nature, rather than particular to the airline involved and the accident studied, and so could have a wider effect in improving safety.

Acknowledgements

The author was greatly encouraged in his studies of formal methodology for the analysis of accidents by Ludi Benner, formerly head of the Hazardous Materials Bureau of the United States National Transportation Safety Board, and by Professor Peter Ladkin, of the University of Bielefeld. Alan Wright, of Massey University, taught the author the use of the Theory of Constraints, and assisted in the development of this methodology to adapt it to accident investigation.

The author's colleagues at the Australian Civil Aviation Safety Authority, Michael Nendick and Melanie Todd, proofread the entire document, and made numerous suggestions relating to style and content. Finally, the authors' gratitude goes to his Supervisor, Dr. Lynn Hunt of Massey University, for her advice and encouragement throughout the study.

Table of Contents

Abstract	ii
Acknowledgements	iii
Table of Contents	iv
List of Tables	vi
List of Figures	vii
Chapter 1: Introduction	1
Chapter 2: Review of the Literature	17
Chapter 3: Research Methods	108
Chapter 4: Case Study – The Ansett Dash 8 Accident	121
Chapter 5: Analysing the Dash 8 Accident with a MES Graph	125
Chapter 6: Analysing the Dash 8 Accident with a WB Graph	175
Chapter 7: Analysing the Dash 8 Accident with the Theory of Constraints	198
Chapter 8: Comparison of Methodologies	301
Chapter 9: Discussion	328
References	341
Annex A: Glossary	

Annex B: The Official Report

Annex C: Author's Qualifications as Accident Investigator

List of Tables

Table 1. General Failure Types	31
Table 2. Ansett CRT: Injections and Reservations	264
Table 3. CAA CRT: Injections and Reservations	282

List of Figures

Figure 1. The Skyferry accident	3
Figure 1A. The Skyferry accident: Years before	4
Figure 1B. The Skyferry accident: Months before	5
Figure 1C. The Skyferry accident: Hours and Days before	6
Figure 1D. The Skyferry accident: Immediately before	7
Figure 2. Jet air transport departures and hull-loss accidents	12
Figure 3. Perceptions of the accident phenomenon	22
Figure 4. Helmreich's Spheres of Influence	27
Figure 5. The structure of an organisational accident	29
Figure 6. Complex interactions in the aviation industry	33
Figure 7a. Flight path diagram: first part	37
Figure 7b. Flight path diagram: second part	38
Figure 8. Events and causal factors analysis	48
Figure 9. Events and causal factors charting	50
Figure 10. Deriving root causes	51
Figure 11. Event link analysis network	53
Figure 12. Fault tree analysis	54
Figure 13. Fishbone diagram	64

Figure 14. MES matrix	67
Figure 15. MES network	68
Figure 16. Current Reality Tree	98
Figure 17. Conflict resolution diagram	99
Figure 18. Future Reality Tree	100
Figure 19. Prerequisite tree	101
Figure 20. Transition tree	102
Figure 21. TOC thinking process	104
Figure 22. Impact diagram	123
Figure 23. Events from the history of the flight	127
Figure 24. Ground proximity warning	129
Figure 25. Undercarriage malfunction	131
Figure 26. Palmerston North approach plate	133
Figure 27. Alternate undercarriage selection	135
Figure 28. Alternate undercarriage selection (modified)	136
Figure 29. Initial approach to Palmerston North	138
Figure 30. MES Graph from initial approach to impact	139
Figure 31. Impact sequence events	142
Figure 32. Impact sequence MES Graph	143
Figure 33. Fire sequence	146
Figure 34. Events in Medical Information	149

Figure 35. Injury MES Graph	151
Figure 36. Impact and fire MES Graph	156
Figure 37. MES Graph of impact sequence	156
Figure 38. Witness mark on undercarriage door	158
Figure 39. Crush lines: view from front	159
Figure 40. Crush lines: view from top rear	160
Figure 41. Port nacelle damage	161
Figure 42. Rear fuselage damage	162
Figure 43. Starboard wing damage	164
Figure 44. Starboard tailplane damage	165
Figure 45. Empennage damage	166
Figure 46. Impact sequence (revised)	170
Figure 47. WB Graph: first step	177
Figure 48. WB Graph: second step	179
Figure 49. WB Graph: elaboration of Figure 48	180
Figure 50. WB Graph further development of Figure 48	183
Figure 51. Attachment to Figure 50	185
Figure 52. Second attachment to Figure 50	186
Figure 53. Third attachment to Figure 50	187
Figure 54. Precursor events	189
Figure 55. Engineering considerations	190

Figure 56. Complete WB Graph	194
Figure 57. Ansett undesirable effects	201
Figure 58. Connections from undercarriage latch design	203
Figure 59. Financial stress and emergency training	205
Figure 60. Lack of continuation training	208
Figure 61. Maintenance aspects	209
Figure 62. Absence of a Safety Manager	213
Figure 63. Shortness of GPWS warning	215
Figure 64. Conflict between financial and safety concerns	217
Figure 65 Ansett Current Reality Tree	219
Figure 66. Undesirable effects at the Civil Aviation Authority	225
Figure 67. Knowledge of crew training	227
Figure 68. Knowledge of recurring events	229
Figure 69. Knowledge of risk management	231
Figure 70. Combination of Figures 67, 68 & 69	232
Figure 71. Audit policy	234
Figure 72. Safe performance and cost	235
Figure 73. Civil Aviation Authority performance	236
Figure 74. Lack of financial information	239
Figure 75. Civil Aviation Authority: Current Reality Tree	241
Figure 76. Crew training	247

Figure 77. FRT: training, Sector 1	240
Figure 78. Forming the CRD	254
Figure 79. CRD: Safety Manager position	255
Figure 80. Assumptions in the Safety Manager CRD	256
Figure 81. FRT: Safety Manager functions	259
Figure 82. FRT: Safety management system, Sector 2	261
Figure 83. FRT: Maintenance, Sector 3	263
Figure 84. FRT: Pressures, Sector 4	265
Figure 85. FRT: Distractions, Sector 5	266
Figure 86. FRT: Ground Proximity Warning System	268
Figure 87. Ansett FRT	269
Figure 88. Positive reinforcing loop	271
Figure 89. Core conflict: CAA CRT	275
Figure 90. Conflict resolution diagram: CAA CRT	276
Figure 91. Funding is not a constraint on safety oversight	279
Figure 92. Oversight: surveillance, audits and safety management	281
Figure 93. Non-viability triggers greater depth of oversight	283
Figure 94. CAA is aware of deficiencies in airline operations	285
Figure 95. CAA FRT	287
Figure 96. Negative branch: perception of CAA performance	288

Chapter 1: Introduction

The Investigation of Accidents

The analysis of accidents, with a view to averting future accidents, is a science of wide application. Industrial accidents range from individual injury to disasters such as the reactor meltdown at Chernobyl. Public health accidents can encompass thousands of deaths, as in the Wittenoom disaster (Hills, 1989), in the unprotected mining and handling of blue asbestos. Medical misadventures, in which patients may become worse off as a result of medical intervention, may also be classed as accidents. In order to avert future accidents, it is necessary to understand those that have occurred: accidents must be investigated in order to learn from them.

The investigation of transport accidents has received much attention. This may be because the results of a transport accident can be spectacular, and the fatalities may be both large in number, and immediately apparent. Whatever the reason, most countries have set up specialist bodies to investigate transport accidents, for example the British Air Accident Investigation Branch (AAIB), and the American National Transportation Safety Board (NTSB). In particular, attention has been given to aircraft accidents, in part because the Chicago Convention on International Air Navigation requires Governments to arrange for the investigation of air transport accidents (ICAO, 1994)¹. The body of expertise that has been built up in the investigation of transport accidents could have applications in the investigation of accidents in other fields (Moray, 1994).

The investigation of accidents is, essentially, the application of expert knowledge (O'Hare, 1994): the investigator must be able to recognise what the evidence is showing. For this reason, attempts at generic investigation are unlikely to succeed. For example, an air accident investigator will not have the specific knowledge to investigate a train accident. However, at a deeper level, the underlying

¹ A glossary of abbreviations commonly used in aviation is at Annex A.

methodology is likely to be common to the investigation of any accident. Whether transport, industrial or medical, any mishap requires that the investigators discover what happened, and why it happened, before useful corrective action can be devised and implemented.

Accordingly, while this thesis examines the possibility of applying formal methods to the investigation of aircraft accidents, methods which are applicable to air accident investigation will lend themselves to the understanding and reduction of accidents in any sphere.

Background to the Study

The difficulty of investigating a complex accident was illustrated by the investigation of the accident to ZK-SFB, a Cessna Caravan turboprop aircraft operated by Skyferry on a scheduled night freight operation. The aircraft encountered severe icing, and stalled and spun into the sea off Kaikoura, on the east coast of New Zealand's South Island. What started as an apparently simple accident resulting from pilot error became a complex matter as deeper ramifications unfolded, and ended with the Attorney General ordering a Court of Inquiry (Carruthers, 1988).

During the investigation, the volume of evidence amassed (13 box files of documentation) was difficult to correlate. Some means of data manipulation was necessary, and a chart showing the linkages between components of the accident was devised, items of information being placed in chronological order and arrayed by the various actors - pilot, company, aircraft, and so on. A condensed form of this chart was produced for the assistance of the Court of inquiry, and is shown (in slightly modified form, and greatly reduced) in Figure 1, and in more detail in Figures 1A to 1D. The principal 'actors', i.e. the various organisations involved, and the pilot and aircraft, were shown down the left hand side. Time ran from left to right, with a quasi-logarithmic timebase: 'years before', 'months before', 'days and hours before' and 'immediately before the accident'. This was because, while the exact chronology was readily determined for the period shortly before the accident, and exact timing might be important over that period, for earlier periods exact timing was less important, and often more difficult to establish. The various actions, conditions and interventions relating to each of the actors were shown in the boxes, the linkages indicating that there was a connection between them.

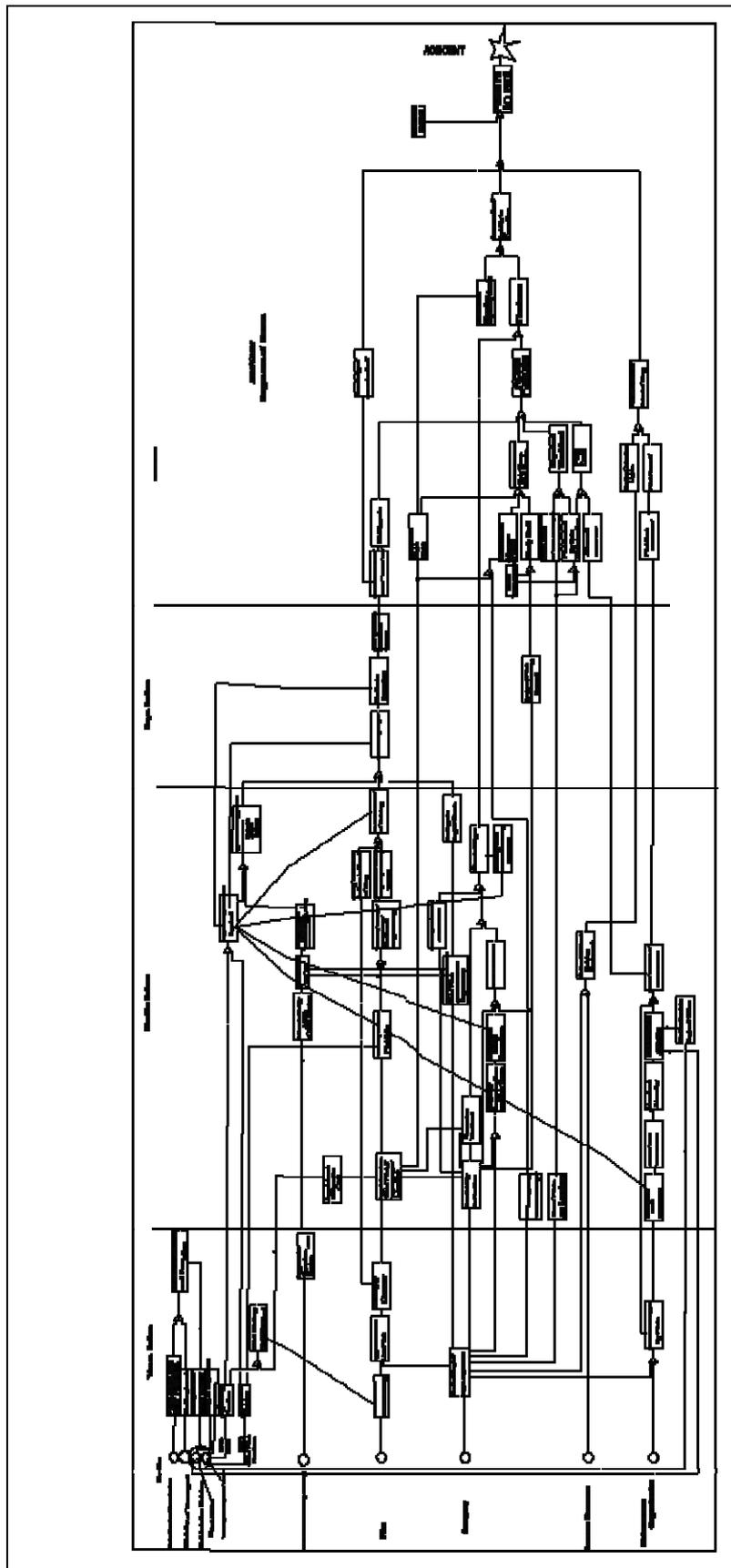


Figure 1. The Skyferry Accident. (Source: Zotov, D. V. (1996). *Reporting human factors accidents*. Paper presented at the 27th International Seminar of the International Society of Air Safety Investigators, Auckland.)

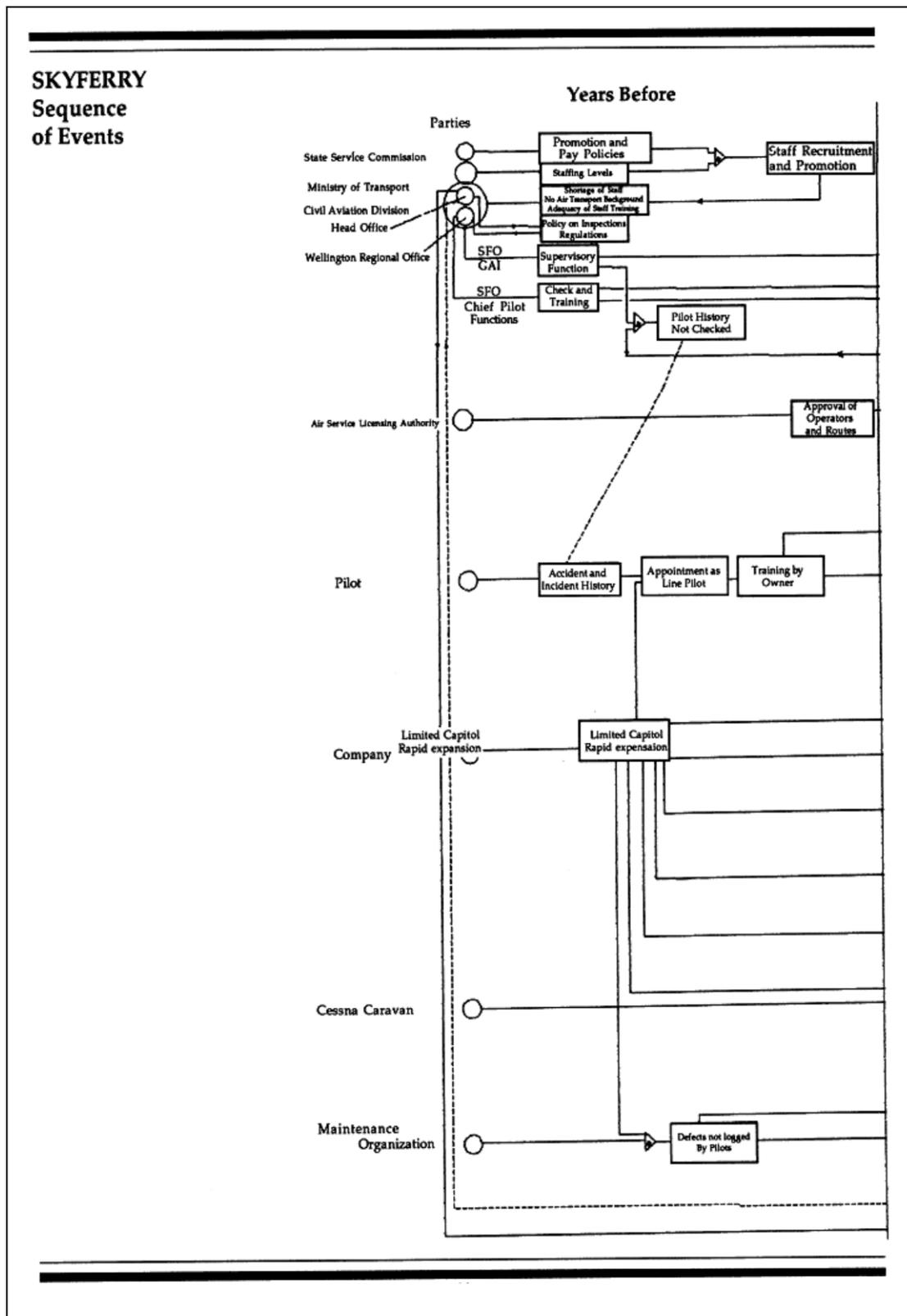


Figure 1A. The Skyferry Accident: Years before. (Source: Zotov, D. V. (1996). *Reporting human factors accidents*. Paper presented at the 27th International Seminar of the International Society of Air Safety Investigators, Auckland.)

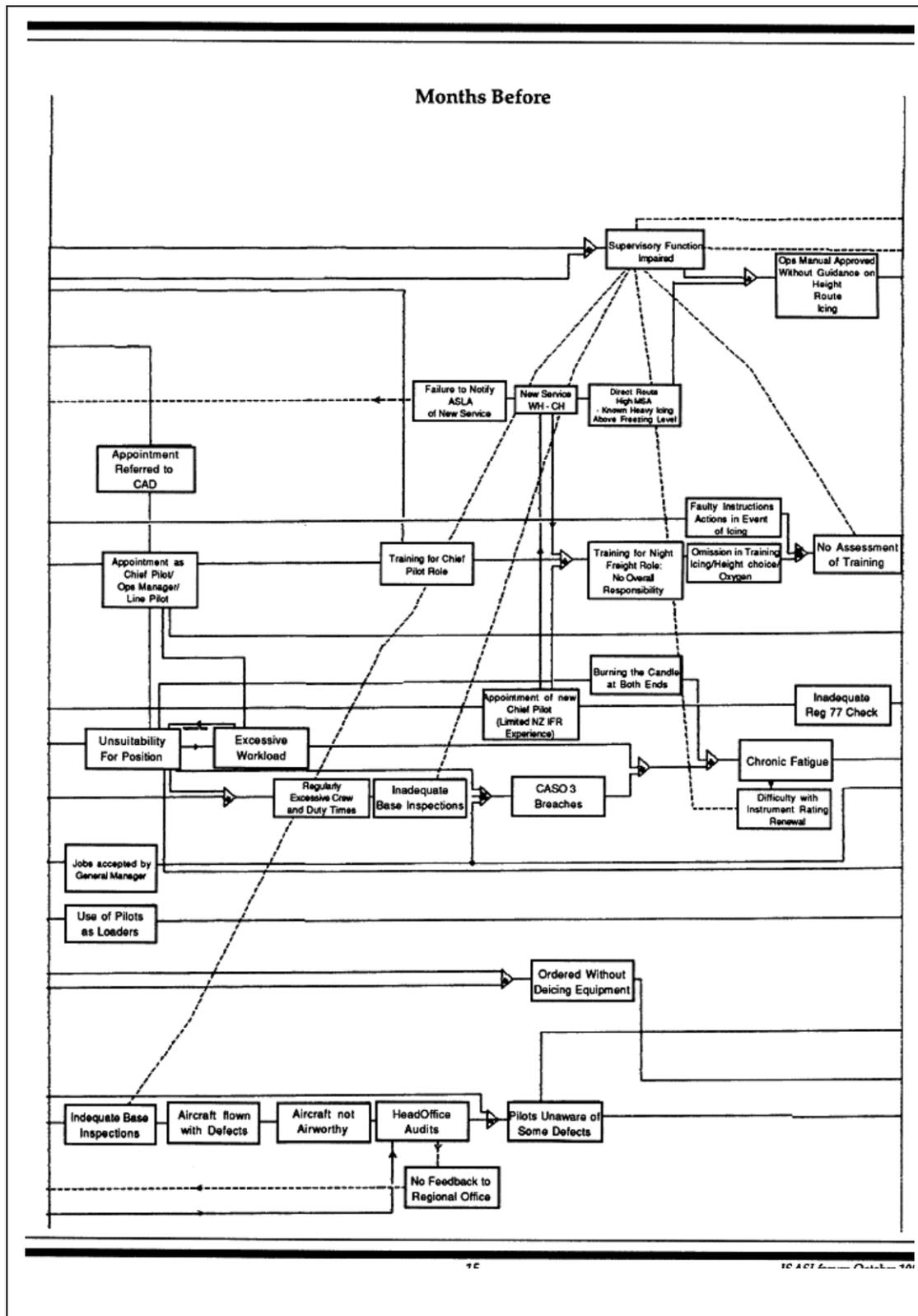


Figure 1B. The Skyferry Accident: Months before. (Source: Zotov, D. V. (1996). *Reporting human factors accidents*. Paper presented at the 27th International Seminar of the International Society of Air Safety Investigators, Auckland.)

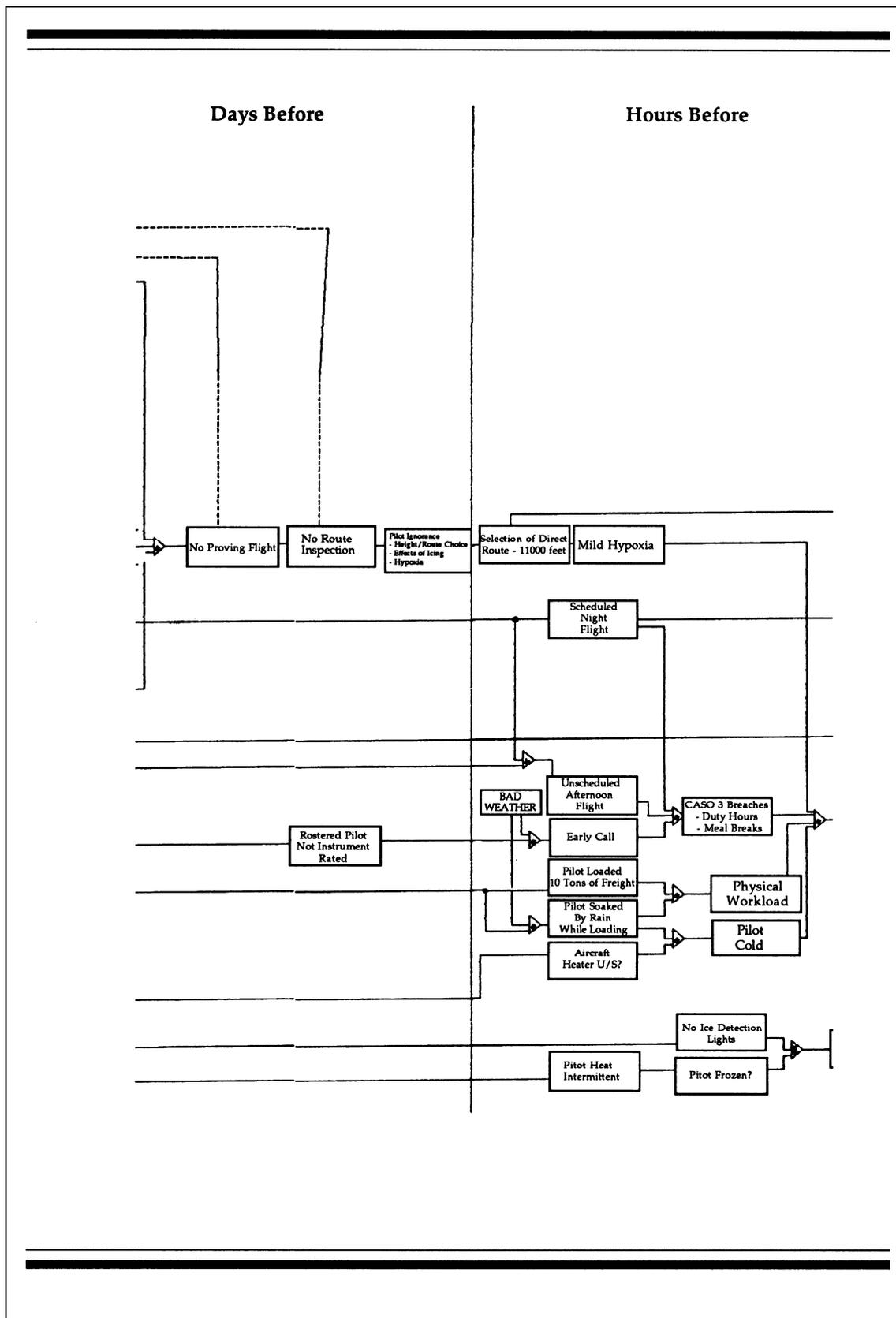


Figure 1C. The Skyferry Accident: Days and hours before. (Source: Zotov, D. V. (1996). *Reporting human factors accidents*. Paper presented at the 27th International Seminar of the International Society of Air Safety Investigators, Auckland.)

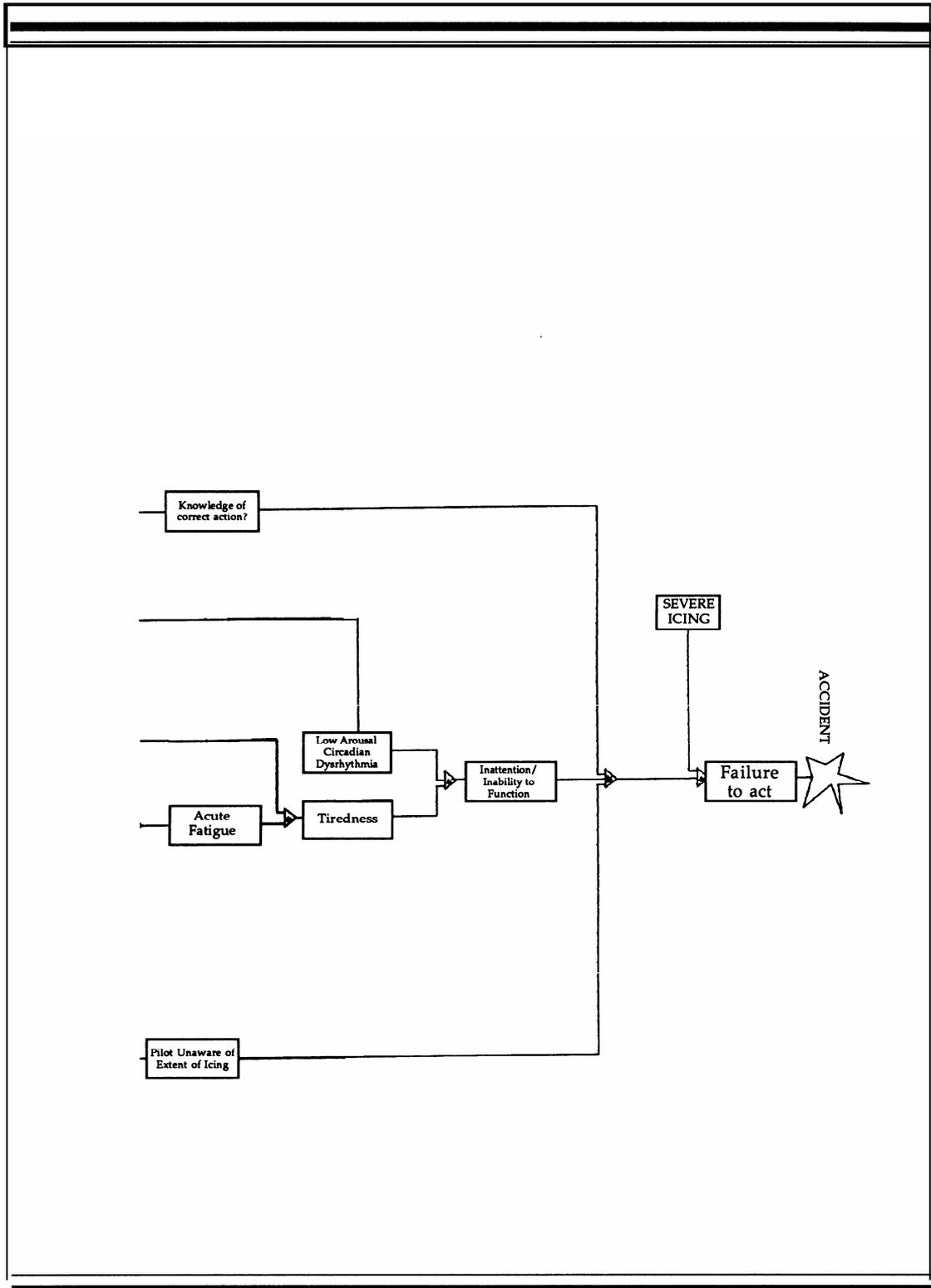


Figure 1D. The Skyferry Accident: Immediately before. (Source: Zotov, D. V. (1996). *Reporting human factors accidents*. Paper presented at the 27th International Seminar of the International Society of Air Safety Investigators, Auckland.)

However, a member of the Court subsequently advised that the Court had found the presentation confusing, and had not relied on it. Clearly, more was needed in order to "sell the product" of the investigation.

The first attempt at improvement was to devise a format for reporting (in particular) human factors accidents, which would present the information more logically than the existing International Civil Aviation Organisation (ICAO) format (ICAO, 1994). It used a combination of the Reason (1991) and Helmreich (1990) models of systems accidents, and presented the information in the order required for analysis using these concepts (Zotov, 1996). This approach has found some favour, and was adapted by the Australian Transport Safety Board (ATSB) for their report on the Qantas B747 over-run at Bangkok (ATSB, 2001). However, this was only a partial answer to the problems of investigating and reporting accidents, and devising recommendations which would avert the recurrence of accidents. It did not necessarily ensure that all relevant data had been gathered, nor did it ensure that analysis was logically sound, and it did not necessarily result in effective safety recommendations.

In order to achieve these aims it is necessary, first, to have a method of data manipulation which will enable the investigators to understand the linkages in the accident sequence as information is gathered. The data display should alert the investigators to missing information needed to understand the accident, while the opportunity exists to retrieve it. Much of the information needed is volatile (for example, witnesses' memories) and will be degraded or non-existent if not gathered during a limited window of opportunity.

Secondly, the analysis of data must be logically sound. This is likely to be more difficult when more abstract matters are considered. For example, the reasons for actions by the pilot may lie in training, and may not be susceptible to concrete proof, but they may be none-the-less real, and may show a need for corrective action. For such linkages to be persuasive, it is necessary that the logical validity of the analysis can be demonstrated.

Thirdly, the investigation will have been of no value unless the corrective actions proposed are sound, and those in a position to take corrective action are persuaded to do so. That this last problem has proved difficult is attested by the

experiences recounted by Taylor (1998), and by the recurrence of some types of accidents, as will be discussed later. Persuasion requires not only that the report of the investigation is sound, and that proposed recommendations will avert future accidents, but also that the difficulties in taking corrective action - inertia, lack of time or money, loss of 'face' and so on - are overcome. In short, change management is needed.

Formal Methods of Analysis

These three areas where improvement is indicated suggest the use of a suite of tools, designed to address each area in turn. Formal tools could be devised for data manipulation, logical analysis, and change management. Formal methods for data manipulation and analysis have been proposed in the past, but have not found wide favour (Wood & Sweginnis, 1995). When these methods are examined in detail, most are found to have limitations, which will be discussed in the Review of the Literature. These limitations range from uncertainty of nomenclature to extreme complexity. None handle, effectively, the question of devising and implementing recommendations.

To achieve acceptability, a tool should be easy to understand and straightforward to apply. The outputs from these tools - usually in the form of flow charts - must also be in a form that the potential audience finds comprehensible. The resulting corrective action must be seen, by those who are in a position to act, as not only correct in itself, but also in their own best interests.

These considerations are predicated on accidents having a complex structure. This is not invariably the case, and it might be that the application of a full suite of data manipulation, logical analysis and change management tools would be an overkill, where the accident is straightforward and the remedy self-evident. The solution is to use the tools in such a way that they act as a three-tiered filter:

- a. All accident reports need to display the information in such a way that the reader can visualise what happened - to form a 'mental movie', as Benner (1994) puts it. In simple cases, this may well be enough: if the accident sequence is understood, the corrective action may be self-evident.

- b. The second stage, logical analysis, will come into play if what happened is understood, but it is not obvious why it happened. The Skyferry accident (Carruthers, 1988) is a case in point, as is the Cali disaster (ACRC, 1996). It may not be necessary to go further than this stage, if the corrective action is understood, and is in fact taken.
- c. The third stage, change management, will be called upon if corrective action is not self-evident when causation is understood, or if apparently reasonable recommendations are not implemented.

It is envisaged that this suite of tools could form the basis of a reporting system. The difficulty with the present written report format (ICAO, 1994), or any modification of it, is that writing is linear, whereas the structure of an accident is often a complex network of interacting events, such as that described by Zotov (1996) and O'Hare (2002). Such a structure may be better explained graphically, and the report could comprise leading the reader through the construction of the flow charts representing the accident structure, with the necessary supporting data in annexes. Such a report might not only be easier to read, but also easier to write - a significant benefit to investigators. Also, if the logical validity of the report can be demonstrated, a subsequent legal challenge would be less likely than is at present the case: a controversy such as that which erupted over the Erebus reports (OAAI, 1980; Mahon, 1981) should not arise.

One final consideration is that, if a collection of tools is to form an organised suite, each of the tools selected should be similar in format, and apply similar logical rules and tests, so that the presentation flows naturally from one to the next.

The Need for Change

So far, it has been taken as read that improvement is needed in the way in which accident investigators go about their work. However, it could be argued that they already work effectively, as shown by the safety record of air transport generally. Why, if that is so, should there be a need for change to existing informal methods of investigation?

The overall accident rate for aircraft involved in air transport operations has declined significantly over the last 50 years (Boeing, 1985; Purvis, 1998). The accident record in other areas of aviation has been less well documented, but where records are available, as is the case with aircraft engaged in agricultural operations in New Zealand, significant improvements can be found (OAAI, 1984a)². It is difficult to apportion this improvement between the benefits from investigation of accidents, and those from improved technology, but some part can be attributed to implementation of safety recommendations arising from investigations of past accidents. However, the decline has become more gradual in recent years, and in air transport the accident rate has been nearly constant for some time. It appears that the rate is approaching asymptotically a level which is well above zero. This state of affairs is unacceptable. The increasing numbers of air transport flights anticipated in future years (Purvis, 1998) could see the number of jet hull loss accidents reach one per week in the future, unless the accident rate can be reduced (see Figure 2).

There have been demonstrable investigation failures (for example Filotas, 1991; Gerdsmeyer, Ladkin, & Loer, 1997; Zotov, 2001), and such failures are unlikely to result in effective action to avert future accidents. The static accident rate can therefore be attributed in part to failures of investigation. Investigations must discover the true causes, before effective remedies can be devised, and recommendations must be implemented if they are to have a beneficial effect on the accident rate.

² The 1984 Agricultural Aircraft Accident Summary (the last year in which this summary was produced) showed that the accident rate per 10 000 hours flown had declined from 32.7 in 1949 to 1.46 in 1983.

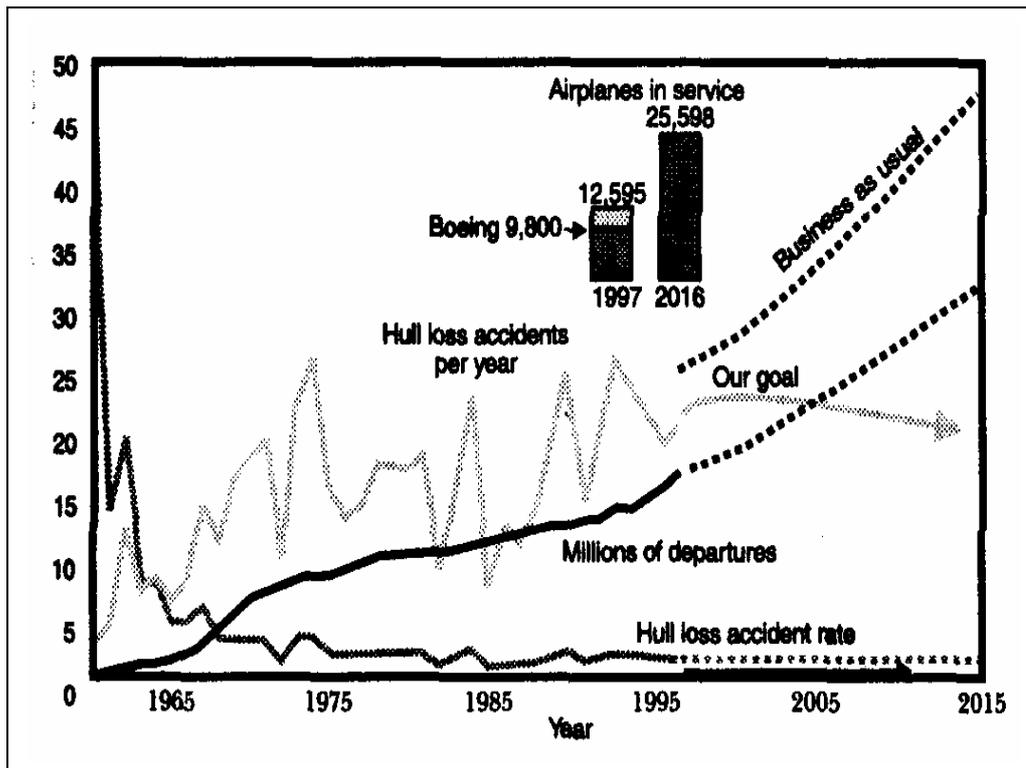


Figure 2. Jet air transport departures and hull loss accidents. (Source: Purvis, J. W. (1998). *The Boeing safety strategy - reducing the worldwide accident rate*. Paper presented at the 29th International Seminar of the International Society of Air Safety Investigators, Barcelona)

Investigative Failure

The reason for investigating aircraft accidents is to determine the causes, so as to be able to avoid recurrence (ICAO, 1994). Generally, investigators are able to discover causes (Ladkin & Loer, 1998), but some accidents recur, for a variety of reasons. In some cases the accident may not be 'solved' correctly by the investigators, or the immediate causes may be found but the underlying causes may remain obscure. Others recur because, although the causes are understood, those responsible for corrective action have not been convinced of the need for it. In terms of the goal of avoiding recurrences, all of these repetitive accidents could broadly be termed 'investigative failures'. These types of investigative failure will be examined in turn.

Incorrect solution of the accident

Incorrect solution of the accident may come about because information which was available has not been gathered, resulting in incorrect appreciation of events. This is, essentially, a quality control failure. An illustration of this type of failure was the accident to a commuter airliner, which turned and flew into a cloud-covered mountain. The official accident report postulated 'lack of horizontal situational

awareness' (TAIC, 1996b). Detailed meteorological data was available but was not gathered, and so the investigator was unaware of the potential for sector whiteout. There was corroborating evidence that sector whiteout brought about a visual illusion which persuaded the pilot that he was some distance off track, and the turn which resulted in collision with the mountain was an attempt to regain the proper track (Zotov, 1997a). Quality control, in the sense discussed above, can be achieved by displaying the information gained in such a way that gaps in knowledge of the accident are readily apparent.

Incomplete understanding of the accident, notwithstanding that all the relevant information has been gathered, points to logical deficiencies. These may arise from the investigators' concept of an accident: for example, if they regard an accident as a single event having a single cause, they are likely to disregard less apparent factors which may have had a part in setting up the accident (Benner, 1975). Alternatively, logical deficiencies may arise from the complexity of the sequence of events, which may present analytical difficulties (Gerdsmeier et al., 1997). In either case, it ought to be possible for those responsible for reviewing the investigation to detect the deficiencies. What is needed is a method of representing the logical flow of the accident sequence (Johnson, Wright, & McCarthy, 1995). Formal proof of the validity of the logic would be highly desirable (Ladkin, 1996).

Unpersuasive recommendations

However, even if the investigation is impeccable, it will have been of no value if those in a position to take action are not persuaded to do so (Charles, 1991). Implementing safety recommendations to avert recurrences is likely to be costly, in terms of expenditure of money, or of effort, so resistance to recommendations arising from an investigation is to be expected. There are a number of reasons why valid recommendations might not be implemented.

In order to make a persuasive case for improvement, it is first necessary that those who can act have a complete understanding of what has happened in the accident under investigation. This may not be easy to impart. The recipients are likely to be busy people, not necessarily having a technical background, and the circumstances of the accident may be complex and thus difficult to impart succinctly without loss of information.

Secondly, the action recommended must be shown to be worthwhile. If it can be said that the circumstances of the accident were so unlikely to recur that no further accident is likely to happen, even without corrective action, then there is a strong case for inaction. Those advocating change must therefore be able to show that the circumstances were not unique, and inaction is not an option.

Thirdly, the recipients may seek alternative options which are less costly in terms of money or effort. This is an apparently reasonable response, but has been the cause of subsequent disasters: see, for example, the report of the DC10 accident at Orly (AIB, 1976; Congress, 1974), discussed in detail later (pp. 83, 84). Some process is needed, therefore, in which alternative actions are canvassed, and inadequate alternatives shown to be inadequate.

Formalism in Investigation

Formalism in investigation is the adoption of standard methodology, both in the gathering and presentation of information, and in logical analysis. It has the potential to improve quality (Johnson et al., 1995; Ladkin, 1996). Formal representation of the data as it is gathered has the potential to show where there are gaps in the information, because a coherent picture cannot be drawn of the accident sequence. Formal logical analysis should forestall logical errors which have been found in a number of recent reports, such as those found by Gerdsmeyer et al. (1997).

Devising and Implementing Recommendations

From consideration of the way in which sequences of events comprise an accident (Hendrick, Benner, & Lawton, 1987) comes a view of an accident which differs from the traditional concept of an unpremeditated occurrence with adverse consequences. From this latter concept of an accident as a single event has come the idea of a single effective 'cause' (variously labelled 'probable' or 'proximate') which over the years has generated much debate (Miller, 1991). See, for example, the report of the official investigation into the Erebus disaster (OAAI, 1980), and that of the subsequent Royal Commission (Mahon, 1981), for alternative views of causation in the Erebus disaster. The idea behind finding 'the cause' is that if the single cause could be eliminated, the accident could not happen again. This has proved a very limiting concept: more recent investigations such as that into the Zeebrugge ferry disaster

(Sheen, 1987) have shown many causal factors, going right back to the boardroom and the regulatory authority. These more remote events have been termed 'latent failures' (Johnson, 1980; Reason, 1990). The concept of an accident having multiple causes has now become officially accepted (ICAO, 1994).

If more than one cause, often remote in time or space, leads to undesirable consequences, the accident might be thought of as being like a Greek tragedy, with a series of events leading to an inevitable denouement. As Benner (1975) has said, it is a process. This idea leads to consideration of how processes may be understood and controlled. Processes are a part of almost any business activity, and methods have been devised for controlling them, so that undesired effects may be eliminated while retaining desirable effects (such as operating at a profit).

Goldratt devised the Theory of Constraints (TOC) as a means of improving continuous production processes (Goldratt, 1987; 1990a; 1990b; 1994). The 'constraint' of the title was a bottleneck limiting production, and Goldratt advocated identifying this limiting factor and concentrating every effort on it, rather than trying to make general improvements across the board. This theory, and the logical tools developed in order to implement it, have been found to have very wide applicability. It is not limited to industrial processes, nor is it limited to continuous processes (Mabin & Balderstone, 1998). It is well suited to identifying undesirable effects and their underlying causes in any system, with a view to eliminating both causes and effects. Since the Theory of Constraints was designed for the improvement of industrial processes, it is designed to produce practical outcomes. The problems of taking action to bring about improvements have been taken into account in its design. It may be, therefore, that this methodology can help to solve the problem of non-implementation of safety recommendations.

However, the Theory of Constraints has not previously been used in the context of accident investigation. In order to see whether it can be of value, it is first necessary to examine whether the information from an accident investigation can be put in the form required for analysis using the Theory of Constraints methodology. If this should prove to be the case, it will then be necessary to consider whether this methodology is able to generate effective safety recommendations which are more likely to be effective than is at present the case. If the Theory of Constraints is able to

perform this function of bringing about change, it could represent the third tier in the suite of formal analytical methods, proposed above.

Chapter 2: Review of the Literature³

Since its inception, the investigation of aircraft accidents has been as much an art as a science. It has been taught by a lengthy apprenticeship, and uses a seemingly unconnected collection of tools which have been found useful over the years: see, for example, the ICAO Accident Investigation Manual (ICAO, 1970). The process is essentially intuitive, and the quality therefore variable. Since the 1970s, there have been attempts to promote formalism in the area of data gathering - having some method for displaying and linking the data (for example Multilinear Event Sequencing (MES) (Benner, 1975)); and formalism in analysis - having some systematic process for analysing the data (for example the Management Oversight and Risk Tree (Johnson, 1975)). As Wood & Sweginnis (1995) have pointed out, none of these methods have found general favour.

In part, this may have been because of resistance to the idea of 'investigating by numbers'. Extensive checklists to guide the course of an investigation have been tried, but found unhelpful (K. Smart, personal communication, 1996). If they were sufficiently comprehensive to cover all foreseeable contingencies, they were unwieldy; and they were unable to deal with contingencies which their authors had not foreseen. Likewise, attempts to use a conceptual approach as a template for investigation have not been completely successful. For example, the elegant simplicity of the Reason model (Reason, 1991) does not accord with the real-life complexity of the structure of the aviation industry, and attempting to treat the industry as a whole as the monolithic 'organisation' envisaged by Reason results in a loss of information. Attempting to fit the analysis to such a template therefore resulted in an unconvincing report (Zotov, 1996).

³ This thesis was completed in 2004, but technical difficulties with word processing delayed its submission until 2005, and it was examined in 2006. The 'line in the sand' for references to be included in the Review of the Literature, related to the completion date, is 2003.

There are methods currently in use which have achieved some level of acceptance, such as MES (Benner, 1994), and the combination of the Reason (1991) and Helmreich (1990) approaches suggested in Zotov (1996) and adapted by the Australian Transport Safety Board (ATSB, 2001). However, these methods may not avert the logical deficiencies in analyses of accident data, and contradictions within reports, pointed out by Ladkin & Loer (1998). They suggested the use of formal logic to overcome these difficulties. Formal logic is able to detect errors in reasoning, and the conflict between contradictory statements in reports can be highlighted. The process they advocate, they have labelled 'Why-Because Analysis'.

This literature review will commence with the development of understanding of accident causation, because the investigator's concept of causation can have a profound effect on the way an accident is investigated. For example, if an accident is seen to be a single isolated event, then there may be perceived to be only one isolated cause. A more elaborate concept of an accident, as the coming together of many prior events, was necessary before the Management and Oversight Risk Tree (MORT) concept of causation (Johnson, 1973) could come into being. With this concept, the investigator is guided to consider the past actions of management, as well as the more proximate actions by operational personnel, which may have contributed to the accident.

Next, the need for formalised methods of investigation is examined, and this is followed by a review of various formal methods proposed in the past. These former methods will be shown to have had limitations, which may explain why they have not been widely adopted.

Two analytical methods in current use - Multilinear Event Sequencing (MES) and Why-Because Analysis (WBA) will then be examined, and their limitations point to the need for an analytical method which should result in safety recommendations which are more effective than is at present the case. No matter how valid the analysis, the investigation will have been of no value unless its primary object, the prevention of recurrence of an accident (ICAO, 1994) is achieved. To achieve this object, it is necessary that corrective action be taken on the basis of the investigation. Unfortunately, experience has shown that this is not always the case (Charles, 1991; Maurino, 1999; Miller, 1999; Taylor, 1998). The general policy of accident

investigation authorities has been to present recommendations for improvement in broad terms, and leave the detailed implementation to those involved in day-to-day operation (Wood & Sweginnis, 1995). This policy has not always served well. An alternative would be for the investigators to work with the operators or regulatory authority to design and implement changes. Such an approach is commonplace in business management, and a possible methodology, Goldratt's Theory of Constraints (Dettmer, 1997; Goldratt, 1990b), which will be examined, may enable a collaborative approach.

For a formal method to be considered successful, it must be practicable. It must be usable by investigators who, by the nature of their calling, will be expert aviators, but are unlikely to have had formal scientific training (Zotov, 2000). If a methodology is to achieve widespread acceptance, it must be straightforward in use, and preferably it should not require extensive training before it can be applied successfully. In the interests of simplicity of use, if at all possible one suite of tools should be applicable in all cases. Also, the methodology must be reliable. By this is meant, that any investigator, confronted with the same circumstances and using the methodology, should arrive at the same conclusions. It is also essential that the methodology is understandable by lay readers, since they may need to be convinced of the validity of what the investigators are telling them.

The Nature of an Accident

The way in which an accident is defined can influence the way in which it is investigated. The traditional concept of an accident is an unforeseen event which causes loss. The International Civil Aviation Organisation (ICAO) still defines an aircraft accident (in the 8th edition of Annex 13 to the Chicago Convention (ICAO, 1994)) as

"An occurrence associated with the operation of an aircraft ... in which:

- a) A person is fatally or severely injured ...
- b) The aircraft sustains damage or structural failure ...
- c) The aircraft is missing ... "

(ICAO, 1994, p. 1).

An accident, thus defined, was seen as having a single cause:

"The investigation shall include the gathering, recording and analysis of all ... information, [and] if possible the determination of cause ... " (ibid., p. 8).

If the cause could be found, then future accidents from the same cause might be averted.

While these definitions were unchanged from previous editions, the 8th edition, in the Appendix on report format, introduced reference to multiple causes:

"The list of causes should include both the immediate and the deeper systemic causes." (p. 18).

This acknowledged the more recent understanding that accidents seldom have a single cause, as will be discussed later.

However, 'an occurrence', whether arising from a single cause or several, is essentially a static concept. By contrast, Hendrick & Benner (1987) used a completely different definition of an accident. To say that an accident is 'an occurrence' says nothing of how the accident came about. Hendrick and Benner adopted the view of Hirschfeld (1963), that an accident is a *process*. Hendrick and Benner defined an accident as:

"a special class of process, by which a perturbation transforms a dynamically stable state activity into unintended interacting changes of states with a harmful outcome" (Hendrick & Benner, 1987, p. 27).

They argued that, because a process involves action, the accident process could be regarded as a set of simultaneous, interacting and cross-linked events. It was the elucidation of these events, they suggested, which was the proper purpose of accident investigation. The construction of the pattern of events they named Sequentially Timed Events Plotting (STEP), or Multilinear Event Sequencing (MES).

They used these two terms synonymously (L. Benner, personal communication, 2000).

Ladkin & Loer (1998) did not address the definition of an accident directly, but instead referred to an accident explanation, which often formed a complex structure. For example, Gerdsmeyer *et al.* (1997) showed that the 60 or so causal states or events in the report of the American Airlines accident near Cali, Colombia (ACRC, 1996) had 73 direct causal connections between them.

In saying that airline accidents often have a complex structure, Ladkin's view was the same as that of Helmreich (1990), who described the 'concatenation of multiple factors' which affected the crew in the Dryden, Ontario disaster (Helmreich, 1990, p. 2). Reason (1990; 1991) referred to 'the accident' as the ultimate harmful consequence of a series of states and actions, but he made it clear that generally it was this sequence that led up to the 'accident'. It was the sequence which must be studied in order to understand the causation of the accident. Thus there is general agreement that there is a process leading up to the harmful occurrence. It may be helpful to adopt Hendrick and Benner's (1987) definition of an accident as being the process leading to harmful consequences, because it encapsulates the dynamic nature of an accident. Processes are widespread in industry, and methods for changing them to avert undesirable outcomes, such as the Theory of Constraints (Goldratt, 1990), might be applicable to averting accidents.

Accident Causation

The interpretation of causation which is adopted by the investigators can have a profound effect on the corrective action which might be devised to avert recurrence of an accident. For example, the 'chain of events' concept might result in events remote in time being considered unimportant, because other events, more immediately concerned with the harmful consequences, have intervened.

The expression 'the cause of the accident' means different things to different people. To the journalist seeking a story, it may be the single event that brought about the mayhem. At the other end of the scale of complexity there is Helmreich's (1990)

description of the factors affecting human performance in the Dryden disaster, where some 20 factors combined to affect a crew's cognitive ability.

In recent years there has been a realisation that, at least in the tightly controlled area of air transport, it is very rarely an action by an individual at the 'sharp end' that precipitates an accident. Rather, the individual is put in an unenviable position by organisational factors (Reason, 1991). To avert accidents, Reason argued that it is necessary to discover and correct these corporate factors.

This section of the literature review commences by examining the development of the understanding of causation, and will then go on to examine approaches to understanding systemic accidents.

Perceptions of the Accident Phenomenon

Benner (1975) described five possible perceptions of accident causation: the 'single event', the 'chain of events' or 'domino', 'branched events' or 'tree', 'stochastic events', and 'multilinear events sequence' or 'process'. These are shown in Fig. 3.

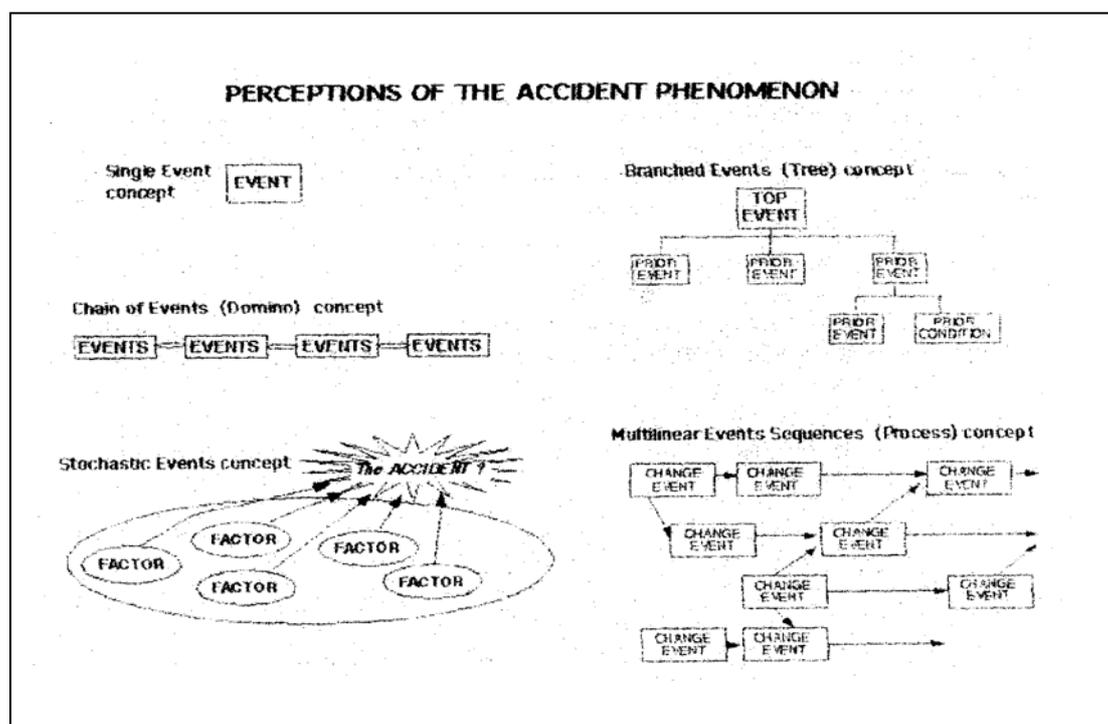


Figure 3. Perceptions of the accident phenomenon. (Source: Benner, L. (1975). Accident investigations: Multilinear event sequencing methods. *Journal of Safety Research*, 7(2)(June), 67-73.).

The Single Causative Event.

The *single event* conception of an accident was instanced by Benner (1975) as that typically adopted by the news media, and the Police. It focuses on 'the cause'. The limitation of this concept is that contributory factors are not pursued because the 'real' cause is obvious and visible. Benner (1975) considers that this older usage of 'the cause' of an accident - a single or dominant cause without which the accident would not have happened - is what led to investigators seeking a 'probable cause'. This is unhelpful, because much effort is dissipated in trying to identify which of many factors is the 'probable cause', when in reality all might be important (Miller, 1991). 'Probable cause', specified as the aim of the investigation in the authorising statutes of a number of investigating bodies, is nowhere properly defined (*ibid.*).

The Chain of Events.

A first step beyond the single cause concept is the *chain of events* (or 'Domino') theory. An accident is considered to result from a sequence of events, each event leading to the next until the accident happens. A caused B, which in turn caused C, and this in turn caused the accident. Intervention at any point could halt the process and so avert the accident. This concept cannot deal with interactions between events, or contributory factors.

This theory is consistent with the legal concepts of 'proximate cause', and also 'remoteness of damage'. The 'proximate cause' is the event which led to the accident, without intervening events, and so the last opportunity to avert disaster. 'Remoteness of damage' indicates that the earlier action was too remote from the harmful occurrence, for that action to be considered accountable for the occurrence: intervening events, "in the favoured legal vernacular...snapped the chain of causation" (Fleming, 1992, p. 216). In terms of aircraft accidents, at least, these legal concepts are unhelpful. The proximate cause, in about 80% of fixed wing aircraft accidents, is some error on the part of the pilot (see, for example, O'Hare, Wiggins, Batt and Morrison, 1994). But all that this says is that the pilot is the penultimate line of defence (Reason, 1991) (the final defences being warning systems). Blaming the pilot for the accident will do nothing to explain the real reasons why the pilot was placed in an unenviable situation in the first place. The concept of 'remoteness of damage'

would deny the part played by 'latent failures' (Johnson, 1980; Reason, 1990), which Reason has described as being analogous to pathogens in the body, waiting for a suitable set of circumstances to arise, to cause harm. Latent failures are, by definition, remote in time and place from the direct harmful occurrence, but they have been shown to be at the root of many accidents (see, for example, Maurino, Reason, Johnston, and Lee, 1995; Reason, 1990). If the accident rate is to be improved, latent failures must be eliminated, or their effects mitigated.

Logic Trees.

The next stage beyond the 'chain of events' in the development of theories of causation was to seek to link the individual elements by a *logic tree*, as exemplified by the Management Oversight Risk Tree (MORT) (Johnson, 1975), discussed later. The tree starts from a broad base, factors coming together at each level to cause a further factor at the next level, and so on until the top of the tree - the accident - is reached. The method is intended to provide a structure to reduce overlooked factors and to identify general causal areas. One limitation is that it can only show fusion of events over time, but the reality may be that logic chains divide, so that there are interactions between various parts of the tree. These interactions are difficult to depict. Also, time is not explicitly available in the presentation, but it is needed for understanding of the accident sequence. Logic trees are discussed further in *Analytical Methods*, later.

The Stochastic Approach.

The *stochastic approach* is to gather facts and data in order to isolate factors not due to chance. A search is made for common variables over a number of accidents. This approach, by its nature, cannot derive results from a single accident. However, it may be useful where individual investigations have not succeeded in preventing repeated accidents, as in TAIC (1992), discussed below.

A serious limitation of the stochastic approach is that reporting of facts may be biased by assumptions about causes, made by the investigators of the individual accidents. An apparently 'obvious' cause may result in facts unrelated to that cause being overlooked or discarded as irrelevant. Thus, in a series of accidents involving

Pterodactyl microlight aircraft, the investigators thought, in each case, that the accident cause was unrelated to the aircraft design (OAAI, 1983; 1984; 1985b; 1988; TAIC, 1992). Apparently valid causes, different in each case, were found. Little attention was paid to the structural failures, and documentation of these failures was inadequate (TAIC, 1992). Subsequent analysis showed that all the accidents were due to design deficiencies (ibid.).

Multilinear Event Sequencing.

Unlike logic trees, *Multilinear Event Sequencing* (MES) incorporates time, and recognises multiple events involving multiple actors. Interactions can readily be shown. MES provides chronological validation (discussed later) and the opportunity to discover possible unknown linking events. It defines an accident as beginning with a perturbing event, and ending with the final damaging event. This definition does not allow for consideration of latent failures and precursor events. Nor does it allow consideration of the aftermath, where events subsequent to the accident may be worthy of attention. For example, the omission to replace an air traffic controller after an airmiss could have the potential for that controller, under the stress of the occurrence, to set up a further possible collision. The reason for that omission should therefore be examined.

The MES concept will be examined in more detail, later.

The Concept of Causation

Benner (1994), Rimson (1998) and Ladkin (1999) all used 'cause' as meaning the link between one event or condition, and its successor to which it is logically related. If all the Event Building Blocks (EBBs) (to use Benner's nomenclature) are necessary and sufficient, it follows that all the causal links are equally important. To single out any one, or even a group of them, may be counterproductive, in that it diverts attention from the rest, and from the overall picture. This view is not in accordance with the concept of a 'core problem' (Dettmer, 1997), in which a single unsatisfactory situation gives rise to later problems. Core problems will be discussed later, when Why-Because Analysis (Ladkin, 1998) and Theory of Constraints (Dettmer, 1997) are discussed. However, the concept of 'Cause' as being a link

between an event or condition and its successor, rather than an event or condition itself, is generally accepted, and will be used in this sense throughout this thesis.

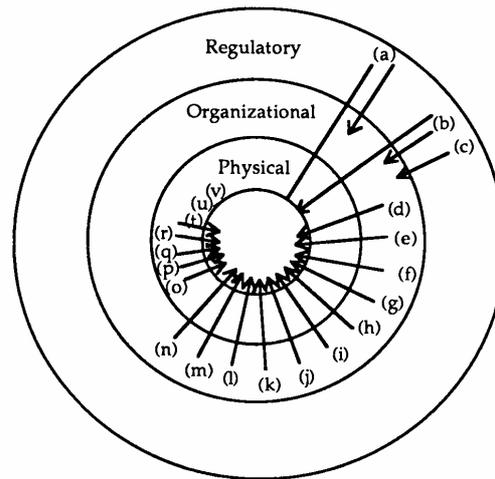
Systemic Causes

Helmreich's Environmental Concept.

In investigating a human factors accident, Helmreich (1990) sought to depict the various factors which could put the crew under pressure. He envisaged the crew working within a series of environments, each of which might put pressure on the crew members, and degrade their performance. This series of environments was envisaged as concentric spheres of influence, each affecting those inside (Figure 4). The innermost environment concerns matters among the crew, such as communications, personality and Crew Resource Management. The crew is affected by the physical environment: the aircraft with its idiosyncrasies, defects and performance characteristics; the weather, both local and general; and the aerodrome environment. Outside these is the organisation of the airline, which purchased and maintained the aircraft, trained the crews, and should support their actions. Surrounding all these is the regulatory environment, in which regulatory action should ensure safe standards of operation.

Helmreich, (1990) considered each of these environments in turn, to discover the deficiencies in them and how they affected the other environments within. To take just one example of many, "Several aspects of the Regulations provided an indirect, deleterious influence on the crew's operational environment" (p. 6). These included *Failure to provide clear guidance* for organisations and crews regarding the need for de-icing. "There are no... approved guidelines which dispatchers or flight and ground crews may use to assist them in making a reasoned judgement..." (See (a) in Figure 4).

This is not strictly a model of the accident structure, since it shows what has happened, but does not deal with how the various factors came about. However, in conjunction with other concepts, it provides an effective means of presenting the human factors aspects of an accident (ATSB, 2001; Zotov, 1996).



Key

- (a) Failure to provide clear guidance about the need for de-icing
- (b) Lack of rigour in regulating and monitoring operations - no Minimum Equipment List; no accepted Aircraft Operations Manual
- (c) Delayed and incomplete audit of operations
- (d) Lack of operational support from Air Canada for financial reasons
- (e) Disruptive effect of mergers and strikes - not conducive to team performance
- (f) High turnover of management personnel following the merger
- (g) Lack of organisational experience in jet operations
- (h) Deficiencies in the dispatching system - untrained dispatchers and pilot self-dispatch
- (i) Lack of standard operating procedures and manuals for the F28
- (j) Inconsistencies in training F28 crew members - various contractors, and internal training by newly qualified pilots
- (k) Deficient leadership for the F28 programme - chief pilot also responsible for the Convair 580 fleet, with little experience on either type
- (l) Informal culture at Air Ontario - indulging in practices in violation of Transport Canada regulations
- (m) Maintenance problems with the F28 exacerbated by groundcrew unfamiliarity with the aircraft, and shortage of spare parts
- (n) Flight Attendant training permitting no questioning of the pilots
- (o) Mechanical problems especially the inoperative APU
- (p) Weather at Winnipeg (original departure point) which had caused earlier delay for de-icing
- (q) Weather at Thunder Bay (previous stop) which had caused an earlier weather hold
- (r) Weather pattern: unsettled weather had increased dispatch fuel requirements, necessitating refuelling stop at Dryden
- (s) Weather at Dryden Snow started to fall during the stop
- (t) Unfamiliarity with the aircraft: each pilot had less than 100 hours on type
- (u) Difficulties in working together: Both pilots accustomed to flying as Pilot in Command; pilots came from different airlines which had merged
- (v) Personal factors: Captain acted as an instructor, which could irritate experienced pilots; both pilots had scheduled personal trips immediately after the final sector

Figure 4. Flight crew: factors affecting performance: Helmreich's 'spheres of influence' (Source: Zotov, D. V. (1996). *Reporting human factors accidents*. Paper presented at the 27th International Seminar of the International Society of Air Safety Investigators, Auckland.)

Latent Failures.

In the field of aircraft accident investigation, Mahon (1981) appears to have been the first to adopt the concept of remote managerial actions setting up an accident. Mahon conducted a Royal Commission of Inquiry into the Erebus disaster:

In 1979 an Air New Zealand DC10 aircraft, on a sightseeing trip to Antarctica, while flying in clear air, collided with the side of Mount Erebus. It was demonstrated that the direct cause of the accident was whiteout, which deprived the crew of visual reference while the aircraft was flying in apparently unlimited visibility. The Report of the subsequent Royal Commission of Inquiry absolved the crew of any blame. Instead, it cited failures within the Company, and in particular the action of changing the computer flight plan immediately before the flight without notifying the crew, so programming the aircraft to fly straight at the side of the mountain.

The accident had already been investigated by the New Zealand Office of Air Accidents Investigation (OAAI, 1980). While some new evidence came to light in the course of the Inquiry, and other evidence was sometimes accorded different weight, there was little material difference between the findings of fact of the two investigations. However, the determinations as to cause were very different: the OAAI Report had found that the probable cause was the pilots' action of descending towards an area of poor horizon definition.

How could two investigations proceed from essentially the same facts, and come to such different conclusions? The OAAI Report used the (then) standard 'Domino theory', and the investigators were directed by the Crown Law Office that in the New Zealand legislation, 'probable cause' was synonymous with proximate cause (R. Chippindale, personal communication, 1989). Within that framework, the finding of probable cause could not be faulted. By contrast, Mahon took the view that earlier actions by the company had set up the accident, and the crew were the victims of these actions: the crew acted properly, in the light of what they knew of the situation. Mahon, therefore, had adopted the concept of 'latent failure' propounded by Johnson

(1980), although Mahon (1981) gave no indication that he was familiar with Johnson's work.

Consideration of the effectiveness of corrective action which could result from each report points to Mahon's view as being more likely to help avert future accidents. From the OAAI report, the possible corrective action would have been to advise crews not to fly in whiteout conditions. Little could be gained by advising crews not to fly in whiteout conditions, when the crews (and the airline) had a defective understanding of whiteout. Conversely, addressing the underlying problem identified by Mahon (1981), of defective communications within the airline, would not only have averted the direct cause of failure to advise the crews of a change. It would also have rectified the defective briefing which contributed to all of the airline's crews' lack of understanding, both of the hazards of Antarctic flying, and of the intended safeguards.

Reason's Model of Systems Failure.

Reason's depiction of the structure of a systems accident is shown in Figure 5.

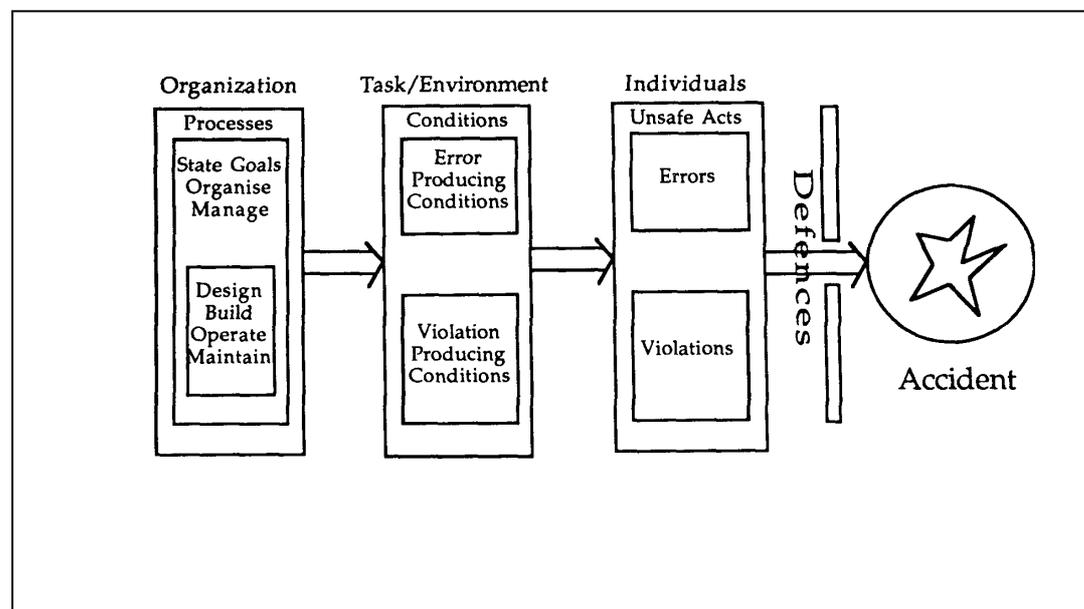


Figure 5. The structure of an organisational accident. (Source: Reason, J. (1991). *Identifying the latent causes of aircraft accidents before and after the event*. Paper presented at the 22nd International seminar of the International Society of Air Safety Investigators.)

Reason (1990; 1991) popularised Johnson's (1980) concept of latent failure. In Reason's terms, the changed flight path towards Mount Erebus, of which the crew had

not been notified, would have been a latent failure. The general problem identified by Mahon (1981) - poor communications within the Company - would be described as a General Failure Type. The various errors by those at the 'sharp end' are seen as mere token failures.

The Reason model is based on the underlying systems structure, and is intended to discover the deficiencies that led to the crew being put in the sort of situation that Helmreich (1990) examined. Reason (1991) takes the view that correcting individual failings is unlikely to prevent future accidents: we must seek out and remedy the underlying causes, which he terms General Failure Types.

He developed the model after studying reports of a number of major disasters. These included the Kings Cross Underground fire in London, the Clapham Junction rail collision, the Piper Alpha oil rig disaster, the sinking of the Herald of Free Enterprise off the Belgian coast, and accidents at nuclear power plants (Reason, 1990).

Reason's model of an organisational accident postulates three basic elements:

1. Organisational *processes*
2. Task and environmental *conditions*
3. Individuals performing a variety of *unsafe acts*

Causality commences with organisational processes, and leads through the task and environmental conditions that promote unsafe acts, to the errors and violations of individuals at the 'sharp end', whether on the flight deck or on the hangar floor. Finally, the defences built into the aircraft such as stall warning and recovery either fail, or are disabled, and the accident occurs. While unsafe acts are performed by individuals, the conditions that encourage or provoke those acts, such as shortage of time allotted to a task, are the province of management.

One limitation of the applicability of Reason's concept of a systems accident to aviation accidents lies in the sorts of cases he examined. Reason (1991) considered that any technical organisation was continuously involved in four related processes: designing, building, operating and maintaining. Surrounding these processes were two

contextual frames, the Goal Statement, and an Organisational framework in which a company is organised to achieve its goals.

Reason treated the "organisation", that is, the company involved in the accident, as being monolithic, and this may very well be true of railways, and nearly true of ferry companies. Such companies may well design and build, or control the building of, their equipment. For example, the former New Zealand Railways Department had workshops in which its locomotives and rolling stock were built, and ships may be built to the specification of the shipping line. However, it is certainly not true of airlines. Airlines generally operate and maintain their equipment, but they are entirely separate from manufacturers who design and build it, with virtually no opportunity to affect the design and construction of their aircraft. Also, as we have already seen in the Helmreich model, they operate within the influence of other organisations - ICAO, the regulatory authority, and air traffic service providers. This difference gives rise to some difficulties in trying to apply the Reason model to the specifics of an aircraft accident, as will be discussed later.

Having identified these organisational and operating processes, Reason (1991) then identified *General Failure Types* associated with each, as shown in Table 1. While these are not the only possible General Failure Types, they are ones that feature in many aircraft accidents.

Table 1. General Failure Types. (Source: Reason, J. (1991). *Identifying the latent causes of aircraft accidents before and after the event*. Paper presented at the 22nd International seminar of the International Society of Air Safety Investigators.)

Process	General Failure Type
Goal	Incompatible Goals
Organize	Inappropriate Structure
Manage	Communications Poor Planning Inadequate Control and Monitoring
Design	Design Failures
Build	Unsuitable Materials
Operate	Poor Operating Procedures Poor Training
Maintain	Poor Maintenance Scheduling Poor Maintenance Procedures
and	Inadequate Regulation

Reason (1991) advocated that the underlying latent failures should be identified step by step. The investigators should backtrack from the accident, via the failed defences, to the unsafe acts, the conditions which gave rise to those acts, and ending with the fallible top-level decisions that set the accident sequence in motion.

The main steps in the analysis using the Reason model would then be:

Defences What aspects of the aircraft's defensive system were absent, failed, or circumvented?

Unsafe Acts What types of actions were involved in breaching or bypassing the defences? Were these individual or group failures?

Preconditions What task, situational or environmental factors promoted these unsafe acts?

General Failure Types Which of the General Failure Types were implicated in creating these preconditions? What factors shaped the underlying conditions? What shortcomings are revealed in the organisation's safety culture?

At each level it may be possible to make detailed connections between the identified accident facts, and their precursors at the preceding level. However, this process will become more problematic at the higher levels, where there may be interactions between a number of top-level decisions and General Failure Types.

The Reason model poses some difficulties for investigators who seek to use it as the basis for analysis, or to structure the analytical section of a report. In the first place, the concept of a monolithic structure for the operator is, as discussed above, by no means true of commercial aviation. There are interactions between the operator (usually the airline) and other organisations, such as ICAO, the regulatory authority, the air traffic control system, and possibly a separate maintenance organisation. Within each of the interacting entities (operator, air traffic control, regulator etc.) errors, unsafe conditions and latent failures can occur. To attempt to portray the totality of the problems and interactions that can occur becomes complex indeed

(Zotov, 1996). Some of the possible interactions are shown in Figure 6, but this diagram does not show the even greater complexity arising from international interactions, which are commonplace in aviation. It would be unsatisfactory to refer to the entire aviation system as 'the organisation', because much information would be lost (*ibid.*).

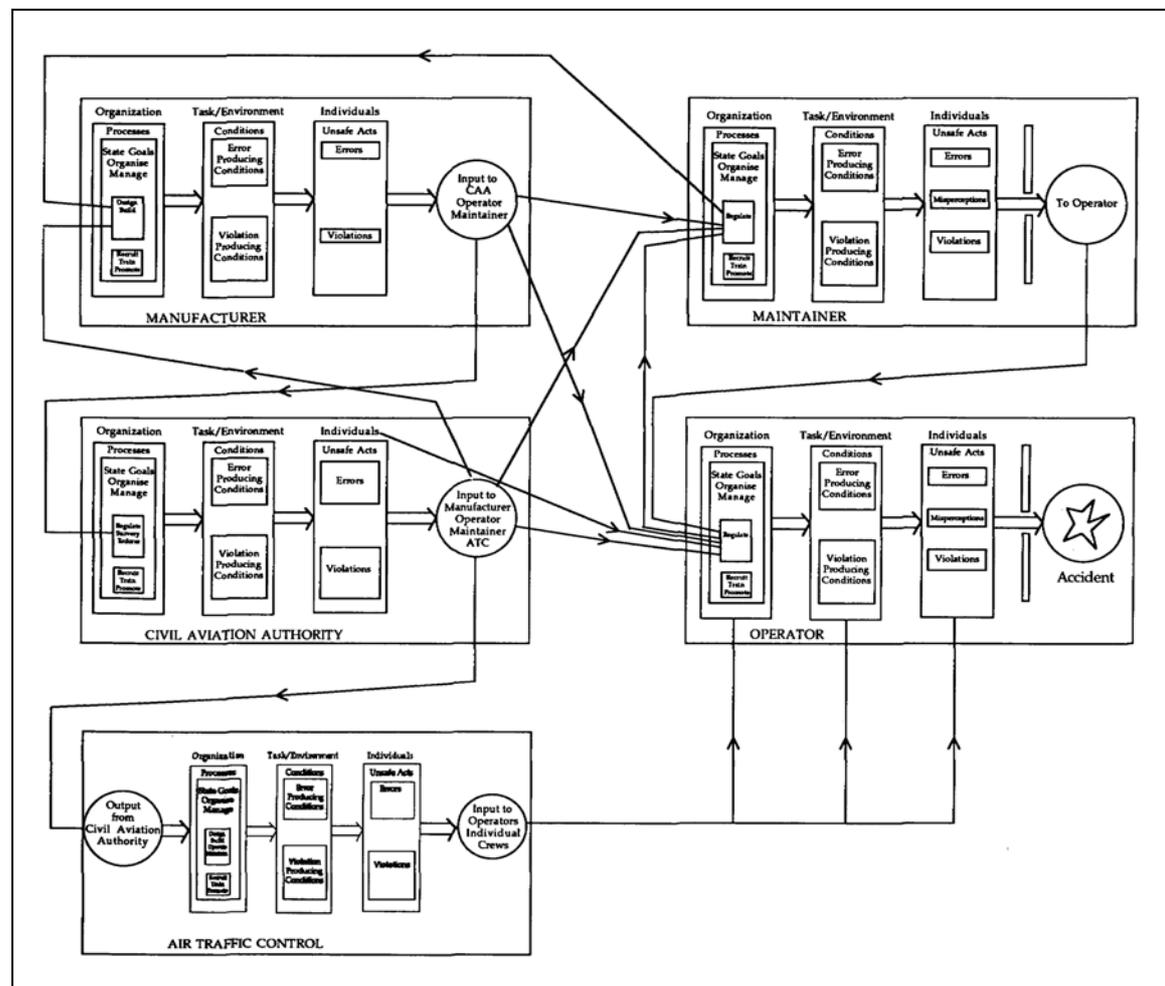


Figure 6. Complex interactions in the aviation industry, using the Reason model.

(Source: Zotov, D. V. (1996). *Reporting human factors accidents*. Paper presented at the 27th International Seminar of the International Society of Air Safety Investigators, Auckland.)

Also, it has been found difficult to demonstrate that crew errors at the sharp end are linked to management actions (the 'backtracking' recommended by Reason, 1991), so that the management actions are seen to be causal factors in the accident. For example, the Mahon Report on the Erebus disaster (Mahon, 1981) remained controversial for many years. Contrast Vette (1999), who argued that any crew placed in the same situation would have been likely to have had the same accident, with L'Estrange (1995), who considered that it was entirely a matter for the crew to avoid

the accident by complying with existing directives and thus the failings of Company officers were immaterial.

Both Zotov (1996) and Johnson (1999) have suggested that the Reason model is best used in conjunction with other techniques. Zotov (1996) suggested that the Helmreich analysis could be used to isolate parts of the accident process for examination using Reason's approach. On the other hand, Johnson (1999) (who was investigating a railway accident) found that the Reason approach could direct attention to parts of that accident, which were then subjected to detailed modelling.

Summary

To summarise this section of the review, the present concept of causation is that it is the linkage between logically connected events and states. It is recognised that, at least in tightly controlled environments such as air transport, an accident is a complex interaction of events and states. Hendrick and Benner (1987) advocated the view that an accident is a process, not a static situation, and this gives rise to the possibility that means of controlling processes, devised in industry, might be of value in averting future accidents.

Helmreich (1990), Johnson (1980) and Reason (1990) have shown that there are likely to be underlying systems failures behind errors by personnel at the 'sharp end' of operations, whose errors are merely token failures. In order to avert future accidents, it is necessary to discover those systemic factors and address them.

Benner (1975; 1994) and Ladkin (1998) have advocated the use of formal methodologies to investigate accidents, in order to gain understanding of their underlying structure, which should enable the systemic factors to be brought to light. Formal analytical methods will be considered in the next section of the review.

Analytical Approaches

The idea of using formal analytical methods, as opposed to an unstructured approach to investigation, is not new. Benner's MES methodology was devised for use by the Hazardous Materials Bureau of the NTSB in the 1970s (Benner, 1975), and

some of the methods discussed in this section of the review are mentioned in Johnson (1980). However, in the past such ideas have not found general favour (Wood & Sweginnis, 1995). In part, this may have been due to limitations of the various methods proposed.

This section of the review commences by considering the advantages of formal methods, and then examines methods which have been proposed in the past. Methods now in limited use are then examined, and the need for further developments is discussed.

The Advantages of Formal Techniques

Wood and Sweginnis (1995) consider that the use of any formal analytical technique is better than an unstructured approach to an investigation. All formal techniques have the following advantages over an unstructured approach:

- They form a framework around which to organise the data as it is collected
- Missing links can be identified and sought
- Integration of team efforts, in a larger investigation, is easier because a model of the potential accident sequences shows how evidence supports or rebuts hypotheses
 - Report writing is simplified when a model of the accident sequence is available as a guide
 - A picture of the sequence of events is a powerful aid to communication, especially in support of recommendations.

Wood and Sweginnis (1995) divide formal analytical techniques into two broad groups: Data Management methods, and Cause Resolution methods. There is also an intermediate stage, where 'barriers' or 'defences' are considered without analysis of causation. These groups are discussed below.

Data Management Methods

Data management methods correlate data from different sources against some baseline, so that the interactions of various events can be seen. They are useful to explain the sequence of events in a complex accident. The baseline can be the aircraft's flightpath, or a timebase (Wood and Sweginnis, 1995).

Flight Path Diagrams.

Flight path diagrams are frequently used in reports. Various factors (including time) are annotated along the aircraft's flight path, as constructed from recorded data or witness evidence (Wood and Sweginnis, 1995). The flight path diagram from the report of the accident to ZK-NZP (OAAI, 1980) is shown in Figures 7a and 7b.

Matrix Analysis.

Matrix analysis is a method of resolving uncertainty generated by apparently conflicting data, such as witness statements about the same event. Observations of events are arrayed by observer, and in sequence, so that observations of the same events are in proximity. This enables discrepancies to be seen, so that the causes of discrepancies may be accounted for. If exact time is available, a timebase could be used.

Sequentially Timed Events Plotting.

In Sequentially Timed Events Plotting (STEP), all known events are plotted against time (Hendrick and Benner, 1987). When possible, the time taken for an event (for example a radio communication) is also shown. STEP is similar in function to flight path plotting, but the baseline is time. However, Hendrick and Benner (1987) take the view that the use of causal linkages in STEP, and the 'necessary and sufficient' test for logical validity of entities, raise STEP into the category of cause resolution methods, discussed later.

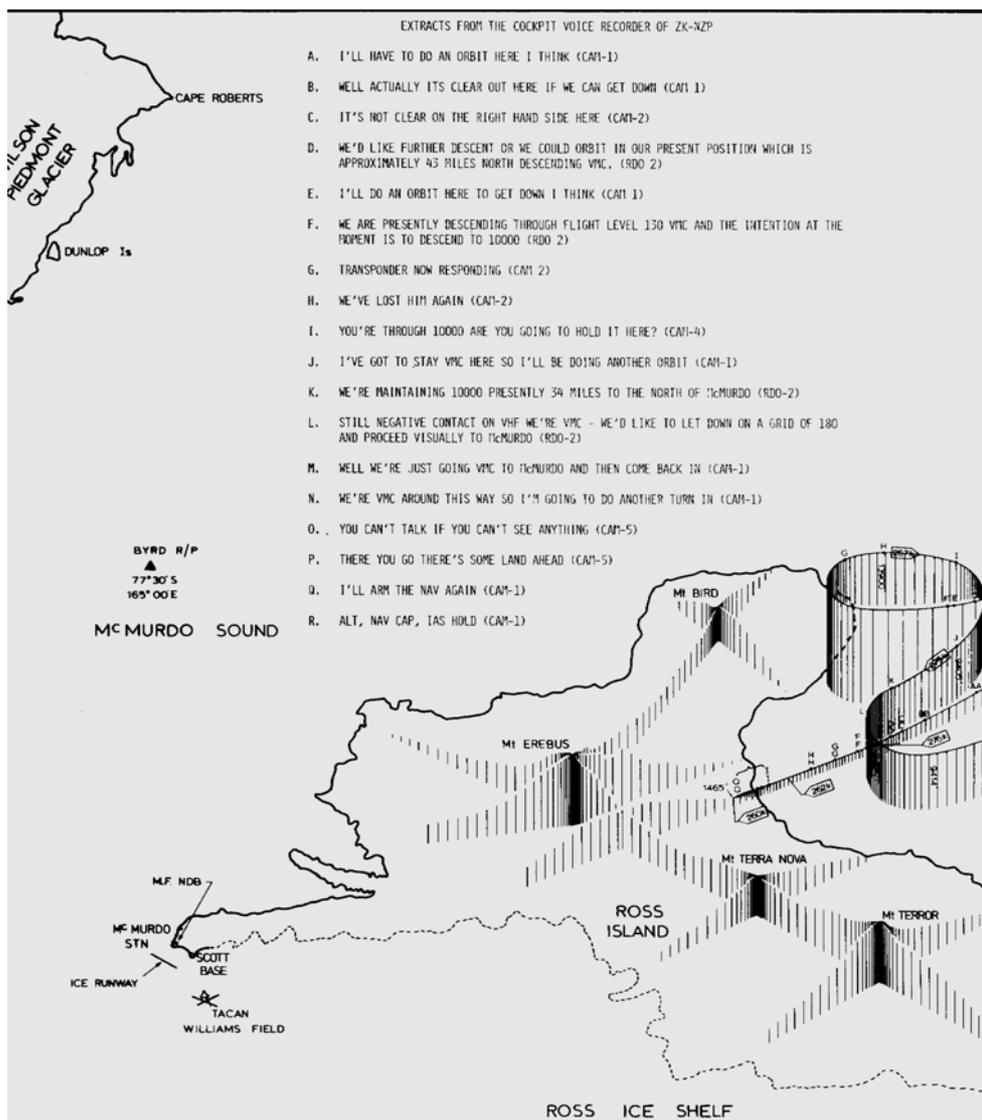


Figure 7a. First part of Flight Path Diagram. (Source: OAAI. (1980). *Air New Zealand McDonnell Douglas DC10-30 ZK-NZP Ross Island, Antarctica* (Aircraft accident report No. 79-139). Wellington: Government Printer.).

Key:

- A. I'll have to do an orbit here, I think
- B. Well actually its clear out here if you can get down
- C. It's not clear on the right hand side here
- D. We'd like further descent or we could orbit in our present position which is approximately 43 miles North descending VMC
- E. I'll do an orbit here to get down, I think
- F. We are presently descending through Flight Level 130 VMC and the intention at the moment is to descend to 10,000
- G. Transponder now responding
- H. We've lost him again
- I. You're through 10,000, are you going to hold it here?
- J. I've got to stay VMC here, so I'll be doing another orbit
- K. We're maintaining 10,000 presently 34 miles to the North of McMurdo
- L. Still negative contact on VHF we're VMC - we'd like to let down on a grid of 180 and proceed visually to McMurdo
- M. Well we're just going VMC to McMurdo and then come back in
- N. We're VMC around this way so I'm going to do another turn in
- O. You can't talk if you can't see anything
- P. There you go, there's some land ahead
- Q. I'll arm the Nav again
- R. Alt, Nav Cap, IAS Hold

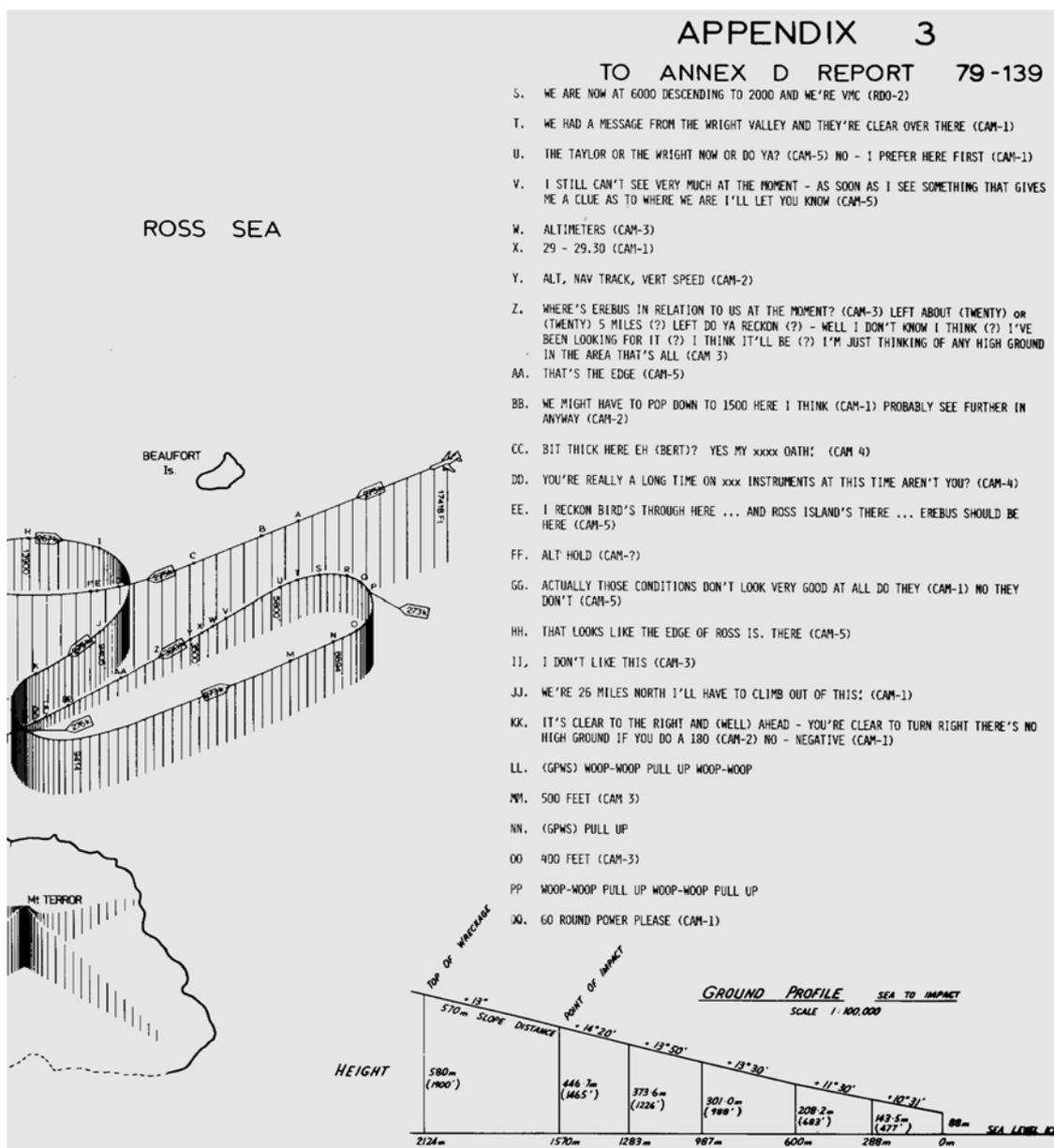


Figure 7b Second part of Flight Path Diagram. (Source: OAAI. (1980). *Air New Zealand McDonnell Douglas DC10-30 ZK-NZP Ross Island, Antarctica* (Aircraft accident report No. 79-139). Wellington: Government Printer.).

Key:

- S. We're now at 6000 descending to 2000 and we're VMC
- T. We had a message from the Wright Valley and they're clear over there
- U. The Taylor or the Wright now or do ya/ No - I prefer here first
- V. I still can't see very much at the moment - as soon as I see something that gives me a clue as to where we are I'll let you know
- W. Altimeters
- X. 29 - 29.30
- Y. Alt, Nav Track, Vert Speed
- Z. Where's Erebus in relation to us at the moment?/ Left about twenty or twenty five miles, I think/ Left do, ya reckon (?) Well I don't know I think (?) I've been looking for it?) I think it'll be (?) I'm just thinking of any high ground in the area, that's all
- AA. That's the edge
- BB. We might have to pop down to 1500 here, I think/ Probably see further in anyway
- CC. Bit thick here, eh (Bert)? / Yes my xxxx oath!
- DD. You're really a long time on xxx instruments at this time, aren't you?
- EE. I reckon Bird's through here... and Ross Island's there... Erebus should be here

FF. Alt Hold

GG. Actually these conditions don't look very good at all, do they?/ No they don't

HH. That looks like the edge of Ross is there

II. I don't like this

JJ. We're 26 miles North, I'll have to climb out of this

KK. It's clear to the right, and (well) ahead – you're clear to turn right, there's no high ground if you do a 180

LL. (GPWS) Woop-woop pull up woop-woop

MM. 500 feet.

NN. (GPWS) Pull up

OO. 400 feet

PP. Woop-woop pull up woop-woop

QQ. Go-around power, please

Barriers and Defences

Reason's (1991) concept of 'defences', as being devices which can retrieve the situation after a potentially catastrophic error, has subsequently been extended to mean any intervention which might prevent the propagation of an accident process: see, for example, Maurino et al (1995). This is analogous to the extension of the idea that 'barriers' can prevent or deflect the unwanted flow of energy, to mean general countermeasure strategies (Haddon, 1973). Proponents of both of these extensions have argued that it is unnecessary to 'solve' the accident (in the sense that the causal linkages are understood): it is sufficient to discover deficient defences and rectify them.

In aviation, this idea was first propounded by BASI in the report of the Monarch investigation (BASI 1994), which attempted to fit the various events and conditions discovered into the Reason model. There are a number of limitations to this approach (Zotov, 1996). In particular, the basic assumptions of the Reason model may not apply to a particular accident. As O'Hare (2000) pointed out, the representation of a linear sequence originating in 'fallible decisions' by high level decision makers, passing through 'line management deficiencies', 'precursors of unsafe acts', 'unsafe acts' and 'defences' may not be in accord with the reality of a particular accident. The Reason model does not allow for stochastic interactions, and it does not consider the possibility of interactions between events. Indeed, the concept of using a template for investigation is not universally accepted. The British AAIB views it as unsatisfactory (K. Smart, 1996, personal communication). The structure of an accident is unknown until the accident is investigated.

Incident Cause and Analysis Model

The Incident Cause and Analysis Model (ICAM) was introduced by BHP Billiton in 2000, as a safety investigation system aimed at producing error-tolerant defences against future occurrences (Gibb & de Landre, 2002). It is based on Reason's concept of an organisational accident stemming from organisational deficiencies such as unsound policies, which give rise to unsafe conditions, which in turn promote unsafe acts by those at the 'sharp end' of the business (Reason, 1990).

When the defences against unsafe acts (or technical failures) fail or are bypassed, an accident results. The premise behind ICAM is that while human error cannot be eliminated, the working conditions can be improved, so as to reduce the probability of accidents. The Australian Transportation Safety Board (ATSB) subsequently adopted this as a stand-alone methodology for aircraft accident investigation (Walker, 2003), on the ground that it is more economical in time than other current methods such as WBA.

The ICAM methodology involves organising ‘causal factors’ (undefined) into four categories:

- Absent or failed defences
- Individual or team actions (errors or violations)
- Task or environmental conditions, conducive to error or violation
- Organisational factors (management decisions, procedures and practices).

The investigators are then required to address all absent or failed defences, and all organisational factors which contributed to the accident.

Available information is arranged in accordance with the above scheme in order to make sense of it. This cannot be called ‘causal analysis’: it is data manipulation. Essentially, ICAM uses four ‘bins’ corresponding to the stages of the Reason model, and information is sorted into these bins. This does not involve logical analysis of causation, nor even an attempt to discover exactly ‘what happened’. If causal linkages are to be discovered, this must be done by some other means.

There is an embedded assumption within ICAM, that the Reason concept is applicable to whatever accident is being investigated. However, the Reason concept was devised from a number of case studies of large-scale organisational accidents. Those organisations, such as railways and chemical plants, were essentially monolithic: Reason stated the basic assumption was that all organisations design, build, operate and maintain their equipment (Reason, 1991). This assumption may well be largely true for BHP Billiton, but it is not valid for the aviation industry (Zotov, 1996), so the assumption that Reason’s concept of an organisational accident

can be used as a template for the investigation of aviation accidents is open to challenge.

An important limitation of the Reason concept in the aviation context is illustrated in Zotov, (1996): how are the different types of failures to be categorised, when a failure of some type in one organisation impinges on another organisation as a failure of another type? Into which bin is it to be sorted? For example, the unsafe action of an engineer in a maintenance organisation, which cracked an engine mount, led to an unsafe condition in the operator's aircraft (an engine mount subject to rapid fatigue) which led to a technical failure, loss of engine and flap drive. This was an unsafe condition which, combined with a latent failure (inadequate training, leading to inadequate understanding of the required response by the pilots) resulted in the loss of a degraded but flyable aircraft (Ladkin, 1996; NTSB, 1979). If a technique involves sorting data into bins, it is critical that the labelling of data be unambiguous.

While ICAM purports to form clear recommendations for identifying and correcting system deficiencies (Gibb & de Landre, 2002), it has no provision for examining whether proposed changes will in fact produce the desired improvement, nor whether undesired interactions may produce a negative outcome. Recommendations are required to address *all* absent or failed defences, and *all* organisational factors: these are not prioritised in any way. This process is likely to result in a plethora of recommendations, which is a recipe for the sort of inaction that (Taylor, 1998) reported.

In summary, ICAM does not show the linkages between events, which would enable understanding of *what* happened; nor does it provide logical analysis showing *why* events turned out the way they did. If this understanding is to be obtained, it must be achieved separately from ICAM. ICAM is a data manipulation which seeks to sort out the matters that need to be addressed to avert recurrence of the accident. The technique provides no prioritisation of recommendations, nor does it show dependencies between them. In Dettmer's terminology, it does not distinguish between undesirable effects and core problems (Dettmer, 1997). It can be expected to produce a plethora of recommendations. It has no facility to discover whether there might be adverse results if recommendations are implemented, nor has it any facility to devise ways of implementing them (or indeed to test for feasibility). Adverse

consequences where a recommendation is implemented are likely to have an adverse effect on the credibility of the investigating organisation. The lack of logical linkages means that there is no clear support for the recommendations, which may be unpersuasive in consequence, and a plethora of unprioritised recommendations is a recipe for inaction.

Barrier Analysis

Hollnagel (1999; 2001) has propounded the use of ‘barriers’ as defined above. Four different types of barriers to the occurrence of an accident are proposed:

- Material – physical prevention of an action e.g. a blast wall
- Functional, impeding action as by an interlock
- Symbolic (warnings) and
- Immaterial – knowledge by the user, e.g. procedures.

The barrier concept was first proposed by Haddon (1973). Harmful energy transfer may be minimised by interposing barriers of ten different kinds, ranging from preventing the initial marshalling of the form of energy, to recuperative measures after an accident. In order to specify the appropriate countermeasure, it is necessary to have a model of the unwanted phenomena.

The term ‘barrier’, which in everyday speech means a physical obstacle, is stretched when it is applied to mental concepts such as procedures known to the operator, and it might be more helpful to replace it with a more general term such as ‘intervention’. Also, Hale, Goossens et al. (2004) argue that ‘immaterial barriers’ are only parts of a total barrier function, since on their own they achieve nothing.

Hollnagel’s initial proposition is that “the very fact that an accident has taken place means that one or more barriers has failed” (Hollnagel, 1999, p. 175). This is in accordance with his view that an accident is due to variability of normal processes, combined with random effects: as such, it is unpredictable. It is therefore more important to have preventive barriers in place than to try to eliminate detailed causal factors, which may never coincide in the same way again. However, he does take the

point that the aetiology of an accident must be understood and causal pathways identified, so that effective barriers can be devised.

The concept of an accident occurring because of failure of a barrier is essentially negative. It denies the possibility of beneficial change averting future accidents. However, such beneficial changes can be made. For example, if it is identified that an accident can be traced to lack of resources, in turn due to insufficient availability of funds, then a remedy could be measures that improve funding, for example business changes which increase profitability. While this could be a valid intervention (see, for example, Mumford (2001)) it would be stretching the concept to breaking point to suggest that it was a 'barrier'.

While rebuttal of Hollnagel's initial proposition does not of itself invalidate the concept of 'barriers' as useful safety devices, it does demonstrate that barrier analysis is simply one available tool, not the whole answer.

Hollnagel asserts (without providing justification) that sequential models such as networks depicting an accident suffer from being oversimplified, and such analysis becomes "a search for recognisable specific causes and well-defined cause-effect links. The underlying assumption is that causes, once they have been found, can be eliminated or enclosed." However, no such assumption can be found in modern charting methods such as MES or WBA (discussed in detail later) which seek to provide understanding of aetiology. The TOC (also discussed later) is expressly designed to go past looking at individual causal links, to locate underlying core problems, and the solutions to these core problems – 'injections', in the TOC literature, or interventions – may well act in the way that Hollnagel advocates.

The core of Hollnagel's argument is that the determination of 'the cause' of an accident is a relative rather than an absolute process. He asserts that a cause 'usually has' the characteristics that

- It can unequivocally be associated with a system structure or a function
- It is possible to do something to reduce or eliminate the cause within accepted limits of cost and time

- The cause conforms to the current norms for explanations, as encapsulated by the theories that are part of the common lore

However, these assertions are open to dispute:

- Causation, as defined by Lewis (1973; 1986) is not in any way associated with a system structure or function. Rather, it is the link showing how the system progressed from one event or condition to another, and it exists if, in the nearest possible worlds in which the first state or event did not occur, neither did the second.
- The ability or otherwise to eliminate a cause has nothing to do with the existence of a cause. For example, it may be that Government policies have had unintended effects which can be shown to have been causal. Merely that changing Government policies may prove impossible does not make them in any way less causal.
- The third point might be true of informal analysis: having found ‘pilot error’, no need might be seen to go beyond this. However, formal analysis will display lack of understanding, and force deeper insight. For example, a WBA showing pilot error, engineering error, and policy errors in training and maintenance, will raise the question as to why such a state of affairs could exist, and prompt the search for underlying reasons. It thus goes beyond token failures towards underlying core problems.

The concept of ‘the cause’ of an accident is embedded in some legislation, such as the law underlying the NTSB’s activities (Miller 1991). The deficiency of this concept has long been recognised, and where it is enshrined in law in this way, it has been circumvented by lengthy causal statements covering the various factors involved.

Hollnagel defines errors as ‘actions which have gone wrong’; i.e. errors are equated with action slips (or possibly, procedural or reasoning mistakes). This approach overlooks memory lapses, which are the largest single category of error in aviation maintenance (Reason and Hobbs 2003), and it takes no account of intentional procedural violations. His definition takes no account of distraction, yet a single distraction can have catastrophic consequences, as where a high rate of descent is not

arrested because the crew is preoccupied with a mechanical failure and the aircraft collides with terrain.

He argues that, from his definition, ‘the verdict of an incorrectly-performed action is clearly a relative rather than an absolute judgement’, and that what has happened is that the normal variability of performance has gone beyond acceptable limits. He asserts that ‘the basis for performance variability is always the same, and it is merely the outcome which causes it to be classified as an error’. However, at least some of the basis of performance variability (believed to be the major element, in Australian road accidents: Dawson, Feyer et al. (2001)) is fatigue. Where it is not present, there must be some other basis for the observed variability. As for ‘relative rather than absolute judgements’, this statement might well be true for informal analysis, but that is simply a case for formality. An express function of MES is the elimination of judgements in regard to error.

Hollnagel concluded that, rather than seeking to identify causes, investigators should seek to control the variability of performance.

In summary, Hollnagel’s view is that ‘causes’ represent an *ex post facto* attribution, based on over-simplified understanding of the nature of accidents. Therefore the variability should be controlled at the various stages of the accident, and this should be done by applying suitable barriers. However, Hollnagel’s views are based on definitions of error which are incomplete, definitions of causation which do not conform to current theory, on assumptions which may be true of informal analysis, but are not valid for formal analysis, and on assumptions as to the aetiology of accidents which are, at best, incomplete.

In a recent paper, Petersen (2005) reviews the concept of Barriers, from Haddon (1973) onwards, and concludes that there are theoretical problems with the extension of the term ‘barrier’ beyond its ordinary meaning. The use of a physical analogy can be unhelpful if taken too far. He prefers the term ‘countermeasure’, and derives a structure of causation exactly analogous to that in MES, where an actor performs an action which impinges on another actor (p. 5).

Cause Resolution Methods

The third type of analytical technique is cause resolution. Cause resolution methods, rather than being descriptive, are directed to organising the significant elements into a cause-and-effect relationship. Wood and Sweginnis (1995) discussed a number of such methods: **E**vents and **C**ausal Factors **A**nalysis (ECAN), Event Link Analysis Network (ELAN), Fault Tree Analysis, and Management Oversight and Risk Tree (MORT). These are examined below.

Events and Causal Factors Analysis.

Some confusion may arise because the terminology used in this application has been used with two distinct sets of meanings. Both will be discussed here, starting with the exposition in Wood and Sweginnis (1995), followed by that in the (US) Department of Energy Accident Investigation Workbook (DOE, 1999).

(1) *ECAN: (Wood and Sweginnis, 1995).*

Events and causal factors analysis (ECAN) is the graphical depiction of a mishap from beginning to end. It shows the relationship between causal factors and conditions that influenced the accident sequence⁴. Analysis commences with a sequential list of events. Each event is reviewed in turn, to decide the factors which precipitated it, and each factor is then reviewed for the root causes which set that factor in motion. The root causes are considered to be the causes of the accident. Figure 8 portrays the DC 10 accident at Chicago O'Hare (NTSB, 1979), which illustrates how 'events' are fed by 'contributing factors' which in turn are fed by 'root causes'.

⁴ For further discussion, see Johnson, W. G. (1973). *MORT, the management oversight and risk tree*. Washington: Atomic Energy Commission.

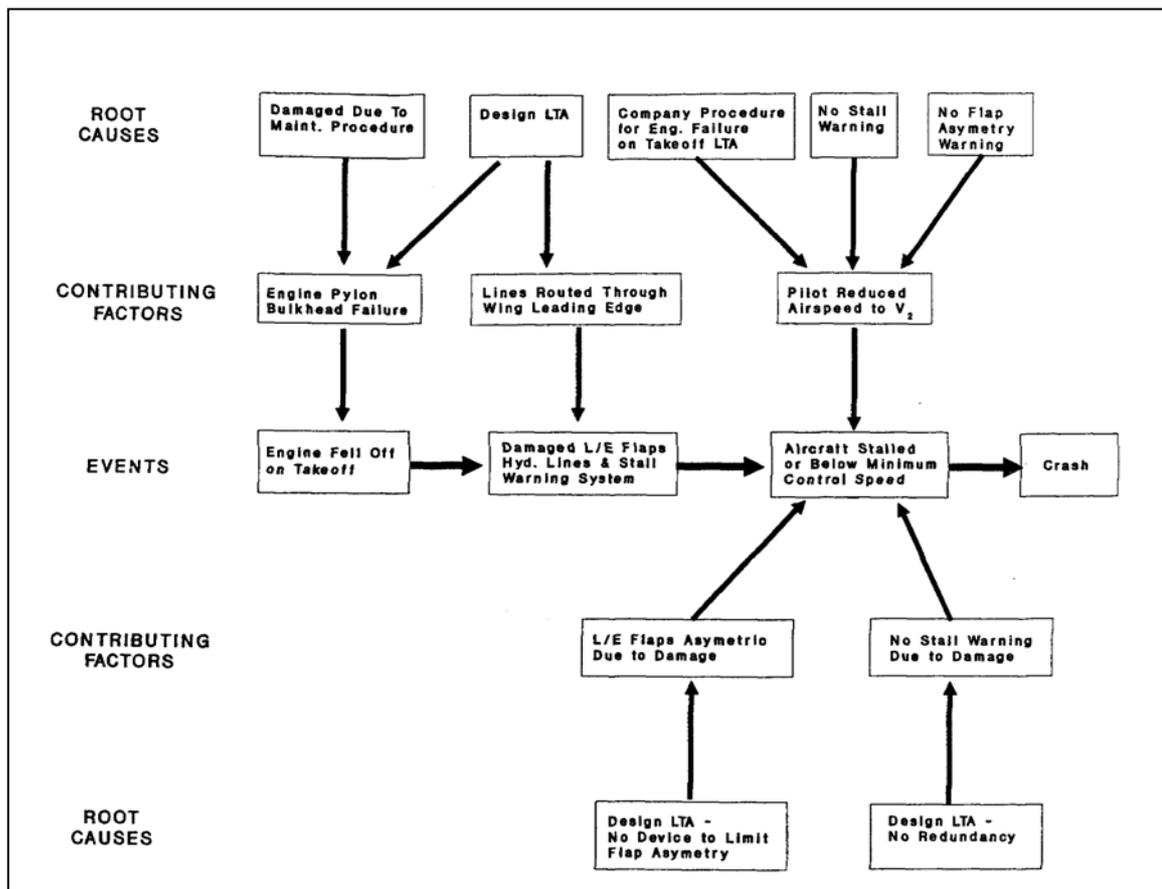


Figure 8. Events and causal factors analysis: The DC10 at Chicago. (Source: Wood, R. H., & Sweginnis, R. W. (1995). *Aircraft accident investigation*. Casper: Endeavour).

One limitation of this approach is its subjectivity, and thus lack of repeatability. For example, in Figure 8, there is no clear reason why 'engine pylon bulkhead failure' was considered to have been a 'contributing factor' rather than an 'event', so different investigators might classify them differently.

The attraction of this system is its simplicity. However, the situations which the system has to represent are not simple, and there are many additional inherent factors which it is not able to represent (Johnson, 1980). For example, the so-called 'root causes' shown in Figure 8 do not address latent failure, a concept which has been available since at least 1980 (ibid.). There is no explanation of why the structure was 'damaged due to maintenance procedure'. This could be considered an 'unsafe condition' (or the damage may have been occasioned by an 'unsafe action').

If ways are to be found to avert future accidents, it is necessary to know not only what unsafe conditions precipitated the accident (perhaps inadequate equipment available to maintenance staff?) but also what management decisions brought those

conditions about. For example, before the accident to a DC 10 resulting from physical loss of an engine, a decision to improvise, rather than to buy specialist equipment, might have led to the use of a fork-lift truck to remove and install the complete engine and pylon assembly. The resulting awkward handling resulted in damage to the pylon mount (NTSB, 1979).

Like any root cause analysis, ECAN derives a list of root causes, but does not allocate priority to one rather than another. As such, ECAN lends itself better to the 'creeping tide' approach to safety, rather than the search for the 'silver bullet'. In the 'creeping tide' approach, improved safety is sought by making many small improvements over a period of time, rather than by discovering a significant factor (the 'silver bullet') which will permit a major improvement to be achieved.

Despite its limitations, ECAN illustrated the 'precede-follow' approach, and was an advance on previous linear thinking. It was suited to long or complex causal factor chains (Gertman, 1994). Wood and Sweginnis (1995) taught this method to US Government investigators because it is simple, and forces logical thinking. The significant events are resolved one at a time. (Wood and Sweginnis (1995) did not discuss how an event is to be defined as 'significant' prior to solution of the accident).

(2) *ECAN: (DOE, 1999).*

A form of ECAN, introduced by the United States Department of Energy (DOE), does address latent failures (DOE, 1999). In the DOE Workbook, both the terms ECAN and Root Cause Analysis are used for rather different concepts than those discussed above. Examples of root causes given in DOE (1999) include failures in management systems to define clear roles and responsibilities for safety, to ensure that staff are competent, ensure safety standards are known and applied, and so on. This usage of 'root causes' is similar to Johnson's (1980) concept of latent failure.

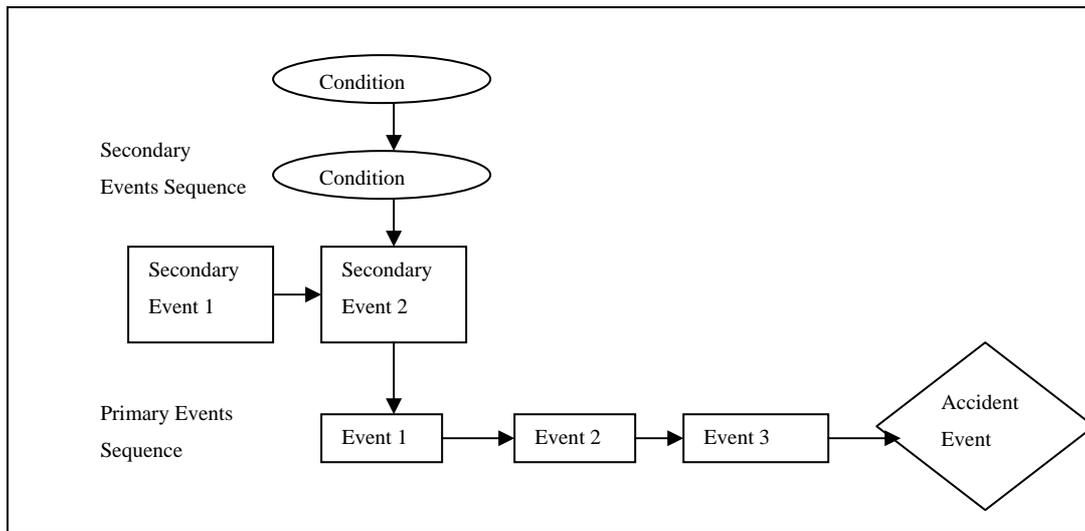


Figure 9. Events and causal factors charting. (Source: DOE. (1999). *Accident investigation workbook*. Washington, DC: Department of Energy).

Events and Causal Factors Analysis is advocated by DOE (1999) as being a simple means of depicting the process leading to an accident, and identifying the 'root causes'. A graphical display of an accident's chronology should be constructed, as information becomes available during the process of investigation. The 'primary chain of events' (defined as "the main events of the accident" (DOE, 1999, pp. 7-11)) is set out on one line. The 'secondary events' (defined as "contributing events" (ibid.)) are placed on a line above, and 'conditions' are placed above or below the events they affect (Fig. 9). 'Events' are defined in the same way as Benner's (1994) EBBs, a single actor performing a single action.

Since 'contributing' causes are defined as 'necessary to the accident', it is not clear how these are distinguished from 'primary events'. The choice would appear to be arbitrary, and so the analysis may lack repeatability.

When the chart has been completed, the significance of events is to be assessed. An event is defined as 'significant' if the accident would not have occurred,

absent that event. The significant events, and the conditions that allowed them to occur, are said to be the causal factors.

In DOE (1999), 'Root Cause Analysis' is defined as "[Identifying] the underlying deficiencies in a safety management system that, if corrected, would prevent the same or similar accidents from occurring" (p. 7-28). This is similar to identifying latent failures, as advocated by Reason.

The process of identifying root causes is illustrated in Fig. 10. There may be more than one root cause of an accident, but the Workbook states that there will probably not be more than three or four.

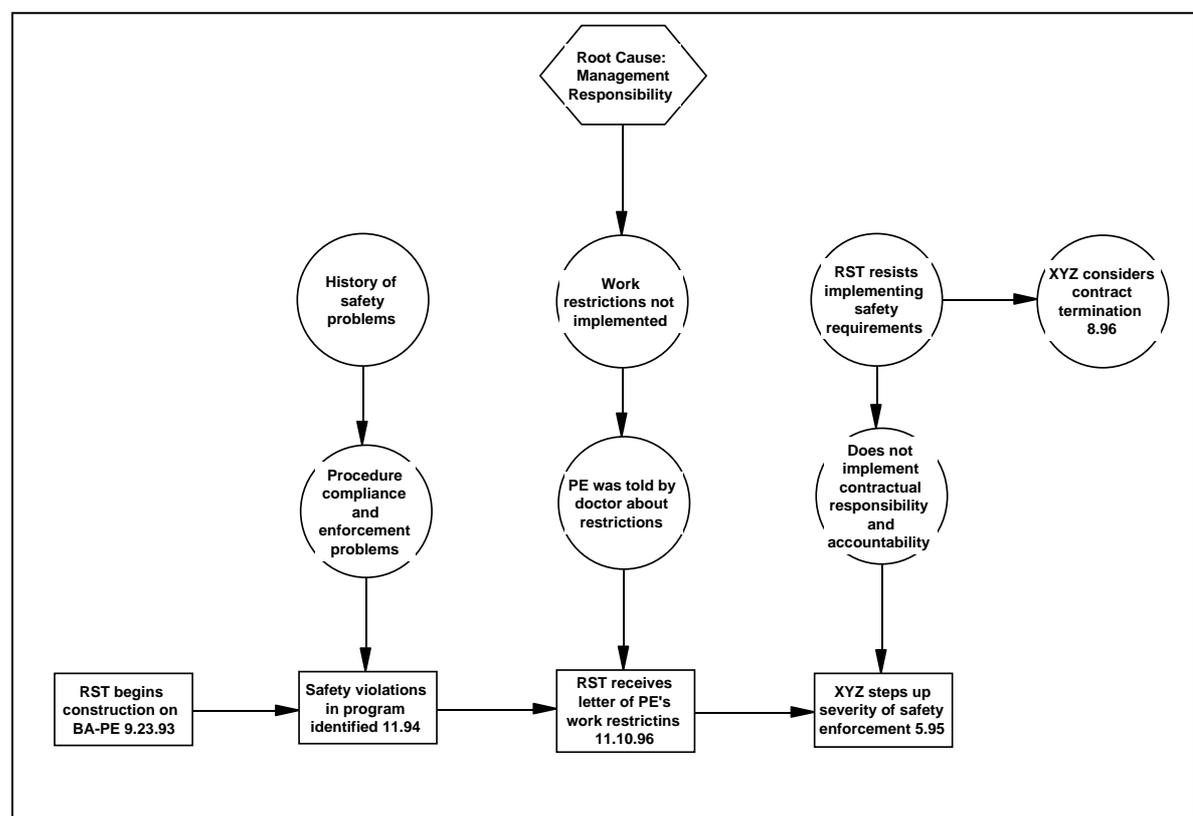


Figure 10 Deriving Root Causes from Events and Causal Factors. (Source: DOE. (1999). *Accident investigation workbook*. Washington, DC: Department of Energy).

This process of identifying root causes is not unlike the 'backtracking' advocated by Reason (1991), in that causality is traced back from actions, through conditions, to management deficiencies. Likewise, DOE (1999) advocates remedying the management deficiencies in preference to sorting out purely local problems. However, limiting consideration of management deficiencies to those in the safety management system appears to pose an unnecessary limitation in this form of root

cause analysis. Root Cause Analysis is acknowledged to be "not an exact science and therefore [requiring] a certain amount of judgement" (DOE, 1999). Any process which is subjective is likely to lack repeatability, i.e. if the analysis of the same facts is done by someone else, different root causes might be identified.

Further limitations of this form of ECAN arise from the layout of the Events and Causal Factors chart. By contrast with MES, the 'Actors', that is, the various participants in the accident sequence, all appear in one of two lines. This may make it more difficult to construct a 'mental movie' than in MES, where the individual actors have lines to themselves (Benner, 1994). Also, it is impossible to show simultaneous strings of events, and the interactions between them, unlike MES, unless one resorts to several 'primary' chains of events.

Event Link Analysis Network.

The Event Link Analysis Network (ELAN) is generally similar to ECAN, but events other than those on the 'major event' line are divided into 'lead-up events' and 'follow-on events' (Wood and Sweginnis, 1995). A central major event time-line is first established, and the events are broken into the smallest possible discrete steps. The lead-up events are placed sequentially above their major events, while the follow-on events are placed sequentially below. Usually, the bottom follow-on event will link to the top of the next lead-in event string, so that a network results. A section of an ELAN network is shown at Fig 11.

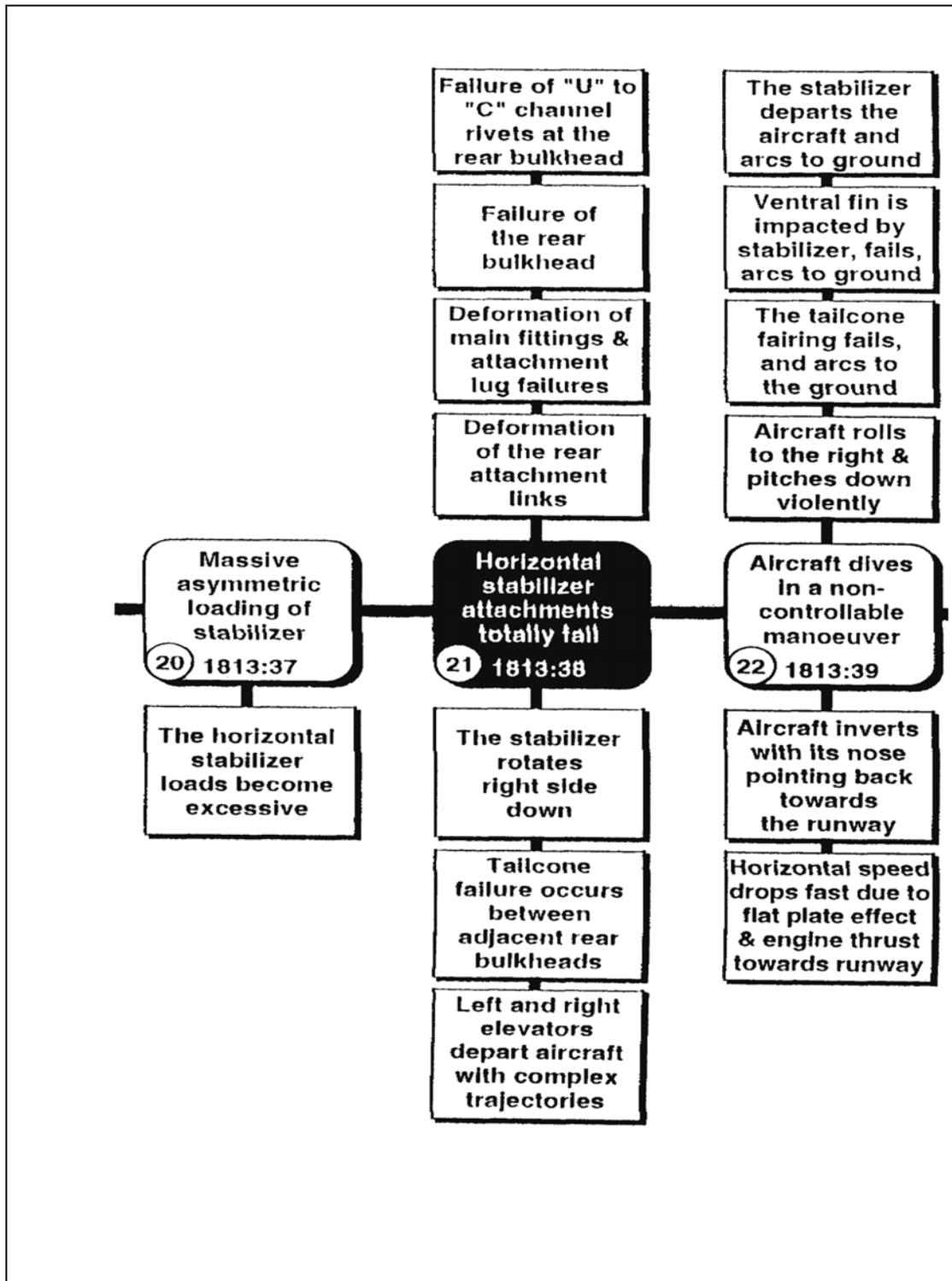


Figure 11. Event link analysis network. (Source: Wood, R. H., & Sweginnis, R. W. (1995). *Aircraft accident investigation*. Casper: Endeavour).

Wood and Sweginnis (1995) comment that this method accounts for more events and data than does ECAN. This appears to arise from splitting the major factors into small steps, each having a multiplicity of surrounding events.

Like ECAN, this method requires subjective judgement as to where items are allocated. However, the absence of a requirement for cause and effect relationships suggests that this method should be considered in the category of data manipulation, rather than cause resolution, since it is essentially descriptive.

Fault Tree Analysis.

Fault tree analysis methods start with a single event at the top, and proceed downward through layers of precipitating events. They employ deductive reasoning, i.e. starting with an accident and arriving at the reasons for it, rather than inductive reasoning which would involve starting with the reasons and showing how they led to the accident. At the lowest layer of the 'tree' are the 'root causes' (see Fig. 12). The advantage of fault tree analysis is that it forces consideration of all possible events and causes. The method is often complex, resulting in diagrams running to several pages.

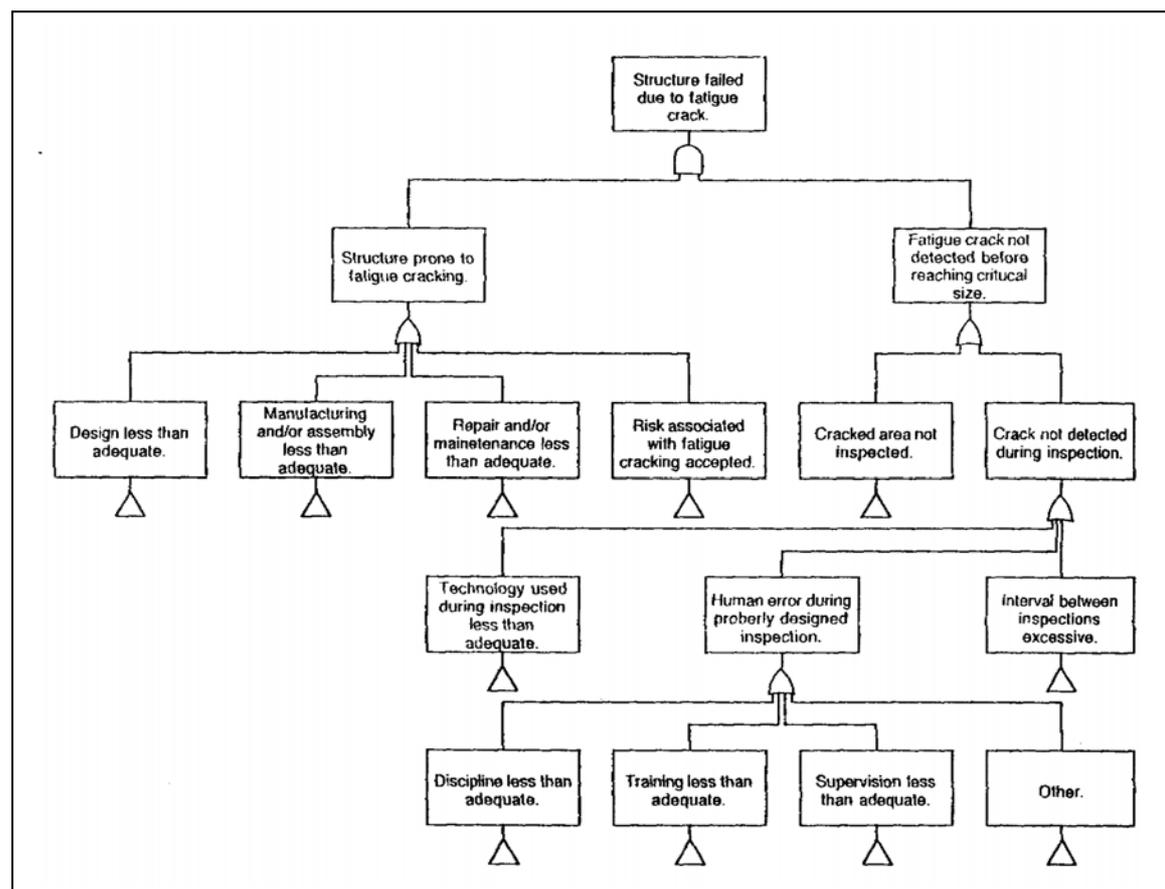


Figure 12. Fault tree analysis: development of one branch to 'Root Cause' level. (Source: Wood, R. H., & Sweginnis, R. W. (1995). *Aircraft accident investigation*. Casper: Endeavour).

While the 'root causes' show what needs fixing, there is no allocation of priorities between them. Not only does this lead to the 'creeping tide' approach to developing safety recommendations, but also it leads to difficulty in getting any recommendation implemented. In theory, *every* root cause is necessary to the accident. Accordingly, the elimination of any one should have averted the accident. Each party to whom recommendations are directed is thus in a position to argue that action by some other party would suffice, and it need take no action.

Proof of elimination of all but one branch leading to an 'or' gate in the tree should be included in the report, provided that it is possible to do so. (An 'or' gate is a point in a logic tree at which either one or the other of two alternatives is possible, but not both or neither). As Conan Doyle said, "Eliminate all other factors, and the one which remains must be the truth" (Conan Doyle, 1987, p. 143). If more than one branch remains, each explanation is feasible, and the uncertainty must be followed throughout the logic tree, to show the uncertainties in the root causes. However, if such elimination is possible but not done, the report will be ambiguous, and the reader is unlikely to be convinced that the analysis is sound. The process of elimination - Sherlock Holmes' Principle - is often inadequately documented (Wood and Sweginnis, 1995), and the graphical illustration of any potential ambiguity is very useful.

A major limitation of fault tree analysis is that time, often a critical factor in accidents, is not evident. Time is not only important for picturing events in the sequence in which they occurred, but also provides an important logical check in testing 'precede-follow' logic. If A caused B, then A must necessarily have preceded B. If the light came on and then the switch was moved, it can be said conclusively that moving that switch was not the cause of the light coming on. (Of course, the mere fact that A preceded B does not prove that A caused B).

Another important limitation of the tree structure is that it does not represent the realities of accidents, because while it shows fusion of events, it does not provide for division of causal pathways. In the tree concept, actions are seen as proceeding along a single narrowing path to the top. However, actions in one part of the tree may also interact with those in another part. Attempts have been made to portray this by the use of reference marks, appearing simultaneously at different points in the tree to

indicate such interactions: this method was used by Waldeck (1997). However, the overall network of events is not easy to visualise with this method, and there is no prompt to consider such interactions while constructing the tree.

Management Oversight and Risk Tree

The Management and Oversight Risk Tree (MORT) (Johnson, 1980) is a pre-designed logic tree intended to force examination of both operational and managerial inadequacies. It has a very elaborate structure: MORT contains some 1500 potential events. It was originally intended to be used at the design stage of system construction, to avert potential failures within the system. It can also be used for accident investigation, in which case the investigation starts with the observed failure, and is traced down the pre-defined tree structure to the system components which have induced the failure.

One fundamental feature is that MORT attributes the losses due to an accident to *either* 'oversights and omissions' *or* 'assumed risk'. 'Assumed risk' means that the appropriate level of authority has analysed and accepted the risk: a conscious decision was made to do nothing about it. This was arguably the case in the Zeebrugge ferry disaster, in which the Company's Board considered the fitting of warning lights to show the bow doors were not closed, but decided not to do so (Sheen, 1987). Where an accident results from 'oversight or omission', this indicates system deficiencies, and these should be the focus of the investigation

MORT suffers from the general limitations of fault trees, as discussed above. Wood and Sweginnis (1995) comment that it is a difficult technique to apply without formal instruction, because of the complexity of the tree structure.

According to Wood and Sweginnis (1995), formal analysis techniques of the sorts discussed above are not widely used in investigations. Possible reasons are insufficient training, or that investigators who have spent weeks gathering data may feel that a formal analysis is unnecessary. A strong reason for using formal analytical techniques is that, while the investigator may understand the accident, others must be convinced that the conclusions of the investigation are correct. For this, it is necessary to show how those conclusions were reached.

Wood and Sweginnis (1995) concluded that there is no 'one-size-fits-all' analytical technique: analysis is a tool, and should be performed in sufficient depth for the investigation concerned. "All [techniques] have their advantages and disadvantages. You should select the one that suits your needs on that particular accident" (Wood and Sweginnis, 1995, p. 414). However, they gave no guidance on making this selection.

Munson (1999) sought to find a satisfactory analytical technique for the investigation of accidents which occurred while fighting forest fires. In addition to those techniques considered by Wood and Sweginnis (1995), he reviewed Change Analysis, Managerial Factors and Multi-faceted approaches.

Change Analysis.

Change analysis was designed by the RAND Corporation for the United States Air Force (Ferry, 1988). Its objective is to consider the system of operations after an accident, in order to identify what changed, in a system that previously operated without mishap. This is analogous to Hendrick and Benner's (1987) 'perturbation' concept, but at system level. Examining changes which had been made to the 'normal' accident free system may enable causal factors to be identified. The limitations of this method are that expert knowledge of normal systems operation is essential to determine which changes from normal caused damage, and it is a very involved method when applied to complex processes. Also, like Hendrick and Benner's concept of 'perturbation', Change Analysis pre-supposes that the 'normal system' is satisfactory just because accidents have not occurred. It denies the stochastic nature of accidents, and the possibility of latent failure.

Managerial Factors Approaches.

Accidents may have their roots in management and organisational failures. Some investigators such as Fine (1976) have gone so far as to suggest that all accidents are indicators of management failure. This may be an overstatement, however, since there are demonstrable exceptions. For example, it is difficult to discern any management failures in the Comet disasters (RAE, 1954):

The Comet was the first jet airliner to enter service. Exactly one year after the first service flight, one broke up in a thunderstorm; the accident report concluded that turbulence caused the airframe to be overstressed. Shortly afterwards, another broke up in clear air near the island of Elba, in the Mediterranean Sea, and the fleet was grounded pending investigation of the accident. Recovery of the wreckage was difficult, because the depth of water was at the limit for the equipment of the day. The BOAC Comet fleet was closely inspected, and many improvements were made. Operational flying resumed, but almost immediately a third aircraft was lost, over very deep water. The fleet was again grounded. Efforts to recover the wreckage of the second aircraft were increased, and the wreckage recovered suggested that there might be a problem with metal fatigue.

An aircraft from the fleet was impressed for experimental purposes. A special tank was built within which the pressure hull of the aircraft could be contained. The wings were left protruding, and attached to these were levers which could impose loads representative of those experienced in flight. The tank was filled with water, so that if failure occurred when the interior of the fuselage was pressurised, the resulting explosion would be damped. The cyclic loads could be imposed at a rate such that the equivalent of thousands of flight hours could be achieved in a short time.

Fatigue failure of the cabin did occur in the experimental aircraft. The damage patterns were sufficiently similar to those found among the wreckage from the Elba Comet that it was concluded that there was a design defect (the use of square cut-outs in a pressure vessel) which made the aircraft vulnerable to fatigue. This defect was rectified, and the aircraft saw many years of trouble-free service.

Analytical methods to identify managerial failures have been tried by the United States Navy (Fine, 1976) and by insurers (Weaver, 1973, cited in Munson (1999)). In each case, a 'checklist' approach, requiring consideration of possible categories of failures, was adopted.

A limitation of any checklist approach is that it can only consider that which has been conceived by the checklist designers. It is incapable of dealing with 'unknown unknowns', i.e. unknown factors whose existence has not been imagined. A good example of such unknowns is the cabin pressurisation fatigue which brought

about the Comet disasters, outlined above. Benner (1994) argues that 'unknown unknowns' will be indicated, in methods such as MES, by the inability to link events. A blank in the MES structure indicates the need for further investigation or research to discover the missing linkages.

Multifaceted Approaches

Root Cause Analysis was described by Ammerman (1998). He defined a root cause as a causal factor that, when eliminated, would prevent recurrence of the problem. (Any factor that was necessary to the accident sequence would meet this criterion for a 'root cause'). A contributory cause, by contrast, may not have directly caused the mishap, but needed corrective action. This usage is different from those previously discussed, in that

- A 'root cause' is neither at the base of the tree, nor is it a form of latent failure. It is nearer to the 'significant cause' of ECAN, as discussed earlier.
- A 'contributory cause', in ECAN and ELAN, is considered to have been something that led to the significant cause, and thus is directly linked to it.

Ammerman (1998) advocated the use of a series of analytical tools to identify the root causes: Task Analysis, Change Analysis, Control/Barrier Analysis, Event and Causal Factor Charting, Interview Techniques, and Root Cause Analysis. In the use of a series of tools, his approach resembles that of Johnson (1980). Johnson advocated the use, as part of the general MORT concept, of a number of analytical techniques. Johnson conceived an accident as having a number of components:

- Energy
- Error
- Change
- Sequences
- Risk assessment

and suggested different analytical techniques for each component; for example, energy barrier analysis for the energy component.

Human Reliability Assessment.

While human error is implicit in any failure of a system designed and operated by humans, none of the analytical techniques discussed so far have been expressly concerned with examining how those human failures came about. Human reliability assessment techniques came to prominence in the nuclear industry, where it was recognised that human error had a major role to play in many mishaps (see Perrow, 1984; Rasmussen, 1980; 1982; Reason, 1990). Such errors could compromise the traditional 'defence in depth' of multiple layers of safety back-up systems.

O'Hare et al. (1994) considered that Rasmussen's (1980; 1982) classification of errors into deficiencies of skill, unsatisfactory application of rules, and deficiencies of knowledge could help investigators to decide *how* an error had occurred. Reason's analysis (Reason, 1990) might show *why* that error had come about. However, in the view of O'Hare et al. (1994) these approaches had overlooked the fundamental step of deciding *what* the error might have been. There was little guidance as to how investigators should do this. O'Hare et al. advocated the use of a taxonomy of cognitive failure, derived from the analysis of a large number of aircraft accidents, to fill this gap. Errors were classified as follows:

- Information of change in system state, not sought or gathered
- Information gathered, but incorrectly diagnosed
- Inadequate selection of a goal
- Inadequate selection of a strategy to achieve the goal
- Incorrect procedure
- Action error

The analysis developed by O'Hare et al. (1994) for use in the analysis of aircraft accidents is very similar to that devised by Hill, Harbour, Sullivan and Hallibert (1990), for consideration of human errors in accidents, for the US Department of Energy. The process devised by Hill et al. followed a sequential path, classifying errors into five steps:

- Input detection
- Input understanding

- Action selection
- Action planning
- Action execution

The first two points are the same as those listed by O'Hare et al. (1994), as is the last. However, O'Hare et al. found it necessary to elaborate on the 'action' area. They defined a goal as an overall aim, which might in itself be faulty: for example, the decision to press on in adverse weather, rather than diverting to an alternate. But even if the goal was sound, there might be more than one way to achieve it (strategies), and that chosen might be less than optimal. Thus a diversion to an alternate aerodrome might be made at high or low level, but the low-level diversion might result in high fuel consumption and so inadequate reserves at the alternate. Also, procedures (groups of actions) might be incorrectly selected or performed out of sequence, in addition to the classical action error - 'action not as intended'.

Since the characteristics of accidents have been shown to be domain-specific (see, for example, van Vuuren, 1998) it may be that the differences between the taxonomies of Hill et al., and O'Hare et al., are due to the differences in the domains considered. For analysis of aircraft accidents, therefore, the more detailed taxonomy of O'Hare et al. may be preferred. It was extensively tested on the United States Navy database (Wiegmann & Shappell, 1997), with satisfactory results. It has also been tested on the entire New Zealand aircraft accident database (Zotov, 1997), and it was found possible to classify all the errors therein using this methodology.

Combinations of Methods

Wood and Sweginnis (1995) commented that in selecting methods of analysis, there is no 'one size fits all'. This view was supported by Munson's evaluation (Munson, 1999), where he found that for his particular purpose (investigating accidents which occurred when fighting forest fires) the best solution appeared to be to use two methods in combination, MES and Fault Tree Analysis. Some methods are appropriate only for major investigations, because they require considerable resources, such as MORT (Johnson, 1980). Others have limitations in depth of investigation, which may be immaterial in simple cases. For example MES would have difficulty in identifying latent failures, but this limitation might be unimportant

in a simple accident. On the other hand, it might well be that advantage could be taken of MES's ability to arrange concrete information, preparatory to further investigation by some other method, as Munson found. The DOE (1999) approach could be regarded as an attempt to combine features of Benner's (1994) and Reason's (1991) methods. This is similar to the experience of Zotov (1996) and Johnson (1999), both of whom found that a combination of methods was advisable for the investigation of systemic errors. It could be considered to be, in effect, an application of the multi-faceted approach recommended by Johnson (1980), and by Ammerman (1998).

Summary

To summarise this section of the review, the present conception of an accident is that a process leads to an undesirable occurrence. The challenge is to understand the systemic weaknesses which resulted in the loss, so that they may be averted in future. Various graphical schemes have been devised as an aid to understanding the complex interactions which may have taken place. It is likely that more than one analytical approach may be needed for full understanding, especially of complex accidents.

Business Analysis Methods

An accident can be regarded as a process with an undesirable outcome. Processes are commonplace in business, and since not all processes may work perfectly, there are methods to control or improve them. Such methods will be examined next, to see whether they have anything to offer in the way of analysing accidents or making safety recommendations.

Control of processes in industry can be considered at three levels:

1. Prevention of deficiencies; for example, through the use of standardised procedures. This is the area of quality assurance, as exemplified by ISO 9000 and its derivatives (International Organisation for Standards, 1994).
2. Detection that some deficiency has occurred, by product sampling. This is the traditional method of quality control.

3. Problem solving, where a deficiency has occurred, so that remedies can be devised. Pareto analysis and Ishikawa Diagrams are techniques used in this area.

The quality control and quality assurance approaches are used both by the aviation industry, and regulatory authorities, in trying to ensure that routine operations are being performed safely. The ISO 9000 approach is that every operation should be reduced to procedures and documented (International Organisation for Standards, 1994). In this context, an unsafe operation must mean that a procedure has not been followed, or an additional procedure is necessary. However, merely determining that some procedure was not followed says nothing about why it was not followed, let alone how to ensure that it will be followed in future. Further, in aircraft maintenance it has been found that standard procedures have not been followed about one third of the time (van Avermaete & Hakkeling-Mesland, 2001); other domains might show similar results. It thus seems unlikely that a recommendation to add yet more procedures would of itself bring about an improvement in safety.

Pareto analysis originated in economics, but has been found to be applicable in other domains (Dixon, 2000). Empirical analysis has found that, in many different domains, about 80% of problems arise from about 20% of the possible causal factors. Accordingly, best returns from the available effort can be achieved by focussing on the important few factors, rather than on the trivial many. However, in order to produce the cumulative distribution function which will identify the important causal factors, there have to be multiple data points, i.e. many accidents. Also, since it is accepted that accidents each have multiple causes (ICAO, 1994), it would be necessary to weight the causal factors in some way, because only the most important could be used in a Pareto analysis. This approach, of weighting the causal factors, could be similar to that adopted by O'Hare et al. (1994); they used the factor which initiated the accident sequence to generate their frequency diagrams. Pareto analysis might have merit in reviewing an accident database, but has no relevance in the analysis of an individual accident.

Ishikawa (1985) developed the Ishikawa Diagram in the 1960s as a way of displaying the way in which factors in a number of areas (e.g. policy, skills and so on) could contribute to an undesired effect (Vanderbilt University, 2005). It is sometimes

called a 'fishbone diagram' because of its shape: see Figure 13. Factors furthest removed from the main stem are considered to be 'root causes,' the same usage of the term as in Johnson (1980). The fishbone diagram is something like a fault tree diagram, on its side. The fishbone diagram has the same limitation as a fault tree, in that it cannot readily show interactions between branches.

While the fishbone diagram purports to show causation, and might therefore be put in the same class as Why-Because Analysis, its primary use today is in 'brainstorming': it allows the ideas generated, in the search for causes of some undesired effect, to be linked to the outcome and grouped into classes. Since it does not have the rigorous analysis of causation found in WBA, and lacks the ability to show networks of factors, it has little to offer for accident analysis.

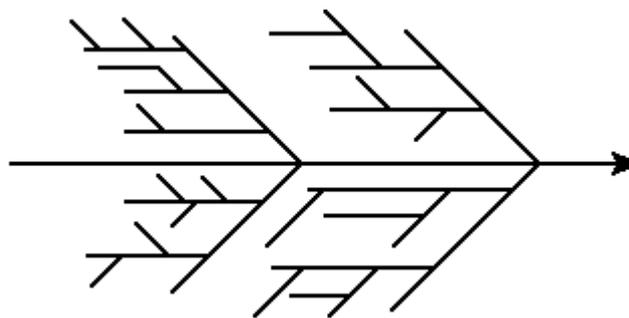


Figure 13. Fishbone Diagram.

Source: *Cause and effect diagram* (2005). [Internet]. Skymark Corporation. Retrieved 6th June, 2005, from the World Wide Web:

Total Quality Management was an industrial approach to achieving high quality products, primarily through involvement of the workforce in achieving the best results in their own areas. Continuous incremental improvement in every area was sought (Schenker, 1998), analogous to the 'creeping tide' approach to safety recommendations. However, on the production side at least, this approach appeared to have reached a point of diminishing returns. Despite efforts to improve in every area, no overall improvement was being achieved (Goldratt, 1984). Improved output in several areas, for example by introducing automation, could result in little or no increase in output from the factory. This problem motivated Goldratt to develop his Theory of Constraints (Goldratt, 1990b). The Theory of Constraints suggests that, instead of seeking piecemeal improvements, it is much more effective to find the one

(or a few) factor(s) constraining the overall performance, and focus on fixing those. Goldratt developed a set of 'thinking tools' in the form of logical flow charts, to enable the constraints to be identified, and to discover how best to fix them without introducing other problems. This approach has now found wide application in business (Mabin & Balderstone, 1998; Mabin & Davies, 2003), in a wide variety of domains. The ability to identify underlying 'core problems' (Dettmer, 1997) and devise remedies for them could make this a promising approach to making safety recommendations. It will be considered in detail in the next section.

Contemporary Analytical Procedures

It has become traditional for investigators to tell the news media that analysis cannot start until all the facts have been gathered. This is untrue (see, for example, Johnson, 1980), but it serves to get the media off the investigators' backs. The standard ICAO Report format is divided into two principal parts, factual information and analysis (ICAO, 1994), tending to perpetuate the myth that the two activities are separate. In reality, as Johnson (1980) pointed out, there is a steady shift in emphasis during the course of an investigation. At first the activity is mainly data gathering, but by the end of the investigation most of the work is analytical. Even the initial stages of data gathering will enable some lines of inquiry to be eliminated, and analysis of facts gathered will direct the investigators' attention to further areas where additional data may be sought. It is highly desirable, therefore, that analytical methods facilitate this interchange between data gathering and analysis.

The analytical methods which will be discussed in this section of the literature review do facilitate this interaction. Multilinear Events Sequencing (MES), Why-Because Analysis (WBA), and the Theory of Constraints (TOC) enable information to be displayed as it is gathered, and indicate where more needs to be obtained. Of all the methods examined so far, these three seem the most promising. They use formal logical methods to link the events and conditions discovered during the investigation, and where gaps in the logic appear, they point to the need for further data gathering. MES, WBA and TOC form a natural suite of tools of progressively increasing abstraction. By discovering weaknesses in the operation which led to the accident,

they have the potential to generate corrective action which can be shown to be effective. By no means the least important point is that they use similar charting methods and logical processes, so that when one procedure has been learnt, learning to use the others should be relatively straightforward.

Only MES is currently formally adopted by major investigating agencies, but the other two systems have a substantial literature, and are in use in other fields. It will be shown that, together, these systems could provide a suite of tools, which should be of value in the investigation of any aircraft accident.

Multilinear Events Sequencing has been in use for many years (Benner, 1975). However, it has been progressively modified (e.g. Benner, 1994) and so need not be considered dated. Unlike other systems discussed in the previous section, it has been adopted by two major investigating authorities, the United States National Transport Safety Board (NTSB) and the Canadian Transport Safety Board, and so may be considered a contemporary system. Like any analytical system, it has advantages and limitations, which will be discussed in the following section.

Why Because Analysis (Ladkin & Loer, 1998) was developed in response to perceived limitations in the analysis and investigation and reporting of some recent accidents (see, for example, Gerdsmeier et al., 1997; Ladkin, 1996). It operates at a higher level of abstraction than does MES, and might be regarded as complementary to that system, rather than in competition with it. To the author's knowledge, it has not been adopted by any investigating agency. However, it has proved effective in the analysis of systemic accidents (see, for example, Zotov, 2001), where it was shown that WBA was able to make the linkages between actions by those at the sharp end, and managerial deficiencies, as advocated by Reason (1991).

Multilinear Event Sequencing

Benner developed Multilinear Event Sequencing as an analytical tool for the NTSB, and the method has been refined over the years (Benner, 1975; Benner, 1994). Multilinear Event Sequencing (MES) is a methodology for the data-gathering phase of an accident investigation, based on the proposition that an accident is a process. A process can be depicted by a flow-chart, which is both an aid to understanding the

process, and also indicates clearly where information is lacking, and must therefore be sought. As Benner has said, "Everyone and everything has to be someplace, doing something" during the accident process (Benner, 1994, p. 1-iv). He therefore devised a system of 'Event Building Blocks' (EBBs), each comprising a single actor performing a single action, to show where everyone and everything was, and what they were doing. These EBBs form the elements of the MES flow chart. The linkages between the elements denote causal relationships. The end result is a network of related events forming a flow-chart depicting the actions comprising the accident sequence.

The MES flow-chart is constructed on a matrix having, vertically, the various actors, and horizontally, the timebase. Time conventionally flows from left to right. The time base is not annotated initially, because actual times may not be known precisely; what is important is that actions should be *in sequence*. As actions become known during the investigation, EBBs are constructed and placed in approximate position. These positions may be adjusted as further information becomes available. (Fig. 14).

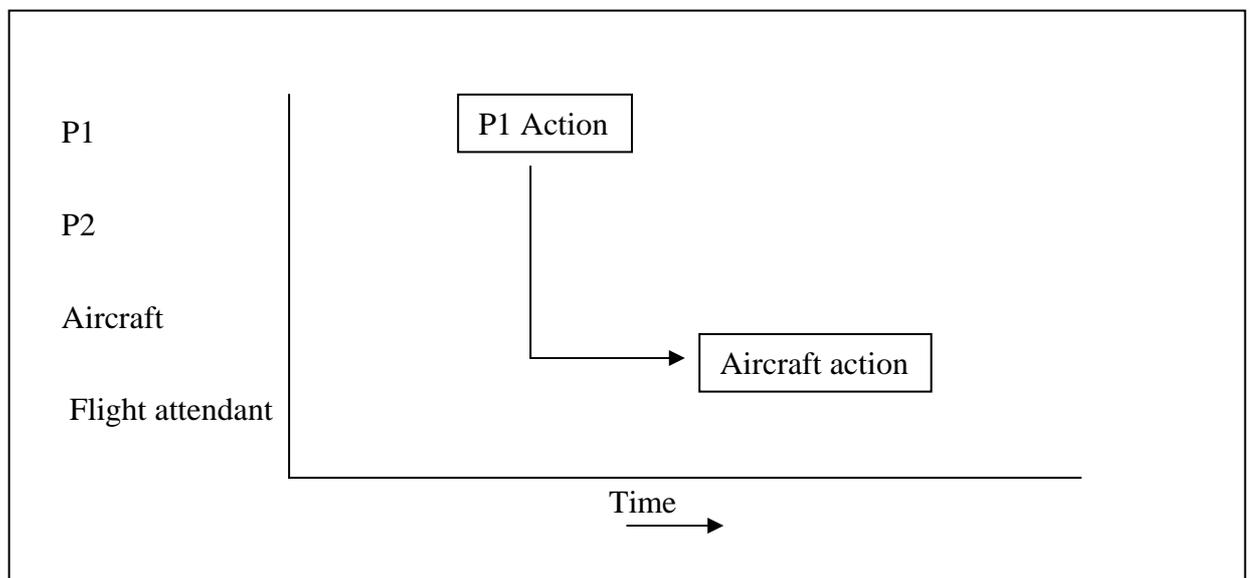


Fig. 14. MES Matrix

It is almost inevitable that there will be interactions between the various actors in the course of an accident sequence. The flow-chart thus takes on the appearance of a network. In this respect MES flow-charts differ from flow-charts based on 'tree'

Benner (1994) attributes the following benefits to MES charts:

- They enable investigators to form a 'mental movie' of the accident sequence.
- They may direct attention to missing information: where logical linkages cannot be found, one or more EBBs must be missing, so further evidence must be sought.
- Flow-charting has benefits in presentation, helping others to understand complex interactions.
- The flow-chart is an effective quality control tool. Deficiencies in logic are readily apparent, because it is easy to trace linkages on the chart.

At what point should an MES analysis commence? Rimson (1998) has suggested that it should begin with the first perturbation from the ordinary smooth flow of operations, since the analysis is designed to construct a 'mental movie' of what went wrong. It could be argued that with such a starting point, the analysis will overlook pre-existing conditions, such as failings in corporate structure, which are at the root of many accidents. Indeed it will, but such criticism would be misdirected. Latent failures, while no doubt originating in concrete actions, can seldom be depicted in concrete terms. Thus, in the Zeebrugge disaster, a latent failure was the Board decision not to fit warning lights indicating that the ferry bow doors were not locked (Sheen, 1987; Reason, 1990). The concrete actions involved in this process were presumably deliberations by the individual Board members, followed by them voting, and the Chairman recording the result of that vote. However, these details are unlikely to be known to the investigators, and would in any case be immaterial to the investigation. Latent failures are thus considered at a higher level of abstraction than the concrete actions with which MES is concerned. MES is intended to focus on concrete actions, and so is not designed to investigate abstract matters.

However, the 'point of perturbation' may not be easy to see, when real examples are examined. Take, for instance, the accident to ZK-SFB (Carruthers, 1988).

Skyferry, a company whose primary operation had been flying passengers across Cook Strait (between the North and South Islands of New Zealand), decided to branch

out into night freight operations between Wellington and Christchurch, using two Cessna 208 'Caravan' single-turboprop aircraft.

A month after the service started, one of the aircraft, ZK-SFB, was lost at sea off the Kaikoura coast. The subsequent investigation showed that at about midnight the aircraft had encountered severe icing while flying at 11 000 feet, stalled, and spun into the sea killing the pilot and a passenger. The aircraft had no airframe de-icing equipment, and there were various deficiencies in maintenance. But why had the pilot continued to fly in severe icing, when he could have escaped by descending to a lower level? In the words of one member of the subsequent Court of Inquiry, "What was he using for a brain?"

Perhaps not much. It transpired that the pilot had worked for 18 hours before the accident, had loaded and unloaded by hand some ten tons of freight, was soaked by rain while doing so (no foul weather gear was provided), had had no proper meal break before the flight and was eating sweets to sustain himself. He had had no oxygen indoctrination course, was not using the aircraft's oxygen system, and would have been mildly hypoxic. Around midnight, his body would have been reaching a low point in its circadian rhythm. The cabin heater may not have been working.

Further investigation showed that the pilot, who was the Operations Manager, and had until recently been also the Chief Pilot, had been having difficulty passing his instrument rating renewal. Previous tests of his general flying had been unsatisfactory. He had a record of previous accidents and incidents which reflected adversely on his judgement.

Surveillance by the Civil Aviation Division (CAD) of the Ministry of Transport ought to have alerted them to these shortcomings, to the excessive hours being worked, and to deficiencies in maintenance. So severe were the deficiencies in surveillance that the Chief Inspector of Air Accidents considered that he was required to bring the matter to the attention of the Attorney General, who ordered a Court of Inquiry under Mr Justice Carruthers.

Here it could be said that the operation was quite normal until ice began to form on the aircraft. But the seeds of this accident were sown in earlier actions. The

ICAO definition of an accident (and the recommended report format) would suggest that investigators should commence examination of the flight when the crew first boarded the aircraft with the intention of flying (ICAO, 1994). But this would exclude considerations of the pilot's flights and actions earlier in the day, which undoubtedly had a bearing on the pilot's actions during the flight. Should the investigation, then, start when the pilot was first woken to undertake the (unanticipated) first flight of the day? But this would preclude consideration of the very short time available for sleep – certainly a factor in the accident. None of these earlier factors were 'perturbations', in that they were not different from ordinary operations in the airline. However, merely because they were ordinary operations did not make them a good idea. In combination, they were an accident looking for somewhere to happen. They can be distinguished from 'latent failures' (Johnson, 1980; Reason, 1990) in that specific actions were involved, whereas latent failures are systemic, for example lack of an adequate surveillance system.

It seems unhelpful to have a preconceived idea of where the investigation should start. MES is a tool to serve the investigator, and it should be left to the investigator to decide how far back the 'mental movie' needs to go.

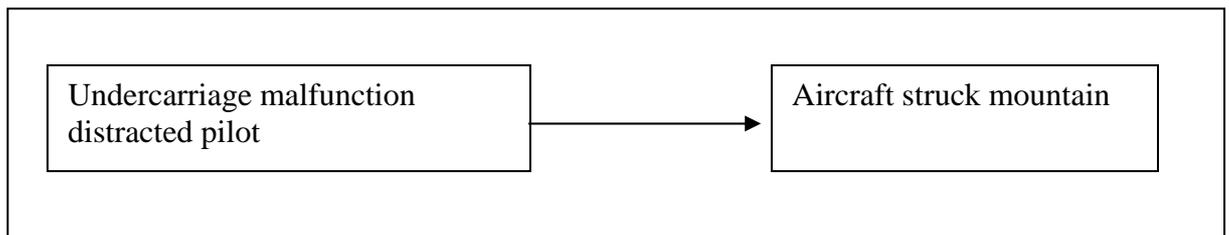
Limitations of MES

The limitations of MES come into two broad categories: limitations arising from the way the rules are defined, and inherent limitations arising from the function of MES.

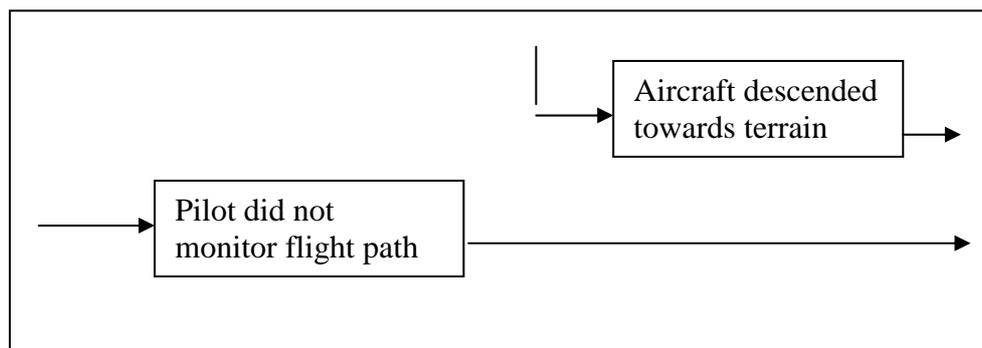
Limitations Arising from the Rules

The logical rules of necessity and sufficiency do not always fit with what is known of accident structures. The limitations of the 'necessary and sufficient' tests will be discussed later, when the Theory of Constraints is considered.

However, there is one rule which causes particular difficulty, namely the prohibition on the use of negatives. While it is undoubtedly useful to focus on what the pilot was doing rather than what, in the investigators' opinion, he should have been doing, at times this constraint causes the logic to suffer. For example,



clearly has something missing. The reality of the matter is that additional information is needed:



'Pilot did not monitor flight path' may not be a matter of opinion: it may be able to be proved by factual evidence (see, for example, TAIC, 1995). It ought not, therefore, to be excluded from the description of the accident sequence. A possible solution attempted by the author is to incorporate a commentary in a time-line across the top of the MES flow-chart, but this seems a somewhat clumsy contrivance. Alternatively, such a negative could be inserted in a different type of box, as an indication that it should be treated with caution.

Hendrick and Benner (1987) stipulate that the only permissible components of an MES chart are EBBs (defined as a single actor performing a single action) and linking arrows. However, an 'event' can take forms other than 'a single actor performing a single action'. Gerdsmeyer et al (1997) define an 'event' as an action, a once only change of state; a 'state' represents a persisting condition. They also find it necessary to define a 'state-event', where a state persists for a time which may be specified by events. An example of such a state-event would be continued descent by an aircraft, at a steady rate for a prolonged period. The initiation of the descent, and

its termination, are events, while the descent is, for that period, a continuing state of affairs.

Also, while an event can certainly cause another event, it can also cause a state, and a state can cause an event (Bennett, 1988)⁶. The MES methodology might be more general if it could be expanded to cover these aspects. In his earlier work, Benner (1975) referred to both events and conditions, 'conditions' being synonymous with continuing 'states'. However, he subsequently eliminated 'conditions', because he wished to focus investigators' attention on concrete matters during the course of an investigation (L. Benner, 2000, personal communication).

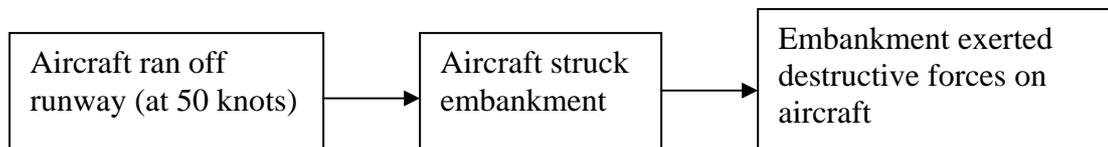
Hendrick and Benner (1978) take the view that the sequence leading up to an accident comprises events which are causally linked. Ladkin & Loer (1998) argue that this view is inadequate, since it does not allow for consideration of steady states which may influence the accident sequence. As an example of the effect of constraining the analysis to EBBs and causal linkages, consider the Airbus A310 over-run at Warsaw (Hoehl, 1997):

The aircraft overran the end of the runway and struck an earth embankment beyond the runway end. The accident investigators described the sequence of events, but did not consider the embankment to be in any way causal, and made no recommendations about it. Yet, as Ladkin points out, had the embankment not been there, the damage and loss of life would not have occurred. The presence of the embankment was a necessary condition for the disaster that ensued; its removal would certainly avert a repetition, so this would seem to be a proper matter for a safety recommendation. How did the investigators come to overlook matters which, thus stated, seem self-evident?

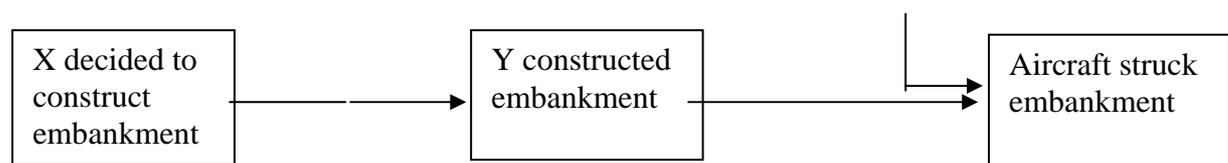
The existence of the embankment was not an event - 'something that happens' (Bennett, 1988). It was a continuing state of affairs: what Bennett refers to as a 'fact';

⁶ Bennett (1988) uses the term 'fact' to denote what Gerdsmeyer et al. (1994) call a 'state'.

and the destructive impact is something which happened – an event. This is an example of a fact causing an event (in conjunction, naturally, with other factors). Such a state of affairs could be handled, using MES, as follows (in summary form):



So far, so good. However, there is no necessary requirement to account for the presence of the embankment. If it was man-made, the graph could show



But there is no prompt to do so, and the embankment might have been constructed many years ago, perhaps before the aerodrome was built. If the embankment was natural, there is no method for injecting it into the flow-chart, and it is not permitted, under the MES rules, to write "aerodrome constructors did not remove embankment", though this might be a valid matter for consideration. It might be useful if such facts could be injected into the flow-chart, rather than arising by implication.

Limitations Arising from Function.

The purpose of MES is the description of the concrete actions which comprised the accident sequence. The focus on the concrete precludes the consideration of abstractions. Difficulties may arise if an attempt is made to apply MES to abstractions. Consider, for example, the various factors which caused the pilot of ZK-SFB to be affected by both chronic and acute fatigue (Carruthers, 1988). There were several factors, but for the sake of simplicity just two will be examined: the 18-hour duty day, and the loading and unloading of ten tons of freight by hand. Loading and unloading ('handling') the freight can be represented by an EBB:

Pilot	(actor)
Handled	(action)
Ten tons of freight	(object)

There is no difficulty in recognising that handling ten tons of freight would be conducive to fatigue, so one could say

Handling freight
Fatigued
pilot

However, this does not comply with the rules for EBBs. The gerund 'handling' is not an actor, performing an action on the pilot; indeed, it was the pilot who performed the action. It is not permitted to use the passive voice: 'the pilot was fatigued by handling the freight' – although this would undoubtedly be true.

In like fashion, while EBBs can readily be established to show that the pilot was on duty for 18 hours, there is no satisfactory way of saying that the 18-hour duty day contributed to the pilot being fatigued.

Indeed, what is fatigue? It is not (in the context of an 18-hour duty day) physical tiredness; nor is it necessarily weariness or sleepiness. A fatigued pilot may feel alert and consider that he is performing well – consider, for example, the subjective feeling of wellbeing reported by the co-pilot immediately before the accident to the DC 8 at Guantanamo Bay (NTSB, 1994). Fatigue can perhaps be described by its consequences such as slowed reaction times, narrowing of attention, lack of alertness, and poor monitoring (Dinges, 1995). It is a higher level of

abstraction than observable physical factors, but its effects are none-the-less real and a methodology for portraying accidents must be able to account for them.

In the accident to ZK-SFB outlined above, the pilot's fatigue was an ongoing state of affairs – a fact. This is an example of a number of events combining to cause a fact. This fact, in conjunction with an event (an encounter with severe icing) caused the pilot to *not detect* the accumulation of ice on the airframe, though evidence of such accumulation (the progressive reduction in airspeed until the aircraft stalled) was available to him. 'Non-detection' was also a fact, and it resulted directly in the subsequent stall and spin.

MES, as Benner (1994) has presented it, can tell us that the pilot handled freight before the accident, that the pilot was on duty for 18 hours before the accident, that there was an encounter with severe icing, and that the airspeed then reduced progressively until the aircraft stalled and spun. In putting these occurrences into order it enables us to visualise the sequence, but the rules do not allow the linkages to be made. Yet many pilots have encountered such unsatisfactory operations and can testify to the reality of the ensuing fatigue.

Naturally, man-made rules can be altered should the need arise. However, to permit greater abstraction would be to detract from the focus on concrete matters, which is the *raison d'être* of MES. This tight focus is of value during the data-gathering phase of an investigation, so rather than weaken MES in this respect, it may be better to seek other tools to deal with abstractions.

The Need for Abstraction.

As has been shown, the inability to represent abstraction in MES can cause difficulty in representing the accident sequence. However, the need for abstraction goes beyond this: it may be essential to the understanding of some accidents, which seem to recur in varying forms, notwithstanding apparent understanding of each accident. This was the case with the airliner misconfiguration accidents, discussed below: it was not until the commonality was realised that the underlying causal factors could be discovered. Also, abstraction may be necessary to display the bigger picture, and avoid being swamped by detail.

Repeated Accidents and Abstraction.

Benner has argued that 'repeated accidents' indicate that the first accident was not properly investigated (L. Benner, personal communication, 1997). Had all the factors and the true sequence of events been identified, it should not have been necessary to group accidents together to look for common factors. It is, he argues, unethical to wait until there have been several accidents before solving them, when solving the first accident correctly should have enabled the remainder to be averted.

In some cases - for example when there has been a fire - there may be insufficient remaining evidence after an accident to solve it with certainty. However, though there may be insufficient evidence to solve the particular accident, the evidence obtained during the investigation can be applied to subsequent similar cases, so that an overall picture emerges. Setting aside these cases, however, there have been groups of accidents where more focus on concrete details should have disclosed the true causal factors earlier than was the case. The Pterodactyl microlight aircraft accidents in New Zealand (TAIC, 1992), discussed earlier, were a case in point.

A series of accidents happened to microlight aircraft of a particular design, which resulted in the aircraft breaking up in flight. The separate investigations found a number of plausible reasons: pilot-induced oscillation, pre-existing damage, turbulence, and so on. However, it was not until the wreckage diagrams from all the accidents were compared that it was realised that all the aircraft had broken in the same way. There were compression fractures in tubular spars and struts, and these fractures were in the same places. From this realisation it was a straightforward process to work out what could have caused such compressive loadings: twisting of the structure, resulting in tension in bracing wires which in turn compressed the tubes. Next, it was shown that the loads were far greater than could be achieved by static forces or turbulence, so evidence of flutter was sought and found. Flutter is caused by excessive speed: it was shown that there was a design weakness (inadequate tailplane volume coefficient) which could result in the aircraft pitching forward uncontrollably when flown at speeds near the maximum permitted. The increase in speed during the ensuing dive was the cause of the flutter.

Benner's argument is that, had MES analysis been applied from the start, it should have been possible to analyse even the first accident and discover the fundamental causal factors. However, knowledge of the occurrence of the pitch-down required coherent witnesses or (as happened with a subsequent accident) a video record of the accident sequence. Nevertheless, the occurrence of flutter could have been discovered from the wreckage, and the reason sought. The explanations accepted at the time, such as pilot inexperience, were abstractions. By focussing on the concrete, MES could have shown that the explanations were not able to account for the wreckage patterns, and thus directed attention in the right direction – for example, wind-tunnel testing.

However, not all groups of accidents are amenable to focussing on concrete matters, as illustrated by the airliner misconfiguration accidents, examined next. These had to be addressed by seeking the common factors underlying the detail of the individual accident reports.

Ladkin has suggested that, when we seek common factors underlying repeated accidents, we need to go to a higher level of abstraction than the fairly detailed accounts usually found in accident reports (P. Ladkin, personal communication, 1998). When we talk of 'a higher level of abstraction', we mean that we are using increasingly general terms. Thus 'That Jersey cow with the lame left foreleg' identifies one particular cow with certainty. But we might find it useful to talk about 'cows' in general, perhaps as being subject to bovine tuberculosis. Or, more generally, 'mammals'. Or, more generally still, 'vertebrates'. These are increasingly higher levels of abstraction.

As an example of the use of a higher level of abstraction being used to bring out the fundamental factors in a group of accidents, consider the 'airliner misconfiguration' accidents in the USA (NTSB, 1988a; 1988b; 1989; 1991). The aircraft were being incorrectly configured for take-off. These misconfigurations followed no set pattern: in one case flaps were incorrectly set; in another the tailplane trim was not set to the take-off position after the previous landing. MES would ensure that the necessary physical evidence was available to confirm that the aircraft had been incorrectly configured for take-off. The cockpit voice recorders showed that the checks which would have resulted in correct configuration were not performed.

Various distracting factors were identified, which accounted for the checks being omitted: a flight attendant entering the cockpit; 'non-pertinent discussion'. Corrective actions were taken, such as the 'sterile cockpit' concept. But still the accidents happened.

The underlying factor did not come to light until the accidents were considered as a group: "the misconfiguration accidents". What had changed from previous times when such accidents did not occur was that traffic density had increased. It had formerly been the practice to perform the pre-take-off checks at the end of the runway; now, in order to save time, they were performed while taxiing to the runway. However, they could not be started before the aircraft started to taxi, because when the flaps were lowered to the take-off position, this reduced the ground clearance, which could be a hazard for personnel working in the vicinity.

The problem arose when there was a distraction of any sort, at about the time when the checks would ordinarily be commenced. If this distraction lasted beyond the time when the checks would be performed, there would be no subsequent 'triggering event' to initiate them: the window of opportunity would be lost. Even though there might still be ample time to perform the checks, there would be nothing to alert the crew to the fact that the checks had been overlooked, and it would be a matter of chance whether the omission was detected before take-off. Once the problem was realised, the introduction of a suitable triggering point, such as had formerly been provided by arrival at the end of the runway, was straightforward, and the accidents ceased.

What had brought to light the fundamental factor – 'lack of a triggering event' – was the realisation of commonality – 'misconfiguration accidents' – and of the common factor – 'distracting events'. All of these concepts are abstractions, and it is difficult to see how the solution could have been identified without them. Certainly, the experienced investigators had correctly solved each of the individual accidents – made their 'mental movies' – and located all the necessary physical evidence. But while MES could perform this function well, it is in no way derogatory to MES to suggest that it is not suited to doing the opposite of what it was designed to do, in going beyond the concrete to the abstract. Those same investigators knew exactly

what had happened, but were baffled as to why experienced crews were not performing the checks which they had performed thousands of times before.

Nesting of Occurrences.

When an accident sequence is analysed, using MES or any other flow-charting technique, it is likely that the description becomes so detailed and elaborate as to hinder comprehension. Take for example, the portion of the accident sequence to ZK-SFB labelled 'accident' (Zotov, 1996). This might comprise:

- Ice on aircraft wings caused drag to increase
- Increased drag caused airspeed to decrease
- Reduced airspeed caused lift to decrease
- Pilot raised nose to maintain height
- Increased angle of attack caused further increase in drag
- Pilot did not detect approach to stall
- Pilot raised nose until aircraft stalled
- Stall under power resulted in yaw at the stall
- The aircraft stalled and spun
- The aircraft spun continuously until it impacted the sea
- Impact with the sea caused destruction of the aircraft

Each of the many boxes representing parts of the accident sequence could be expanded in this way. While the investigation is in progress, all of the various steps and linkages must be traced and verified, but in order to 'see the wood for the trees' it is necessary to keep the overall scheme in mind. To do this, the various occurrences are 'nested' into convenient larger groupings. The above sequence was labelled the 'accident', while other nested groups (e.g. icing, hypoxia, and fatigue) led to it. These in turn were traced back to yet other nested groups: ultimately to 'under-capitalisation' and 'Civil Aviation Division supervision'. For presentation purposes, the nested groups will generally suffice to explain the accident sequence; recourse can be had to the detailed linkages should the validity of a group be challenged. The alternative, a flow-chart with hundreds of individual components and linkages, would be of little practical value either for analysis or for presentation.

Nesting is also of value in the search for commonality in repeated accidents. We might find one airline using second-hand aircraft whose cockpit layouts were not standardised (TAIC, 1996) another whose aircraft were bought without de-icing equipment (Carruthers, 1988), yet another whose aircraft had the flaps wire-locked up (OAAI, 1985a). The common underlying feature is under-capitalisation: the airlines lacked the funds to equip and maintain their aircraft properly. Under-capitalisation, in turn, resulted from the Government's policy of de-regulating the air transport industry, since the requirement for an airline to prove its financial viability was removed ("The Civil Aviation Act", 1990). Thus, nesting leads to the higher level of abstraction which is desirable in the search for common features in repeated accidents.

Conclusion

Multi-linear Event Sequencing produces a flow-chart showing the relationships between events in the accident sequence. It could perhaps be expanded in scope by permitting facts as well as events to be considered as parts of the flow chart. However, Benner (2000, personal communication) is averse to the idea because to do so might distract from the investigator's focus on concrete factors.

MES is not well adapted to considering higher levels of abstraction, which may be needed both to present information on accidents, and to analyse in depth. It deals with *what* happened, rather than *how* it happened, or *why* it happened. This is not a matter of criticism; MES was not designed for these latter functions. Its function is at the earlier stage of an investigation, focussing the investigators' attention on concrete information, and linkages between events, and also showing where more information is needed.

Abstraction is necessary for analytical and presentation purposes, so it is necessary to have available a tool which permits the consideration of abstractions. This is an important function of Ladkin's Why-Because Analysis (Ladkin & Loer, 1998), to be considered next.

Why-Because Analysis

'Why-Because Analysis' (WBA) (Ladkin & Loer, 1998) is an attempt to apply formal logic to the facts derived from an investigation. It has been found possible, using this technique, to demonstrate the logical linkages from an accident back to its corporate origins in a way that can be validated by formal logic (Zotov, 2001), thus giving practical effect to the process of back-tracking advocated by Reason (1991). In addition, it is sometimes possible with WBA to discover single 'core problems', whose eradication will eliminate whole classes of accidents (Zotov, 2001): the 'silver bullet' approach to improving safety. Recommendations dealing with core problems focus on a narrow area, and such recommendations may be more likely to be implemented than a raft of more detailed recommendations would be.

In advocating a formal system of analysis, Ladkin took as a simple example the probable cause statement in the NTSB report on the DC-10 engine loss accident at Chicago (NTSB, 1979). Describing the sequence of events in the statement of Probable Cause, using formal logic, disclosed a significant omission. The Report mentioned the following events:

- (1) Ground impact
- (2) Aircraft rolled
- (3) Asymmetric stall
- (4) Uncommanded retraction of the leading edge slats
- (5) Loss of the stall warning system
- (6) Loss of the slat disagreement system
- (7) Separation of the No. 1 engine at a critical point
- (8) Improper maintenance procedures

From the Probable Cause statement, one could infer that

(8) \sim > (7) \sim > (4) \wedge (5) \wedge (6) \sim > (3) \sim > (2) \sim > (1) (where \wedge is the logical and).

However, (5) and (6) could not lead directly to (3), (2), or (1): loss of the stall warning system or the slat disagreement system affected the pilots' perceptions or actions, not the physical control of the aircraft.

Alternatively,

$$(8) \sim\> (7) \sim\> (4) \sim\> (3) \sim\> (2) \sim\> (1)$$

would be a valid causal chain, but tests showed that the aircraft *could* have flown, had the speed remained above the stalling speed for the damaged wing. Thus, (4) did not lead inevitably to (3). Something is missing from the Statement of Probable Cause. It is to be found in the text: the aircraft was flown in accordance with Standard Operating Procedures for flight under asymmetric power, which entailed reducing speed to V_2 . This was below the stalling speed for the damaged wing, but the crew had no way of knowing this, or indeed that the wing was damaged. Thus, the missing factor is

(9) Pilots flew aircraft below stalling speed for damaged left wing

And the causal chain is

$$(8) \sim\> (7) \sim\> (5) \wedge (6) \wedge (4) \sim\> (9) \sim\> (3) \sim\> (2) \sim\> (1)$$

The importance of this omission is seen in the McDonnell Douglas response to the report (McDonnell Douglas, 1979), which stated that the stall warning system redundancy exceeded the industry standards for transport aircraft. Clearly, the stall warning system redundancy did not suffice, since the aircraft remained flyable, yet flying 'by the book' resulted in the port wing stalling. If the redundancy exceeded industry standards, then those standards did not suffice.

Ladkin (1996) concluded that formalisation can demonstrate and rectify omissions in the logic of the report, and addressing these may improve safety recommendations and the responses thereto. Why-Because Analysis is a means by which formalism can be implemented.

The basis for Why-Because Analysis (WBA) is Lewis's counterfactual definition of causal factor and causation (Lewis, 1973; 1986). "If A is a (necessary) causal factor of B, then in the nearest possible worlds in which A did not happen, neither did B" (Ladkin, 1999, p. 9). Gerdsmeyer et al. (1997) first applied this method to check the validity of the report on the American Airlines accident near Cali, Colombia (ACRC, 1996), and it has subsequently been tested on a number of other accidents, for example Hoehl (1997); Zotov (2001). It has the advantage over other methods of accident analysis, in that it can be subject to formal validation, as discussed later. There is no reason why it should not be used during an investigation, as well as in a subsequent test of validity. Doing so might improve both the logic of the report, and the persuasiveness of recommendations. It can also provide a quality control check.

Where a system failure is one of behaviour, rather than 'something broke', and where there are interactions between machine, humans and the environment, it may be unclear where faults can be traced. Aircraft accidents involve such interactions. They are among the most meticulously researched of industrial accidents, yet Ladkin (1999) has commented that the final reports on them are often inadequate. Once all salient events and contributing system states have been discovered, there remains the task of analysing causality. It is mostly in this area that deficiencies are found.

WBA extends techniques that were originally developed to specify what is expected of a digital system, to the causal analysis of systems. It is intended to handle the failure analysis of complex, open, heterogeneous systems. 'Open', in this context, means that the system is highly affected by its environment, and 'heterogeneous' means that the system has components of different types that are all supposed to work together. An aircraft is such a system.

Ladkin reviewed a number of reports of high-profile aircraft accidents, and found logical deficiencies in them (Ladkin & Loer, 1998). For example, the report of the accident to the Boeing 757 near Cali (ACRC, 1996) discussed some 60 important events or states, but the findings mentioned only a quarter of them. One finding directly contradicted a causal factor mentioned in the body of the report. One reason for mistaken logic in reports could be that an accident explanation often forms a complex structure: the causal states or events in the Cali report have 73 direct causal

connections between them (Gerdsmeier et al., 1997). WBA allows objective evaluation of events and states as causal factors.

The first step in the analysis is to develop a Why-Because Graph (WBG), showing a complete statement of the causal relations between all the elements and system states which explain the failure scenario. The graph is similar in concept to Benner's MES flowchart (Benner, 1994), the principal difference being that it includes states as well as events. The WBG is based on a formal semantics of causality introduced by Lewis, known as counterfactual argument (Lewis, 1973; Lewis, 1986). Consider the A 310 over-run at Warsaw (Hoehl, 1997), discussed previously:

... as Ladkin points out, had the embankment not been there, the damage and loss of life would not have occurred

This is a counterfactual argument.

In the usual case, where many causal factors come together to make something happen, two events or states are examined at a time, and so on pair by pair until all possibilities are covered.

The second step is verification. To ensure that the Why-Because Graph correctly represents the causal relations, and that enough factors have been identified to provide a sufficient causal explanation, a formal proof is required. The method of formal proof in Why-Because Analysis, is based on a technique used in the specification and verification of digital systems, and is discussed in detail in 'Why-Because Analysis: formal reasoning about incidents' (Ladkin & Loer, 1998).

It is not unusual for an accident investigation to be incomplete, in that the investigators are unable to find evidence relating to some state or event, and they are aware that their knowledge is inadequate. Why-Because Analysis deals with the situation where there is simply insufficient evidence to formulate a unique description, by providing an alternative description, representing the alternative possibilities as a 'Predicate-Action Diagram'. This enables the area of uncertainty to be defined, so that corrective actions can still be devised. The Predicate-Action Diagram is discussed fully in Ladkin & Loer (1998).

However, a more difficult situation arises in the case where the investigators don't know that they don't know something. These are called 'unknown unknowns' - things the investigators have not even imagined. A good example of such unknowns is the cabin pressurisation fatigue which brought about the Comet disasters (RAE, 1954), discussed earlier. Possibly, if the investigators were aware of the deficiency, a further search might find the necessary evidence. Why-Because Analysis applies a variant of Mill's Method of Difference (Mill, 1873):

To find a causal explanation of a significant fact, ask how the system behaviour would have been different had that fact not pertained. Compare the behaviour with and without that fact. The first significant place that those behaviours diverge contains a causal factor: try to identify it, and repeat the process with the new factor.

Consider again, the series of accidents to Pterodactyl microlight aircraft, involving in-flight break up (TAIC, 1992). These were postulated to have occurred through static overload, from a variety of causes: overstressing by an inexperienced pilot, gust loads from turbulence near trees, drag or bending forces arising from excessive speed, and so on. In the wreckage from one accident, it was found that a bracing wire was strained almost to breaking point, in one part of the wire only. Since static loads throughout a wire are uniform, all the factors which might have caused a static overload could have been eliminated from consideration. All that is left is dynamic (i.e. oscillatory) loading - flutter. Other evidence could then be sought, to show that torsional flutter of the wing was the damage mechanism. The structural damage in all cases was identical, so flutter was the immediate cause in all of them. The reason for the flutter could then be sought, and perhaps dealt with.

Ladkin (1999) observes that this is just an explicit formulation of good investigation practice, but has the advantage that what is explicit is also methodical. That which is methodical can be taught, and so the many can be brought up to the standard of the best (Zotov, 2000).

To deal with human actions, Ladkin (1999) uses a taxonomy to describe the sequence of stages of situational response:

Perception - Attention - Reasoning - Decision - Intention – Action (PARDIA).

There is a close similarity between PARDIA and the cognitive failure taxonomy developed by O'Hare et al. (1994), mentioned earlier. On the basis that the latter taxonomy has a sound basis in cognitive theory and has been thoroughly tested (Wiegmann & Shappell, 1997; Zotov, 1997) it might seem preferable to use it. However, Ladkin considered that the factor analysis leading to the taxonomy of O'Hare et al. is partly intuitive, whereas PARDIA is based on rigorous criteria for application. Where it was intended to do formal validation of the Why-Because Graph, it was necessary to use PARDIA, at least for this application (P. Ladkin, personal communication, 2000).

Finally, Why-Because Analysis is able to deal with the operating procedures and the regulatory framework in the same way as it handles the behaviour of the physical or digital components of a system. Both the cognitive failure taxonomy and the procedures and regulations can be specified in the same formal language that the WBA proof system uses.

Ladkin (1999) has commented that the formal proof, and other steps such as devising a predicate-action diagram, are really matters for specialists in formal logic. This is not, of itself, any barrier to the use of Why-Because Analysis in investigation. Accident investigators are well used to consulting specialists in many fields (Zotov, 2000). What is necessary is that they should understand the need for specialist input, and that they should understand what the specialists are telling them. However, it may well be that in the field stage of an investigation, Benner's simpler concept of Multilinear Event Sequencing (Benner, 1994) - forming mental movies, as Benner puts it - will be sufficient, and easier for investigators to apply.

Limitations of Why-Because Analysis.

A potential limitation of Why-Because Analysis in dealing with multiple causative factors lies in the area of the over-specified accident, such as that involving the Air Ontario F28 at Dryden (Moshansky, 1992).

A Fokker F28 operated by Air Ontario attempted to take off from Dryden, Ontario, in a snowstorm. It got airborne but failed to climb out of ground effect, and crashed into trees beyond the runway. The airframe and engines were serviceable, and the principal question for the investigators was, "Why would a captain with 24 000 hours flying experience attempt to take off with four inches of snow on the wings?"

The human factors investigation disclosed some twenty factors tending to put the crew under pressure, and the conclusion was that the crew was under such pressure that they were incapable of making a rational decision not to take off. (Helmreich, 1990; Moshansky, 1992).

In effect, what happened here was that the load on the crew exceeded some threshold value beyond which their cognitive ability declined severely. There were more than sufficient factors to bring this about: the accident was over-specified. We cannot say that absent factor x, the accident would not have happened; absent x, y, and z it might still have been feasible, and alternatively the absence of a, b and c might not have averted the accident. Yet it would be incorrect to say that the factors identified by Helmreich (1990) were not causative: some or all of them needed to be present for the accident to occur.

A second difficulty appears to lie in the binary nature of the decision: would the event or state have occurred, absent the precursor? It may be that the real answer is that it would be more likely to occur, if the precursor was present; also, it is possible that variation in the degree of the precursor would cause a subsequent factor to be present in greater or lesser degree. To take a simple example, excessive speed at touchdown will cause a longer than expected landing roll; still higher touchdown speed will cause the landing roll to be even longer, and may cause it to exceed some threshold value beyond which obstacles are encountered.

These limitations may necessitate further development.

Adding a Timebase.

As originally devised by Ladkin (Gerdsmeier et al., 1997), the WBG had no timebase, but nothing is lost by incorporating one, and there are significant advantages to doing so (Zotov, 2001). A logical test based on the sequence of events (discussed earlier) becomes easier, and also it makes the graph easier to present to a lay audience. When the graph is drawn with a timebase, there is likely to be more crossing of causal links than without a timebase, but this reflects the complex network of interacting events that may be found in reality (e.g. Zotov, 1996). Events during the flight may be placed in exact time sequence, using information from the aircraft and ATC recordings. As we go back earlier in time, our knowledge of exact timing becomes less precise, but also less important. It may be found convenient to use a quasi-logarithmic format as suggested in Zotov (1996), where the timebase is divided into 'hours before', 'days before', 'months before' and 'years before' the accident. If precise time is not available, the graph need not have an explicit timebase: arranging events in chronological order will suffice.

Conclusion.

Why-Because Analysis is able to use a wider definition of 'event' than is permissible with MES, and can also deal with continuing states, and with abstractions. The penalty for this greater flexibility may be that investigators would be less focussed on concrete matters during the early stages of an investigation, and may find it harder to visualise the accident sequence. This suggests that WBA might be best used in conjunction with MES. While the Why-Because Graph, as originally devised, did not incorporate a time-base, no penalty arises from doing so, and this addition provides significant advantages both for the investigator in understanding the accident, and in presentation. The technique is relatively new, and further development may be needed to ensure general applicability.

The Theory of Constraints

Safety Recommendations: the present system

Safety recommendations are the end point of an accident investigation (ICAO, 1994). There is no value in an investigation which gathers all the facts, and analyses them accurately, unless those who are in a position to take action to avert recurrence know what needs to be done. On superficial inspection, one might expect that the investigators, who are aware of the accident sequence and could be expected to know how to improve matters, should be empowered to issue directives, but nowhere in the world is this done, at least as far as aircraft accidents are concerned. The argument is that, while investigators know what outcome should be achieved, the way in which that outcome is achieved is best left to those familiar with the day-to-day operation of the system (Wood & Sweginnis, 1995). Also, it has been found useful to have a separation between the investigating and enforcement authorities, since those with information about an accident are less likely to be forthcoming about what might be perceived as their own shortcomings if they are speaking to an enforcement body. A further consideration is that, with present day emphasis on systemic failures, an investigating body which is part of the enforcement authority might find itself in the embarrassing position of having to report on the failings of its parent body.

If the purpose of safety recommendations is to improve the operation so that further accidents are averted, it follows that those recommendations must be sufficiently persuasive that those in a position to act are persuaded of the need to do so. Any improvement is likely to have a cost, in time, money or effort, so it is likely that resistance to change will be encountered. Charles (1991), Taylor (1998), Miller (1999; 2000), and Maurino (1999) have discussed many cases where an apparent pressing need for change was not acted upon. If the investigation results in valid safety recommendations, but no actions are taken, then the failure to persuade could be looked on as an investigative failure. By this standard, many investigations have failed in their purpose.

The Windsor accident (NTSB, 1973), the precursor to the Orly disaster (AIB, 1976), was a spectacular demonstration of a failure of persuasion, but there have been many such failures.

A DC-10 airliner was climbing over Windsor, Ontario, when an explosive decompression caused part of the cabin floor to bulge downward, and a hole appeared in the floor. A flight attendant fell into the hole and was trapped by wreckage, but was ultimately able to release herself and climb out. The distortion of the floor affected the control runs to the tail, which passed beneath the floor. Only partial elevator control remained, but by applying power to the low-mounted underwing engines, the crew were able to retain control. The aircraft landed safely. It was found that an outward-opening cargo door had been blown off by the difference between internal and external pressure as the aircraft climbed, because the door locks had not been closed correctly, and the resulting depressurisation of the hold had permitted cabin pressure to deform the floor. Recommendations included redesign of the cargo door, increased floor beam strength in wide-bodied aircraft, and blow-in ports which would equalise pressure between cabin and hold in the event of a depressurisation. These recommendations were resisted by the manufacturer on grounds of cost, and the Federal Aviation Agency accepted that improvements to the door latching system were all that was required. These improvements were not made mandatory.

18 months later, a DC-10 was climbing out from Orly near Paris, when a similar cargo door failure occurred. This time the crew were not able to operate the controls, and the aircraft flew into a forest near Orly in a shallow dive, with the loss of 346 lives. A Congressional Inquiry stated that "through regulatory non-feasances, thousands of lives were unjustifiably put at risk" (Congress, 1974). Legislation was subsequently introduced to strengthen the floors of all wide-bodied airliners.

There is a pressing need for better ways to devise and present safety recommendations so that the results of investigations can be put to work.

Outline of the Theory of Constraints

So far, a method of depicting and understanding the sequence of events in an accident process has been examined (MES), and WBA has been seen to provide a means of understanding why the accident occurred. However, as Charles (1991) and others have shown, this understanding may still leave the investigation far from achieving the stated goal, of preventing the recurrence of accidents (ICAO, 1994).

Hendrick and Benner's (1987) concept of an accident as a *process* may point the way forward. Processes and their control are commonplace in industry; perhaps methods used in industry may deal with problems sufficiently analogous to those of accident investigation, that they may be applicable. The object would be to modify the accident process so as to avert the undesirable outcomes, while interfering as little as possible with such desirable outcomes as operating profitably.

Mabin & Balderstone (1998) refer to the Theory of Constraints as a unique management philosophy. Goldratt's works are conceptually different from other books on business management, in that they are based on the methods and principles of logic used by the physical sciences. The emphasis on rigorous logic is in keeping with that of Hendrick and Benner (1987) and Ladkin and Loer (1998), and suggests the use of Goldratt's Theory of Constraints as one of a suite of related tools for accident investigation. The Theory of Constraints is examined in the following section.

Theory of Constraints Overview

The Theory of Constraints is based on the idea that a system can be likened to a chain, or more generally a network of chains, of cause and effect. The strength of any chain is dependent on its weakest link: in a system, this weakest link is the constraint on overall performance. The aim of the TOC is therefore to identify such constraints, and make the necessary changes to eliminate them.

'The Goal' (Goldratt, 1984) is a novel based in an engineering plant. Goldratt himself appears in it as a Socratic professor, Jonah, who has given his name to Goldratt's teaching system, the Jonah Programme. In the novel, Goldratt explains his ideas on managing constraints to improve the overall performance of the plant, rather

than seeking to make piecemeal local improvements. In a second novel ('It's Not Luck', (Goldratt, 1994)) he introduces methods of logical thinking to make decisions, solve problems and resolve conflicts. Non-literary works include 'The Race' (Goldratt, 1986) on production scheduling.

The TOC comprises separate but related processes:

- Performance measures
- Focussing steps
- Logical thinking processes
- Logistics

Performance measures should be those applicable to the system as a whole, not to components of it. Goldratt advocates 'throughput', the rate at which the system generates money through sales, rather than the building of inventory, as being the principle measure. This suggests that conventional accounting practices, which treat inventory as an asset lead to unsatisfactory decision-making: there was an incentive to build inventory and keep machines busy. This view has, to some degree, been accepted by the accounting profession (Noreen, Smith et al., 1995).

Anything that prevents a company from reaching its goal of making more money, now and in the future, is termed a constraint. Examples are lack of capacity, market demand, behaviour and management policies. The focussing steps are an aide memoir to locate and deal with constraints in the system's performance:

- Identify the system's constraint
 - Decide how to exploit the constraint, i.e. make the best of what is there
 - Subordinate every other improvement activity to Step 2
 - Try to break the constraint
 - If the constraint is broken, go back to Step 1 and look for the problem which has now become the constraint
- (Goldratt, 1984).

The iterative nature of this process is along the lines advocated by Deming (1993) in seeking continuous improvement.

Identifying and eliminating constraints has proved of value in production. Dettmer (1998) cites the case of improvement in custom-building cars at General Motors. The improvement was so great that this became the primary means of car

sales in the USA. More recently, the Callender Company wrote a case study of their experience of various management systems (Callender, 2004). They had had little success with such methods as 'Just-in-time' and TQM, and decided to adopt a single business theory, influenced by *The Goal* (Goldratt, 1984). They trained not only management, but the entire workforce. Over-production and waste were eliminated, and among other results lead-time reduced from 5-6 weeks to 3-4 days.

Ford Electronics recognised the transferability of TOC principles from heavy engineering, and greatly reduced cycle-time thereby. Likewise, the principles have been found to be transferable to the problem of reducing waiting times and congestion in medical treatment (Garner and Bailey, 1992; Retstein et al., 2002) while drug companies reported favourable results by focussing their efforts on promising candidates for production (Heard, 2004). In banking, identification of constraints in the form of obsolete policies and procedures was reported to have significantly improved operational performance (Bramorski et al., 1997).

The logical thinking processes developed in 'It's Not Luck' (Goldratt 1994) use a series of cause and effect diagrams to analyse the problems and their solutions. They are directed to finding the one or a few core problems from which all the other undesirable effects in a system spring: these are the system constraints.

As with the search for constraints, the application of the Logical Thinking Processes has been found not to be restricted to production manufacturing. For example, Hunnink (2001) used one of the logical tools (the Conflict Resolution Diagram, discussed later) to enable clinicians to discuss underlying assumptions, search for the best available evidence, and make well-founded decisions.

The Thinking Process tools were used by the British infrastructure group, Network Rail, who applied them to modelling the flow and capacity of the rail network (Network Rail, 2005).

The Logistics tools have received wide acceptance in the US military. For example, Air Logistics Command adopted the TOC principles officially, under the name 'Lean Logistics' (Hinnenburg et al., 1996).

Dettmer (1998) gives two illustrations of the possible use of the Thinking Process tools in aircraft accident investigation. First he illustrates the need for profound knowledge of a system being analysed, and then goes on to examine the use of a Current Reality tree to organise the information in an accident report.

Deming (1993) said that effective transformation of a system is not possible without profound knowledge of that system. (This is in line with the view of O'Hare (1994) that the investigation of accidents is the application of expert knowledge). Deming advocated, as part of that 'profound knowledge, a 'Theory of Knowledge': knowing *what* is known about the system, whether guesswork, or from observation, or from generalising observations into hypotheses. Confidence in knowledge about the system comes from the source, structure and reliability of that knowledge (p. 45).

Dettmer relates this need for profound knowledge to the need for understanding cause and effect, as in the Thinking Process logic trees. He illustrates the need for a profound depth of knowledge of how the system is supposed to work by reference to the mechanics of a take-off accident involving a B 52 bomber. It would not be possible to comprehend this accident without understanding of the fuel system, the flight control system, propulsion and aerodynamics. The CRT which he produces to display the known information is exactly analogous to a MES graph, but since the participants are not separately identified as in MES, visualisation is more difficult. This description of the detail of the accident sequence would probably be a nested element of a CRT showing underlying causation, but has no advantages over MES, and the drawback of more difficult visualisation.

The use of a CRT to organise the information from an accident investigation is illustrated using the Challenger report (Presidential Commission 1986). The purpose here is similar to that used by the present author to organise the complex information to assist the Skyferry Inquiry (Zotov 1996). While the demonstration is successful, the lack of specific relative timing, and of clear lines showing the various participants, again makes visualisation more difficult. Such a presentation could be a precursor to a search for core problems, and the construction of a FRT, but Dettmer does not pursue these developments.

Notwithstanding the limitations of these two examples, they do show that the information from accidents may be able to be displayed in a Current Reality Tree. That being so, it should be possible, in principle, to isolate underlying core problems behind the 'undesirable effect' of an aircraft striking the ground.

While Throughput Accounting and the logistics methods are not applicable to safety analysis, the concept of core problems is analogous to the 'silver bullet' approach to system safety. In arguing against attempts at piecemeal improvement, Goldratt (1984) is in effect arguing that the 'creeping tide' approach to improvement is ineffectual. The Logical Thinking Process will be examined in detail in the next section.

The Logical Thinking Process

The principle aim of Dettmer (1997) is to explain Goldratt's 'thinking process', comprising five tools. The intention is that these tools should be used to identify and execute the one or two focussed changes that will result in maximum improvement to the system being examined, with minimum expenditure of time, energy and resources. Dettmer has developed Goldratt's original concepts (Goldratt, 1984; Goldratt, 1990a; Goldratt, 1994), with the aim of making them easier to understand and apply, and also to increase their universality of application.

A 'system' is defined (Dettmer, 1997, p. 3) as "a collection of inter-related, interdependent components or processes that act in concert to turn inputs into some kind of outputs in pursuit of some goal".

The aim of the TOC is to focus effort (that is, the limited resources available) on the one point where significant overall improvement can be achieved – the constraint. The TOC provides tools to answer three questions:

- What to change (the constraint)
- What to change to (what to do with the constraint)
- How to change.

Dettmer (1997) argues that these are *system-level*, not process-level, questions. For example, in the case of a factory, it is necessary to examine the entire manufacturing system, not just the process which appears to be causing problems.

The Theory of Constraints as a Prescriptive Theory

The TOC is a prescriptive theory: it not only explains *why* things happen, but also indicates *what to do* to bring about improvement. This is unlike descriptive theory; for example the law of gravitational attraction tells us why things accelerate under gravity, but not what we can do about it. It could be argued that both MES (Hendrick and Benner, 1987) and WBA (Ladkin, 1998) are descriptive theories.

In analysing systems, the basic premise of the TOC is that "all systems operate in an environment of cause and effect. Something causes something else to happen" (Dettmer, 1997, p. 13). Undesirable effects are *not* problems, but indicators: they are the resultant effect of underlying causes. There is a parallel here, with Reason's concepts of token failure and latent failure (Reason, 1990). Remedial action on an undesirable effect, which Goldratt abbreviates to UDE (Goldratt, 1990b), provides only a temporary benefit. Eliminating the core problem which is at the root of UDEs both eliminates all UDEs stemming from that problem, and prevents their recurrence.

Dettmer (1997) considers that most constraints stem from *policies*, not physical things. Again there is the parallel with Reason's concepts of corporate failure (Reason, 1990). Reason treats 'unsafe acts' and the psychological precursors (such as time pressure) which give rise to them, as *token failures*. He argues that there is little point in addressing token failures, as they will recur in one form or another unless the underlying *failure types* are addressed. These failure types are deficiencies in line management, and underlying them, fallible decisions by top management. One example is defective policy. Many such policies were valid when first instituted, but have outlived their *raison d'être*.

The Logic Tools

The tools which are used to bring the Theory of Constraints to life are five logic trees:

a single core problem. The core problem will usually be the constraint which is being sought. The CRT, therefore, tells us *what to change*: the one measure which will have the greatest positive effect on the system. In terms of accident analysis, the core problem is similar in nature to the 'silver bullet' approach to safety measures, already discussed.

A recent development in construction of the CRT is to try to discover the core problem ab initio, by generalising known deep seated conflicts within the system, and constructing the links to the UDEs (A. Wright, 2001, personal communication). In other words, this approach commences with the conflict resolution diagram, to be discussed next.

The Conflict Resolution Diagram.

Why does the core problem exist? Goldratt (1984) postulated that this is because there is some underlying conflict preventing straightforward resolution: otherwise the problem would already have been solved. The conflict resolution diagram (CRD) is designed to disclose such conflicts. Because it is also a creative engine, it answers the first question to be asked in a change process: '*What to change?*'

The standard form of the CRD is shown in Figure 17.

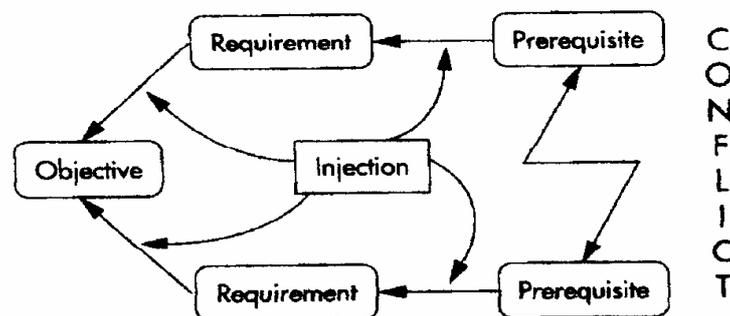


Figure 17. Conflict Resolution Diagram. (Source: Dettmer, H. W. (1997). *Goldratt's theory of constraints: a systems approach to continuous improvement*. Milwaukee: Quality Press).

The prerequisites (things which 'must' exist for the system to work) which are apparently in conflict are established, then the requirements which give rise to those prerequisites. The requirements stem from the goal (for example 'to run a profitable

airline'). The 'injections' shown are changes which, if made, will break the links which make the logic valid. Often, there will be hidden assumptions behind 'the way things are done', and if one or several of those assumptions can be shown to be no longer valid, the apparent conflict, shown by the zigzag line, may vanish - what Goldratt calls an 'evaporating cloud' (Goldratt & Fox, 1987). A fully-worked example is shown in the case study of the use of the TOC to analyse an accident, in the latter part of this thesis

The Future Reality Tree.

The Future Reality Tree (FRT) shows the system as it should be, free from UDEs. By constructing the FRT, it can be shown that the proposed changes will in fact produce the desired results. The FRT has the further benefit that any new undesirable consequence of such change (known as a Negative Branch) can be identified, so that it can be nipped in the bud. Thus the logic of proposals can be tested before too much time or too many resources have been expended. This tool answers the second question to be answered in a change process, 'What to change to?' by validating the proposed new system. (See Figure 18).

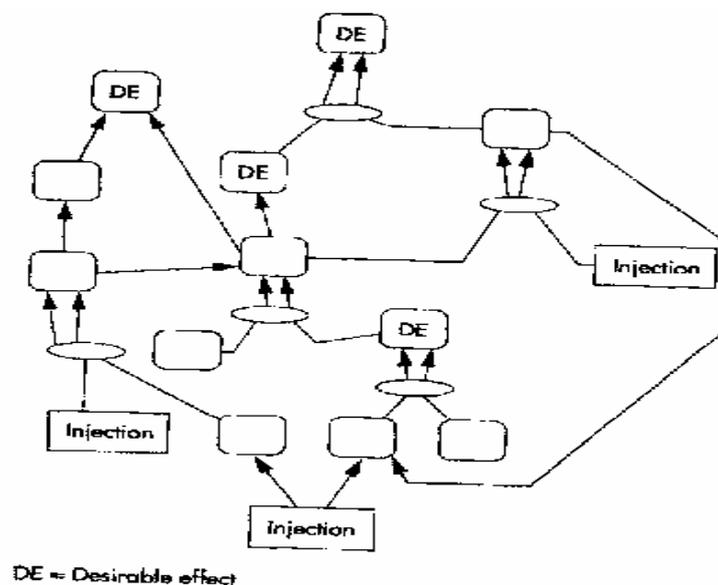


Figure 18. Future Reality Tree. (Source: Dettmer, H. W. (1997). *Goldratt's theory of constraints: a systems approach to continuous improvement*. Milwaukee: Quality Press)

Initial 'injections' have been made to change the system, in such a way that the UDEs are replaced by 'Desirable Effects' (DEs). However, in tracing the effects of these injections through the system, it is possible that they may be found to give rise

The Transition Tree is not always needed. It is employed where the way to reach an intermediate objective in the PRT is not immediately apparent. It has been likened to a ladder, leading to intermediate objectives, in a three-dimensional diagram (A. Wright, personal communication, 2001). Needs are matched with specific actions, to produce a series of effects which lead in due course to the objective sought.

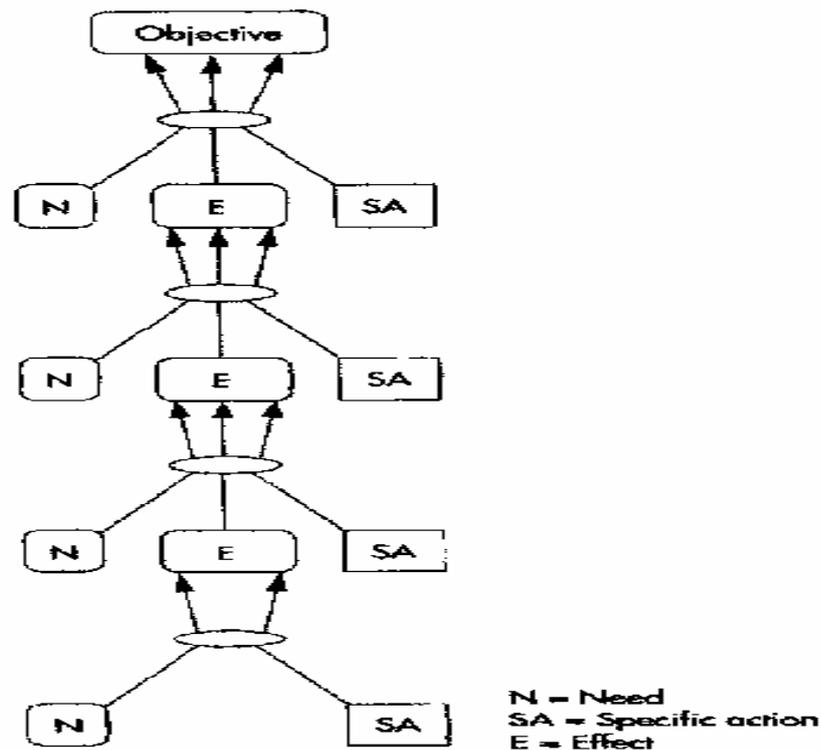


Figure 20. The Transition Tree. (Source: Dettmer, H. W. (1997). *Goldratt's theory of constraints: a systems approach to continuous improvement*. Milwaukee: Quality Press).

The Categories of Legitimate Reservation

Dettmer (1997) describes the Categories of Legitimate Reservation as the logical glue that holds the trees together. They comprise eight logical rules that govern the construction and review of the trees. They are discussed in detail in Dettmer (1997):

- Clarity
- Entity existence
- Causality existence

- Cause sufficiency
- Additional Cause
- Cause-effect reversal
- Predicted effect existence
- Tautology

Not only are these rules used in the construction and review of trees, but also they have been found to be a good way to express disagreement with others during the construction and review processes, so promoting understanding instead of the animosity which might otherwise be encountered.

The 'Thinking Process'

The individual tools outlined above can be used separately; there is no requirement to use all of them. For example, if all that is necessary is to discover what is happening in a system, it might suffice to construct just the CRT. This might be the case where the remedial action, once the problem is identified, is self-evident and non-controversial. However, used together the tools form an integrated 'thinking process'. The TOC can be seen as a methodology for managing change. It may be that adoption of this methodology could allow investigators to go beyond the present concepts of accident investigation. By finding how best to reach a situation where accidents are avoided, and presenting this finding in a logical fashion, it may be possible to overcome the sorts of difficulties described by Charles (1991) and Taylor (1998)

An overview of this 'thinking process' appears in Figure 21. Dettmer (1997) observes that "non-quantifiable problems of broad scope and complexity are particularly prime candidates for a complete thinking process analysis" (p. 26). There could hardly be a better description of an aircraft accident investigation.

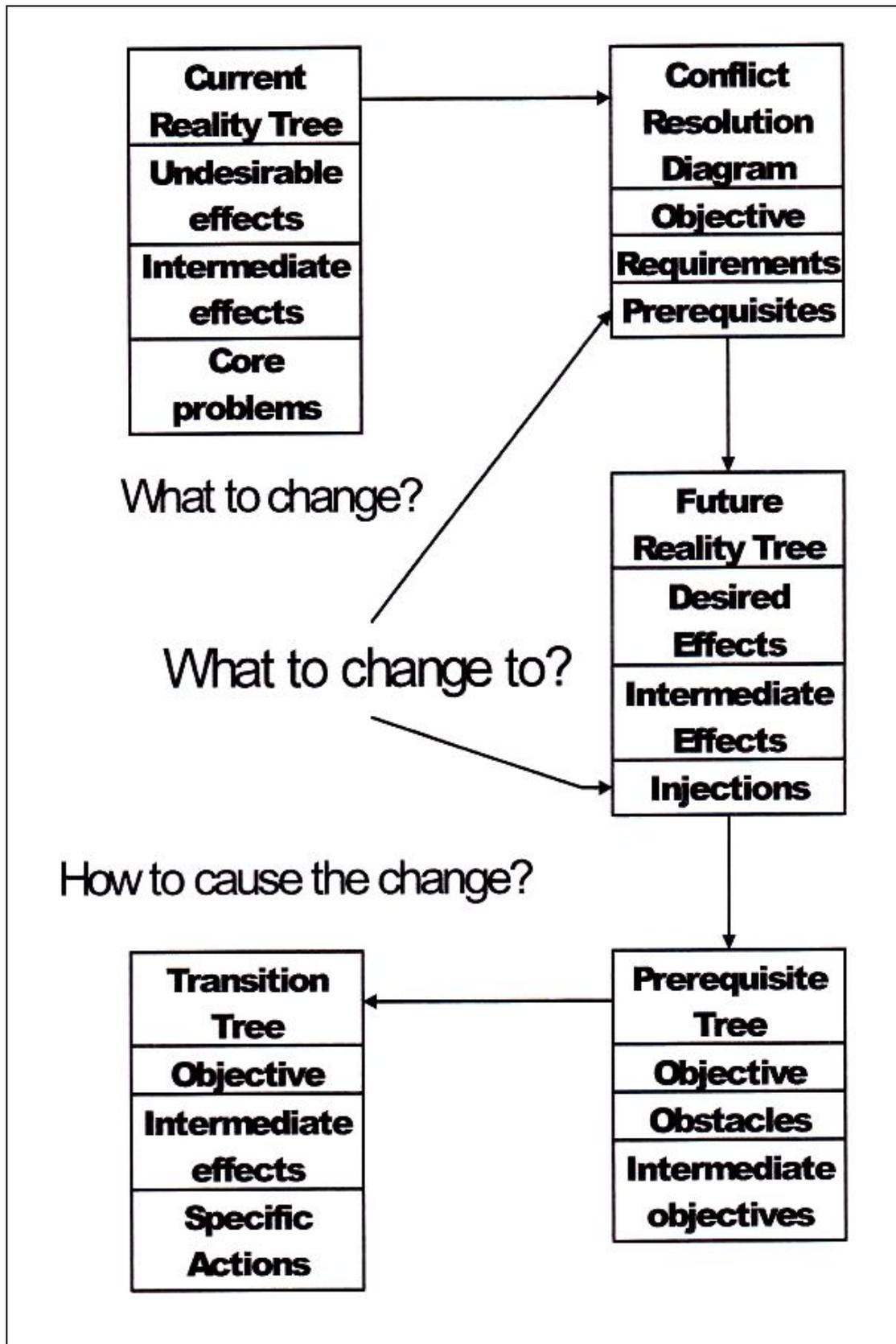


Figure 21. The Thinking Process. (Source: Dettmer, H. W. (1997). *Goldratt's theory of constraints: a systems approach to continuous improvement*. Milwaukee: Quality Press).

Summary

From the early concepts of an accident as being an undesirable event having a single cause, the present concept of an accident as a process having a multiplicity of causal factors has developed. The idea that an accident is a process gives rise to the possibility that methods used in business for the improvement of processes could have the potential for improving accident processes, so that the undesirable outcomes do not occur. Since these business methods have been developed from the need to discover effective changes *and to implement these changes*, these methods may offer a way to overcome the seemingly insuperable resistance to safety recommendations which has led to repeated accidents even when the causes of accidents have been known.

Formal methods for the analysis of accidents have been proposed for many years, but few have found favour. Formal methods should ensure that all data are gathered, and analysis is logically sound and therefore persuasive. However, earlier attempts at devising formal methods were either very complex, for example MORT, or were unlikely to produce consistent results because they contained subjective elements. Also, no advice was available as to which of the plethora of possible methods should be used in particular cases.

The use of Multilinear Event Sequencing as a data-managing tool and a means of visualising the accident sequence has stood the test of time. Because it is designed to focus the investigators' attention on concrete matters, it is not well suited to handling abstract considerations, yet these may be important for the understanding of the accident. However, the recent introduction of Why-Because Analysis provides a complementary method, able to answer the question '*Why did it happen?*', whereas MES deals with '*What happened?*'

Neither of these formal analytical methods is well suited to answering the final part of the safety question, '*How to prevent recurrence?*' This is the realm of process improvement. The Theory of Constraints is a change management methodology widely adopted in business, which has the potential to answer that question.

The Theory of Constraints was developed for the solution of business problems, and in particular for dealing with processes which were producing undesirable outcomes. There is no reference to it being used in aircraft accident investigation, but there is a wide literature of its applicability to a large variety of problems. A particular feature of the TOC is the emphasis on achieving change: in moving from the undesirable 'current reality' to a 'future reality' in which the undesirable effects do not occur. In terms of accident investigation, this offers the possibility of moving from the unsatisfactory situations disclosed by the accident under investigation, to a system without the undesirable features that precipitated the accident. Additionally, the ability to discover 'core problems' - fundamental problems which give rise to a large range of undesirable effects - offers the possibility of discovering 'silver bullets' when these are available to be found, by analysis rather than by intuition.

No one of these systems (MES, WBA or TOC) could be a universal panacea on its own. MES, with its emphasis on the concrete matters, is unable to deal with latent failure. WBA, at a higher level of abstraction than MES, is able to make the linkages advocated by Reason, but has need of inputs from MES during the data-gathering phase. TOC could not be used without the insights provided by MES and WBA, as to the current reality which needs to be changed. However, used as a suite of tools, they have the potential to make a substantial improvement to the quality of investigations.

In this thesis, an accident case study will be analysed with this suite of methodologies, in order to see whether they offer an improvement over existing informal analytical methods.

Objectives

The object of this thesis is to examine the various tools available, with a view to selecting a suite of tools which are rigorous and compatible with each other. The feasibility of using an integrated suite of tools to investigate an accident will be examined by a case study in which the known facts of an accident are treated with the suite of tools. The results of this treatment will be compared with the existing formal report of that investigation. The formal methodology would be considered successful if the output is more readily understood; more effective corrective actions are devised; and in particular if flaws in the existing report are disclosed by the application of formal methods.

Research Questions

The research questions are

1. Could the application of the methodology of the Theory of Constraints, to the data from an accident investigation, discover underlying core problems? If so,
2. Can the Theory of Constraints methodology generate improvements (i.e. Safety Recommendations) likely to be more effective than those generated by traditional analytical methods? If so,
3. Whether the use of a suite of formal tools is likely to bring about an improvement in the effectiveness of accident investigation.

Chapter 3: Research Methods

Object of the Study

The principal object of this study is to examine the potential value of the Theory of Constraints methodology as a tool for the analysis of aircraft accidents.

The defining characteristic of the Theory of Constraints methodology, as opposed to other analytical methods using flow-charting, is the ability to discover core problems, those few problems from which stem all of the other undesirable effects disclosed by the investigation. This enables attention to be focussed on 'leverage points' so that a few decisive actions can be devised to bring about improvements, rather than trying to make piecemeal improvements to all the undesirable effects which may come to light during an investigation.

Study Propositions

“Case studies, like experiments, are generalisable to theoretical propositions, and not to populations or universes” (Yin, 1994, p. 10). The aim is not to enumerate frequencies, but analytic generalisation. Propositions in case study research are broadly equivalent to hypotheses in statistical analysis. They direct attention to something that ought to be studied. However, Yin considers that where a topic is the subject of exploration (as is the present study) it may not be necessary to state propositions. Instead, “the design of an exploratory study should state a purpose, as well as the criteria by which an exploration will be judged successful” (p. 21). (Criteria for success will be discussed later). Nevertheless, it is possible to state a theoretical proposition, that

“The data from an accident investigation, when analysed using the methodology of the Theory of Constraints, will disclose one (or a few) core problems.”

If this is not found to be so, then the methodology of the Theory of Constraints would be of limited utility, at least in the case under examination.

Research Design

The usefulness of the Theory of Constraints (TOC) methodology in the analysis of an aircraft accident will be examined by using that methodology to re-examine the data from an existing accident report⁷. In order that any shortcomings in the existing report do not adversely affect the Theory of Constraints analysis, the report will first be examined with Multilinear Events Sequencing (MES), since critical review of existing reports is one of the functions which MES can perform (Benner, 1994). Additionally, the findings of the original report as to causality will be reviewed using Why-Because Analysis (WBA) (Ladkin & Loer, 1998).

The double review process will have the beneficial side effect of comparing the performance of the MES and WBA methodologies when employed on a real accident, something which has not been done before⁸.

The investigation of an accident has been shown to be case study research (Zotov, 2000). Accordingly, the plan of action calls for repeated case studies of the same accident, using different methodologies. Yin (1994) has categorised such a research design as an embedded single-case study. The objective of the repetition is not to provide a spread of data for statistical analysis, as might be done with multiple (different) cases, but to gain insight into the utility of the various analytical methods available.

The question of the ability to generalise from the results of a single case could be thought to weigh in favour of a multi-case design, but there can be strong grounds for a detailed study of a single case. "Single-cases are a common design for doing case studies... overall, the single-case design is eminently justifiable under certain

⁷ Testing during the course of an investigation in progress was considered, but rejected because of the unpredictability of a suitable accident, and because of the length of time (typically three years) which a major aircraft accident investigation takes.

⁸ Collectively, MES, WBA and TOC are referred to in this thesis as 'formal methodologies', in contrast to the present intuitive methods of analysis.

conditions” (Yin, 1994, p. 44). A single-case study is appropriate where the case represents a critical test, or is a rare or unique event, or serves a revelatory purpose. A revelatory case is one where the investigator has an opportunity to observe and analyse a phenomenon previously inaccessible to scientific observation.

It is rare indeed for access to all the data relating to an aircraft accident to be available outside official investigation agencies. However, due to unusual circumstances – civil litigation and criminal proceedings - access to all such data was available in the case of the accident to the Ansett (New Zealand) de Havilland Dash 8 aircraft near Palmerston North. In addition to all the data gathered by the official accident investigators, other documentation which had been available to them, but not gathered, was produced under the legal rules of disclosure in civil litigation. Further evidence was brought to light when the Captain of the aircraft was prosecuted for manslaughter. Additionally, unrestricted access to the aircraft wreckage was available to accident investigation classes at Massey University, while the wreckage was stored in a hangar pending the outcome of legal action. This unique access to all relevant information classifies the Ansett Dash 8 accident as a revelatory case, and so worthy of a single-case study.

There were two aspects to this case study:

1. How did the accident happen? Essentially, this question was answered several times, by using each methodology in turn, to analyse the accident as though it had just occurred, and the official investigation was being conducted using the methodology as a tool.
2. Would using the Theory of Constraints methodology enable the investigators to do a better job? The answer to this question is the research product. It involves comparison of the insights achieved by using each of the formal methodologies, and by the official investigators who were using conventional methods of analysis.

In order to answer the second question, it is of course necessary to answer the first. The individual case reports have to be written, showing in each case how the accident happened (according to the methodology being tested). Then the results from

the various methods will be compared, and general conclusions drawn. Finally, general policy implications will be discussed.

Validity

In any empirical research such as a case study, there are four aspects of quality control:

1. Internal validity – establishing causal relationships
2. Construct validity – establishing sound operational measures for the concepts being studied
3. External validity – establishing the domain to which the findings can be generalised
4. Reliability – demonstrating that operations such as data collection could be repeated, with the same results.

(Yin, 1994).

Internal validity

Internal validity deals with spurious effects in causal or explanatory case studies. Yin (1994) comments that it is inapplicable to descriptive or exploratory studies, which are not concerned with making causal statements. The present study is exploratory, as already discussed, so it might seem that internal validity need not be discussed further. However, each of the analyses comprising the separate parts of the case study could be classified as explanatory or causal: they are concerned with determining the causal relationships between events and conditions leading up to the accident. As discussed in the Review of the Literature, each methodology has safeguards built in to guard against accepting spurious relationships:

- MES is subject to tests for necessity and sufficiency
- WBA can be tested by formal logic
- TOC is subject to review using the Categories of Legitimate Reservation.

Internal validity is therefore addressed by the safeguards built in to the methodologies being examined.

Construct validity

Construct validity has been said to be especially problematic in case study research (Yin, 1994). It is necessary to develop a sufficiently operational set of measures, to avoid subjective judgement. For example, a prime function of the Theory of Constraints is the discovery of core problems, but how can the analyst know what these are? In Goldratt's original concept (Goldratt, 1987a) there was only a single core problem, and it was at the base of the Current Reality Tree. However, Dettmer (1997) points out that in reality there may be more than one core problem: these are 'undesirable effects' which have causal links to several other undesirable effects. It has been suggested that an undesirable effect that links to 70% of the effects above it in the Current Reality Tree could be classed as a core problem (V. Mabin, 2003, personal communication). However, given the complexity of the Current Reality Tree from a systems accident (as will be demonstrated later) the extent of linkage would not be easy to establish, and in any case 70% is itself an arbitrary figure. Why not 80%, or 60%? As will be shown, one of the strengths of the Theory of Constraints is the limited number of core problems to be addressed, and the approach adopted in the present study was to classify as core problems only those which generated the maximum number of effect lines⁹.

The other problematic construct in the Theory of Constraints is 'undesirable effects'. Undesirable to whom, and why? Here the concept of expert knowledge (discussed later) comes into play. An accident investigator requires expertise both in aviation and in accident investigation, and accident investigation is the application of

⁹ It may well be that the number of core problems is the same as the number of interacting systems within a complex 'system of systems.' Thus where there are four systems (e.g. Flight Operations, Maintenance, Corporate Safety and Parent Company) there may be a single core problem, as postulated by Goldratt (1987), within each system. However, to establish whether that is the case is beyond the scope of the present study, which is concerned with whether the methodology can be used to analyse an accident.

expert knowledge (O'Hare, 1994). Such an investigator is qualified to consider various effects 'undesirable', in that they are likely to lead to bad outcomes. The remedy for idiosyncratic judgement in this regard is peer review, using the Categories of Legitimate Reservation described by Dettmer (1997). The qualifications of the author as an accident investigator are stated in Annex C.

In the overall study, the major problem is to establish whether the results from formal analytical methods are 'better' than those currently being achieved by traditional methods of analysis. To some extent the question of whether formal or traditional methods have produced superior results might be self-evident. For example, if a formal method demonstrated that a conclusion of fact in the existing report was erroneous, then to that extent the formal method is better. Likewise, if the formal method resulted in insights into the causation of the accident which were overlooked by the official investigators, again the formal method is better. However, other matters may be opinions, and it would be desirable to substantiate the author's opinion by reference to others who can form authoritative opinions. This is likely to be particularly the case in considering whether Safety Recommendations derived from formal methods of analysis are likely to be more effective than those resulting from traditional analytical methods.

One way to canvas opinions would be to form focus groups comprising experts in the field of accident investigation, i.e. the proposed users. Unfortunately, the potential field of panellists available in the Southern Hemisphere is effectively limited to Australia and New Zealand. As discussed elsewhere, the Australian Transportation Safety Board has stated that it considers formal analysis is unnecessary, and in the interests of saving time, it is only concerned with 'finding the failed defences and fixing them' (Walker, 2003). In the case of the New Zealand Transport Accident Investigation Commission, most of the present members were involved in the official investigation of the accident being used for the case study (TAIC, 1995), and so might find it difficult to form an impartial view.

An alternative would be to form an international expert review panel, comprising academic staff with aviation safety expertise, and others with expertise in application of the Theory of Constraints. Their opinions could be summarised in the 'Comparison of Methodologies' section of this Thesis. This method was tried, but

only a very limited number of panellists could be found. Their views were generally supportive, but were not provided in a format which would permit detailed analysis.

External validity

External validity “deals with the problem of knowing whether a study’s findings are generalisable beyond the immediate case study” (Yin, 1994, p. 35). If the present study shows that a particular accident could be analysed successfully using the Theory of Constraints, does this imply that other accidents could also be analysed in this way?

It could be argued that the findings should be re-examined using a second or even a third accident (replication logic). However, “no set of cases, no matter how large, is likely to deal with the complaint [that generalisability has not been proven]” (Yin, 1994, p. 37). Instead, Yin advocates that one should try to generalise from a case study to a theory.

In the present study, there is an existing theory, the Theory of Constraints. The proposition to be examined is that the theory can be applied to the facts of an accident investigation. If the case study shows that application of the Theory of Constraints can bring out core problems as described by Goldratt (1987a) and Dettmer (1997) then, for the case in question, the proposition will have been substantiated.

The Theory of Constraints was designed for discovering and solving problems which were preventing organisations from achieving their goals. The theory has been widely tested (Mabin & Balderstone, 1998; Mabin & Balderstone, 2003). An organisational accident, such as those described by Reason (1990) where organisational deficiencies provided the conditions leading to disaster, is an impediment to that organisation achieving its goals. Organisational accidents should therefore be susceptible to analysis using the Theory of Constraints. Most (though not all) air transport accidents are a subset of organisational accidents, so likewise they should be susceptible to analysis using the Theory of Constraints. If the particular accident chosen for the case study can be analysed successfully using the Theory of Constraints methodology, this illustrates the general principle that any such organisational accident can be so examined. This was the approach used by Ladkin to

illustrate the applicability of Why-Because Analysis to accident analysis, using the Cali disaster (ACRC, 1996) as a case study (Gerdsmeier et al., 1997).

Yin (1994) argues that further studies, rather than seeking to replicate the present study, could be directed to the development of theory. One such area of study might be the Theory of Constraints itself, e.g. ‘the number of core problems will be a reflection of the number of interacting systems within an overall system’. Another area could be an examination of propositions brought to light by the present study; for example, if the present study indicates that financial stress contributed to the conditions predisposing to the accident, it would be desirable to examine the general proposition that ‘financial stress in an airline increases the propensity to accidents’. Such a proposition, if substantiated, could have significant policy implications.

Reliability

Reliability seeks to assure that, if a later investigator follows exactly the same procedures that were used in the present study, and conducted *the same* case study all over again, the findings would be the same. The aim is to reduce errors and biases.

In order that another investigator could repeat the case study, the procedures must be documented. As many steps as possible should be operationalised. In the present study, data-gathering was performed using well-established sets of procedures, namely the ICAO Accident Investigation Manual (ICAO, 1970), and the rules of disclosure in litigation. Copies have been kept of all documentation¹⁰. A complete set of wreckage photographs has been made. Additional information has been obtained from public records, including the official Report (TAIC, 1995).

The preliminary analysis using Multilinear Events Sequencing (MES) will be performed under the strict rules of that procedure (Benner, 1994). Why-Because Analysis (WBA) (Ladkin & Loer, 1998) will use the MES information. While WBA lacks the procedural rules of MES, the resulting Why-Because Graph will be tested by

¹⁰ Some witness statements taken in the course of the investigation were not copied, in accordance with privacy protocols. They are available on the official file.

formal logic. However, to some extent WBA depends on expert knowledge and intuition. Thus, in the analysis of the Cali disaster (Ladkin & Loer, 1998), a significant factor was that there were two beacons on the same frequency and with the same call-sign (the single letter 'R'), one directly ahead of the aircraft, and another not too distant, on the port beam. Ladkin & Loer (1998) did not consider the proposition that the settings on these beacons might have been default settings. This proposition comes from the knowledge that a single letter identification code is unusual, as would be known by a pilot holding an instrument rating. To some extent, therefore, a WBA might not be precisely replicated by another investigator.

A similar reservation applies to the generation of the Current Reality Tree (CRT) in the Theory of Constraints. Goldratt (1990b) has commented that the analyst needs insight into the system, and another investigator might have more or less insight. This does not make the method invalid: it should enable any investigator to do the best job possible. However, different investigators may produce somewhat different CRTs. Dettmer (1997) points out that to some extent this limitation is overcome when the Future Reality Tree (FRT) is constructed, since weaknesses in the CRT will be brought to light and addressed at the FRT stage.

As far as possible, therefore, following exactly the same procedures with the same data should produce an exact replication of the present case study. While varying insight on the part of the analyst might result in different analyses, the documentation of the analytical processes should enable the rationale for the present study to be seen.

Criteria for Success

The criticisms of contemporary investigations come into three categories:

- The investigation may be considered in some way inadequate, either because all the relevant facts were not discovered, or because there are logical flaws in the analysis, or
- The investigation may be sound, but the report may be difficult to follow, or

- The investigation might still be considered a failure if valid corrective action is not taken.

(Taylor, 1998)

Proposed methods of investigation ought therefore to result in improved quality of investigations, more readily understandable reports, and valid corrective actions which are likely to be acted upon.

In terms of the quality of investigations, the proposed methods would represent an improvement if they are able to discover facts which the official investigation missed, or new logical linkages of facts which may have been dismissed as unimportant, or logical deficiencies in the original reports. It is expected that MES will discover limitations in gathering facts, since that is one of its intended roles (Benner, 1994). Improvement in logical analysis can be achieved by the use of WBA, as shown by the case study by Gerdsmeyer et al. (1997), the analysis of the Cali disaster (ACRC, 1996). It is expected that a similar improvement in logical analysis could be achieved in the present study.

Readability of reports is important, but it is necessarily subjective, and thus difficult to assess. It is generally accepted that reports in the recommended ICAO format (ICAO, 1994) are disjointed and difficult to read (Zotov, 2001). Part of the problem lies in the unsuitability of a written (serial) format to describe things which have been interacting in parallel (Johnson et al., 1995). MES, WBA and TOC analyses all result in graphical depictions of events and conditions, which should be easier to follow. The assessment of reports which are derived from the proposed methods will be discussed later.

Validity of corrective actions derives in part from the validity of the investigation. Where re-examination discloses new facts or logical linkages, it is expected that the need for different or further corrective actions will become apparent. Even more important is the possibility of discovering core problems, whereby a single corrective action may address a wide range of problems, since such actions may be more likely to be implemented. To the extent that the proposed methods disclose

either further or different corrective actions, or core problems, the new methods would represent an improvement over those currently in use.

TOC is a 'change methodology'; its *raison d'être* is to make improvements in existing systems (Dettmer, 1997). It could therefore be expected that recommendations devised with the use of the TOC would be more likely to be implemented than is at present the case. However, while such recommendations might seem to be more persuasive, there cannot be a guarantee that they will prove so in practice, since at least some of the opposition to changes in the past has been irrational (see, for example, TAIC, 1992a). To gain a true assessment, it would be necessary to track the response to recommendations made in this way, from actual investigations. While this should certainly be done, to do so would be beyond the scope of the present study, which is a revelatory case study, concerned to see whether the TOC methodology can be applied to the information from a particular accident.

The extent to which revised recommendations are an improvement on those in the official report must be left to the reader. As Westrum has said (personal communication, 2000) a case study must stand on its own merits.

Expertise

The New Shorter Oxford English Dictionary (1993) (OED) defines an expert as 'A person with the status of an authority (in a subject) by reason of special skill, training or knowledge; a specialist'

1. A person... who has gained skill from experience.

Palmer, Stough, Burdenski & Gonzales (2005) reviewed the general expertise literature, before focussing their attention on expertise in teaching. They found that one or more marker categories were generally used, in determining whether someone could be considered an expert:

- Years of experience
- Social recognition
- Professional or group membership

- Performance-based criteria.

These criteria are in accord with the OED definition: ‘years of experience’ correlates with ‘gaining skill from experience’; social recognition’ correlates with ‘status as an authority’, as does ‘professional or social group membership’.

The OED stipulates that the status of an authority is ‘in a subject’: Palmer *et al.* (2005), in their review of the literature on expertise, found that “individual expertise is unique to a specific domain of activity” (p. 15). It requires thousands of hours of dedicated practice within that domain (Berliner, 1994).

Expertise is, in part, a social attribution (Agnew *et al.*, 1997). “Individuals... are selected as experts because others consider them to be experts” (Palmer *et al.*, 2005, p. 15). One form of social recognition is membership of a group, such as a learned society, or a University faculty.

Performance-based criteria would *prima facie* be the optimum way to discover who could be termed an expert, but may be more problematic to define. While those who consistently win competitions against opponents are considered experts (Ericsson, 1996, cited in Palmer *et al.*, 2005) in other fields performance criteria may have to be subjective. For example, while it might be possible to define elements of a musical performance which could be enumerated, these could not capture the quality of performance by a master.

Overall, Palmer *et al.* (2005) that identification of experts was somewhat idiosyncratic. They recommended a multi-gated approach, using as many different criteria as appropriate in a particular case.

Accident Investigator Criteria

Criteria for qualifying as an expert in accident investigation follow the principles outlined above, of years of experience, social recognition, professional or group membership, and performance-based criteria. General prerequisites are a high aviation professional qualification, followed by specialist training, and a minimum of five years of practical experience (Zotov, 1999). Most investigators work, initially at least, in an official investigation agency, and most become members of the

professional body, the International Society of Air Safety Investigators, after completion of 5 years of full-time experience as investigators. Performance is acknowledged in part by promotion to the role of Investigator in Charge of accident investigations, and in part by such matters as presentation of papers at international symposia.

The qualifications of the author as an expert accident investigator are detailed in Annex C.

Summary

This case study is intended to bring about a general improvement in the safety of air transport by showing how the analysis of data from an accident investigation can be improved, and more effective safety recommendations can be generated. The case study seeks to show:

1. How core problems can be derived from accident investigation data,
2. How effective safety recommendations can be developed, so as to minimise the risk of other similar accidents.

This will be done by examining the data from a revelatory case, the Ansett (NZ) de Havilland Dash 8 accident near Palmerston North (TAIC, 1995). The accident will be examined using three formal methods, MES, WBA and TOC, and the results compared with those produced by the official investigation using traditional methods. Success will be measured by the extent to which the proposed methodology better establishes the facts of the accident, or generates deeper insights into the structure of the accident, or generates safety recommendations more likely to be effective.

Chapter 4: Case Study – The Ansett Dash 8 Accident

The Accident Sequence

On 9th June 1995, de Havilland DHC-8 ('Dash 8') ZK-NEY, operated by Ansett Airlines, was on a non-precision instrument approach to Palmerston North aerodrome after a flight from Auckland. The right main leg stayed up when the undercarriage was selected down. The crew attempted to lower the leg using the emergency system, and while they were doing this the aircraft struck a hill. Of the 21 occupants, 4 were killed, and fourteen seriously injured. The Transport Accident Investigation Commission (TAIC) investigated the accident, and issued an official report (TAIC, 1995)¹¹¹²

The crew had expected to make the approach to Palmerston North from the west (over low ground), but were directed to make a DME arc approach from the east, over hilly terrain, to avoid conflict with departing traffic. This put the approach path into cloud. The aircraft was high on the glidepath after it turned inbound for Palmerston North, so the Captain (the handling pilot) reduced power to descend rapidly and so join the optimum glidepath.

Once established inbound, the undercarriage was selected down, but the right main leg did not lower. At about the time that the Captain noticed the undercarriage warning, the aircraft crossed through the optimum glidepath. Undercarriage main leg 'hang-up' was a known defect of the Dash 8, and the Captain decided to attempt to rectify the malfunction while continuing the instrument approach. The First Officer

¹¹ The official report (TAIC 1995) is reproduced at Annex B.

¹² In this case study, reference to a section number (viz. 1.12.25) indicates a section in the official report (TAIC, 1995). Ansett company documents are referred to by title and date (viz. Technical Memorandum 12 2 94), while references to the manufacturer's and other correspondence are given in full.

was directed to implement the procedure in the Quick Reference Handbook (QRH), while the Captain continued to fly the aircraft.

When the First Officer commenced the emergency lowering procedure, the initial steps that he read out from the QRH had already been completed. The Captain directed him to omit these, and proceed directly to the applicable section. This the First Officer did, but he missed a step in the undercarriage lowering sequence. The Captain noticed this omission, and sought to have it put right. The rate of descent increased as the aircraft encountered a smooth downdraught of about 400 feet per minute, to about 1500 feet per minute. A minute later, as the First Officer pulled the emergency release which would have allowed the undercarriage leg to descend, the Ground Proximity Warning System (GPWS) alarm sounded. About 5 seconds later the aircraft struck the ground at 1272 feet above mean sea level (amsl).

The initial impact occurred on the nosewheel, which contacted a gently rising grassy knoll, with the aircraft laterally level. The belly of the aircraft also contacted the ground briefly, but with little structural damage. Slash marks made by the right propeller indicated a groundspeed of 122 knots. There were no marks from the right wheel.

Some 42 metres further on, the right wingtip gouged the ground for 7 metres; 28 metres further yet, the fuselage and right engine nacelle struck a terraced spur which had a local upslope of 30 degrees (see Figure 22). The aircraft lofted, and there was a flash fire. Some 60 metres further on, the aircraft struck the ground again. About half way between the two major impact sites, a portion of the outer part of the right wing was found on the centreline of the wreckage trail, and the empennage was found adjacent to the second major impact site.

During the second major impact the entire left wing assembly separated from the fuselage and slid inverted a further 200m. The fuselage and loosely attached right wing root and nacelle "continued uphill until brought to rest against a bank on the hillside, having traversed a total distance of about 235 metres from initial impact. The fuselage was slewed through some 150 degrees, and lay across the slope on a heading of 040 degrees magnetic partially rolled on its side, at an elevation of 1345 feet amsl." (1.12.17, p. 36).

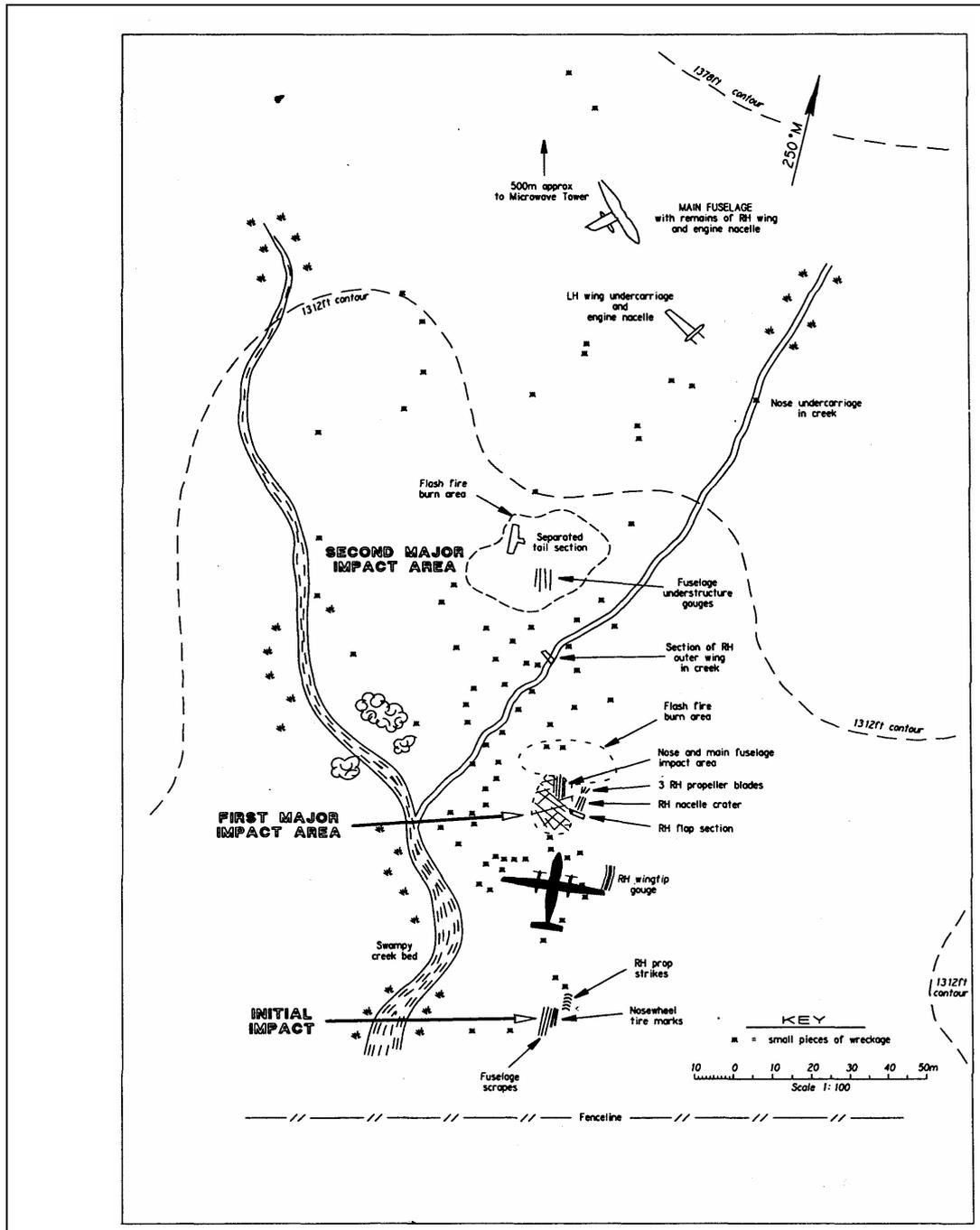


Figure 22. Ansett Dash 8 impact diagram. Source: TAIC. (1995). *De Havilland DHC-8, ZK-NEY controlled flight into terrain near Palmerston North, 9 June 1995* (Aircraft accident report No. 95-011). Wellington: Transport Accident Investigation Commission.

A subsequent short-lived fire erupted after the aircraft had come to rest and fatally burned one of the passengers who was outside the aircraft at the time.

During the accident sequence the aircraft floor was split longitudinally. Some of the rearward seats became detached, while most of the forward seats remained

intact. This is unusual, because impact forces at the rear of an aircraft tend to be attenuated as energy is absorbed by deformation of structure further forward.

Ansett (New Zealand), the operator of the De Havilland Dash 8 involved in this accident, was a wholly-owned subsidiary of Ansett Australia. Throughout this case study, 'Ansett' refers to the New Zealand subsidiary; Ansett Australia is generally referred to as 'the parent company'.

The Ansett Dash 8 accident will be analysed using the proposed suite of formal methods: Multilinear Events Sequencing (MES), Why-Because Analysis (WBA), and Theory of Constraints (TOC), commencing with MES.

Chapter 5: Analysing the Dash 8 Accident with a MES Graph

The History of the Flight

MES is a tool for manipulating the data gathered during an investigation, so as to be able to form a coherent picture of the occurrence. It is intended to display the logical linkages between the events in the accident sequence, and to indicate where insufficient evidence has been gathered, so that this deficiency can be rectified. It can be used either during an investigation, or as a post-investigation review. In this case study, it will be used primarily to review the official report (TAIC, 1995), but where deficiencies in the report are found, reference to other evidence will be made to resolve these deficiencies. The purpose of this part of the analysis is threefold:

- To demonstrate the function of MES as an investigation and quality control tool
- To lead into the interaction between MES and WBA
- To ensure that, as far as possible, valid data is used for the subsequent WBA and TOC analyses.

Benner (1994) advises that, when constructing an MES graph from an existing report, the following procedure should be adopted:

- Underline every actor and every action
- For each actor, tag all the verbs which say or imply that someone did something, especially where someone moved, decided or concluded something
- Circle the specific actions by the person that initiated a change of state in that person or in someone or something else
- Prepare EBBs for each circled action, in the 'actor-action' format.
Annotate the source on the EBB
- Check for 'poison words': plural actor names ('aircrew'), passive verbs, pronouns, opinion ('misjudged'), editorial adjectives ('incorrectly'), or statements of what did not happen ('did not descend').

In Benner's view, passive voice should be treated as an indicator that the investigator is covering up unsatisfactory investigation practices. Statements of what did not happen introduce investigator bias, unless supported by data describing the pre-existing standard on which a logical comparison of expected and actual action can be made (Benner, 1994).

The procedure advocated by Benner (1994) was adopted, and the MES graph was constructed in the stages described in the following section.

History of the Flight (1.1, pp. 7, 8)

Information from the history of the flight is shown in Fig. 23. Generally, the wording from the report is used. Where the passive tense required by the ICAO recommended report format (ICAO, 1994) has been used in the report, it has been retained.

The ambiguity which can arise from compound words is evident ("the pilots briefed themselves": in reality, one briefed the other, as indicated in the CVR transcript (TAIC, 1995 (Annex B), Appendix C, p. 111 et seq.)), but it could be argued that at this point, precisely what happened during the briefing sequence is immaterial. However, the ambiguity arising from the use of passive tense could potentially be relevant at other times, for example "the aircraft power levers were retarded" raises the questions "by whom?" and "was this the normal power setting?" Certainly the aircraft was not the actor, nor did the levers retard themselves. The 'mental movie' is incomplete at this point. (It would be reasonable to infer that the Captain retarded the throttle levers, as he was the handling pilot, and he gave no instruction to the co-pilot to do so).

Constructing the graph also brings to light out-of-sequence statements in the report: 1.1.3 (p. 7) "The aircraft...intercepted the final approach track." "During the... turn ... the aircraft's power levers were retarded ". While there is no ambiguity, out of sequence statements make the report harder to read.

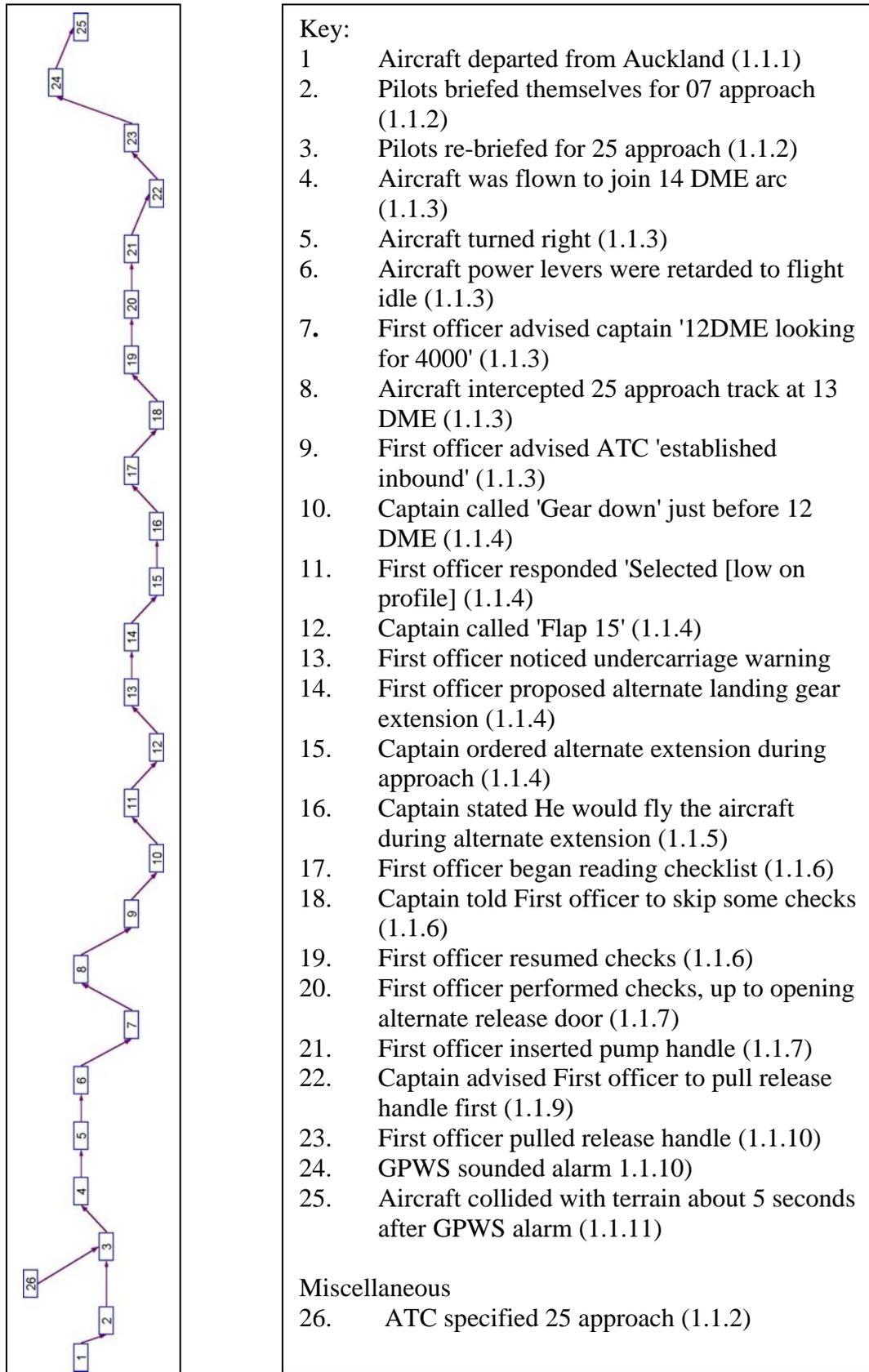


Figure 23. Events from 1.1 (History of the flight)¹³

¹³ MES graphs are customarily drawn with time running from left to right (Benner, 1994) but this one has been rotated 90° to better fit the space available, with time running up the page.

However, the principle limitation of section 1.1 of the report, 'History of the Flight' (pp. 7, 8), which is intended to provide the reader with an understanding of what happened, is seen when the links between events are examined. Take for example, the final sequence

- First officer pulled release handle
- GPWS warning sounded
- Aircraft collided with terrain

There are no logical links between any of these events. The action of pulling the release handle did not cause the GPWS warning to sound, and the GPWS warning did not cause the aircraft to collide with the terrain. The links, as drawn, serve only to show sequence, and do not comply with the MES requirements for logical links, i.e. that the linkages should show that preceding actions were *necessary* and *sufficient* for those following. Clearly, more information must be sought before the reader can understand the sequence of events.

Where logical links cannot be drawn, the gaps between unlinked EBBs point to potential unknowns in the understanding of what happened (Benner, 1994).

More information may be found in other sections of Part 1 of the report. Information on the GPWS is provided at 1.6.65-1.6.82 (pp. 19-23).

The Ground Proximity Warning System (1.6.65-1.6.83, pp. 19-23)

The GPWS operated in a variety of modes depending on the aircraft configuration, using inputs from the air data computer and radio altimeter, and if applicable the glidepath indication (not relevant in this case) (1.6.67, 68 (p. 20)). The mode applicable in this case was Mode 2A, excessive rate of closure with terrain, and 17 seconds of warning should have been provided in the particular circumstances (1.6.81, p. 23). The cockpit voice recorder (CVR) showed that terrain warning occurred about 5 seconds before impact (1.6.69, p. 21), and the digital flight data recorder (DFDR) showed that 3 1/2 seconds before impact there was a nose-up elevator input and corresponding change of pitch attitude (1.6.70, p. 21).

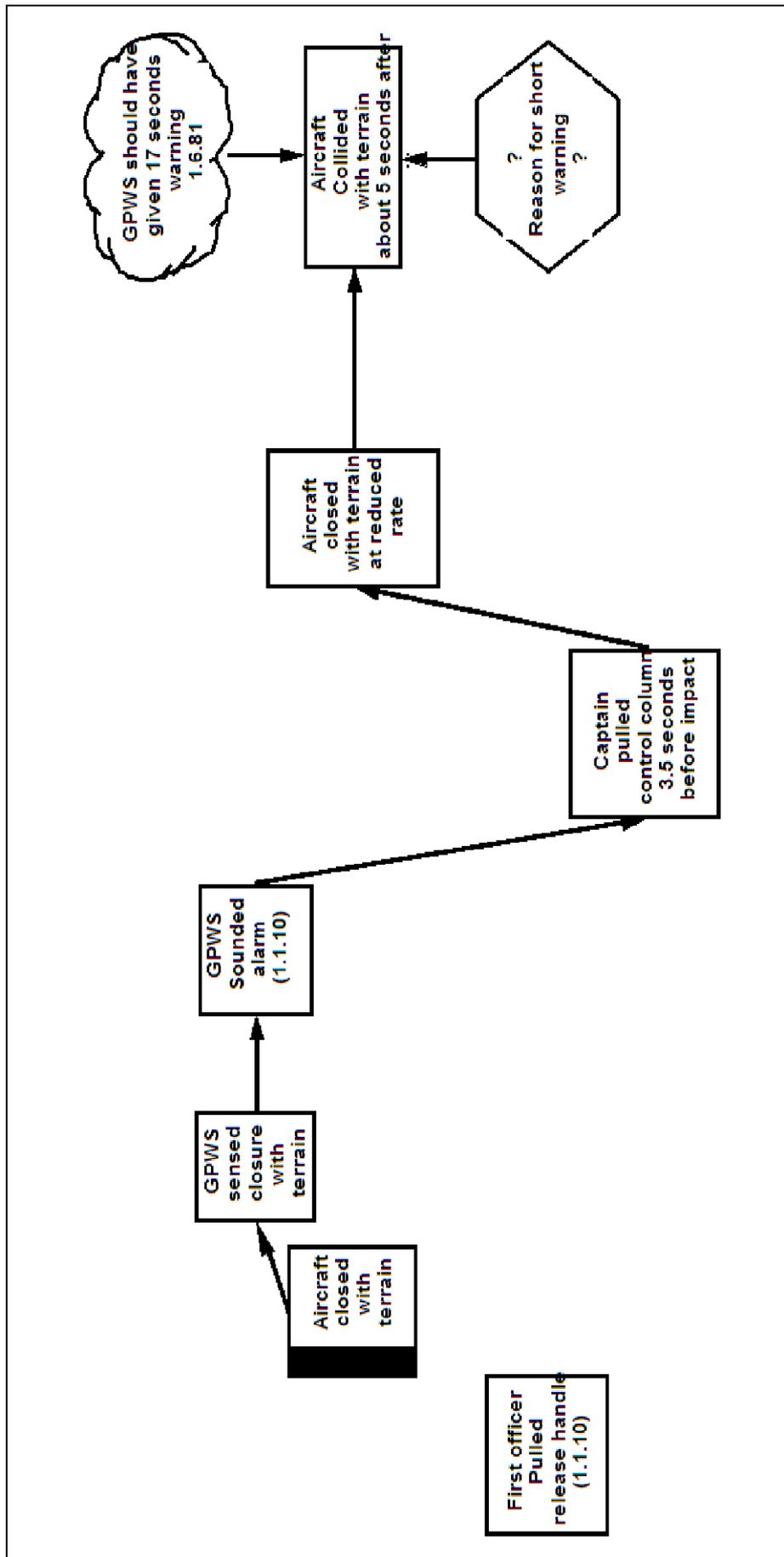


Figure 24. Ground proximity warning.

The captain was the handling pilot, and in view of the very rapid response to the GPWS warning it may be inferred that it was he who applied the nose-up input. So the final section of the MES graph may be re-drawn as in Figure 24.

These linkages meet the test of necessity and sufficiency. If the aircraft was closing with terrain and the GPWS sensed this, the warning would sound. If the warning sounded, the handling pilot would commence avoiding action by raising the nose. If raising the nose resulted in a flightpath change insufficient to avoid terrain, the aircraft would strike the terrain. Without further evidence, it is not possible to include information on why the GPWS did not sound earlier: in MES, the emphasis is on what *did* happen. However, the graph does flag the need to seek such further information.

One limitation is that 'aircraft closed with terrain' is not strictly an *event*; it is a continuing state of affairs, i.e. a *state*,¹⁴ as Ladkin terms it (Ladkin & Loer, 1998). For this reason, it has been flagged with a different symbol (a solid bar to the left of the EBB).

Having completed one section of the MES graph from information in the report, the next stage will be to examine the sequence in Figure 23 involving the undercarriage, from 'Captain called "gear down" ' to 'First officer pulled release'.

The Undercarriage

In the sequence relating to the undercarriage malfunction, the Captain's call of 'gear down' did not result in the First Officer's warning 'low on profile', and the Captain's call for 'flaps 15' did not cause the First officer to notice an undercarriage warning (refer Figure 23). As with the section relating to the GPWS, additional information must be sought. The nosewheel was down at impact (1.12.11, p. 35), indicating that the First Officer not only responded to the Captain's call, but also selected the undercarriage lever to the down position. However, the First Officer's warning 'low on profile', was unrelated to his action of lowering the undercarriage.

¹⁴ Strictly, this is a *state-event*, i.e. a state which is initiated and terminated by events. A state, per se, is of longer duration, for example the existence of a hill.

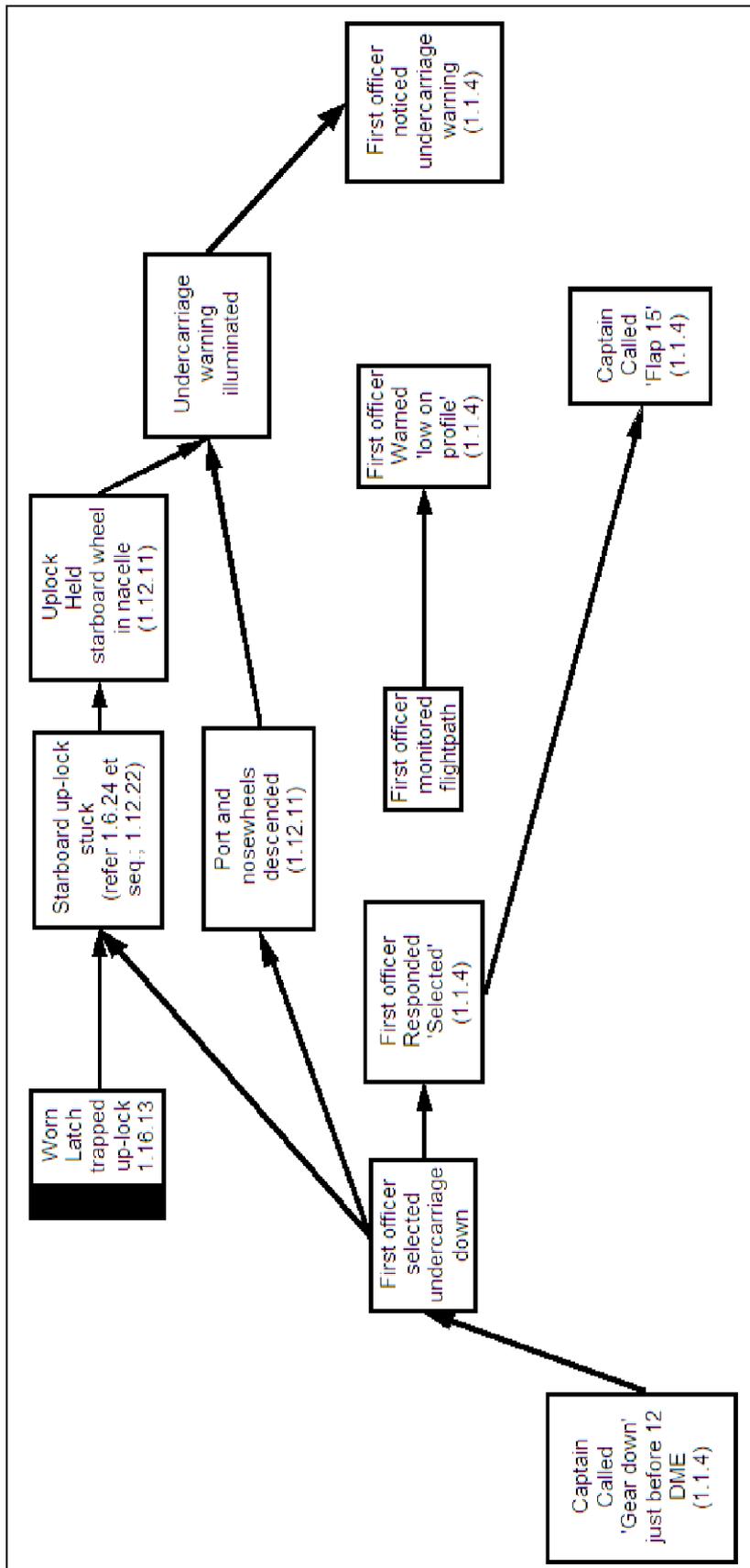


Figure 25. Undercarriage malfunction.

It implies that he was monitoring the approach path, and that the aircraft had descended below the optimum descent path at this point. The Captain's call for 'flaps 15' (i.e. select 15 degrees of flap deflection) was the logical consequence of the First Officer's response to the 'gear down' call, because this was the next action required to configure the aircraft for landing. But again, the detection of the undercarriage warning by the First Officer is unrelated to the 'flaps 15' call; it is a consequence of the right undercarriage leg remaining retracted after the undercarriage had been selected down. This section of the graph is shown in Figure 25.

From Figure 25, it can be seen that there were four streams of events going on in parallel: hence '*Multilinear* Events Sequencing'. Although 'left and nose wheels' is a compound actor, this does not give rise to any ambiguity. The EBBs and linkages now meet the logical requirements.

The First Officer's comment 'low on profile' appears 'out of the blue', and will need to be linked to some other events. The actual comment was

"On profile, ten sorry hang on ten DME we're looking for four thousand aren't we, so a fraction low" (TAIC, 1995 (Annex B), Appendix C, 0920:14, p. 128; the transcript of the Cockpit Voice Recorder).

However, according to the vertical profile shown in the Report (Fig. 3, p. 28) the aircraft was at 3100 feet at ten miles DME. According to the Palmerston North Approach Plate (Figure 26) the optimum height at 10 DME was 3420 feet, so the aircraft had just crossed the optimum descent path. 3120 feet was the optimum height at 9 DME. While the First Officer was correct in saying the aircraft was 'a fraction low', the reference to 4000 feet had the potential to be confusing. (The consequences of this will be discussed later, when examining the Why-Because Analysis of this accident). The next stage in the sequence was the attempt to lower the right wheel by means of the alternate procedure.

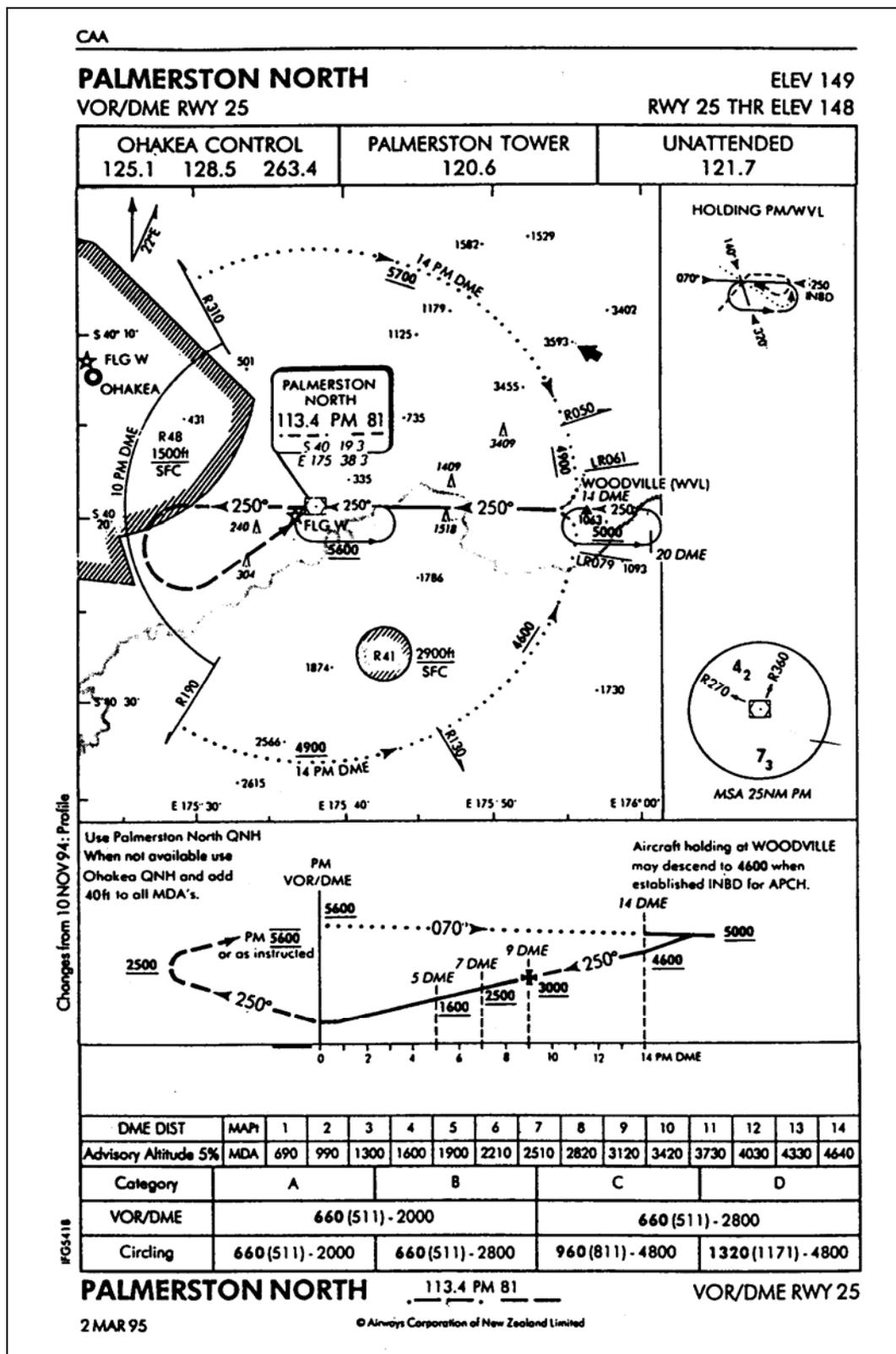


Figure 26. Palmerston North Approach Plate. Source: TAIC. (1995). *De Havilland DHC-8, ZK-NEY controlled flight into terrain near Palmerston North, 9 June 1995* (Aircraft accident report No. 95-011). Wellington: Transport Accident Investigation Commission.

Alternate Undercarriage Extension

While the EBBs in the sequence relating to the use of the alternate undercarriage extension method follow logically from one to the next in Figure 23, some additional information is necessary. It is necessary to know why the Captain ordered the First Officer to omit some checks, and why the First Officer performed actions out of sequence. Also, it would be helpful to know why the Captain decided to attempt to rectify the problem while continuing the approach (see Figure 27).

The first and third boxes in the time sequence have no paragraph references; they are necessary inferences from the material in the report, rather than direct references. However, supporting evidence should be available in the CVR transcript, Appendix C. Appendix C (p. 128; 09:20:30 et seq.) shows that the sequence in 1.1.4 (p. 7) is misleading. It was the captain who observed the undercarriage warning ("Oh #") and then whistled, before the First Officer noticed it. So the MES graph must be modified as in Figure 28.

Although a minor matter, this change illustrates the use of MES as a quality control measure for checking an existing report. MES would function in exactly the same way if used to check the work during the preparation of a draft.

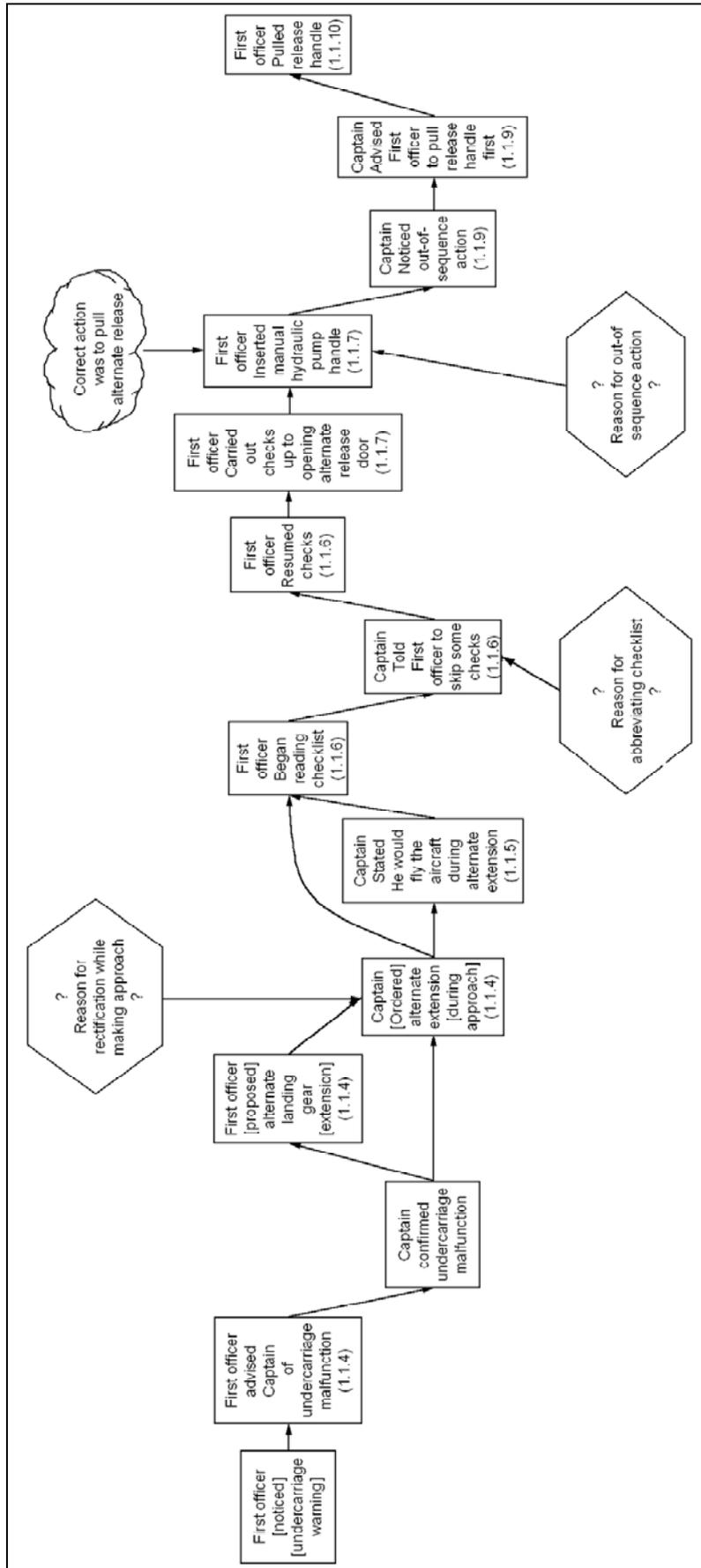


Figure 27 Alternative Undercarriage Selection.

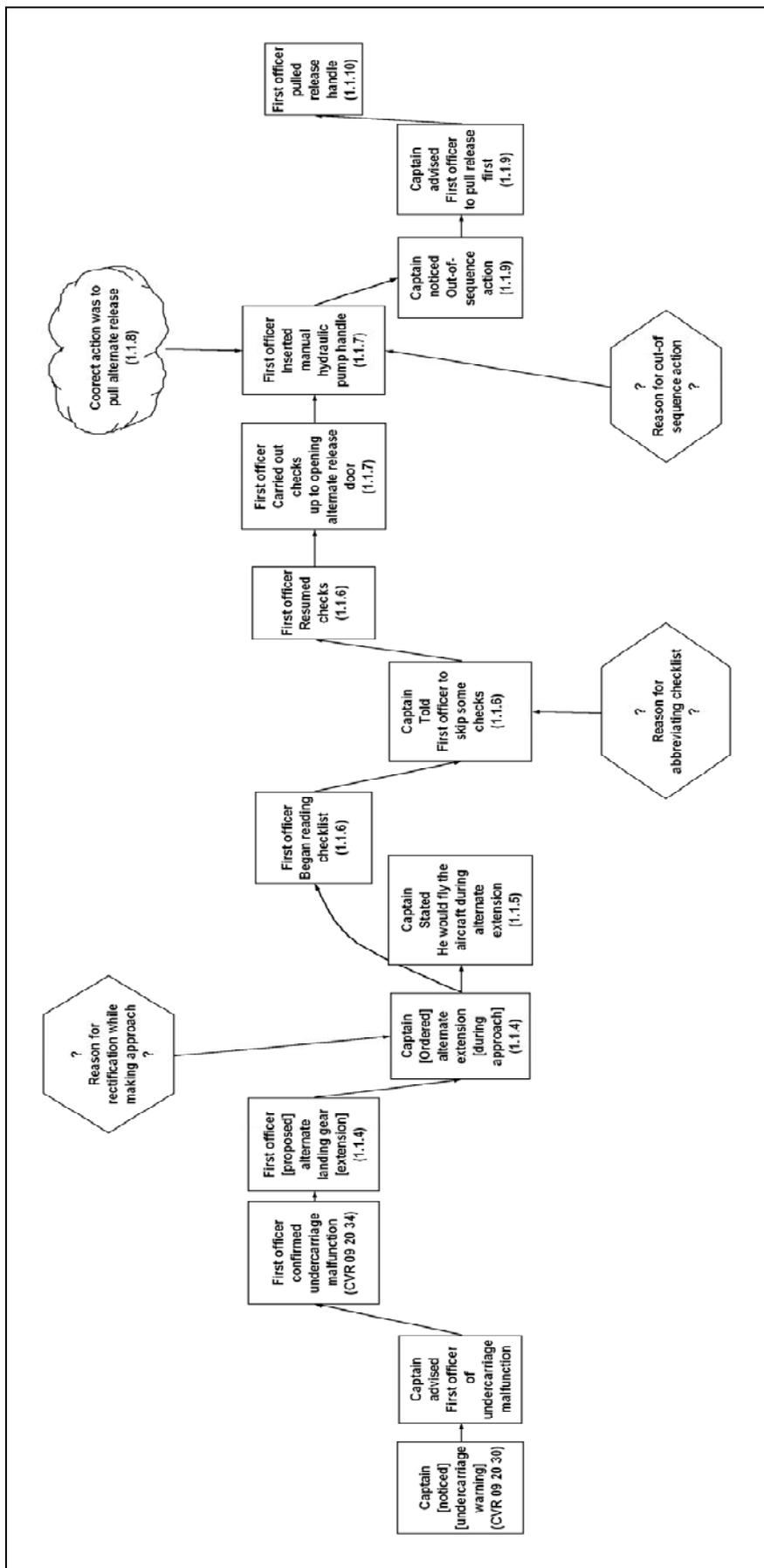


Figure 28. Alternate undercarriage selection (modified).

The approach to Palmerston North

The initial section of Figure 23 now requires logical linkages. 'Aircraft departed from Auckland', though only remotely related to 'Pilots briefed themselves for the 07 approach'¹⁵, sets the scene, and does not need elaboration. The initial perturbation has not yet been reached, and the flight is proceeding routinely. The initial perturbation was the specification by ATC of the 25 approach. This was a recently introduced approach (1.10.6, p. 31), which the Captain had flown only once before (1.18.35, p. 64; Appendix C, p. 111). MES does not provide a means to display this information, which will be considered later in 'Why-Because Analysis'. The crew had briefed themselves for the usual 07 approach, and so had to re-brief themselves, and this in turn led to them flying the required 14 mile radius arc about the Palmerston North DME beacon. Notwithstanding some misunderstanding with ATC as to the heights to fly around the arc, the aircraft reached the lead-in radial at the correct height, and then turned right, onto the final approach to Palmerston North (Report, Figures 3 and 4, pp. 28; 30).

The right turn did not cause the power levers to be retarded to flight idle. This action was needed because the aircraft had become high on the glidepath by the time it completed the turn, and this excessive height was the result of the descent being interrupted during the turn (Report, Figure 3, p. 28). MES flags the need to examine *why* the aircraft had become high on the glidepath; this is discussed later in the Why-Because Analysis.

This initial section of the MES graph is shown in Figure 29.

¹⁵ Runways at an aerodrome are designated by the magnetic direction of take-off and landing, in tens of degrees: Runway 07 is aligned approximately 070 degrees Magnetic.

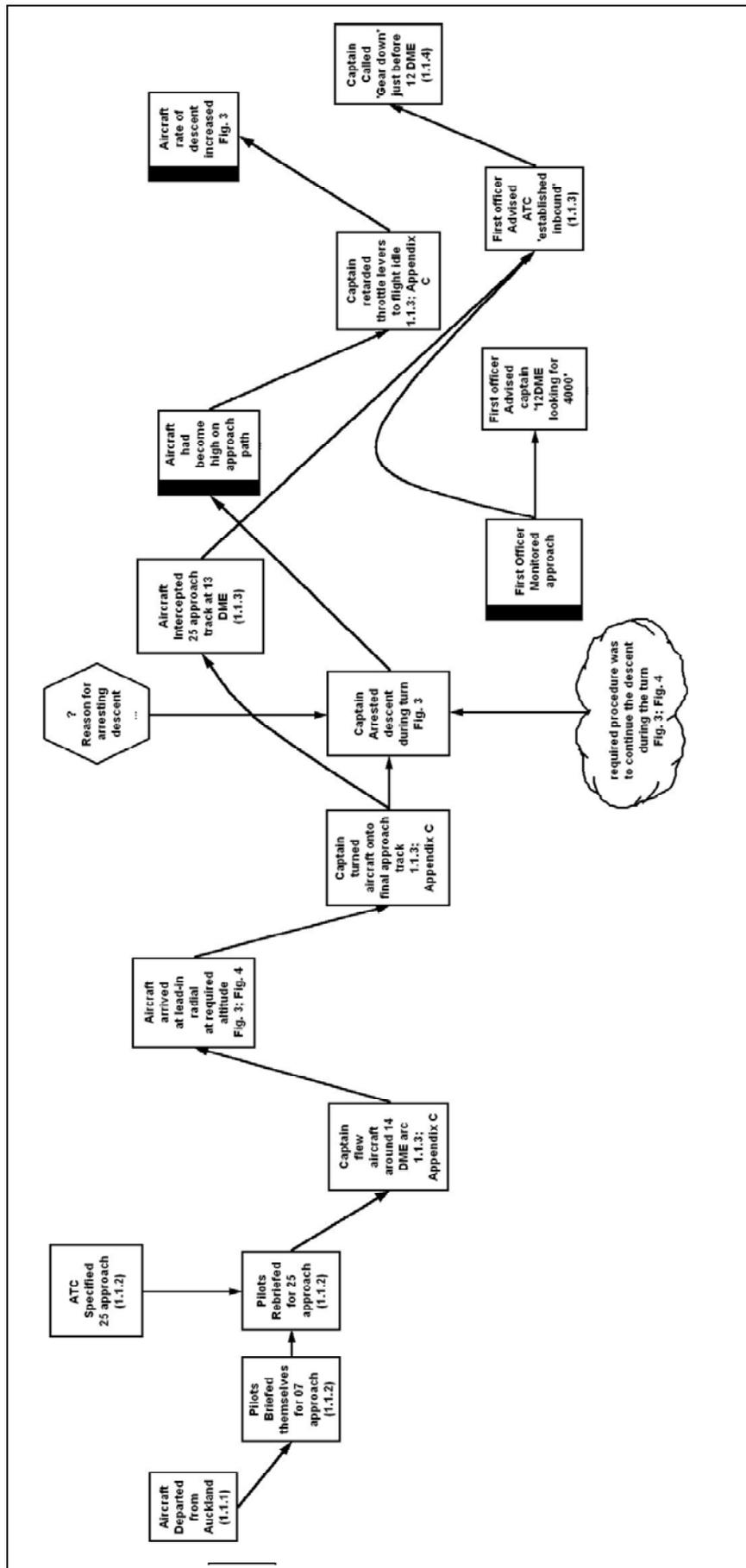


Figure 29. Initial approach to Palmerston North.

MES Graph from Initial Approach to Impact

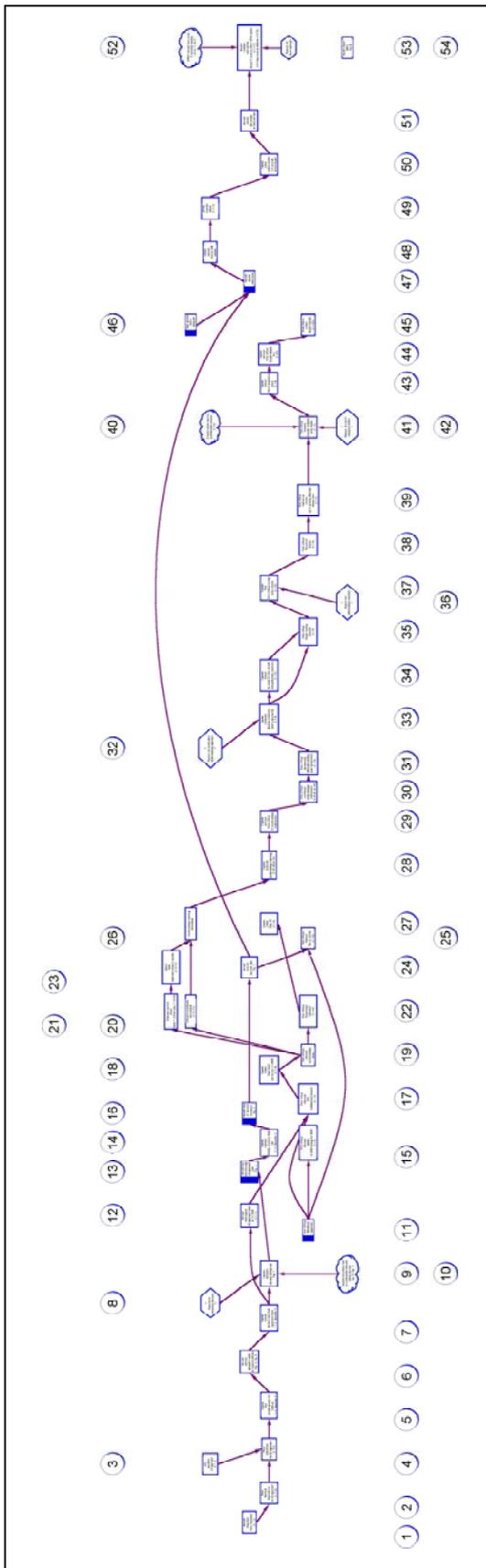


Figure 30. MES Graph from initial approach to impact

Key to Figure 30:

- 1 Aircraft departed from Auckland (1.1.1)
- 2 Pilots briefed themselves for 07 approach (1.1.2)
3. ATC specified 25 approach (1.1.2)
- 4 Pilots re-briefed for 25 approach (1.1.2)
- 5 Captain flew aircraft around 14 DME arc (1.1.3; Appendix C)
- 6 Aircraft arrived at lead-in radial at required altitude (Fig. 3; Fig. 4)
- 7 Captain turned aircraft onto final approach track (1.1.3; Appendix C)
- 8 Reason for arresting descent?
- 9 Captain arrested descent during turn (Fig. 3)
- 10 Required procedure was to continue the descent during the turn (Fig. 3; Fig. 4)
- 11 First officer monitored approach
- 12 Aircraft intercepted the 25 approach track at 13 DME (1.1.3)
- 14 Captain retarded throttle levers to flight idle (1.1.3; Appendix C)
- 15 First officer advised Captain '12 DME looking for 4000' (1.1.3)
- 16 Aircraft rate of descent increased (Fig. 3)
- 17 First officer advised ATC 'established inbound' (1.1.3)
- 18 Captain called 'Gear down' just before 12 DME (1.1.4)
- 19 First officer selected undercarriage down
- 20 Port and nose wheels descended (1.12.11)
- 21 Starboard up-lock stuck (1.16.24 et seq.; 1.12.22)
- 22 First officer responded 'selected' (1.1.4)
- 23 Up-lock held starboard wheel in nacelle (1.12.11)
- 24 Aircraft crossed descent path (fig. 3)
- 25 First officer warned 'low on profile' (1.1.4)
- 26 Undercarriage warning illuminated
- 27 Captain called 'Flap 15' (1.1.4)
- 28 Captain noticed undercarriage warning (CVR 0920:30)
- 29 Captain advised First officer of undercarriage malfunction
- 30 First officer confirmed undercarriage malfunction (CVR 0929:34)
- 31 First officer proposed alternate landing gear extension (1.1.4)
- 32 Reason for rectification while making approach?
- 33 Captain ordered alternate extension during approach (1.1.4)
- 34 Captain stated he would fly aircraft during alternate extension (1.1.5)
- 36 Reason for abbreviated checklist?
- 37 Captain told First officer to skip some checks (1.1.6)
- 38 First officer resumed checks
- 39 First officer performed checks up to opening alternate release door
- 40 Correct action was to pull alternate release (1.1.8)
- 41 First officer inserted manual hydraulic pump handle (1.1.7)
- 42 Reason for out-of-sequence action?
- 43 Captain noticed out-of-sequence action (1.1.9)
- 44 Captain advised First officer to pull release first (1.1.9)
- 45 First officer pulled release handle (1.1.10)
- 46 High ground below glidepath
- 47 Aircraft closed with terrain
- 48 GPWS sensed closure with terrain
- 49 GPWS sounded alarm (1.1.10)
- 50 Captain pulled control column 3.5 seconds before impact
- 51 Aircraft closed with terrain at reduced rate
- 52 GPWS should have given 17 seconds warning (1.6.81; 1.16.17)
- 53 Aircraft collided with terrain about 5 seconds after GPWS alarm (1.1.11) in 8 degree nose-up attitude (1.16.70)
- 54 Reason for short warning?

Figure 30, showing the overall picture from initial approach to impact, is constructed by amalgamating the individual sections previously discussed.

There is an important deficiency in the presentation so far. Just as a landing is not complete until the aircraft has reached the end of its landing roll, so the accident sequence is incomplete until the final loss-inducing event has occurred. It is therefore necessary to seek information relating to the impact sequence.

Ground Impact Sequence

Section 1.1 (pp. 7, 8) is silent on the impact sequence, though as injuries and some fatalities occurred, the impact sequence is of importance in understanding the accident. Some information is contained in 1.12 (pp. 33-37), 'Wreckage and Impact Information', and the events are displayed in Figure 31.

As with the information from Section 1.1, History of the Flight (pp. 7, 8), not all events can be joined by logical linkages: there is essentially a catalogue of events, in sequence, but additional information must be adduced before a 'mental movie' can be formed. For example, 'left wing and engine and undercarriage assembly broke away from fuselage' did not, without more, cause 'left wing (assembly) slid inverted along hillside', and there is no obvious reason why 'fuselage assembly struck bank on hillside' should cause 'fuselage assembly was slewed 150 degrees (to right)'.

Figure 32 shows the construction of a MES Graph for the impact sequence. The first step is to change the format of the events to that permitted for EBBs: primarily, this involves changing to active voice. As before, it is necessary to incorporate a number of states (i.e. continuing states of affairs) in order to make the sequence of events comprehensible. Consider the group at the beginning of the time sequence in Figure 32, representing the initial contact with the hill. In order to make sense of the points of contact, additional information is needed. For the nosewheel to make rolling contact, which was able to pitch the nose upward (1.12.12, p. 35), it is not sufficient that the aircraft collided with the hill. It is also necessary that the flightpath and the terrain profile were not greatly different. The report advises that the terrain sloped upward to the right of the flightpath (1.12.8, p. 35) - a state - and that the aircraft was laterally level (1.12.4, p. 35) - likewise a state, not an event. These two states account for the absence of contact with the left undercarriage (1.12.8, p. 35). Also, the slope together with the absence of the right undercarriage accounts for the right propeller contacting terrain (1.12.9, p. 35). The states are necessary to understanding the impact, and are included, suitably flagged to show that they are not EBBs.

Although 1.12.4 (p. 35) gives the terrain slope of 5°, it is necessary to refer to 1.6.70 (p. 21) to discover the pitch attitude (8° nose-up). The dispersion of information makes the official report harder to follow, and this dispersion is readily evident from the MES graph. Accordingly, had this graph been constructed during the investigation, the information could have been re-arranged or duplicated to assist the reader in visualising the occurrence. There is no information in the report on the aircraft flightpath immediately before impact. The pitch attitude alone is insufficient information to assess the impact without knowledge of the flightpath (USAAMRDL, 1971).

Additional states are needed to help explain the second and third impacts. Like the initial states mentioned above, they are also incorporated and flagged.

There is a significant omission (not readily determined from the construction of the MES graph) in that the effect of the loss of the right propeller blades is not discussed. It is suggested that the impact of the right engine with terrain would have yawed the aircraft to the right (1.12.5, p. 35), but this yaw would have been damped

by the fin and rudder during the rebound. A more prolonged rotation in yaw could have resulted from asymmetric thrust, if the left engine continued to generate power. The report is silent on this point. In view of the subsequent comment that the fuselage had yawed through 150 degrees (1.12.17, p. 36), with no discussion as to how this happened, the effect of asymmetric thrust should not have been ignored.

A major factual omission in the official report is the lack of reference to the detachment of the outboard section of the right wing, shown in Report Figure 1, the wreckage distribution diagram. The significance of this will be discussed later.

The series of queries after the second major impact also points to deficiencies in the report. It proceeds directly from 'aircraft struck hillside' (1.12.15, p. 36) to 'left wing assembly broke away' (1.12.15) and 'tail section fell onto hillside' (1.12.15) without saying how these things happened. Also, there is no obvious reason why the left wing assembly should have slid inverted (1.12.16, p. 36). Especially significant is the unexplained damage to the flight deck roof (1.12.20, p. 36), which will be discussed in relation to pilot injuries and additional evidence.

Further events during the impact sequence are contained in 1.14, Fire (pp. 39, 40), and 1.13, Medical Information (pp. 37-39).

The Fire Sequence

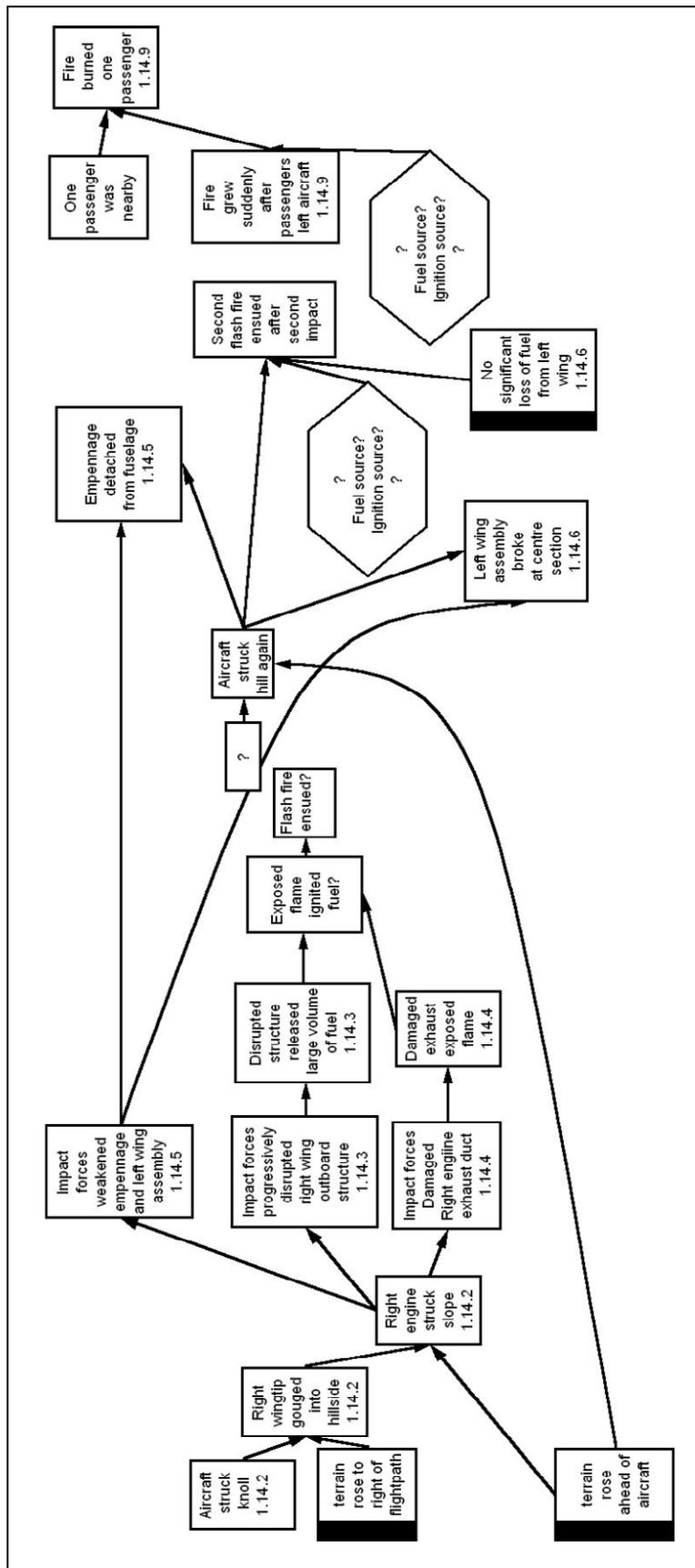


Figure 33. Fire sequence.

The fire sequence is shown, in MES format, in Figure 33. Three weaknesses in the report are evident from Figure 33 relating to weakening of the structure, burns to a passenger, and the second flash fire.

There is an attempt to explain the detachment of the empennage, and of the left wing which broke off at the centre section. However, the comments as to the initial impact weakening the structure of the left wing assembly and empennage (1.14.5, p. 39) are unsupported by any evidence, and must be considered speculative in the absence of further information.

The disconnected group at the end of the time sequence, events leading to fatal burns to a passenger (1.14.9, p. 40), indicates an absence of linkage to the rest of the report. There is no information as to the source of the fuel, nor why this fire suddenly flared up. A small slow fire in the neighbourhood of an engine could well have been an oil fire, ignited by the hot section of the engine. However, this would not account for the way in which the fire suddenly flared up, which is characteristic of a kerosene fire where the kerosene has soaked into the ground. The report speaks of 'residual fuel', without saying where this originated (1.14.7, p. 40). Since the left wing with its fuel tank had departed, and the right fuel tank had completely ruptured (see Figure 43, later), the only remaining source of fuel would have been the small quantity contained in the cross-feed lines in the wing centre section. Accordingly, the linkages to the remainder of the fire information are rupture of the cross-feed lines, draining of fuel from these lines, and ignition by a small engine fire. This matter will be addressed when the post-impact diagrams are amalgamated.

No evidence is adduced as to the origin of the second flash fire (1.14.5, p. 39). There was no significant loss of fuel from the left wing, and no indication of fire around the left wing or engine (1.14.6, p. 40), so the source of fuel had to be either the right wing or engine nacelle. As the fuel tank, contained in the outer panel of the right wing, had already separated, the only source of fuel was residual fuel in the fuel lines in the nacelle, or perhaps fuel which had leaked and accumulated in the nacelle (1.6.6, p. 10). It is difficult to envisage either source being a sufficient supply of fuel for a flash fire. Also, there is little evidence as to whether the second flash fire occurred. The alternative, that there was fuel adhering to the empennage which was still burning, is canvassed in the report (1.14.5, p. 39). Further information is needed on

this point. Figures 44 and 45, later, shows that the sooting patterns around the rivets are consistent with a static fire. (There was also evidence of in-flight fire, consistent with the first flash fire). Since the static fire could only have occurred after the empennage came to rest, and there was no source for this fuel other than droplets already on the tailplane, it may be inferred that this second fire was a static fire rather than a flash fire. This matter will also be addressed when the post-impact diagrams are amalgamated.

A further limitation in the report is shown by the inconsistency between Figures 32 (the impact sequence) and 33 (the fire sequence). Figure 32 indicates that, for a short period after rebounding from the knoll, the right wing tip scraped the ground, and then the aircraft struck the ground again with the fuselage and the right engine. This is not at all the same as the progressive impact described in Figure 33 - right wing tip, right wing and engine - producing the progressive disruption of the right wing structure alluded to in 1.14.3 (p. 39). While the impact description in section 1.14 would account for the disruption of the integral tanks and so the flash fire, Figure 5 in the report (the wreckage diagram) shows that the description in Figure 32 is accurate. Accordingly, the impact sequence in Figure 33 is wrong. The scrape by the right wing was a transient affair; loads on the wing would have been minor and in-plane, and unlikely to have caused significant damage. The subsequent impact was taken by the right engine, and the belly of the aircraft. Although the engine struck the ground sufficiently hard to damage the engine, the underside of the outer right wing, found further along the wreckage trail, did not display evidence of a major impact. The detachment of the wing, and the fire, remain to be explained. Further evidence must therefore be sought. This will be discussed later, in 'evidence from the wreckage'.

While the discrepancy in the descriptions of the impact sequence might have been detected by diligent reading of the official report, neither the original authors of the report, nor the Commissioners whose task it is to vet reports, detected the inconsistency. The graphical presentation of MES makes the detection of such a discrepancy more probable.

Turning now to the crew and passenger injuries, the sequence is shown in Figure 34. As with the section on fire, there is also information on the impact sequence, in this section.

A difficulty arises in trying to determine what events are described in the section on medical information, because of missing and conflicting information.

- While the report states that impact forces have been calculated for the impact sequence (1.13.7, p. 37), these calculations are not shown, and the forces are not stated.
- 1.13.7 refers to Table 1 in the report (p. 38), which details the damage to seats and injuries to passengers by seat location. However, there is some conflict between the written report and Table 1. Section 1.13.13 (p. 39) states that a passenger was thrown two rows forward and fatally injured, while Table 1 states that the only fatally injured passenger in a detached seat (in seat 6G) was ejected from the aircraft. Unmentioned in the written report is another passenger ejected from the aircraft (in seat 3G), who suffered non-fatal chest injuries (Table 1, p. 38).
- Paragraph 1.13.8 (p. 39) states that "most of the occupants' injuries... were to the head, neck and chest". Table 1 indicates that there were 3 head injuries, 1 neck injury, and 5 chest injuries. Taken together (9 injuries), these were commonest overall, but in general these injuries did not happen to the same occupants, e.g. those who suffered head injuries did not generally suffer chest injuries. After chest injuries, the commonest injury among the passengers was back injury (4 injuries).
- Table 1 (p. 38) is silent on the injuries said to have been caused by the entry of foreign objects (1.13.10, p. 39).

To produce the MES graph for the events relating to injury, the events described in Figure 34 are first converted to EBBs, and then linkages are made where possible. The MES graph of this section is shown in Figure 35.

The pilots' head injuries (1.13.11, p. 39) are attributed to forward and downward motion on impact (1.13.1, p. 37), but this lacks face validity, since the pilots would have been restrained by inertia reel seat harnesses. Figure 6b in the report (p. 42) shows that there was disruption of the cockpit roof in way of the pilots' heads, and the photograph on p. 4 in the report shows that this disruption was due to external impact. Since the report implies that both major impacts were upright (Figure 1; 1.12.13, 1.12.15, pp. 35, 36) this disruption must have occurred, not at the major impacts, but during or at the end of the ground slide. (This matter is addressed when the graphs are amalgamated, as discussed below).

The split in the cabin floor appears to be attributed to torsional forces (1.13.2, 1.13.3; p. 37) but this attribution also lacks face validity. Supposing that the wing breakage could cause torsional forces in the fuselage (and this is difficult to visualise, since the rotational inertia of the fuselage about its longitudinal axis is low) the expected mode of failure of a cylinder (the outer fuselage skin) would be a spiral twist. There was no evidence of this. An internal diaphragm (the floor) would be subject to diagonal loading, and would tend to tear at 45° to the fore-and aft axis, and this did not happen. (The split in the floor will be discussed later, in considering other evidence).

The EBBs as shown have the multiple actors used in the report's terminology. While multiple actors are not permitted in EBBs (Benner, 1994) it does not introduce ambiguity to say that 'passengers' or 'crew' were affected by impact forces, unless there were material differences in the forces experienced by different persons. It is possible to visualise all passengers being thrown forward and downward at the same time, for example. Also, the general term 'impact forces' is unavoidable, absent information on these forces.

However, both the written report and Table 1 (p. 38) indicate that there were material differences in the forces experienced: 1.13.1 (p. 37) indicates that seats in the forward area did not break free, while those further aft did so (Table 1). This implies that forces along the fore-and-aft axis (expressed in multiples of the force of gravity, in that axis, G_x) were greater, towards the tail of the aircraft. This is unusual, since forces within the aircraft are attenuated by the distortion of crushable structure further forward (see, for example, USAAMRDL, 1971). Likewise, the presence of vertical

deceleration (Gz) at the rear bulkhead, sufficient to distort it and so injure the back of a passenger in a rear seat, is abnormal. Such an unusual state of affairs merited explanation.

The imprecise language used in the report caused some difficulty. Thus, where 1.13.1 (p. 37) speaks of the impact forces from two major impacts, it is difficult to visualise what occurred separately on each. In general, the forces at first impact are likely to be more severe than those after a rebound, because energy is absorbed during the initial impact. However, this is not necessarily so: if for example, the initial impact is a glancing blow and the second deceleration is more sudden, then more severe forces could be experienced during the second impact. Also, if seats or structure are damaged in the initial impact, there may be less occupant protection during a subsequent impact. Although the report states (1.13.7, p. 37) that the impact forces were calculated (and so the investigators were presumably aware of the severity of each impact) the absence of this information has led to the duplication seen in Figure 35. Nevertheless, it can reasonably be inferred that the unrestrained cabin attendant fell to the floor at the first impact: she could hardly have fallen far enough to suffer a fatal head injury (1.13.12, p. 39) in the second impact if she was already on the floor.

Where there was insufficient information in the report to construct valid EBBs and linkages, the missing information has been shown by question marks. These indicate areas where further information should have been sought during the investigation, for a full understanding of the impact sequence. Presumably, it was the lack of full understanding which led to the use of imprecise language. If a MES graph had been used when this section of the report was being drafted, the ambiguities introduced by imprecise language should have been evident, and they could have been addressed. The inconsistencies between the written report and Table 1 (p. 38) might also have come to light.

Figure 35 shows a number of loose ends. Although it is stated that structure and debris entered the cabin (1.13.6, p. 37) and injured passengers (1.13.10, p. 39), these injuries are nowhere detailed, so it is not known whether they were serious or minor. More importantly, the report's authors considered the forces transmitted to the seats in rows 5-9 (1.13.6, p. 37), and the split in the floor (1.13.3, p. 37) worthy of

mention, but these events are not followed up. Likewise, the event of the passengers striking each other or the fuselage side (1.13.4, p. 37) was no doubt material, but it is left hanging in the report.

These lapses are apparent from the MES graph, and had the authors used such a graph, it should have brought the lapses to their attention. In summary, the use of an MES graph while compiling the section on injuries, or when subsequently reviewing the text, would have shown where information was missing, or logical connections needed to be made, or further information needed to be obtained.

The Complete MES Graph for the Impact Sequence

The complete MES graph for the impact sequence, shown in Figure 37, is produced by combining the impact, fire and injury graphs, Figures 32, 33 and 35. Where it has been possible to resolve inconsistencies from the report, this has been done.

First, the 'impact' and 'fire' sequences are combined (Figure 36). (The detail in this graph is too small to be visible at this scale, but is essentially the same as in the individual sectors). Then, the 'injuries' sequence is combined with the already amalgamated information in Figure 36, to form the overall picture of the impact sequence shown in Figure 37¹⁶.

(The anomaly, between 'left wing assembly broke off' (1.12.15, p. 36) and 'both wings broke away' (1.13.2, p. 37) is a matter of loose phrasing in 1.13.2; in fact the right engine and remains of the right wing remained loosely attached (1.12.17, p. 36)).

¹⁶ Figures 36 and 37 show the overall arrangement of the MES graph at this stage. Figure 46 shows the finalised MES graph for the impact sequence, and has a complete key.

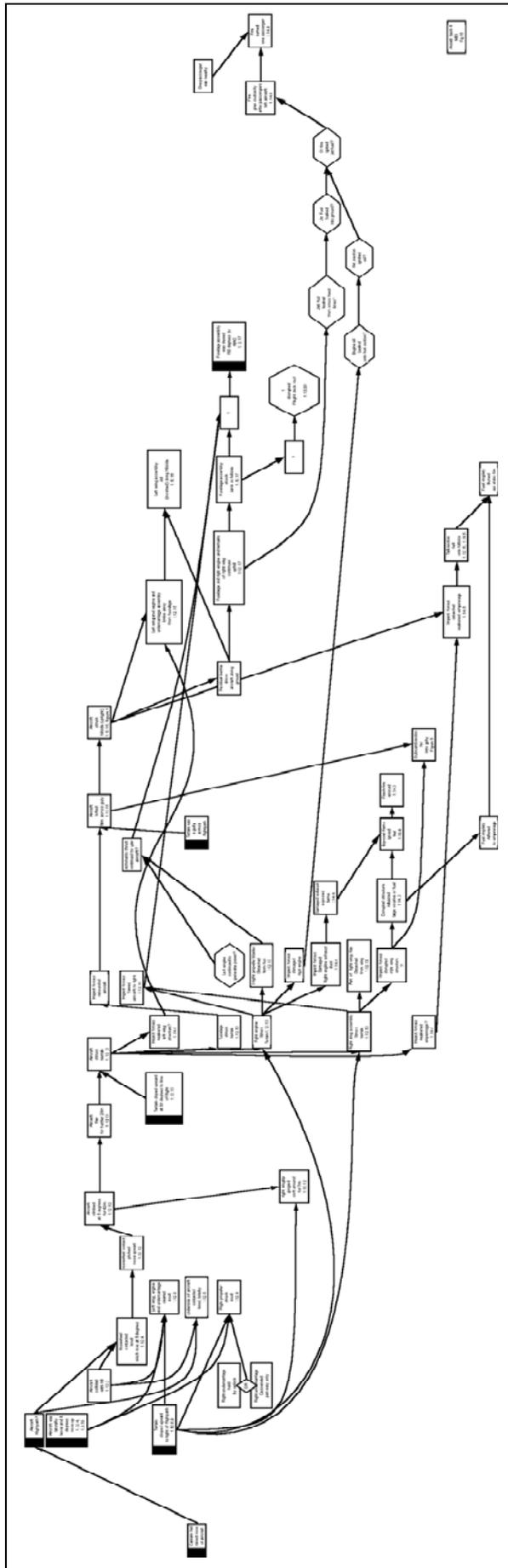


Figure 36. Ansett Dash 8 MES, combining the Impact and Fire sequences.

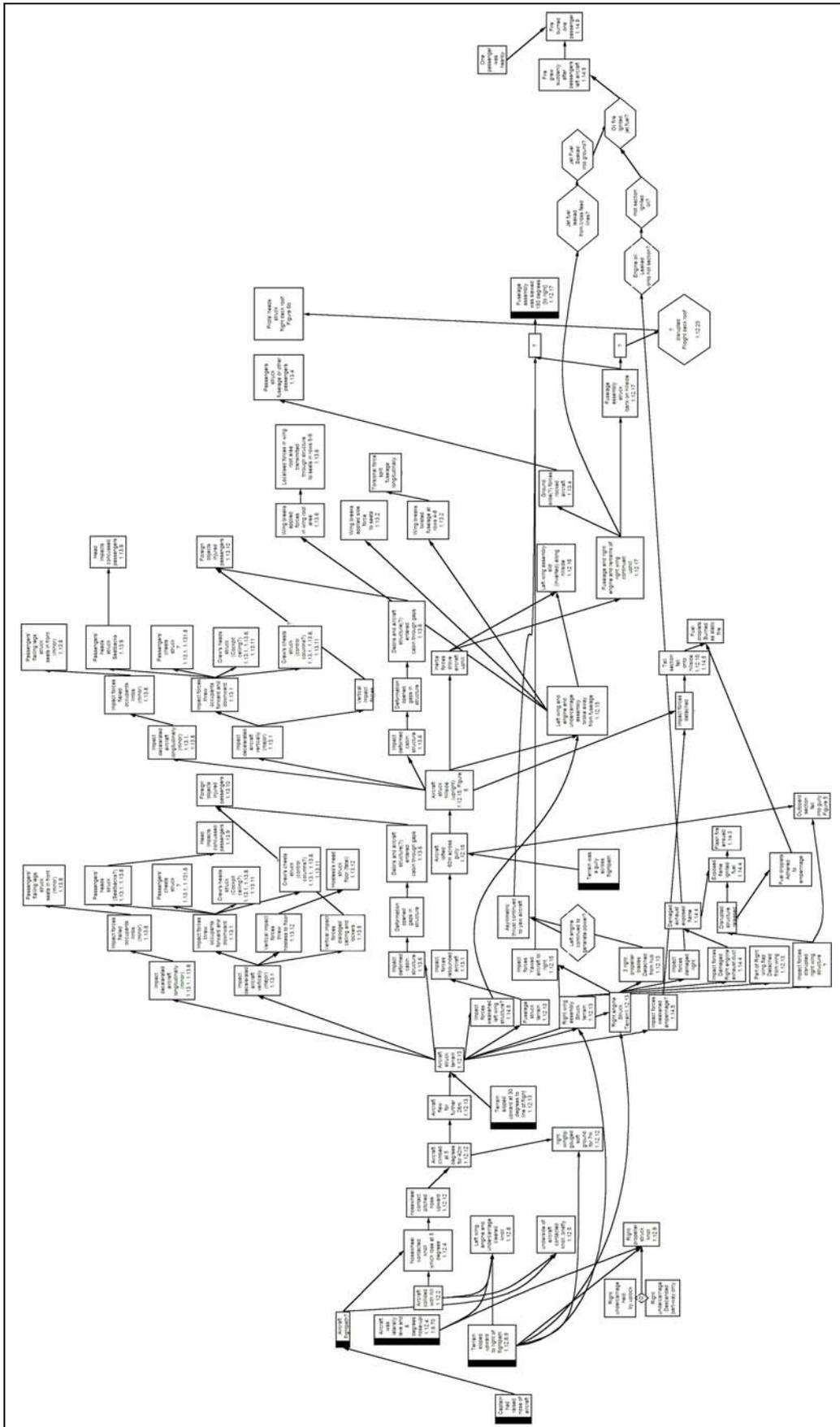


Figure 37. Ansett Dash 8 combined MES graph of impact sequence.

Evidence from the Wreckage

Evidence from the wreckage was used to resolve some of the queries raised by the development of the MES graph. The photographs in the following section, taken by the author and his students while the wreckage was stored in a hangar at Palmerston North aerodrome, illustrate the various points discussed.

The first unresolved point on the MES graph of the impact sequence is whether the right hand undercarriage was unlatched or not. The question is relevant in determining whether the indentation on the undercarriage latch was entirely due to wear, or whether it might have been, in part, due to impact from the retaining roller during the impact sequence. This point should be easily resolved by examination of the undercarriage doors, since immediately after release of the undercarriage the wheel would pass between the doors; subsequently the undercarriage leg would be between the doors. If the undercarriage had started to descend, there should be witness marks on the doors, i.e. marks made by contact between the doors and the undercarriage, showing what position the undercarriage was in relative to the doors when the marks were made.

Figure 38 shows the interior of an undercarriage door, alongside a tyre. The tyre manufacturer's name is embossed on the side of the tyre, and the witness mark is a mirror image of that name, impressed on the inside of the door by contact between the tyre and the door. To make the mark in this position, the wheel had to be partly descended, its sidewall being parallel to the door, at the moment of impact. If the wheel was retracted at impact, with the door open, the door would simply have been broken off. Likewise, if the wheel was retracted, and the door closed at impact, it would not have been possible to achieve this orientation of wheel and door by breakage of the door. Even had the broken door been forced into the undercarriage bay, there would have been no way of generating the necessary sideways force on the door so as to strike the wheel parallel to it, while the wheel was fully retracted. Accordingly, the uncertainty is resolved: the undercarriage was unlatched, and the wheel had partly descended, when the engine nacelle struck the ground.



Figure 38. Witness mark on right hand undercarriage door.

The report by the manufacturers of the undercarriage, Messier-Dowty (cited at 1.16.13, p. 46), stated that it was not possible for the manufacturer to determine whether all of the depression measured in the uplock hook was due to wear, or whether some might have been due to impact loading (1.16.13). Since the leg was partly extended, the uplock roller was not in proximity to the hook, and all of the measured depression was due to wear. The MES graph shows that there was an

unresolved issue here. Had the investigators been using this method of data display and manipulation, their attention could have been drawn to the deficiency, and the matter resolved.

The next question to be considered is the injuries to the pilots' heads. As already discussed, this came about because of exterior damage to the roof of the cockpit, but the question is, how did this damage come about? It could not have occurred during an upright impact, and it is hard to envisage it happening during the ground slide, or resulting from the impact with the small bank at the end of the ground slide.

Photograph on p. 4 of the report shows the aircraft looking from the front. The upper part of the cockpit roof has been flattened. Figures 39 and 40 show that this crushing is continued as a line along the aircraft skin, along the cabin roof and more or less parallel to it. This line is termed a 'crush line': it shows where structure has been crushed in, and has then rebounded to something like its original form. Earth is ingrained in the roof area. The only way to produce such crushing is for the aircraft to



Figure 39. View from front of fuselage, showing crush lines and ingrained dirt.

strike the ground or other solid object, with the part which has been deformed. In other words, the evidence from the photograph on p. 4, and figures 39 and 40, is that *the aircraft struck the ground inverted, in a slightly nose-down attitude.*

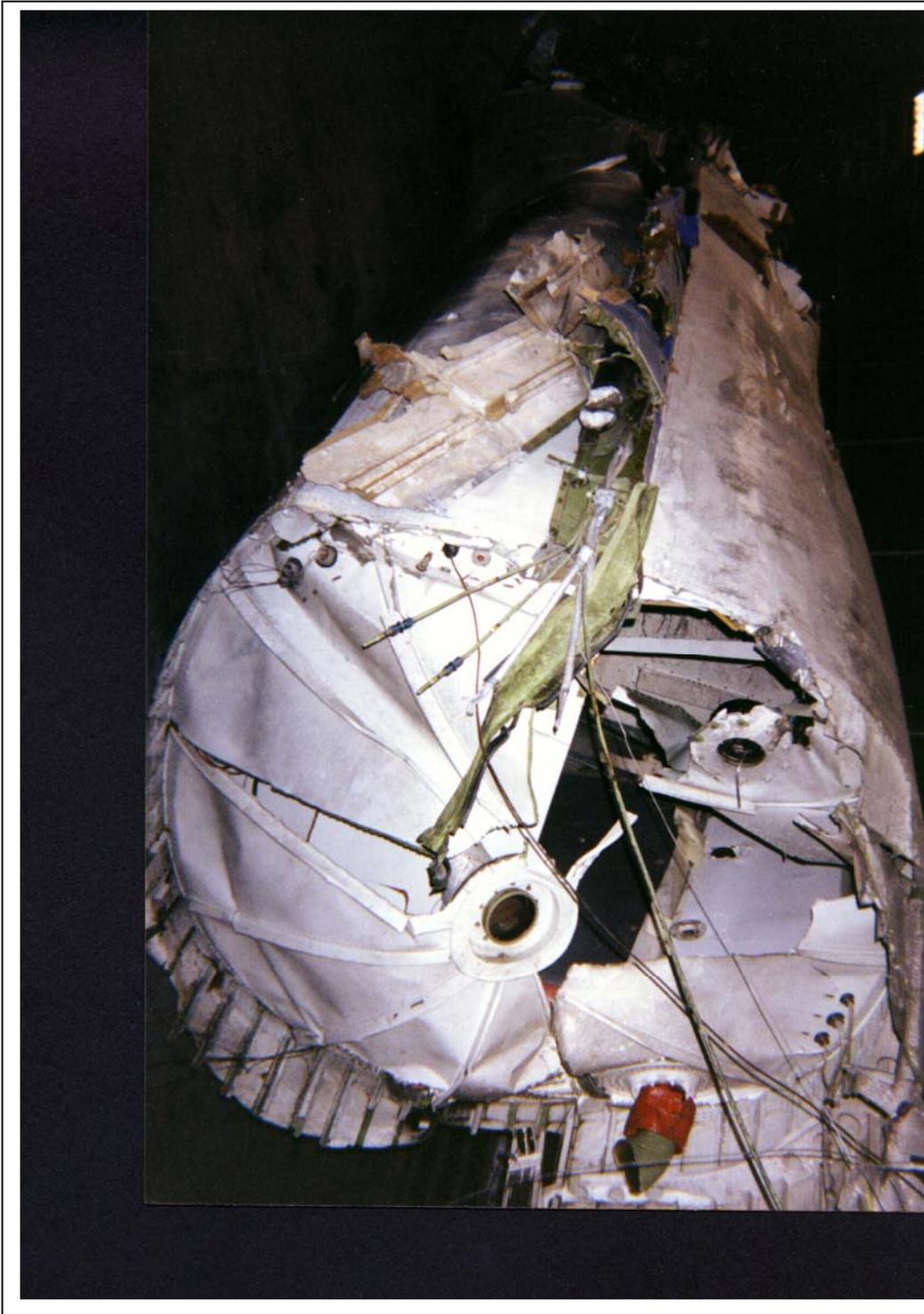


Figure 40. View from top rear of fuselage, showing crush line, torsional damage to rear bulkhead, and stub of fin wiped to the left.

Evidence supporting the inverted impact is the lack of damage to the left undercarriage leg, which remained intact and extended throughout (photograph of the accident site, report p. 2), and the absence of damage to the underside of the left engine nacelle (Figure 41). Further supporting evidence is the crush damage to the front top of the engine nacelles made (like the damage to the cockpit roof) by an inverted impact in a somewhat nose-down attitude. Figure 42 emphasises the pronounced flattening on the top of the rear fuselage.



Figure 41. Left engine nacelle, showing lack of damage to underside, and inverted ground contact. Damage to the propeller shows that it was in this position, and rotating, when the nacelle struck the ground.



Figure 42. View from bottom rear of fuselage. Impact damage is ahead of rear bulkhead. Note flattening at top of rear fuselage.

Clearly, the first major impact (after the touch on the grassy knoll) was upright: there was nothing which could have caused the aircraft to roll inverted. This initial upright impact is consistent with crush damage to the belly of the aircraft (Figure 42). There was little structural damage likely to detach the empennage, and had it become detached at this point its subsequent flight path would have been random, because its weight in relation to its area was low. It would have been unlikely to have come to rest in the vicinity of the second impact, because its weight in relation to its area would have been much lower than that of the fuselage and wings.

A potential cause of roll after the first impact was asymmetric thrust, which would have caused both yaw-roll coupling, and asymmetric lift due to the flow of slipstream over one wing but not the other. However, this cannot account for the rate of roll. The distance between the first and second major impacts was 60 metres, and at 122 knots (the groundspeed of initial contact) the aircraft would have covered this distance in 0.96 seconds. Even allowing for reduction of speed during ground contact, the rate of roll required to go from upright to inverted would have been about 180 degrees per second. The answer to the achievement of the high roll rate lies in the

removal of the right wing, outboard of the engine nacelle (Figure 5 in the report). The nose was rising before the first major impact (perhaps because of the initial nosewheel impact) so the wings would have been at a larger than normal angle of attack, and lifting strongly. Removal of the outboard part of one wing would have left the lift from the other wing unbalanced, so the aircraft would have rolled at a rate constrained only by the roll damping of the remaining wing.

How did the right wing come to be removed? There were gouges in the ground from the right wingtip, but these alone do not indicate that the wing was torn off backwards. Wings of airliners form a shallow box structure, which is strong in-plane, and so unlikely to be torn off at part span by contact at the tip. Were the wing to have been torn off by tip contact, it would probably have failed at the point of highest stress, i.e. at the root, but this did not happen. Also, if the outer portion was torn off by ground contact it seems unlikely that it would have finished on the centreline of the wreckage path (Figure 5 in the report): it would have been expected to have been somewhat to the right of track.

Was the structure critically weakened by bending normal to the plane, as the result of ground impact, thus leading to failure? There was no evidence of bending of the spar before failure when the author examined the wreckage in the hangar at Palmerston North. The spar shear web showed no deformation due to shear loading, in the region of separation. Besides, contact between the ground and nacelle would have alleviated the load.

However, what *was* visible were two indications of in-flight explosion: the wing skins had been forced outward on both sides of the break; and bellling of the spar web, where pressure has forced the web rearwards between the stiffened areas. This suggests that an explosion must have been initiated while the structure was still intact, as otherwise the pressures necessary to deform and tear the metal could not have been generated. (The best photograph available is Figure 43. Unfortunately, attempts to photograph these features were unsatisfactory: they were black features against a black background, in a dimly lit hangar, and no special lighting was available. Ansett Airlines were permitted to destroy the wreckage before this evidence could be properly documented).



Figure 43. Starboard wing outboard of nacelle. Downward deflection of lower surface; spar web pulled away from spar caps. There has been no loading of the web in shear.

A possible way for ignition to have occurred while the structure was intact would have been via a tank vent. If there was a flame trap in the vent, it would have had to have been ineffective, for ignition by this means to have occurred. However, the evidence was destroyed before the matter could be further investigated. If the ignition was via a tank vent, what was the ignition source? It is unlikely to have been flame from the engine. Flame from the jet-pipe would have gone aft of the tank vent. The report does mention that there had been a fuel leak within the nacelle during refuelling (1.6.6, p. 10): perhaps fuel had accumulated within the nacelle, and initiated a flash fire when the nacelle struck, the flash being sufficient to reach the tank vent. The evidence having been destroyed, there is no way of being certain.

The position of the outer wing portion in the wreckage trail can be accounted for if the wing panel was loosely retained by a small portion of the structure, until it was finally torn off as the aircraft rolled. Such a portion, distorted in a manner consistent with such action, is visible in Figure 43, and some of the damage to the right tailplane is consistent with impact from the wing (Figure 44).



Figure 44. Damage to upper skin of starboard tailplane. The square hole has extensive sooting inside; the deflection damage has very little sooting. Soot deposits around rivets are fairly even, suggesting static fire.

The next point to consider is the split in the lower fuselage. Rupture of the floor because of torsional forces has already been discounted. However, inverted impact could account for the split in the floor in two ways:

- The inverted impact would set up severe hoop stresses in the fuselage formers, tending to cause tensile overload failure of the floor beams, simultaneously at a number of stations. This would lead to the floor splitting longitudinally.
- When the left wing struck the ground inverted, the roll would be stopped virtually instantaneously. The rolling moment of inertia of the fuselage, though low, was not non-existent, so the fuselage would continue to roll for a short period. With the floor beams already stressed or broken, the floor would then split longitudinally.

When the aircraft struck the ground inverted, the empennage would also have struck the ground. The aircraft had a 'T' tail, and it would be expected that the entire empennage would separate at the fin root. It separated at the former just ahead of the fin root. Supporting evidence is impact damage to the upper surface of the tailplane (Figure 45). Additionally, Figure 40 shows that the fin spar has broken off under a

sideways loading, and the stub has been smashed flat against the top of the rear fuselage, indicative of inverted impact with the fin in place. Together with the juxtaposition of the empennage and the impact marks, this is evidence that the inverted impact removed the empennage.



Figure 45. Damage to leading edge of fin and upper surface of tailplane. There was no corresponding damage on the outer portion of the right wing.

Evidence from the Injuries

The pilots suffered head injuries. They were restrained by full harnesses. How, then, could their heads come into contact with the cabin structure? The photograph from the front of the aircraft (report, p. 4) shows that the top of the cockpit was crushed in by the inverted impact, to an extent greater than subsequently found when the wreckage was examined. Since the occupiable space in the cockpit was significantly reduced as found (report Figure 6b, p. 42), it may be concluded that the pilots' head injuries were due to transient lack of occupiable space, while the structure was crushed in by the inverted impact.

The Flight Attendant was not restrained at the time of the accident. She was leaning over the back of a seat in the front row, talking to the passenger behind. This passenger had previously noticed that the right wheel had not extended, and had notified her of this; she had gone into the cockpit to ensure that the pilots were aware of the malfunction, and came back to explain to the passenger that the pilots were dealing with it. She died from head injuries. Lack of flailing injuries to the passengers' limbs (1.13.8, p. 39) shows that longitudinal deceleration was low, and there was little room for her to accelerate relative to the structure, if she was thrown against the bulkhead behind her. Such an impact is therefore unlikely to have been the cause of death. The report attributes her death to falling to the cabin floor, in an upright impact. Injuring one's head while falling to the floor is perhaps less likely than injuring it by being thrown against the inverted ceiling, which would be forced inward as the aircraft struck the ground inverted. The pathologist's report did not indicate a contre coup incident, which might have explained a fatal head injury in a fall to the floor.¹⁷

¹⁷ A contre coup injury is related to head injuries where the brain is propelled forward and then back. The skull is a rigid outer vault that houses the jelly-like organ, the brain. When subject to a sudden jolt, the protective cushioning fluid is no longer effective, allowing sudden acceleration/deceleration.

Primary injury to the brain in blunt trauma as in Ansett is caused by the acceleration/ deceleration of the brain within the skull. What is seen in the brain can be either haemorrhage, contusion or laceration.

In the Ansett case, the Flight Attendant was standing at the time of the crash, unrestrained, and leaning across the back of the seat in the first row, and the distance from the ceiling of the aircraft and the front bulkhead could not have caused her injuries, in an upright impact.

The source of information is photographic evidence and the description of injuries from the St John

Two passengers towards the rear of the cabin (seats 6G and 7B) suffered fatal head, and neck or back, injuries. The bases of their seats were broken, even though the bases of most of the seats forward of them were undamaged (Table 1 in the report, p. 38). In an upright impact with relatively low forward deceleration, it would be unusual for passengers to suffer fatal head and spinal injuries, especially towards the rear of the cabin. Some facial injuries might occur as the passengers were thrown against the seatbacks in front, but seatbacks are made frangible in order to avoid more serious injury in such circumstances. However, an inverted impact would impose loads for which the seats were not designed, which could account for the structural failure. If the passengers' heads struck the cabin roof in the course of an inverted impact, fatal head and spinal injuries might be expected. The severity of the impact at the rear of the aircraft could be explained by a whiplash effect, as the rear fuselage was slammed into the ground following the nose-down inverted contact. Such an event is demonstrated by the flattening of the roof at the rear bulkhead (figure 41). This flattening was also the cause of the distortion of the rear bulkhead, which caused back injury to the passenger in 10F (Table 1 in the report, p. 38).

It has been shown that

- The inverted impact was responsible for some of the injuries
- The aircraft became inverted because of the loss of the right wing
- The right wing came off because of an explosion in an intact fuel tank

Accordingly, the explosion and inverted impact were significant factors in the survivability of this accident: they should have been addressed as a safety concern. It is unfortunate that this deficiency in the report was not recognised and addressed before the evidence was destroyed, after the wreckage had been released by the Commission. Discovering such deficiencies *during the course of an investigation*, while there is still time to rectify them, is an important function, and one which Multilinear Event Sequencing seeks to address.

Evidence from Crown v Sotheran

The Captain of the Dash 8, Captain Sotheran, was charged with manslaughter, in relation to the deaths of the passengers¹⁸. At the trial, evidence was given as to the failure of the GPWS to provide the expected warning, by the designer of the warning system. The official report did not note that the radome for the radio altimeter aerial had been painted over, contrary to instructions. Nor was there any information on the condition of the aerial. At the trial, evidence was given by the designer of the GPWS system, that the aerial was seriously corroded. In the designer's opinion, the corrosion of the aerial (which would have had an adverse effect on the signal strength available to the radio altimeter) would explain the shorter than expected warning time. The paint on the radome could also not be ruled out as a contributory factor (Morgan, 2001). Had the warning time been the expected 17 seconds, there is no doubt that the response by the crew would have averted the accident, so the corrosion of the aerial was a causal factor in the accident. It would therefore have been appropriate to consider how the aerial came to be so corroded, without the corrosion being detected during normal maintenance. The use of an MES graph would have flagged to the investigators the deficiency in their investigation, and so directed their attention to the additional evidence that was available.

Complete MES Graph with All Available Information

The completed MES graph, showing the overall picture of the impact sequence, is shown in Figure 46. It is formed by correcting the various boxes with the information derived from the evidence already discussed. For example, the box containing 'upright impact' in Figures 32 and 37 is amended to 'inverted impact' in Figure 46, and concomitant changes to the causes of injuries follow.

¹⁸ Captain Sotheran was acquitted.

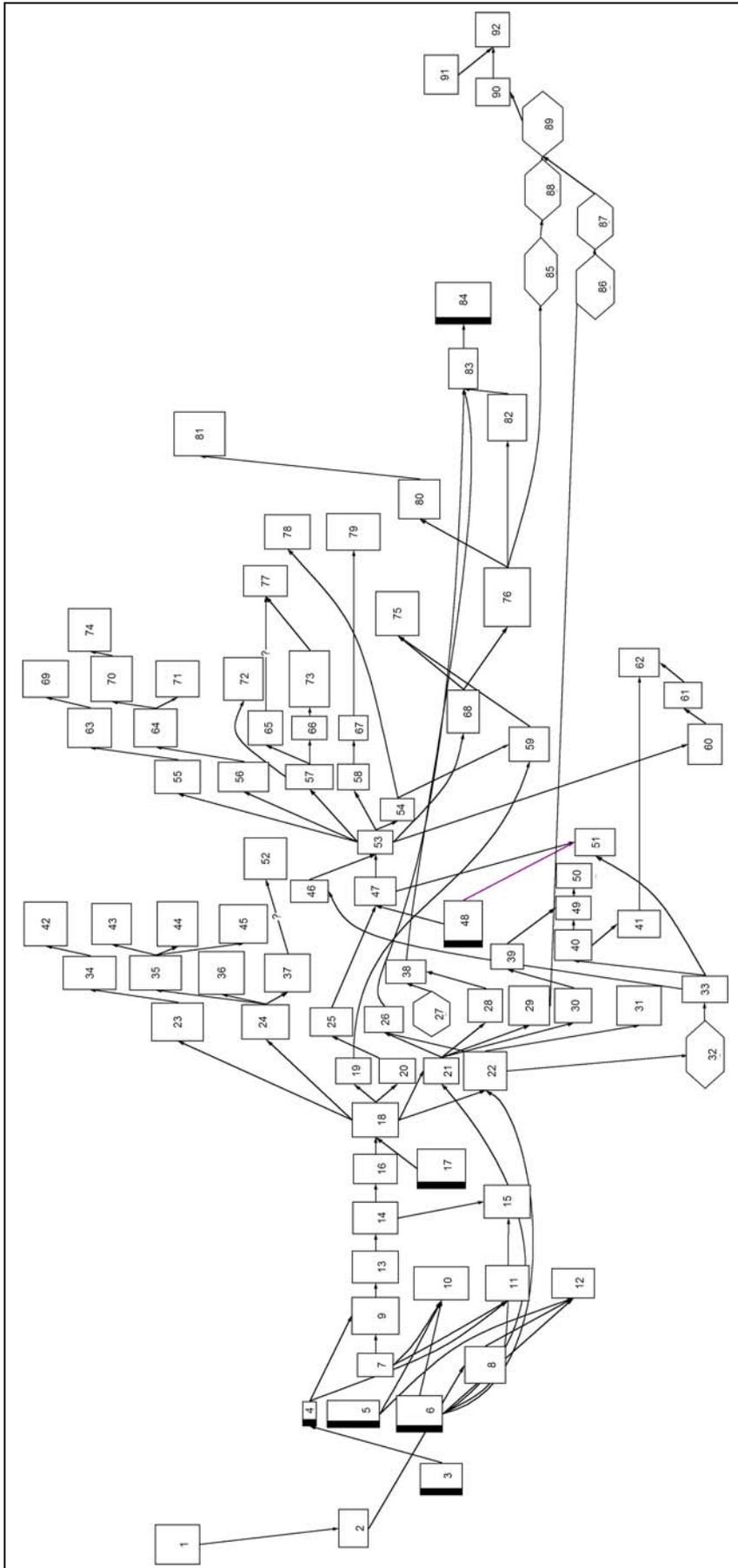


Figure 46. Complete MES Graph using all available information.

Key to Figure 46

1. Co-pilot pulled emergency undercarriage release
2. Undercarriage latch opened
3. Captain had raised nose of aircraft
4. Aircraft flightpath?
5. Aircraft was laterally level and 8 degrees nose-up 1.12.4; 1.6.70
6. Terrain sloped upward to right of flightpath 1.12.8,9
7. Aircraft collided with hill 1.12.2
8. Right undercarriage Descended part-way only
9. Nosewheel contacted knoll which rose at 5 degrees 1.12.4
10. Left wing, engine and undercarriage cleared knoll 1.12.8
11. Underside of aircraft contacted knoll, briefly 1.12.5
12. Right propeller struck knoll 1.12.9
13. Nosewheel contact pitched nose upward 1.12.12
14. Aircraft climbed at 5 degrees for 42m 1.12.12
15. Right wingtip gouged soft ground for 7m 1.12.12
16. Aircraft flew for further 28m 1.12.13
17. Terrain sloped upward at 30 degrees to line of flight 1.12.13
18. Aircraft struck terrain 1.12.13
19. Impact forces weakened left wing structure? 1.14.5
20. Fuselage struck terrain 1.12.13
21. Right engine struck Terrain 1.12.13
22. Right wing assembly struck terrain 1.12.13
23. Impact decelerated aircraft longitudinally (minor) 1.13.1, 1.13.8
24. Impact decelerated aircraft vertically (major) 1.13.1
25. Impact forces rebounded aircraft 1.13.1
26. Impact forces yawed aircraft to right 1.12.15
27. Left engine continued to generate power?
28. 3 right propeller blades detached from hub 1.12.13
29. Impact forces damaged right engine
30. Impact forces damaged right engine exhaust duct 1.14.4
31. Part of right wing flap detached from wing 1.12.13
32. ? Ignited fuel vapour/droplets in right tank

33. Fuel explosion blew off outer part of wing
34. Impact forces flailed occupants limbs (minor) 1.13.8
35. Impact forces threw occupants forward and downward 1.13.1
36. Vertical impact forces threw Flight Attendant to floor? 1.13.12
37. Vertical impact forces dislodged ceiling and lockers 1.13.5
38. Asymmetric thrust continued to yaw aircraft
39. Damaged exhaust exposed flame 1.14.4
40. Fuel tank disruption released large volume of fuel 1.14.3
41. Fuel droplets adhered to empennage
42. Passengers' flailing legs struck seats in front (minor) 1.13.8
43. Passengers' heads struck (seatbacks?) 1.13.1, 1.13.8
44. Passengers' chests struck? 1.13.1, 1.13.8
45. Crew's chests struck (control columns?) 1.13.1, 1.13.8, 1.13.11
46. Asymmetric lift rolled aircraft inverted
47. Aircraft lofted 60m across gully 1.12.15
48. Terrain was a gully across flightpath
49. Exposed flame ignited fuel 1.14.4
50. Flash fire ensued 1.14.3
51. Outboard section fell into gully (Figure 5)
52. Foreign objects injured passengers 1.13.10
53. Aircraft struck hillside inverted
54. Left wing (striking ground) stopped roll abruptly
55. Impact decelerated aircraft longitudinally (minor) 1.13.1, 1.13.8
56. Impact decelerated aircraft vertically (major) 1.13.1
57. Impact deformed cabin structure 1.13.6
58. Impact deformed cockpit roof
59. Left wing and engine and undercarriage assembly broke away from fuselage 1.12.15
60. Empennage struck ground (inverted)
61. Tail section fell onto hillside 1.12.15; 1.14.5
62. Fuel droplets burned as static fire
63. Impact forces flailed occupants' limbs (minor) 1.13.8
64. Impact forces detached some passenger seats
65. Deformation of cabin roof dislodged ceiling and lockers 1.13.5

66. Deformation opened gaps in structure
67. Deformation generated hoop stresses
68. Inertia forces drove aircraft uphill
69. Passengers' flailing legs struck seats in front (minor) 1.13.8
70. Some passengers' heads struck cabin roof
71. Passengers' chests struck? 1.13.1, 1.131.8
72. Crew's heads struck cockpit ceiling 1.13.1, 1.13.8, 1.13.11
73. Debris and aircraft structure (?) entered cabin through gaps 1.13.6
74. Head impacts concussed passengers 1.13.9
75. Left wing assembly slid (inverted) along hillside 1.12.16
76. Fuselage and right engine and remains of right wing continued uphill
1.12.17
77. Foreign objects injured passengers 1.13.10
78. Rolling inertia applied side force to seats 1.13.2
79. Impact stresses split fuselage longitudinally 1.13.3
80. Ground slide (?) forces rocked aircraft 1.13.4
81. Passengers struck fuselage or other passengers 1.13.4
82. Fuselage assembly struck bank on hillside 1.12.17
83. ?
84. Fuselage assembly was slewed 150 degrees [to right] 1.12.17
85. Jet fuel leaked from cross feed lines?
86. Engine oil leaked onto hot section?
87. Hot section ignited oil?
88. Jet fuel Soaked into ground?
89. Oil fire ignited jet fuel?
90. Fire grew suddenly after passengers left aircraft 1.14.9
91. One passenger was nearby
92. Fire burned one passenger 1.14.9

Summary of MES Analysis

The MES analysis, using information from the report, from examination of the wreckage, and from subsequent litigation, shows why it is difficult to form a coherent picture of the occurrence from the report. Information has to be collected from widely dispersed sections of the report, and put into proper order, to form a 'mental movie'. Also, as indicated by the graphs, some information is missing from the report. The use of MES during the investigation would have highlighted these deficiencies, and further data could have been gathered. A further benefit of MES during the investigation would have been the identification of conflicting information, or uncertainty of information, and these matters could also have been addressed.

Although the rules for construction of MES graphs stipulate that the graphs comprise only logically related *events*, it has been found necessary, in this case study, to use *states* (i.e. a continuing state of affairs) in order to form a complete picture. Where this has been done, a different symbol has been used in order to distinguish such states from EBBs.

Some matters have been identified as being beyond the scope of MES: it is not suited to consideration of abstractions, since its purpose is to focus on concrete matters. More abstract matters will be considered in the next section, Why-Because Analysis.

Chapter 6: Analysing the Dash 8 Accident with a WB Graph

Why-Because Analysis

The basis for Why-Because Analysis (WBA) is Lewis's counterfactual definition of causal factor and causation: 'If A is a necessary causal factor of B, then in the nearest possible worlds in which A does not exist, neither does B'. A Why-Because Graph is constructed by asking this question of any factors taken two at a time: it may be convenient to start with factors close to the final event. In the analysis of causality of the Dash 8 accident which follows, the initial information comes from the MES analysis of events leading up to the impact on the mountainside.

The Ansett Dash 8 Accident

The crew were attempting to rectify an undercarriage 'hang-up' while on final approach to land, and the aircraft collided with a hill. The Transport Accident Investigation Commission (TAIC) investigated the accident (TAIC, 1995). The report identified the following causal factors:

- *The Captain not ensuring the aircraft intercepted and maintained the approach profile*
- *The Captain's perseverance with his decision to get the undercarriage lowered without discontinuing the instrument approach*
- *The Captain's distraction from the primary task of flying the aircraft safely during the First Officer's endeavours to correct an undercarriage malfunction*
- *The First Officer not executing the Quick Reference Handbook procedure in the correct sequence*
- *The shortness of the ground proximity warning system warning*

Construction of the Why-Because Graph may show whether these were valid causal factors, or whether there were others which should also be addressed.

In preparing the Why-Because Graph of the Ansett Dash 8 accident, attention was focused on the underlying corporate actions which had resulted in the crew being put into a position to make unsafe actions (Reason, 1991). Other factors, such as Air

Traffic Control (ATC), were not analysed in depth, because less information was available. Had the WBA been performed at the time of the investigation, the attention of the investigators might have been drawn to relevant factors which they might otherwise have overlooked.

A Why-Because Graph is constructed by starting from a significant event, and working forward or back in time. It is convenient to start with the initial impact with the hill, which happened at 09 22 30 local time. As originally devised by Ladkin & Loer (1998), the graph had no timebase, and states and events were arranged so as to minimise the crossing of causal linkages. However, nothing is lost by arranging the events and states in sequence. This makes the graph easier to present, and makes chronological validation easier. With sequential arrangement, there is likely to be more crossing of causal links, but this reflects reality the 'complex network of interacting events' discussed previously. Events during the flight may be placed in exact time sequence, using information from the aircraft and ATC recordings. As the investigation goes back earlier in time to events before the flight, knowledge of exact timing becomes less precise, but also less important. As with the MES graph, it may be found convenient to use a quasi-logarithmic format as suggested in (Zotov, 1996), where the timebase is divided into 'hours before', 'days before', 'months before' and 'years before' the accident. However, the graph presented now has no explicit timebase, but events are arranged in chronological order.

So, starting with the initial impact, the first question is 'Why did the aircraft strike the hill?'

The first answer has to be 'Because the hill was there'. It is immaterial that many approaches are over hills, or whether the approach complied with ICAO Procedures for Air Navigation Services - Aircraft Operations (PANSOPS) (ICAO, 1993) criteria. Had the approach been from the opposite direction, the accident *would not have occurred*, because the approach to runway 07 at Palmerston North would have been over level terrain at the same height as the airfield, and the aerodrome level was below cloudbase (the counterfactual argument). The presence of the hill was therefore an essential causal factor. Likewise, the next answer is 'because the aircraft was in cloud'. Had the aircraft been in VMC, the accident would not have occurred, because the crew could have seen the proximity to the ground.

Clearly, the accident could not have occurred had the aircraft been stabilised on the proper glidepath, since this was clear of terrain. Continued descent below the glidepath was therefore a factor.

But there is yet another factor. The purpose of Ground Proximity Warning Systems (GPWS) is to alert the crew to the fact that they are getting too close to terrain. In the case of this accident, the warning time should have been 17 seconds (1.6.81, p. 23)¹⁹, and this would have been more than sufficient for the crew to take avoiding action. Instead, they had only about 5 seconds (1.6.69, p. 21), and this was insufficient (1.18.56, p. 69). So the inadequate GPWS warning was a causal factor.

So far the causal factors identified are the presence of terrain and cloud, descent below the glidepath, and inadequate GPWS. (See Figure 47).

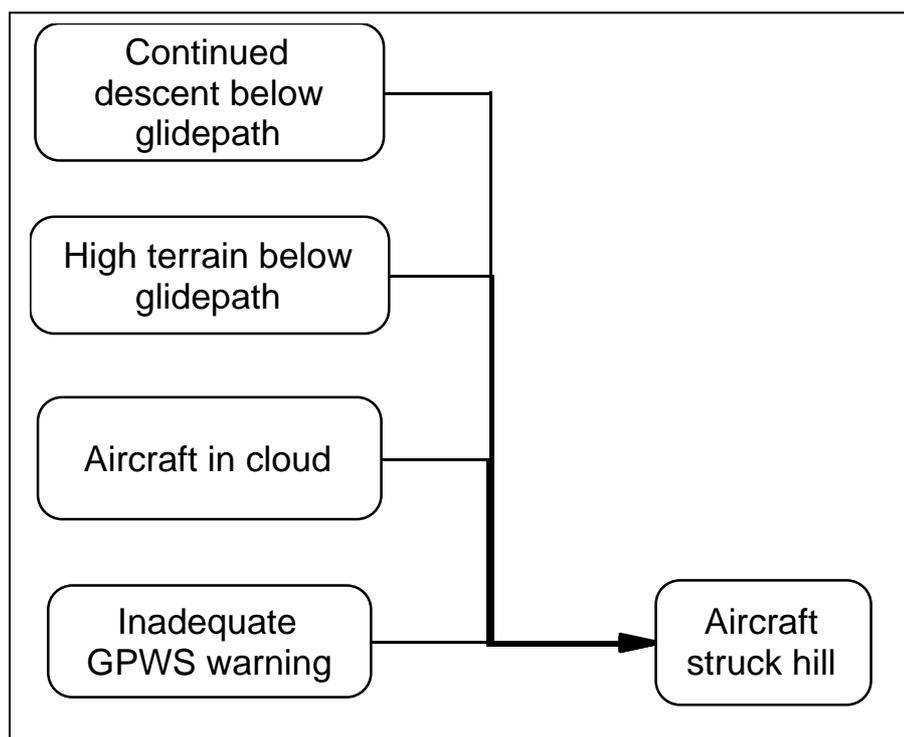


Figure 47. Ansett Dash 8 Why-Because Graph construction: first step.

¹⁹ Throughout this case study, section references (viz. 1.12.34) are to sections in the official report, TAIC (1995).

It may be that some of these factors are things usually taken for granted. Indeed, when the analysis is complete, it might be concluded that such conditions as descent over high ground, and descent in cloud, are such normal matters that they do not merit further consideration. However, they should be left in for the time being: merely because a matter is 'normal' does not make it optimal. For example, although the approach safety margins met the ICAO PANSOPS criteria, those margins might be considered inadequate for New Zealand conditions. And the fact that the aircraft was in cloud may be the answer to the question 'why did the accident not occur before?' There had been previous incidents of undercarriage malfunction which were sorted out by the crews, as discussed later, and these did not result in accidents. However, as far as can be determined, all the previous incidents happened in visual meteorological conditions (VMC).

The next stage is to consider each of these factors in turn, starting with descent below the glidepath.

A causal factor was that the Captain was not monitoring the approach effectively. *Why* his monitoring was ineffective comes later. But there is more to it than that. If he was not monitoring it at all, but the descent rate had been appropriate to maintain the glidepath, then the aircraft would have arrived at the aerodrome in good order. Inadequate monitoring is a *necessary* condition, but it is not *sufficient*. The aircraft was descending at a greater rate than that needed to maintain the glidepath. (Again, *why* it was descending at this rate will be considered later). But even this was insufficient, on its own, to cause the aircraft to strike the hill. Had the aircraft descended at the rate established by the speed and power setting, it might have cleared the hill. The crew might have been surprised to find the aircraft so low, but no accident would have ensued. The official report states that the rate of descent increased by about 400 feet per minute, over the last 4 miles before the accident, bringing the descent path below the height of the hill (1.7.19, p. 26)

Why was the overall descent rate greater than that required to maintain the glidepath? The approach, as flown by ZK-NEY, required a steep descent to reach the normal glidepath, after completion of the initial DME arc approach. Had the initial approach been completed at a height appropriate to the normal descent path, standard power settings would have resulted in a descent path closely approximating to that

desired. The high initial approach was thus instrumental in setting up the high descent rate.

However, the high initial descent rate in itself was insufficient to cause the accident: had the standard power setting been applied when the aircraft had descended to the normal glidepath, there would have been no problem. But, before the proper glidepath could be established, the crew were distracted by an undercarriage malfunction, and standard descent power was never applied.

So to recap thus far:

- The initial descent rate was excessive because the final approach was started above the normal level,
- The standard descent power settings were never applied because the crew was distracted.
- For the same reason the glidepath in the later stages was not monitored effectively.
- In the final stage of the descent the descent rate was increased (because a smooth draught was encountered) and the resulting glidepath intercepted the hill. (See Figure 48).

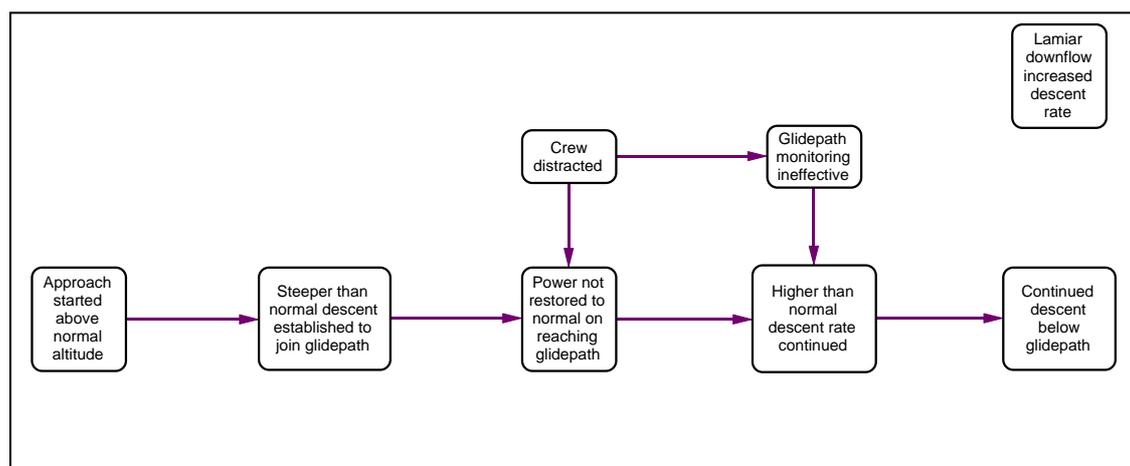


Figure 48 Why-Because Graph: second step.

Notice that the abstraction "The crew were distracted" has been used to cover two quite different things: the *event* of the undercarriage warning occurring just at the point at which normal descent power was about to be re-established, and the *condition*

of continued distraction from monitoring the glidepath by the subsequent problems in rectifying the malfunction. There is too much information loss here. The initial distraction was unavoidable as far as the crew were concerned, whereas the second could have been avoided by choosing a different strategy, or by better Crew Resource Management (CRM). This section therefore needs to be elaborated, as shown in Figure 49.

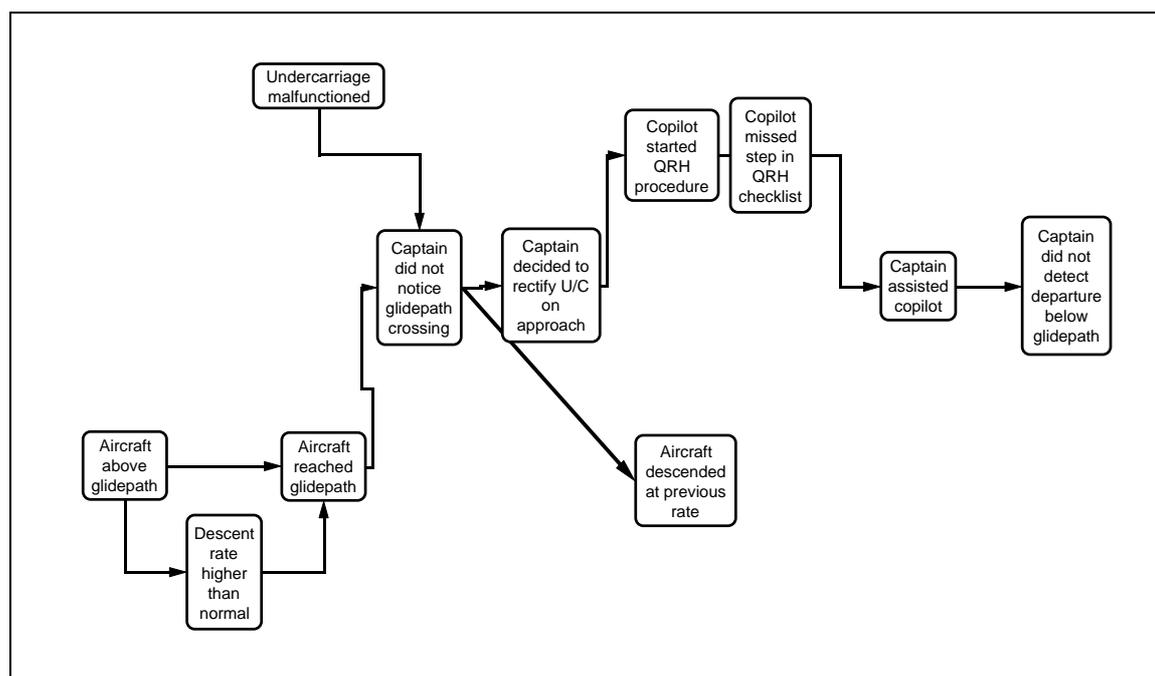


Figure 49. Elaboration of Fig. 48.

However, there are still inadequacies here. 'Captain helped Co-pilot' seems a rather inadequate explanation for 'Captain did not detect departure below glidepath'. Were there other factors which might, singly or in combination, have contributed to this result? There are a number of potential factors which are alluded to in the report: fatigue, inadequate CRM, and (possibly) misreading of the altimeter.

While the report acknowledges the loss of sleep occasioned by the early start of the duty day (1.18.18, p. 62), fatigue is dismissed as a factor because the crew had had adequate sleep on the two previous nights (*ibid.*). This implies that a sleep surplus can be 'banked' against a future deficit. There is no evidence that this is the case (Gander, 2001; Harrison, 2000; Kryger, 1998; Rosekind, 1995). There is a lengthy list of slips, lapses, and mistakes (1.18.12, pp. 60, 61), but no alternative explanation is adduced as to why an experienced crew should have made such a catalogue of errors

in a half-hour period. The co-pilot's comment (p. 114) "Oh gee, excuse me, I'm tired" would have been deathbed testimony had he not survived. Indicators of fatigue include consequences such as slowed reaction times, narrowing of attention, lack of alertness, and poor monitoring (see, for example, Dinges, 1995). Since the crew would have been deprived of the normal length of sleep by the early start, and displayed symptoms of fatigue which could not otherwise be explained, it may be concluded that the crew *were* affected by fatigue, and that this was a factor in the captain's ineffective monitoring, and in the co-pilot's incorrect performance of the QRH checklist.

There is also evidence to suggest that the captain may have misread his altimeter (1.16.21, p. 48). While the drum and pointer display is less likely to be misread than the older three-pointer altimeter (O'Hare and Roscoe, 1990), it still requires a conscious effort to read the height. If the pilot looks away from it, and a short time later looks back and finds the pointer in an expected position indicating rather lower than before, it is feasible that he might not read the 'thousands of feet drum', and so not notice that the aircraft was a thousand feet lower than he thought. When he did subsequently read the drum, it is reasonable that he would attribute the discrepancy to a 'jump' in the altimeter reading. That is what he said he saw. A factor tending to potentiate such misreading was the co-pilot's comment

"...We're looking for four thousand feet aren't we, so a fraction low" (Annex C, p. 128).

However, according to the vertical profile shown in the official report (Fig. 3, p. 28) the aircraft was at 3100 feet at ten miles DME. According to the Palmerston North Approach Plate (Figure 26) the optimum height at 10 DME was 3420, so the aircraft had just crossed the optimum descent path. 3120 feet was the optimum height at 9 DME. While the First Officer was correct in saying the aircraft was 'a fraction low', the reference to 4000 feet had the potential to be confusing. If the Captain's attention was focussed on the 'hundreds of feet' hand, he may have believed the aircraft to be one thousand feet higher than in fact it was.

As indicated in the official report, Ansett's CRM training (1.17.37 - 1.17.41, p. 55) was deficient (2.88-2.92, p. 81). It had consisted solely of a few lectures some

time before, with no Line Oriented Flight Training (LOFT - flight simulator training in which complete flights are simulated, so that crews can learn to interact to best advantage). Proper application of CRM could have resulted in better monitoring of the flightpath by both pilots (2.95, p. 81).

These matters need to be addressed in the graph.

The performance of the check-list can be examined in the same way. 'Co-pilot performs QRH procedure' is a necessary factor in 'co-pilot misses a step in the check-list', but it could hardly be considered sufficient. Other factors must have been at work here. The Report refers to defective design of the checklist (1.18.51, p. 66), but this deficiency alone does not account for poor performance. Equally relevant is that there is no record that the co-pilot had *ever* practised the procedure, and may have never been taught it. (His Base Training Record dated 17 November 1994, showed that Alternate Gear Extension was signed off, along with eleven other items, on a flight primarily devoted to asymmetric handling. However, the actual record of this flight (Endorsement Period 2, 17 November 1994), showed that alternate gear extension was neither intended nor performed. In any case, this flight was six months before the accident).

These matters, too, need to be incorporated.

And why did the captain choose the strategy of attempting to rectify the malfunction while continuing the approach? There was no written Standard Operating Procedure (SOP) to the contrary (1.18.41, p. 65). Instead, the company culture suggested that this should be done. Of seven other occurrences²⁰, on only two the captains' post flight reports state that the aircraft climbed away before the problem was rectified²¹. One report expressly stated that the rectification was done while continuing the approach²².

²⁰ Ansett General Flight Reports (GFRs) dated 22 March 1988, 8 December 1993, 16 January 1994, 21 March 1994, 20 April 1994, 8 March 1995, 13 April 1995

²¹ GFRs dated 21 March 1994, 13 April 1995

²² GFR dated 20 April 1994

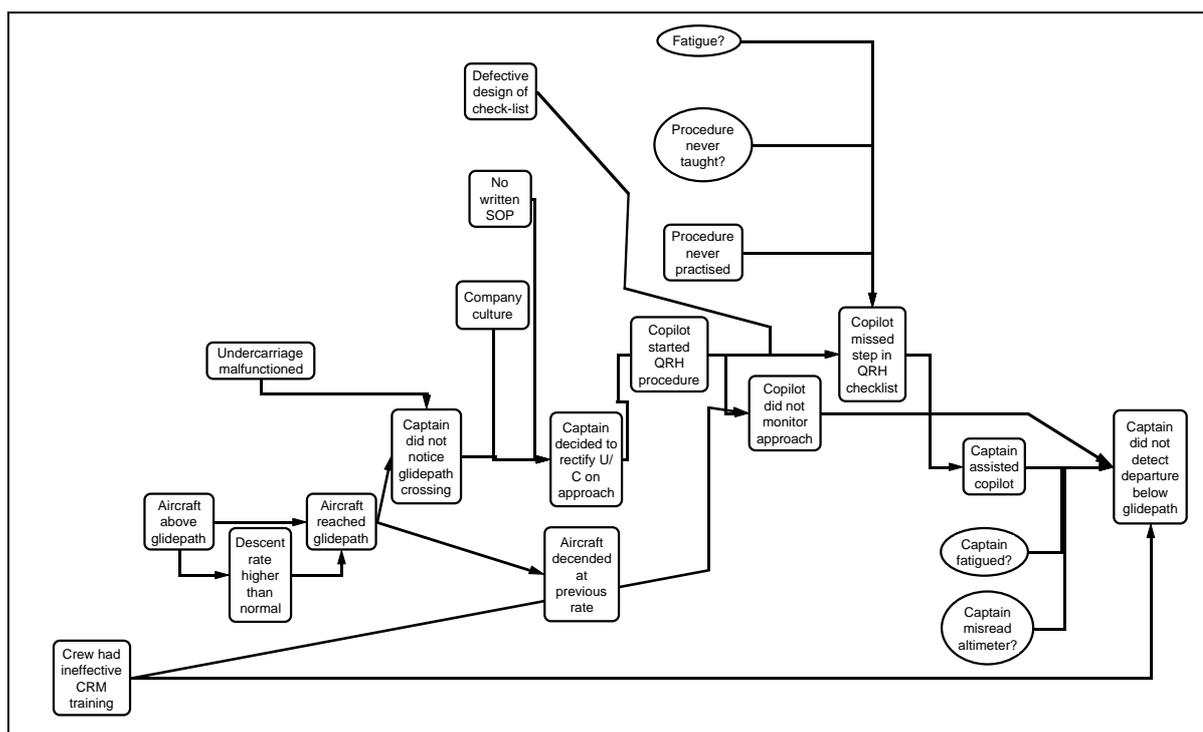


Figure 50. Further Development of Figure 48.

It is not discussed in the official report, but it is likely that crews generally were aware that this was 'the way things are done around here' (Maurino et al., 1995). After the accident, an internal Company response to representations by the CAA²³ stated "It is up to the crew to decide if the procedure can be safely carried out whilst on approach - a fairly normal situation not limited to this procedure."

This part of the graph now looks as shown in Figure 50.

There are a number of loose ends in this section of the graph, which need to be addressed next:

- Why was the aircraft initially high on the glidepath?
- Why was the co-pilot untrained in the emergency lowering procedure?
- Why was the CRM inadequate?
- Why did the undercarriage not lower when selected down?

Each of these points will be covered with a separate diagram, which will subsequently be incorporated into the overall picture.

²³ Ansett memorandum dated 19 October 1995.

Why did the approach require an initial steep descent? The final part of the DME arc up to the lead-in radial had a minimum altitude of 4900 feet (Figure 26). Assuming the turn onto final approach could be completed and the aircraft established inbound by 12 nautical miles (n. m.) DME, where the glidepath altitude was 4030 feet, the aircraft needed to lose nearly 900 feet while making the turn. The aircraft reached the lead-in radial at 4900 feet (Figure 3, p. 28 in the official report), and so was on profile at this point. However, during the turn the descent was stopped at 4700 feet, and the aircraft was some 500 feet high on completion of the turn. Why did the pilot stop the descent, and so find himself above the glidepath? The reason appears in the CVR transcript at 09:11:42 (p. 116), where the crew were re-briefing themselves for the (unanticipated) approach to runway 25:

Captain: Inbound two fifty down the approach not below forty six hundred to start off with and not below three thousand at nine miles...

This was incorrect. The 4600 feet altitude restriction applied to aircraft inbound from the Woodville holding pattern which was outside the DME arc (Figure 26). The restriction was inapplicable inside the 14 n.m. DME arc, where the appropriate restriction was 3000 feet until reaching 9 n.m. The Captain had only flown the approach once before (Appendix C, p. 111), and not as handling pilot (1.18.35, p. 64), so the confusion is understandable. According to the report, the co-pilot had 'flown the procedure several times before' (ibid.), but it does not state whether he was handling the aircraft on those occasions. His comment (at p. 111) does not suggest familiarity with this approach. Accordingly, the answer to 'why was the aircraft high on the approach?' is 'because the pilots were unfamiliar with the approach'. This of itself is insufficient: many pilots fly approaches with which they are unfamiliar, and manage to fly them accurately. So again it is necessary to look for additional factors. One might consider the approach plate to be potentially confusing; certainly the pilots were confused. And fatigue might have been a factor in the pilots' confusion, as in the errors identified in the official report.

And why were the pilots unfamiliar with the approach? In an airline, one would expect that pilots would receive recurrent training, either in a simulator or in the aircraft. The introduction of a new approach procedure to an aerodrome routinely used by the company would be a matter which would normally be addressed in such

recurrent training. The nearest simulator was in Seattle (1.17.41, p. 55), and Ansett decided that they would therefore train their crews in the aircraft rather than in a simulator. However, the company had some difficulty making the two Dash 8 aircraft available for engineering, because the demand for line flying was high²⁴. This high demand may explain why the crews training records showed no recurrent training in the aircraft²⁵. See Figure 51.

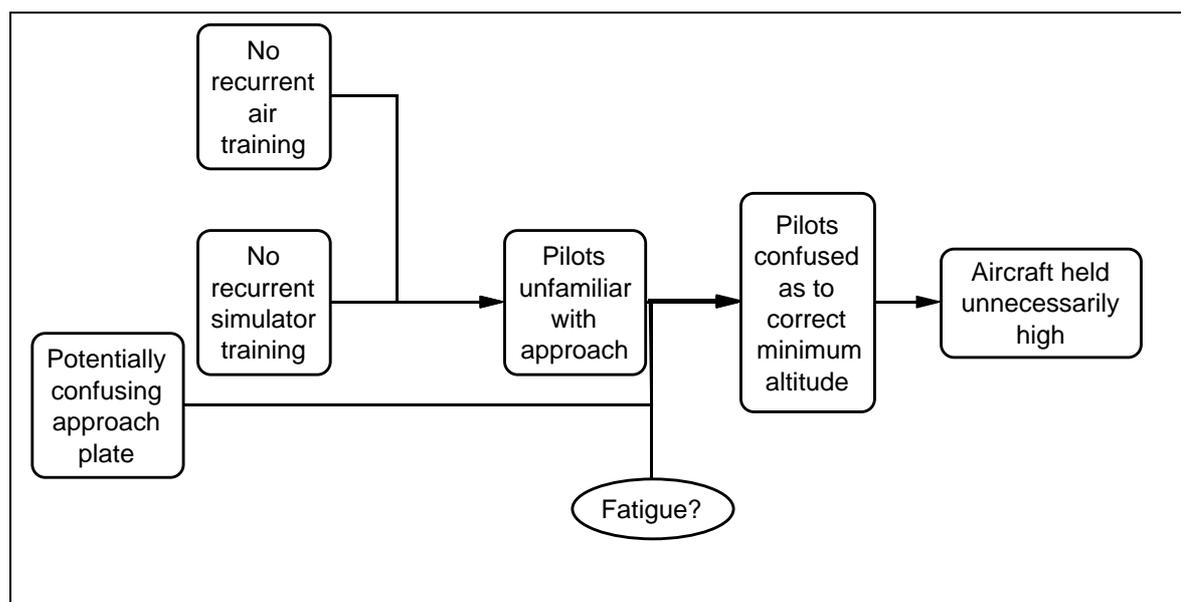


Figure 51. Attachment to Figure 50.

There are two factors which led to the incorrect actions by the co-pilot:

- The unsatisfactory QRH (1.18.44 et seq., pp. 65-68) had not been recognised as such. The potential for error could have been detected earlier if the exercise had been practised, in simulator sessions or even in a simplified Crew Procedure Trainer. The defective pages could then have been re-designed and re-issued.
- The specific emergency had never been practised as such, either in the aircraft or in a simulator. The nearest simulator was in Seattle, and the company decided that training would be performed in the aircraft. However, emergencies are not permitted to be practised during revenue flights, and there was no

²⁴ See, for example, the Observations and Recommendations of Ansett New Zealand's Flight Operations, by Captain I. Gemmill, 28 July 1995; and Ansett Memorandum AMM-M544 dated 13 March 1995

²⁵ DHC-8 Line Training Files, Captain Sotheran and First Officer Brown.

evidence that aircraft had ever been made available for continuation training in emergencies. The co-pilot said in evidence (R v Sotheran) that he had never operated the emergency undercarriage mechanism, though it was signed off in his training record. (See Figure 52).

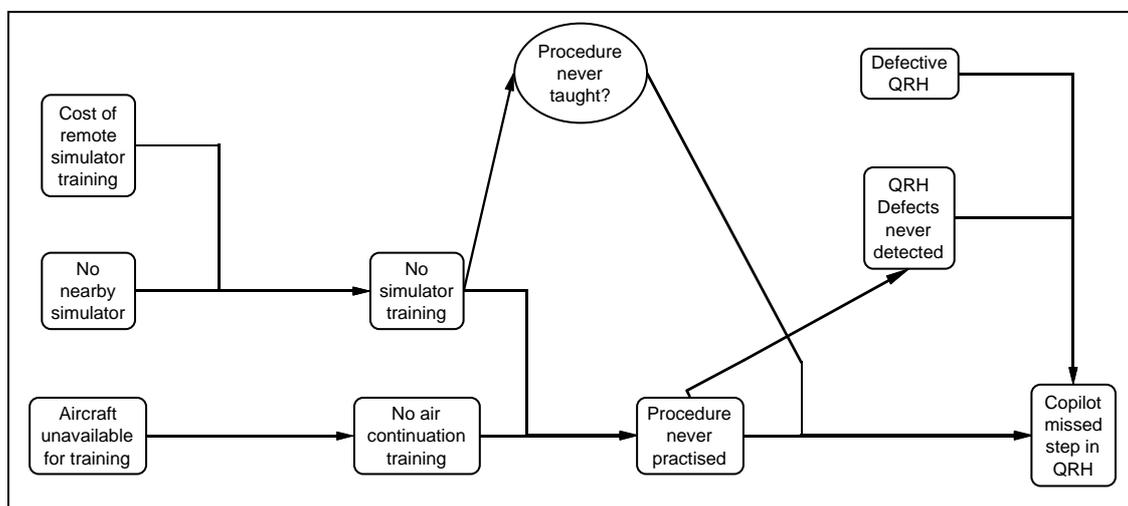


Figure 52. Second attachment to Figure 50.

It is worth digressing, at this point, to consider the effect of missing out the step in the emergency undercarriage lowering procedure, as the co-pilot was about to do. Opening the cover in the cabin ceiling, gave access to the cable release, and also released pressure from the hydraulic system, so removing the force which prevented the undercarriage up-lock from releasing. Pulling the cable then forced the up latch open, so the leg could free-fall down. Pumping the floor-mounted handle, as the co-pilot was about to do, then re-pressurised the system to ensure that the leg remained down under landing forces. This latter action was not reversible in the air. It thus appears that pumping up the pressure before the leg was lowered would have re-pressurised the system, locking one wheel up and the other two down. Again, the official report is silent on the matter, but if this was the captain's understanding, the co-pilot's actions would have grabbed his attention.

It could also be argued that Crew Resource Management (CRM) training should have enabled the crew to deal with the distraction so that it did not become hazardous. Indeed, the captain's action in monitoring the actions of the co-pilot could be construed as good CRM. However, the co-pilot made no attempt to monitor the height while he was trying to perform the QRH procedure, and the captain was

unaware of the absence of height calls by the co-pilot; these are matters which should have been covered in CRM training. The crew's CRM training on the Dash 8 consisted of a few hours of lectures (1.17.41, p. 55): absent a simulator, there was no possibility of Line Oriented Flight Training (LOFT), to provide practical reinforcement, so their inadequate performance is understandable. (Figure 53).

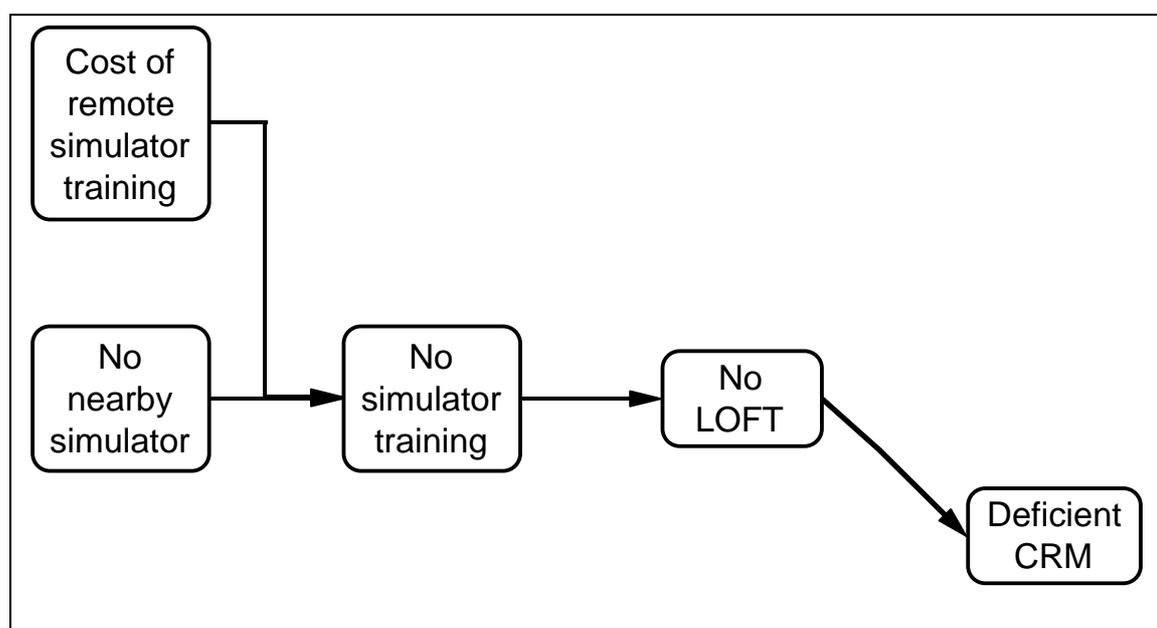


Figure 53. Third attachment to Figure 50.

A recurring theme is the absence of simulator training. A post-accident review by Ansett Australia, the parent company, decided that not having simulator training was acceptable, provided that air training was provided instead²⁶. This might be questioned, in view of the accepted benefits of CRM and LOFT training (see, for example, Helmreich & Merritt, 2000). These benefits can only be fully realised with simulator training. Besides, the decision to use air training in place of simulator training implies a commitment to making airtime available for training. It appears that the co-pilot's training was skimped as far as emergency procedures were concerned, and there is no record of any continuation training at all.

This section has concentrated on the crew's handling of an emergency. The next step is to consider how the emergency came about: what was it that put the crew in the position to make the active failures that led to the accident? The immediate

²⁶ Ansett Australia Memorandum dated 19 July 1995

emergency, of course, was that one undercarriage leg did not extend when the undercarriage was selected down

Why did the leg hang up? The mechanical cause was that the up-lock was worn to the extent that the aircraft hydraulic system could not generate sufficient force to dislodge the lock and allow the leg to descend²⁷. But how did the aircraft come to be flying with such a defective uplock? The engineering staff were aware of the possibility of wear, and the shop floor mechanics had been told to 'inspect for wear'²⁸. The mechanics interpreted this instruction to mean that they should 'rub a fingernail over it' (the surface of the latch), to detect wear²⁹. In fact, a smooth depression in the surface of the latch of a few thousandths of an inch depth was sufficient to cause a leg to hang up³⁰, but this advice was not passed on to the shop floor. Accordingly, the necessary and sufficient factors for a leg to hang up were wear on the latch, and the failure to detect such wear, which in turn arose from an inadequate instruction. The faulty instruction was a simple human error, made by a manager. But why had it not come to light before the accident, and why, in any event, was the wear occurring?

Consider the wear first. The wear occurred because of inadequate design. The latch had been re-designed, and the manufacturer offered replacement units at a total cost of about \$US20,000 for both aircraft³¹. Ansett rejected this offer, on the ground of cost. The Engineers considered that there were no safety implications: the crew could always lower the remaining leg with the alternate procedure³².

The faulty inspection procedure could have been expected to become evident as soon as an undercarriage leg hung up again, notwithstanding that the latch had been inspected. There were, in fact, a number of such 'precursor events' (Reason, 1990) before the accident: See Figure 54

²⁷ Messier Dowty report DS-611 Ansett New Zealand Accident Investigation of Uplock Assembly dated July 1995

²⁸ Ansett Technical Instruction TI 008-32-74, dated 27 November 1992

²⁹ Annotation by Senior Inspector of Air Accidents, on Ansett Memorandum dated 27 March 1996

³⁰ Messier Dowty report DS-611 Ansett New Zealand Accident Investigation of Uplock Assembly dated July 1995

³¹ Bombardier fax dated 15 April 1994

³² Ansett Defect Investigation Report 33/93; Ansett Memorandum QTSM-F390 dated 30 March 1994; Ansett Service Information Evaluation and Action Record SBB-32-98 dated 19 April 1994; Bombardier All Operator Message No. 389; Ansett post-accident review, Engineering Report (undated)

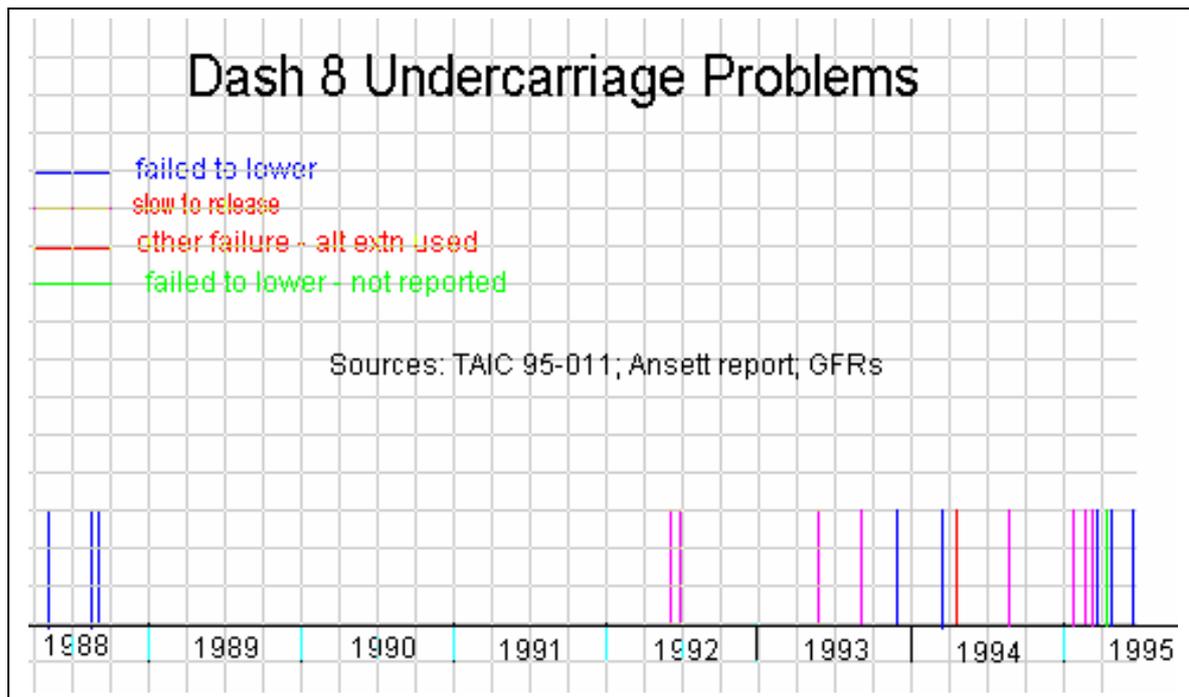


Figure 54. Precursor events (based on TAIC, 1995, p. 18, and Ansett engineering records).

However, no one appears to have asked why these precursor events had occurred despite the inspections. All that happened was that 'corrective' action, such as dressing the face of the latch, was taken, and the aircraft was put back into service. It appears that no one at Ansett realised that the events were occurring at shorter and shorter time intervals, a sure sign of deterioration. One could reasonably say that the engineers did not know what they were doing, and that no one 'was minding the shop'. (See Figure 55).

the crews could always lower the undercarriage using the emergency system. Overall, operational risk management was deficient. The department responsible for operational risk management in any airline is the Safety Department. But for a considerable time before the accident, Ansett had no safety department. The position of Safety Manager had been abolished in 1993, with the comment that 'safety is everybody's business'³³. It could fairly be said, that everybody's business became nobody's business.

How might having a Safety Manager have averted the accident? This question was discussed with the former Safety Manager of a major airline (Oldfield, personal communication, 2000). Some matters would have been routine in a safety department. A recurring fault, which would have been reported to that department, would have been charted, and the increasing frequency would have been evident: see ICAO (1984).

A recurring undercarriage malfunction would certainly not have been classed as having no safety implications. The Safety Department would have pressed for specific training in handling the emergency, either in a simulator or in the aircraft. Such training should have brought to light the unsatisfactory format of the QRH checklist. The absence of continuation training would have come to light, and it would probably have been possible to make a case for sending crews to Seattle for simulator training, given the high demand for the aircraft for line flying.

Reports of malfunctions being corrected while the aircraft continued on approach were certainly a matter likely to attract the attention of the safety manager, and the absence of a Standard Operating Procedure (SOP) requiring a climb to safe height before rectification would have come to light.

So, in answer to the question 'Why was there no risk management which could have averted this accident?' it may reasonably be said 'Because there was no Safety Manager'. And why was there no Safety Manager? Documents on this point, such as the Board minutes, were not available. However, in view of Ansett's history of losses, year by year, saving the Safety Manager's salary may well have looked attractive. The

³³ Ansett New Zealand Flight Operations Policy manual, Section 6 - Flight Safety Programme, dated June 1993: "Each and every operative within this division is responsible for applying commonsense flight safety principles to each and every activity".

absence of a Safety Manager is, in Dettmer's terminology, a core problem (Dettmer, 1997): many different factors stem from it. The absence of a Safety Department affects such a large range of factors that it is probable, had this accident not occurred, that some other accident would have arisen from factors within the province of the department. Identifying such a core problem should therefore enable a major safety improvement to be made.

Cost affected other factors. The decision not to modify the undercarriage up-locks, when modification kits were offered by the manufacturer, was to avoid the cost of about US\$20,000 for both aircraft. This decision was made without any input as to the safety implications. Presumably, the decision not to send crews overseas for simulator training was also based on cost, and without regard to the safety issues. Thus, the financial ability of the airline to meet normal costs is also a core problem. In the past, an airline was required to demonstrate its financial viability. However, this requirement was done away with, in New Zealand, as a matter of Government policy (Civil Aviation (Reform) Act, 1990).

The overall layout of the Why-Because graph is shown in Figure 56.

Naturally, other factors figured in this accident. There are factors such as the defective GPWS that should be considered. The corrosion of the radio altimeter aerial, disclosed in *R v Sotheran*, was a sufficient reason for the inadequate GPWS performance (Morgan, 2001). However, for this information to be put to use, further inquiry is necessary. How did the aerial come to be corroded in this way? Why was the corrosion, and consequent reduction in performance, not detected during routine maintenance? And why was the GPWS not designated a safety-critical system, having redundancy and in-flight self-test? (R. Howard, personal communication, 2005).

The design of the approach to runway 25 at Palmerston North might merit further consideration. Nor has the question of why auditing by the Civil Aviation Authority (CAA) was ineffective, been addressed. The CAA had not realised that there was no longer a Safety Manager. Although the company documentation had been amended to reflect the new system, it appears that no-one at CAA had

appreciated its significance³⁴. Evidently, the CAA did not concern themselves with the various matters which would have been the province of the Safety Department.

The Why-Because graph of the Ansett Dash 8 accident shows three features which could be of value to investigators:

- It enables identification of what Dettmer calls 'core problems', that is, single features from which a significant number of subsequent factors stem (Dettmer, 1997). Eliminating these may not only avert future accidents from the same immediate causal factors, but also other, quite different potential accidents. They are similar to 'latent failures' (Gibson, 1961, cited in Johnson, 1980; Reason, 1990), except that core problems do not necessarily stem from management decisions.
- It points to the need for the investigators to obtain further evidence, while the opportunity exists. Analysis leading back to the corporate factors in the accident pointed to the need for the Ansett Board minutes, to establish the reason for the abolition of the Safety Department. The absence of a Safety Department was a core problem which led to the various underlying conditions not being corrected, and to the crew being put into the position of making a series of errors that brought about the accident.
- It enables the effects of management decisions to be linked to the accident, as advocated by Reason (1991) in a way which has proved somewhat elusive in the past.

The application of Why-Because Analysis has generated many more causal factors than the five identified in the official report. All are necessary to the accident, and in that respect none is more significant than any of the others. As C.O. Miller put it, "Down with probable cause!" (Miller, 1991). However, the core problems stand out: they are the factors from which a number of causal links stem. They provide leverage points on which corrective efforts can be focussed. If the purpose of investigation is averting future accidents (ICAO, 1994), this is a valuable feature of the Why-Because Analysis.

³⁴ Letter 95/SAI/114 MBS dated 10 October 1995

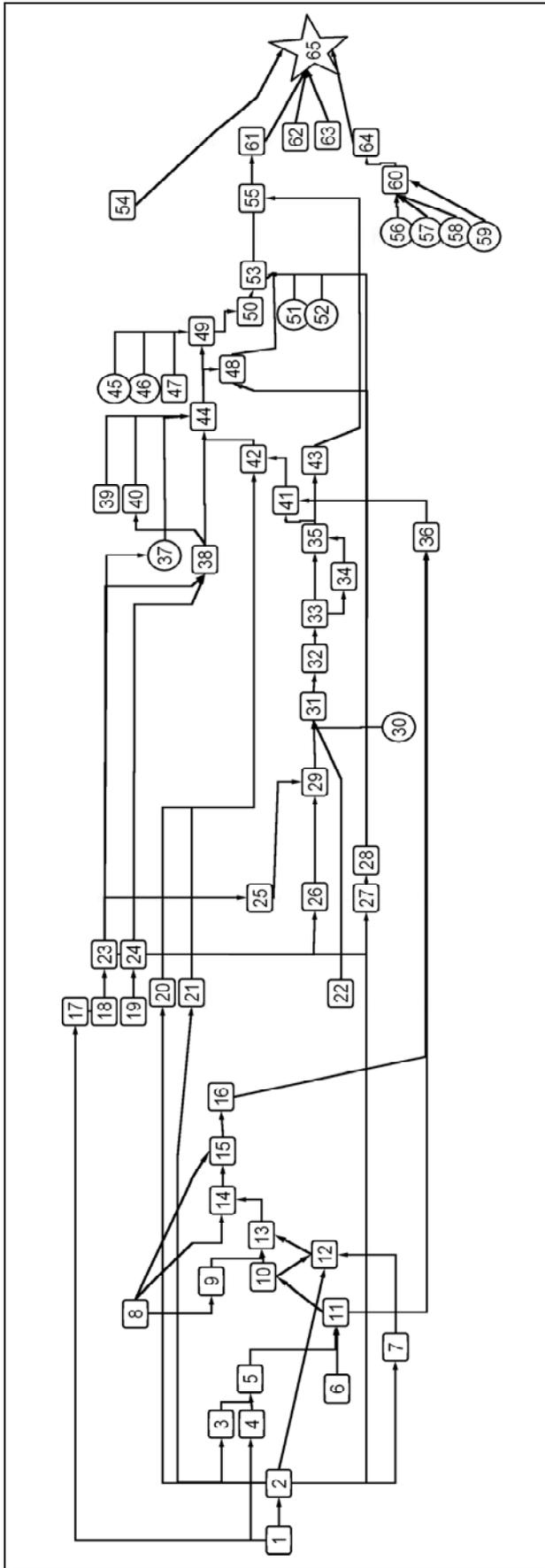


Figure 56. Final WB Graph of the Ansett Dash 8 accident

Figure 56: Key

1. Company making large losses
2. No Safety Manager
3. Considered 'Not a safety matter'
4. Cost \$20,000 US for fleet
5. Decision not to fit new design latches
6. Design faulty
7. No one monitored frequency
8. Error by maintenance manager
9. Inadequate understanding by maintenance staff
10. Precursor events
11. Up lock latch worn
12. Increasing frequency of precursors not recognised
13. Precursor events addressed by ad hoc fixes
14. Faulty instruction unrecognised in precursor events
15. Inspection instructions inadequate
16. Wear not detected by inspections
17. Cost of remote simulator training
18. No nearby simulator
19. Aircraft unavailable for training
20. No written SOP
21. Company culture
22. Potentially confusing approach plate
23. No simulator training
24. No air continuation training
25. No recurrent simulator training
26. No recurrent air training
27. No LOFT
28. Crew had ineffective CRM training
29. Pilots unfamiliar with approach
30. Fatigue?
31. Pilots confused as to correct minimum altitude
32. Aircraft held unnecessarily high

33. Aircraft above glidepath
34. Descent rate higher than normal
35. Aircraft reached glidepath
36. Undercarriage leg hung up
37. Procedure never taught?
38. Procedure never practised
39. Defective QRH
40. QRH Defects never detected
41. Captain did not notice glidepath crossing
42. Captain decided to rectify U/C on approach
43. Aircraft descended at previous rate
44. Co-pilot started QRH procedure
45. Fatigue?
46. Procedure never taught?
47. Procedure never practised
48. Co-pilot did not monitor approach
49. Co-pilot missed step in QRH checklist
50. Captain assisted co-pilot
51. Captain fatigued?
52. Captain misread altimeter?
53. Captain did not detect departure below glidepath
54. Laminar downdraught increased descent rate
55. Continued descent below glidepath
56. Aerial corrosion?
57. Cable routeing?
58. Paint on radome?
59. Plugs and sockets?
60. Inadequate radar altimeter
61. Continued descent below glidepath
62. High terrain below glidepath
63. Aircraft in cloud
64. Inadequate GPWS warning
65. Aircraft struck hill

Summary of Why Because Analysis

The Why-Because Graph differs from Benner's Multi-linear Event Sequencing graph in that MES is constrained to deal only with events, whereas WBA deals with both events and states. In this case study, institutional deficiencies such as the lack of a Safety Manager have been identified. Many if not all of these institutional deficiencies are states, not events, and states as such cannot be represented in MES. WBA supports Reason's concept of institutional 'latent failures': it provides the 'backtracking' advocated by Reason (1991) which, up till now, has proved an elusive concept.

This is not to say that WBA is 'better' than MES. They have different functions. MES aims to provide the investigator with a 'mental movie' of *what* happened; WBA seeks to explain *why* things happened the way they did. The two methods are complementary, MES providing the 'front end' to the WBA.

It is suggested that the pictorial format of the Why-Because Graph is easier to assimilate than the written format of the usual report. As discussed in the consideration of MES, writing is essentially linear; but as has been shown, the reality is a network, and this is almost impossible to put into words. A better report format might be to develop the graph, and lead the reader through it. Naturally, the supporting factual material must also be provided, but this could be relegated to annexes where it would be available to those who need it.

By presenting the report in a format that readers can assimilate, the investigators would be more likely to persuade those in a position to act on safety recommendations, to do so.

Chapter 7: Analysing the Ansett Dash 8 Accident with the Theory of Constraints

Introduction

An accident does not come out of the blue. Any accident comes about as the result of a variety of undesirable effects. In aviation, unsatisfactory conditions may be found within systems, either during investigations of accidents or incidents, or during surveillance or audits. In dealing with unsatisfactory situations, the questions to be addressed are:

- What to change
- What to change to, and
- How to change

It has been customary to try to address each of the unsatisfactory situations separately, and we find statements such as '43 safety recommendations were made in the course of this investigation'. However, this approach diffuses the corrective effort available. It would be better if one or two effective actions could be identified so that resources could be focussed on them. Further, Taylor (1998) has shown that in reality few safety recommendations are implemented, even when they originated from such prestigious authorities as the US National Transportation Safety Board (NTSB) and the British Air Accident Investigation Branch. For example, regulations to address flight crew fatigue have been on the NTSB's 'most wanted' list since 1990 (NTSB, 2004). Either the proposed actions were rejected as being ineffective, or those in a position to implement them were not persuaded of the need to do so.

The first two parts of this case study have used Multilinear Events Sequencing in order to understand *what* happened, and Why-Because Analysis to examine causation – *why* the accident happened. But knowing why something happened, and being able to do something about it, are two quite different things. A safety recommendation is an attempt to introduce a change mechanism. In the third part of this case study, an effective change mechanism used in business is examined, to see whether it can be applied to the information from an accident investigation.

The Theory of Constraints (TOC) is a method for analysing and improving systems. It originated in the 1980s when Goldratt applied the logical methods of the physical sciences to business problems (Goldratt, 1987, 1990). The method was first applied to continuous flow processes; the ‘constraints’ in the title were bottlenecks in those processes, and Goldratt showed that it was better to concentrate efforts on dealing with the constraints rather than seeking to make general improvements. The method is now widely used in many fields (see, for example, Mabin & Balderstone, 1998, 2003). The objective is the identification of core problems, so that these may be addressed, rather than trying to address all the undesirable effects to which the core problems give rise. Further, the Theory of Constraints not only has the ability to diagnose what is wrong, but to identify what changes to make, and how to implement them. Changes that might appear ‘too hard’ can be addressed in manageable steps, and potential obstacles to implementation can be foreseen and overcome.

It could be argued that the future is unknowable, but this is not necessarily so. Audits and surveillance bring to light undesirable effects, in exactly the same way as an incident investigation. Analysis of these undesirable effects will then bring out the underlying systemic deficiencies. Addressing these deficiencies may avert accidents, rather than having to have the trauma of an accident to bring remedies to light.

Methodology

The Theory of Constraints appears as though it should be useful. However, it has not previously been used in an aviation safety context. Can it be applied to reducing the ‘undesirable effect’ of aircraft accidents? This question can be considered in two parts:

- Can the information from an accident investigation be put into the form required for analysis using the methodology of the TOC? And, if so,
- Can the TOC be used to formulate safety recommendations likely to be effective?

If the first question can be resolved satisfactorily, the second should be largely a matter of form: the TOC has been demonstrated to be an effective change mechanism. The first question is addressed next.

The Ansett Dash 8 Accident

The aircraft was on a non-precision instrument approach to Palmerston North. The starboard main leg stayed up when the undercarriage was selected 'down'. The crew attempted to lower the leg using the emergency system, and while they were doing this the aircraft struck a hill. The official report listed 26 Safety Recommendations intended to minimise the possibility of a similar accident recurring (TAIC, 1995).

The information from the MES and WBA analyses, comprising the first two parts of the case study, is used in this part, generally without further citation

The TOC uses a set of logical networks to depict the existing situation, the situation one would like to bring about, and the way to make the transition from the existing situation to the desirable future situation. The existing situation is called the 'Current Reality Tree', and it is the formation of the current reality tree from the accident information that is the subject of this section. The analysis starts by listing the undesirable effects brought to light by the preliminary analyses, MES and WBA. These undesirable effects include:

- The impact of an aircraft on a mountain,
- A Ground Proximity Warning System (GPWS) that did not work properly,
- An undercarriage that malfunctioned,
- A pilot who was untrained in emergency procedures.

These undesirable effects can be put into a chronological array (Figure 57). The following figures are set out on a somewhat similar basis to a MES graph. Undesirable effects are arranged in time sequence, and causal sequence (or time) forms the vertical axis (by convention, in TOC literature). Similar undesirable effects are grouped horizontally. Thus, in Figure 57, the central group (items 1, 4, 6 and 11) all relate to the undercarriage, while in the bottom left-hand corner is the sole reference to the CAA. On the right are company-related matters, with a subset (engineering) to the left of them. Item 7, relating to both engineering and the undercarriage, could have been in either column – its exact position is unimportant.

The layout is somewhat arbitrary, but in practice arraying it in this fashion has been found to minimise subsequent shuffling of elements as linkages are discovered.

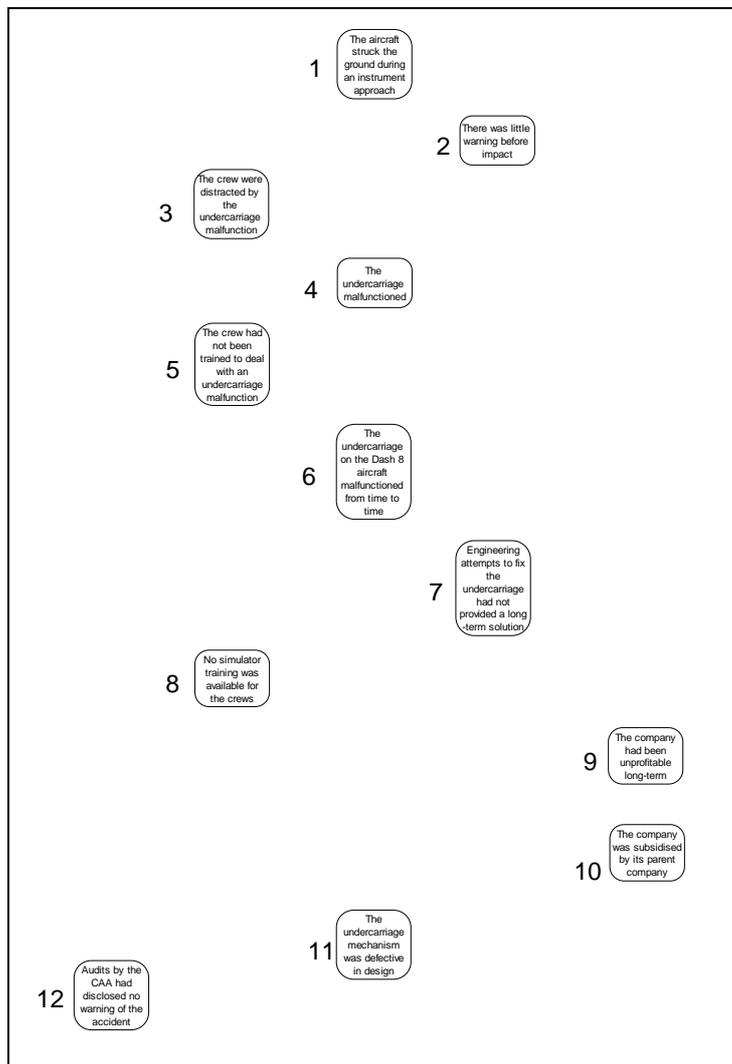


Figure 57. Undesirable effects in the Ansett Dash 8 accident.

Key:

1. The aircraft struck the ground during an instrument approach
2. There was little warning before impact
3. The crew were distracted by the undercarriage malfunction
4. The undercarriage malfunctioned
5. The crew had not been trained to deal with an undercarriage malfunction
6. The undercarriage on the Dash 8 aircraft malfunctioned from time to time
7. Engineering attempts to fix the undercarriage had not provided a long-term solution
8. No simulator training was available for the crews
9. The company had been unprofitable long-term
10. The company was subsidised by its Australian parent company
11. The undercarriage mechanism was defective in design
12. Audits by the CAA had disclosed no warning of the accident

Notice that the entities are called ‘effects’. They are not causes: they have come about because of underlying conditions. It is those conditions that are now sought, as the linkages between effects are discovered. This can be done in any order, but it may be convenient to start near the base – that is, early in time.

In general these will not be direct links, and additional information must be found, to provide necessary and sufficient connections³⁵. One stream³⁶ of linkages is shown in Figure 58: the connection between the defective design of the undercarriage latch, and the potential for the aircraft to strike the terrain. This stream, starting from the bottom left of the figure, reads:

If the design of the undercarriage latch is defective and the engineering instructions for the rectification of the undercarriage latch are ineffective, then the undercarriage latch defect is not rectified.

If the undercarriage latch defect is not rectified, then undercarriage latch malfunctions occur.

If undercarriage latch malfunctions occur and the engineering instructions for rectification of the undercarriage latch are ineffective, then the undercarriage latch malfunctions repeatedly.

If the undercarriage latch malfunctions repeatedly, then crews encounter undercarriage malfunctions from time to time.

Turning now to the crew training stream:

If the crews get no simulator training and the crews get no in-flight training in undercarriage malfunction, then the crews are not trained to handle an undercarriage malfunction.

³⁵ In depicting necessary and sufficient conditions, an ellipse represents a logical ‘and’. Where arrows enter an entity without passing through an ellipse, there is an additive effect.

³⁶ The term ‘stream’ is a convenient label, since it shows a sequence of cause and effect. One could also refer to a ‘chain of causation’, but this terminology is in wide use for a theory of causation which is essentially linear. The TOC demonstrates that there are interlinked streams of causation which, in general, form a network.

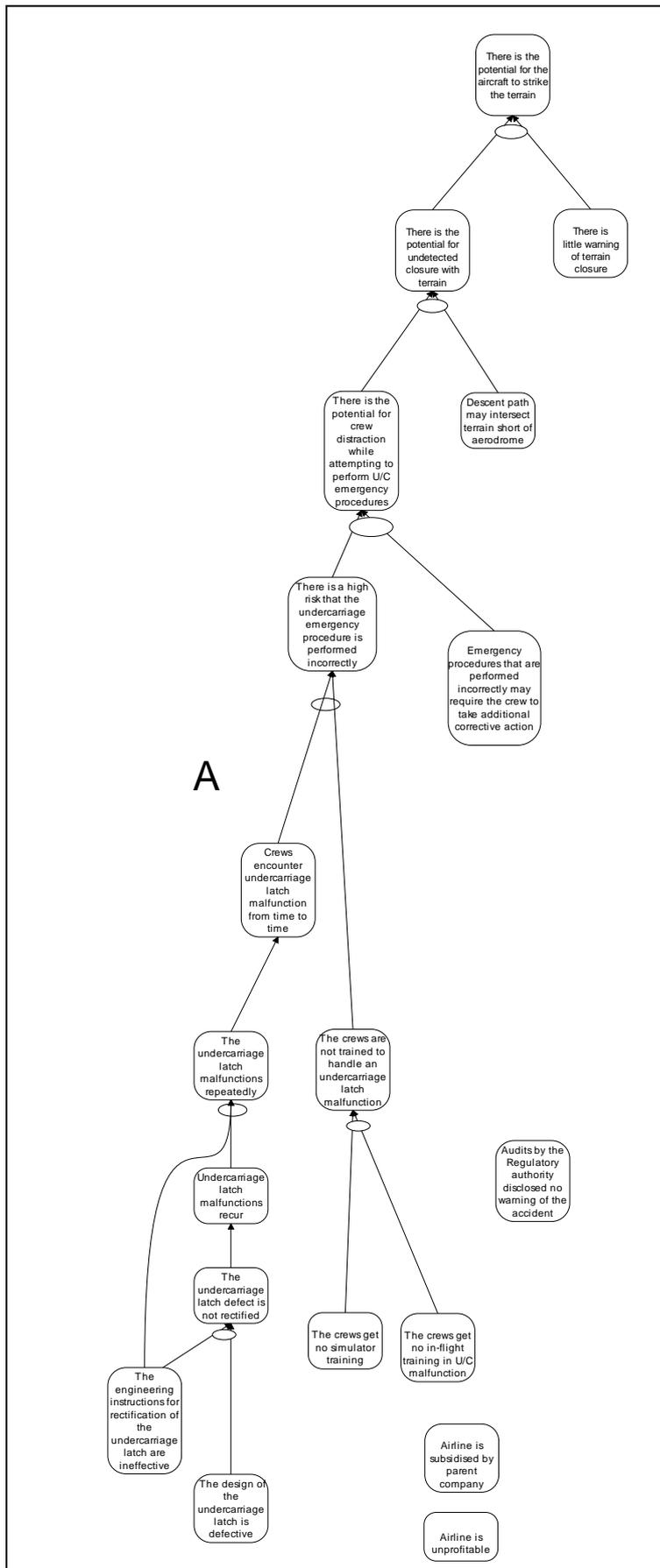


Figure 58. Connections between undercarriage latch design and potential to strike terrain.

Combining these two streams:

If crews encounter undercarriage malfunctions from time to time *and* the crews are not trained to handle an undercarriage malfunction, *then* there is a high risk that the undercarriage emergency procedure is performed incorrectly.³⁷

If there is a high risk that the undercarriage emergency is performed incorrectly *and* emergency procedures that are performed incorrectly may require the crew to take further corrective action, *then* there is the potential for crew distraction while attempting to perform undercarriage emergency procedures.

If there is the potential for crew distraction while attempting to perform undercarriage emergency procedures *and* the descent may intersect terrain short of the aerodrome, *then* there is the potential for undetected closure with terrain.

If there is the potential for undetected closure with terrain *and* there is little warning of terrain closure, *then* there is the potential for the aircraft to strike the terrain.

There is a common theme underlying some of the early effects: the engineers decided not to spend US\$20 000 to modify the undercarriages of the Dash 8 fleet and so avoid malfunctions (Ansett (NZ), 1994a; Bombardier, 1994), while the training of pilots to handle such emergencies was skimped or non-existent, and there was no record of any recurrent training (Ansett (NZ), (n.d. a), (n.d. b)). These are indicative of financial stress, and the way this stress came about can be seen in Figure 59.

³⁷ The company relied, in effect, on the crews reading the emergency procedures from the aircraft documentation, as a substitute for training. However, in the accident sequence the co-pilot missed one step, and there was the possibility of locking the undercarriage irretrievably, with one main wheel up and one down. This got the Captain's attention.

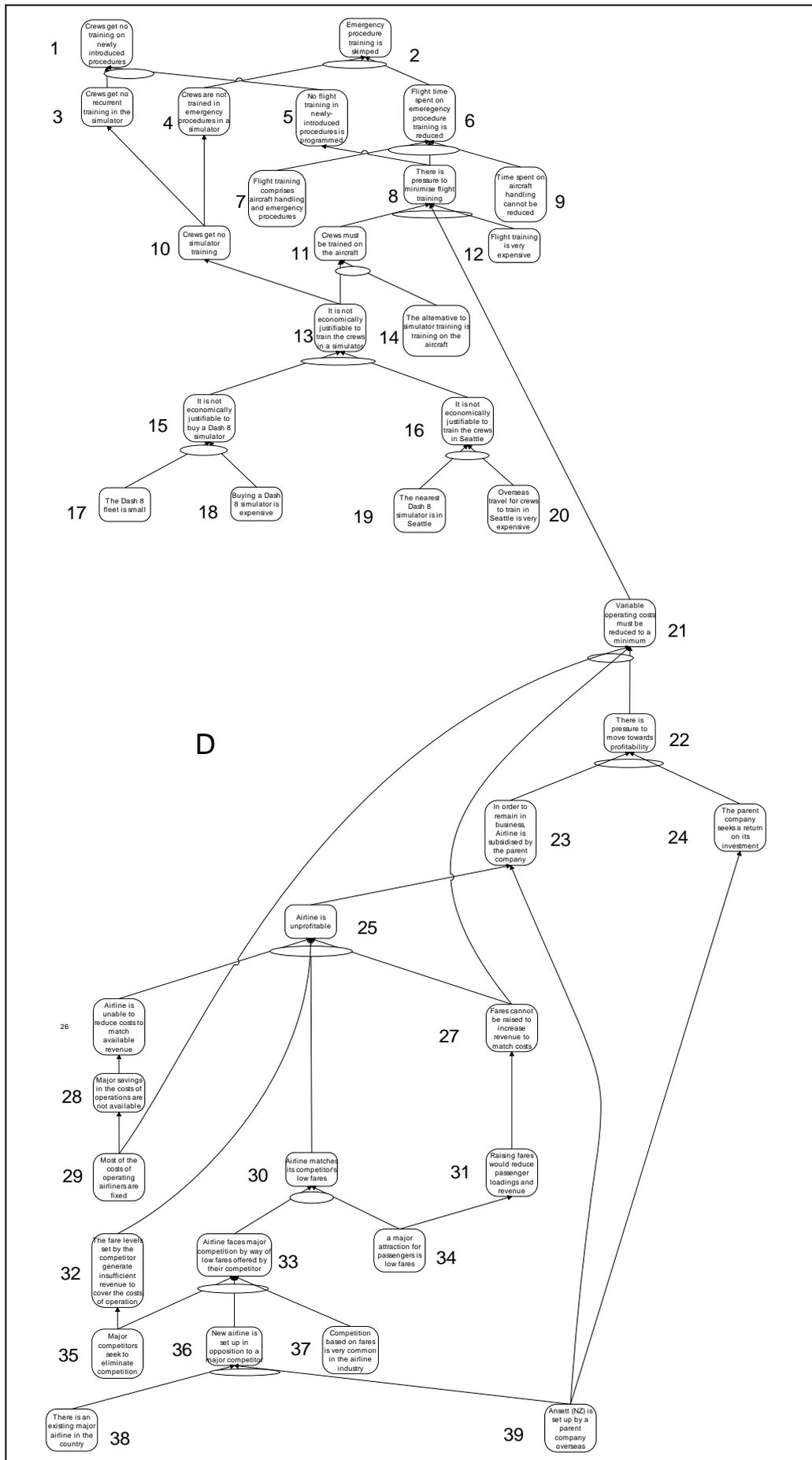


Figure 59. Financial stress and emergency training.

Key:

1. Crews get no training on newly introduced procedures
2. Emergency training is skimped
3. Crews get no recurrent training in the simulator
4. Crews are not trained in emergency procedures in a simulator
5. No flight training in newly introduced procedures is programmed
6. Flight time spent on emergency procedures is reduced
7. Flight training comprises aircraft handling and emergency procedures
8. There is pressure to minimise flight training
9. Time spent on aircraft handling cannot be reduced
10. Crews get no simulator training
11. Crews must be trained on the aircraft
12. Flight training is very expensive
13. It is not economically justifiable to train the crews on a simulator
14. The alternative to simulator training is training on the aircraft
15. It is not economically justifiable to but a Dash 8 simulator
16. It is not economically justifiable to train the crews in Seattle
17. The Dash 8 fleet is small
18. Buying a Dash 8 simulator is expensive
19. The nearest Dash 8 simulator is in Seattle
20. Overseas travel for crews to train in Seattle is expensive
21. Variable operating costs must be reduced to a minimum
22. There is pressure to move towards profitability
23. In order to remain in business, Ansett (NZ) is subsidised by the parent company
24. The parent company seeks a return on its investment
25. Ansett (NZ) is unprofitable
26. Ansett is unable to reduce costs to match available revenue
27. Fares cannot be raised to increase revenue to match costs
28. Major savings in the costs of operations are not available
29. Most of the costs of operating airliners are fixed
30. Ansett matches its competitor's low fares
31. Raising fares would reduce passenger loadings and revenue
32. The fare levels set by the competitor are insufficient to cover the costs of operation
33. Ansett faces major competition by way of low fares offered by their competitor
34. A major attraction for passengers is low fares
35. Major competitors seek to eliminate competition
36. Ansett is set up in opposition to a major competitor
37. Competition based on fares is very common in the airline industry
38. There is an existing major airline in New Zealand
39. Ansett (NZ) is set up by a parent company in Australia.

The Government of the day said it wanted to ‘stoke up competition’ in air transport ("Safety in the Sky", 1990), and an overseas airline, Ansett Australia was encouraged to set up in opposition to the national carrier, Air New Zealand. The established airline was determined to preserve its position, and was well able to do so, because it could cross-subsidise internal flights from its international operations. The effect was that the fares the new airline, Ansett (New Zealand) was able to charge were too low to generate a profit ("Ansett announcement", 1994, "Ansett loss announcement", 1995).

The overseas parent company would expect a return on its investment in due course, but the avenues available for cost reduction were few. These cost reduction efforts were necessarily focussed on maintenance and flying training.

The Dash 8 fleet was small (initially two aircraft, later increased to three) and the parent company did not operate this type. The purchase of a simulator could not be justified, and the nearest simulator was in Seattle. To avoid the expense of sending crews to Seattle, it was decided that all training would be performed on the aircraft. However, air training is very expensive, and in any case the aircraft were needed for line flying, so there was pressure to minimise crew training. It was established that the co-pilot on the accident aircraft had *never* been shown the emergency undercarriage operation, let alone practised it (Zotov, 2001). Defects in the checklist, which should have come to light if the procedure was practised, were not found. And with the absence of recurrent training, new ATC procedures were not practised in a controlled environment (see Figure 60).

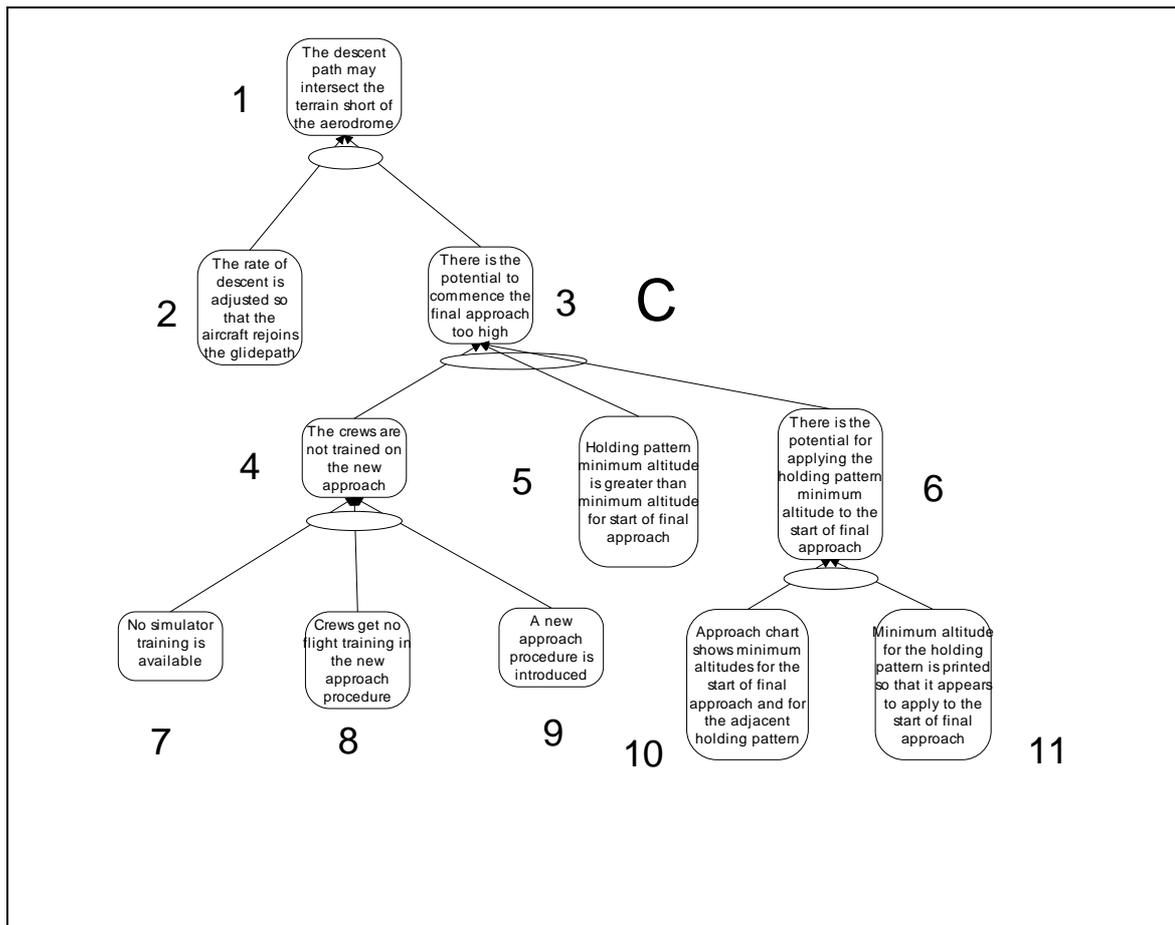


Figure 60. Lack of continuation training – approach procedure.

1. The descent path may intersect the terrain short of the aerodrome
2. The rate of descent is adjusted so that the aircraft rejoins the glidepath
3. There is the potential to join the final approach too high
4. The crews are not trained on the new approach
5. Holding pattern minimum altitude is greater than minimum altitude for start of final approach
6. There is the potential for applying the holding pattern minimum altitude to the start of final approach
7. No simulator training is available
8. Crews get no training in the new approach procedure
9. A new approach procedure is introduced
10. Approach chart shows minimum altitudes for the start of final approach and for the adjacent holding pattern
11. Minimum altitude for the holding pattern is printed so that it appears to apply to the start of the final approach

Turning now to maintenance aspects:

The Engineering review committee decided that \$20,000 was too much to spend on replacement undercarriage parts. Without consulting with any other Department, they decided that an undercarriage hang-up had no safety implications, because the pilot could always use the emergency procedure (Ansett (NZ), 1993a, 1994a, 1994b, (n.d. c); Bombardier, (n.d.)) (Figure 61).

Instead of replacing the defective parts, the problem would be fixed. Unfortunately, the 'fix' was an instruction to 'check [the up-lock latch] for wear' (Ansett (NZ), 1992). The shop floor workers interpreted this as 'run a thumbnail over it' (Ansett (NZ), 1996), unaware that the wear they were looking for was of the order of a few thousandths of an inch, over an area perhaps a quarter of an inch wide (Messier Dowty, 1995). Not surprisingly, the wear was not detected, and hang-ups recurred. No-one in maintenance realised that the hang-ups were recurring more and more often (Zotov, 2001) – a sure sign of increasing wear – but the nuisance value of repeated unscheduled hangar visits finally persuaded the engineers to order replacement parts. However, by this time there were insufficient parts available from the manufacturer to replace all units, and the starboard leg latch on the accident aircraft was not replaced.

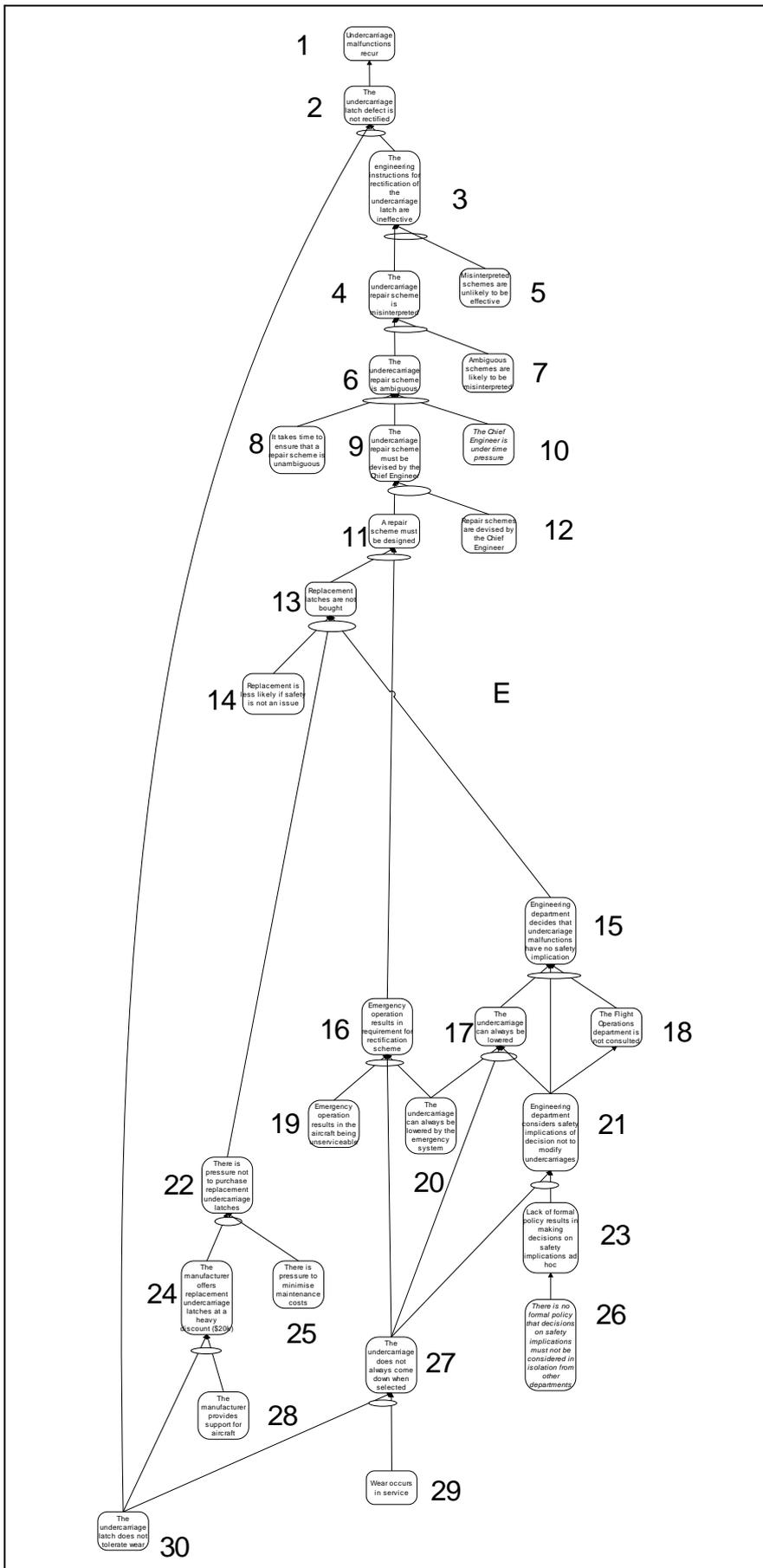


Figure 60. Maintenance aspects.

1. Undercarriage malfunctions recur
2. The undercarriage latch defect is not rectified
3. The engineering instructions for rectification of the undercarriage latch are ineffective
4. The undercarriage repair scheme is misinterpreted
5. Misinterpreted schemes are unlikely to be effective
6. The undercarriage repair scheme is ambiguous
7. Ambiguous schemes are likely to be misinterpreted
8. It takes time to ensure that a repair scheme is unambiguous
9. The undercarriage repair scheme must be devised by the Maintenance Manager
10. *The Maintenance Manager is under time pressure*³⁸
11. A repair scheme must be devised
12. Repair schemes are devised by the Maintenance Manager
13. Replacement parts are not bought
14. Replacement is less likely if safety is not an issue
15. Engineering decides that undercarriage malfunctions have no safety implication
16. Emergency operation results in a requirement for a rectification scheme
17. The undercarriage can always be lowered
18. Flight Operations are not consulted
19. Emergency operation results in the aircraft being unserviceable
20. The undercarriage can always be lowered by the emergency system
21. Engineering considers safety implications of decision not to modify undercarriages
22. There is pressure not to purchase replacement undercarriage latches
23. Lack of formal policy results in making decisions on safety implications ad hoc
24. The manufacturer offers replacement undercarriage latches at a heavy discount (\$20k)
25. There is pressure to minimise maintenance costs
26. There is no formal policy that decisions on safety implications must not be considered in isolation from other departments
27. The undercarriage does not always come down when selected
28. The manufacturer provides support for the aircraft
29. Wear occurs in service
30. The undercarriage latch does not tolerate wear

³⁸ Italicised items in this and subsequent graphs are used to show matters which are reasonable inferences, and generally are supported by hearsay evidence. They could not be substantiated by documentary evidence, because that evidence was not documented by the investigators at the time of the official investigation. They are included here for completeness, and serve a similar function to Ladkin's Predicate Action Diagram: there is evidence either side, and the italicised item provides a bridge. Had the investigators been using formal analytical methods during the investigation, the italicised information could have been confirmed, or indeed rebutted.

Various matters should have come to the notice of the Safety Department. The repeated hang-ups, and increasing frequency, were readily apparent using standard methods detailed in the ICAO Accident Prevention Manual (ICAO, 1984). Risk management would suggest that, at least, the crews should have been given recurrent training in handling undercarriage emergencies. Internal audit should have brought to light the lack of recurrent training.

None of this happened. The Safety Department had been very small – basically one man, but none-the-less a good deal better than nothing at all. But two years before the accident it was abolished (Figure 62)³⁹. The implication is that this was done to save money, but evidence on this point is not available⁴⁰. Instead of a Safety Department, it was announced that ‘safety was everybody’s responsibility’ (Ansett (NZ), 1993b). A part-time Safety Coordinator was appointed, who perceived his function as developing Crew Resource Management training (TAIC, 1995).

³⁹ The ‘F’ in the lower right of the segment is a key letter. Each of the completed segments has a key letter, which shows its position on the completed CRT (Figure 65). Thus, although Figure 65 cannot display the text within the boxes, the reader can refer back from Figure 65 to the earlier segments should detail be required.

⁴⁰ Shortly after the Board minutes dealing with the abolition were demanded by Counsel for the passengers, in litigation against Ansett, the Company settled out of court

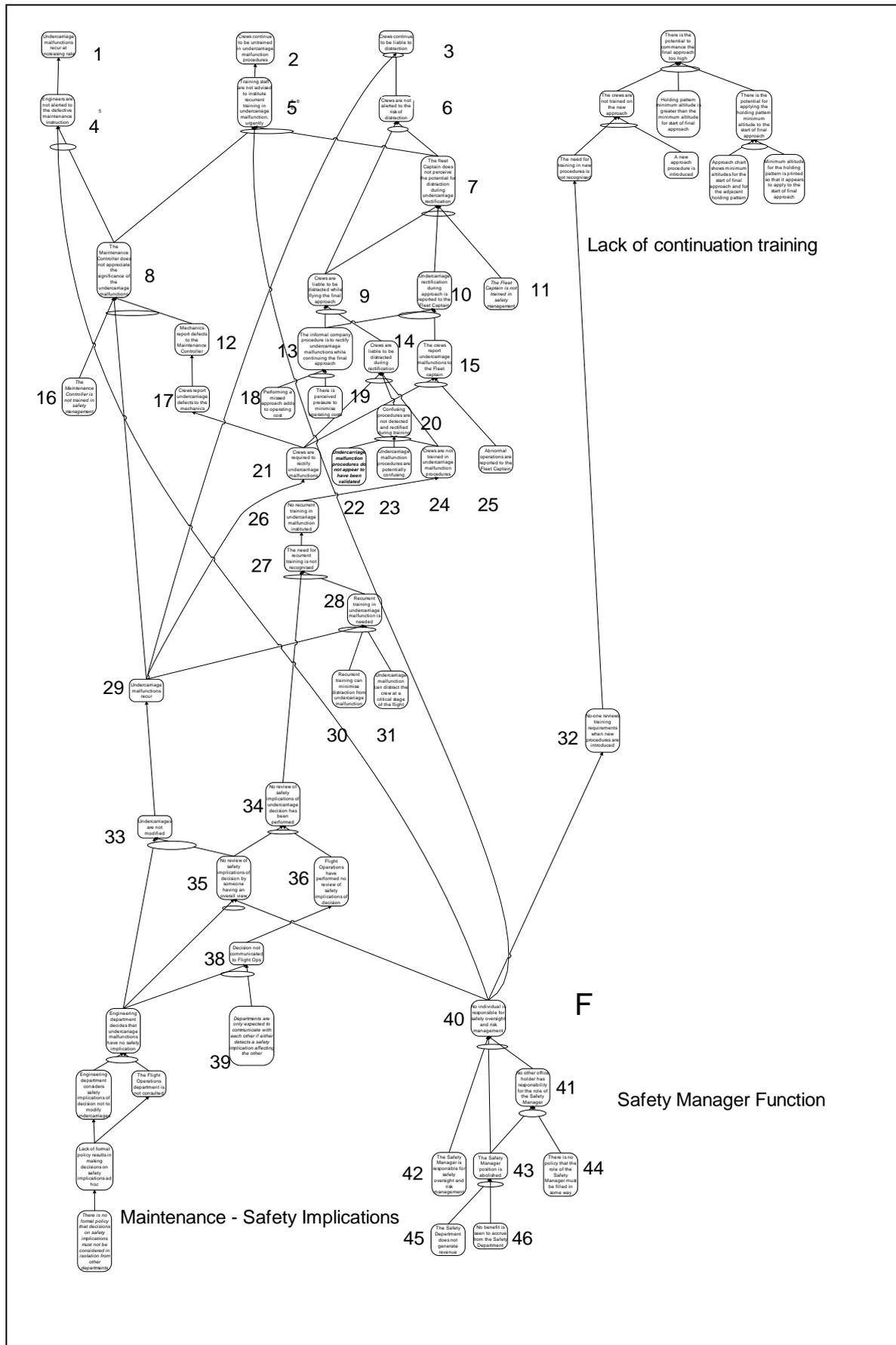
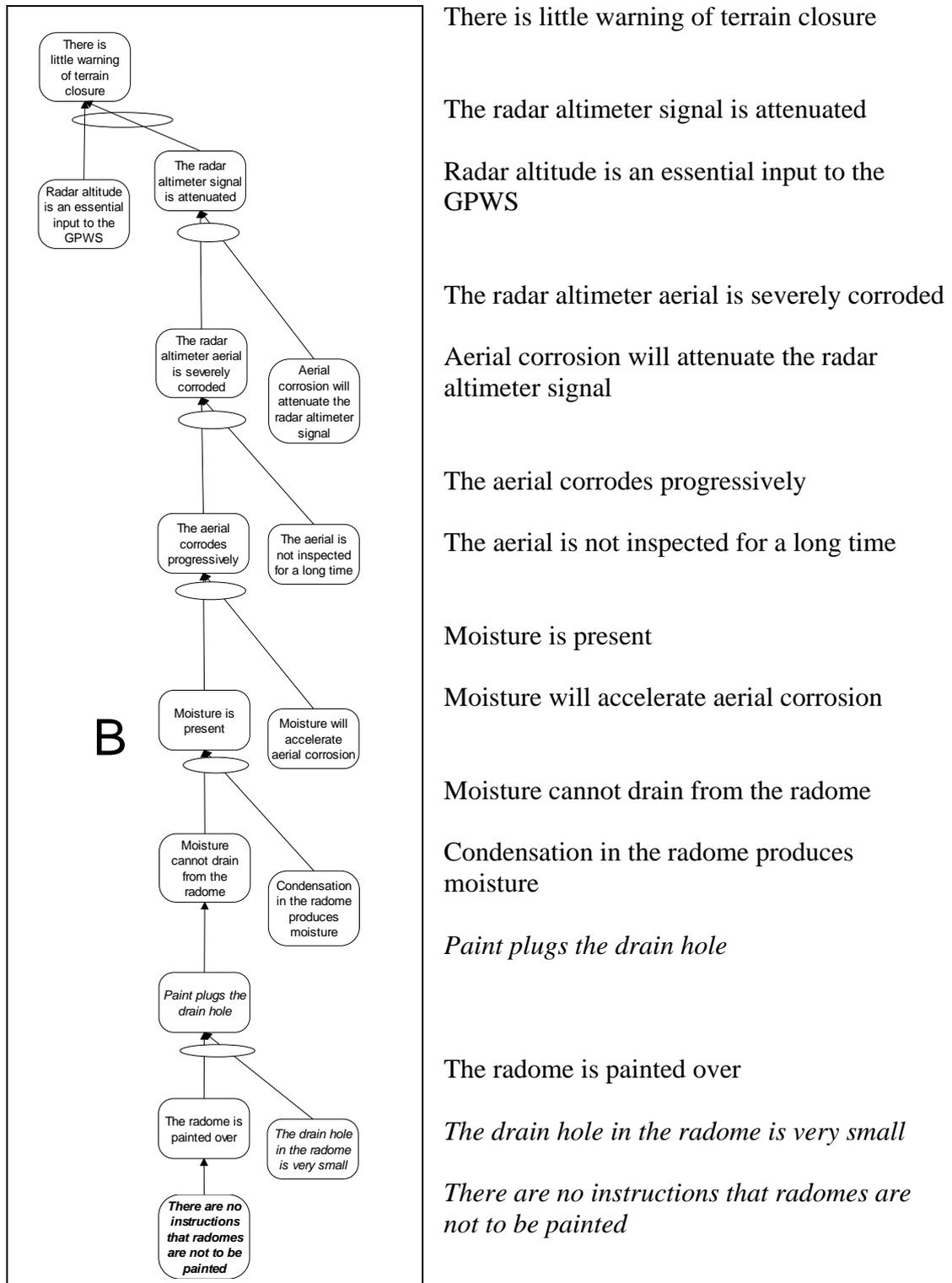


Figure 62. Absence of a Safety Manager.

1. Undercarriage malfunctions occur at increasing rate
2. Crews continue to be untrained in undercarriage malfunction procedures
3. Crews continue to be liable to distraction
4. Engineers are not alerted to the defective maintenance instruction
5. Training staff are not advised to institute recurrent training in undercarriage malfunction procedures, urgently
6. Crews are not alerted to the risk of distraction
7. The Operations Manager does not perceive the risk of distraction during undercarriage rectification
8. The Maintenance Controller does not appreciate the significance of the undercarriage malfunctions
9. Crews are liable to be distracted while flying the final approach
10. Undercarriage rectification during approach is reported to the Operations Manager
11. *The Operations Manager is not trained in safety management*
12. Mechanics report defects to the Maintenance Controller
13. The informal Company procedure is to rectify undercarriage malfunctions while continuing the final approach
14. Crews are liable to be distracted during rectification
15. Crews report undercarriage malfunctions to the Operations Manager
16. *The Maintenance Controller is not trained in safety management*
17. Crews report undercarriage defects to the mechanics
18. Performing a missed approach adds to the operating costs
19. There is perceived pressure to minimise operating costs
20. Confusing procedures are not detected and rectified during training
21. Crews are required to rectify undercarriage malfunctions
22. *Undercarriage malfunction procedures do not appear to have been validated*
23. Undercarriage malfunction procedures are potentially confusing
24. Crews are not trained in undercarriage malfunction procedures
25. Abnormal procedures are reported to the Operations Manager
26. No recurrent training in undercarriage malfunction procedures is instituted
27. The need for recurrent training is not recognised
28. Recurrent training in undercarriage malfunction is needed
29. Undercarriage malfunctions recur
30. Recurrent training can minimise distraction from undercarriage malfunction
31. Undercarriage malfunction can distract the crew at a critical stage of flight
32. No-one reviews training requirements when new procedures are introduced
33. Undercarriages are not modified
34. No review of safety implications of undercarriage decision has been performed
35. No review of safety implications of decision, by someone having an overall view
36. Flight Operations have performed no review of safety implications of decision
37. (Intentionally omitted)
38. Decision not communicated to Flight Operations
39. *Departments are only expected to communicate with each other if either detects a safety implication affecting the other*
40. No individual is responsible for safety oversight and risk management
41. No other office holder has responsibility for the role of Safety Manager
42. The Safety Manager is responsible for safety oversight and risk management
43. The Safety Manager position is abolished
44. There is no policy that the role of Safety Manager must be filled in some way
45. The Safety Department does not generate revenue
46. No benefit is seen to accrue from the Safety Department

Other factors didn't help the crew, not least the shortness of warning from the Ground Proximity Warning System (GPWS) (Figure 63).



- There is little warning of terrain closure
- The radar altimeter signal is attenuated
- Radar altitude is an essential input to the GPWS
- The radar altimeter aerial is severely corroded
- Aerial corrosion will attenuate the radar altimeter signal
- The aerial corrodes progressively
- The aerial is not inspected for a long time
- Moisture is present
- Moisture will accelerate aerial corrosion
- Moisture cannot drain from the radome
- Condensation in the radome produces moisture
- Paint plugs the drain hole*
- The radome is painted over
- The drain hole in the radome is very small*
- There are no instructions that radomes are not to be painted*

Figure 63. Shortness of GPWS warning

It can be deduced that the aerial corrosion which resulted in deficient GPWS performance (Morgan, 2001) was a consequence of the radome being painted (it should not have been). How the radome came to be painted over is not known, but it does not reflect favourably on the airline's maintenance procedures.

Before joining the various clusters to form the Current Reality Tree (CRT) it is necessary to consider the balance between financial and safety concerns – the double bind described by Mumford (2001). This is shown in Figure 64, where linkages to other parts of the overall CRT are also shown.

Naturally, Ansett did not intend to operate unsafely. Pilots were trained to fly the aircraft, the Maintenance Department was set up to assure that aircraft were in airworthy condition, and the Safety Department was set up to detect and mitigate hazards and emerging threats to safe operation. However, while these were responses to the pressure to undertake actions aimed at reducing risk, there was also pressure to move towards profitability, as already discussed. It was this pressure that led to the CEO's directive that costs must be reduced to a minimum ("Ansett loss announcement", 1995). This in turn links to the perceived need not to purchase spares if it could be avoided, to minimise training costs, and (presumably) to abolish the Safety Manager position.

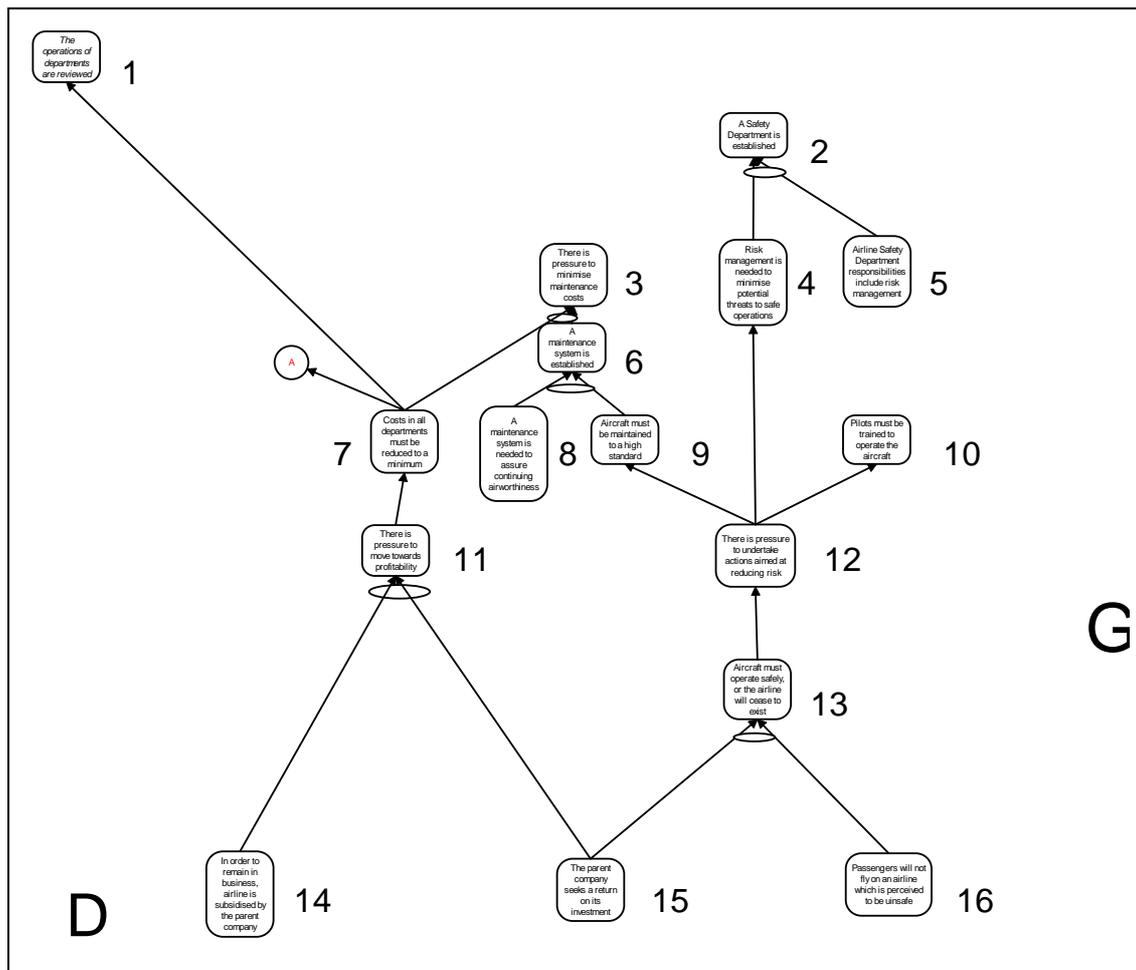


Figure 64. Conflict between financial and safety concerns.

Key:

1. *The operations of departments are reviewed*
2. A Safety Department is established
3. There is pressure to minimise maintenance costs
4. Risk management is needed to minimise potential threats to safe operations
5. Airline Safety Department responsibilities include risk management
6. A maintenance system is established
7. Costs in all departments must be reduced to a minimum
8. A maintenance system is needed to assure continuing airworthiness
9. Aircraft must be maintained to a high standard
10. Pilots must be trained to operate the aircraft
11. There is pressure to move towards profitability
12. There is pressure to undertake actions aimed at reducing risk
13. Aircraft must operate safely, or the airline will cease to exist
14. In order to remain in business, airline is subsidised by the parent company
15. The parent company seeks a return on its investment
16. Passengers will not fly on an airline which is perceived to be unsafe

These various clusters of conditions can be joined to form the Current Reality Tree (Figure 65). The real origin of the CRT is the conflict between profitability and safety. The Theory of Constraints argues that, if one can address such fundamental problems, then – since *all* the undesirable effects stem from them, the entire problem is resolved. However, this core conflict arose from fundamental Government policy, that air travel should be opened up to competition, and was thus likely to prove intractable.

In practice, though, a CRT will often disclose a number of ‘core problems’ (perhaps three or four) from which a significant number of effects stem (Dettmer, 1997)⁴¹. Eliminating one of these ‘core problems’ will eliminate all of its downstream effects. In the Ansett CRT, the maximum number of outgoing effect lines from a single entity was four (prior to inserting linkages to the CRT for the NZ Civil Aviation Authority (CAA), discussed later). For this case study, core problems were defined as those from which stemmed four or more effects⁴². These, emphasised in Figure 65, should be fruitful points to address:

- The need to minimise costs in all departments
- The Engineering department decision that undercarriage failure had no safety implications
- There was no individual responsible for safety oversight
- Undercarriage malfunctions recurred
- The undercarriage latch was adversely affected by normal wear.

⁴¹ It may be that this happens where there is a ‘system of systems’: potentially, there might be a core problem in each system. However, this has not yet been established.

⁴² For the rationale, see ‘construct validity’, p. 112. When both Ansett and CAA CRTs had been completed, it was found that there were linkages between them; these are shown by the short lines leading to circles, and labelled with red capitals which are also shown in the CAA CRT. These additional lines can form a fifth effect line, but the original selection of four effect lines was retained, since we are concerned with core problems within each separate CRT, i.e. looking at the problems within each organisation, where they could usefully be addressed.

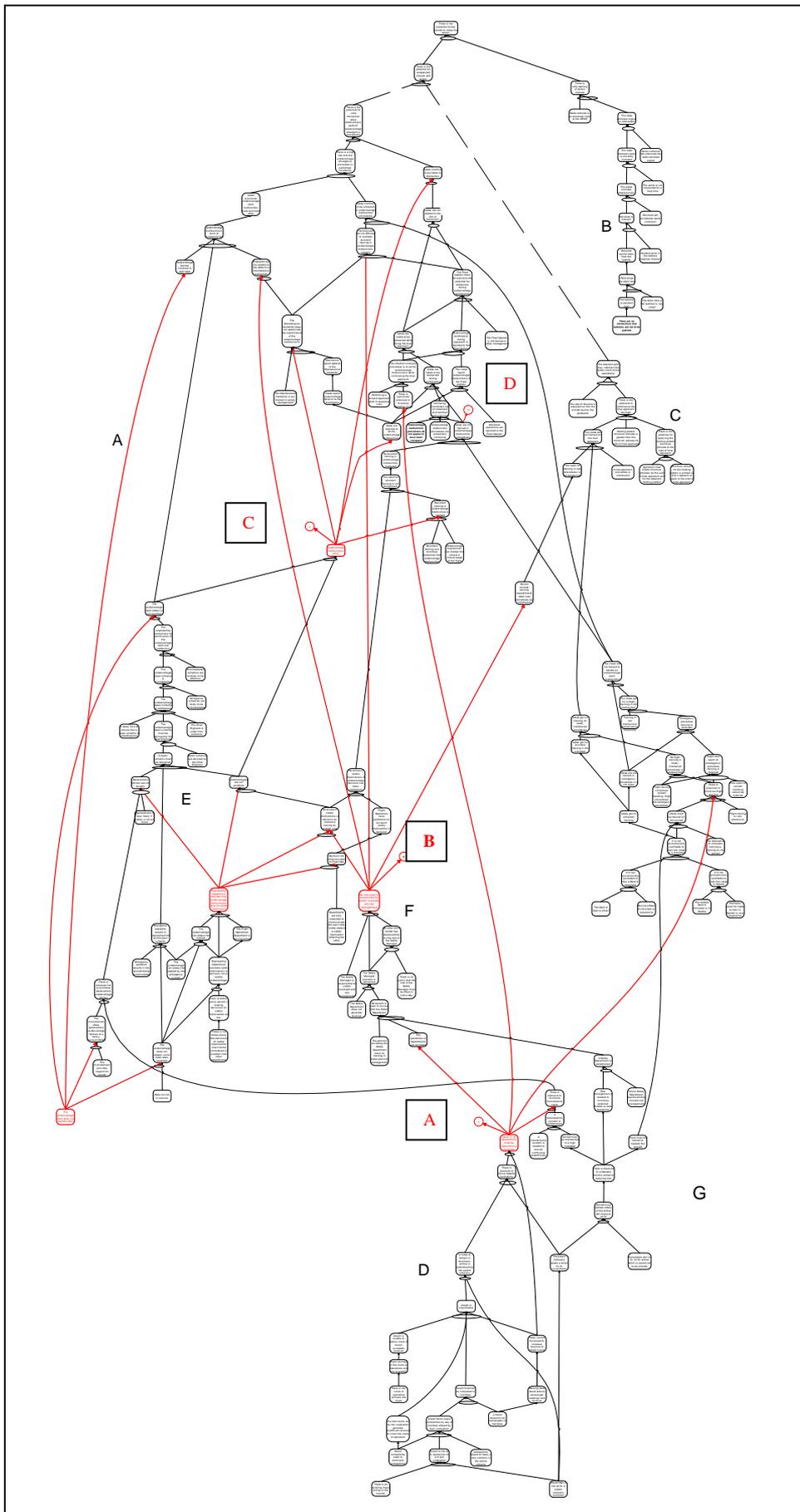


Figure 65. Ansett Dash 8 Current Reality Tree.

The dashed lines at the top of the tree indicate potentiation, as opposed to necessary and sufficient conditions. Potentiation means that the accident has been made possible, but it is not certain to occur. The combination of seemingly minor hazards has made an ordinarily benign condition, low cloud, potentially dangerous, and a random factor may tip the accident from potentiality to actuality. This concept will be discussed in the summary at the end of this chapter (p. 296).

The five effect lines from the condition ‘No individual is responsible for safety oversight and risk management’⁴³ categorise it as a core problem, and highlight the lack of wisdom in deciding to abolish the position of Safety Manager. It is perhaps not surprising that the Ansett Board should seek to save money on an apparently unproductive area such as the Safety Department. The position of Safety Manager might, therefore, be an area in which prescriptive regulation is proper, since the *raison d’être* of the CAA is risk management on behalf of the public.

The condition ‘undercarriage malfunctions recur’ also has five effect lines radiating from it, indicating that the decision not to modify the undercarriage was flawed. But this was a matter of ordinary company operation. Erroneous decisions are to be expected from time to time: perfect human performance cannot be expected. What is essential is that the effects arising from faulty decisions should be recognised before they can do harm. There were many precursor events before the accident resulted, and thus many opportunities to recognise that there was a problem and intervene. Ordinarily, the Safety Department would be the department responsible for risk management; having abolished the position of Safety Manager, the company had deprived itself of an important source of what Weick and Sutcliffe (2001) refer to as ‘mindfulness’, the ability to detect the unexpected and react to it before serious harm can result. However, the CAA on behalf of the public also had a duty to detect that all was not well, and intervene to prevent an accident. Given that there were many precursor events, how did it happen that the CAA was unaware of the potential for disaster?

Were there features of the CRT that would have justified action by the CAA, had it been aware of them?

⁴³ Refer to Segment F, Figure 62, item 40. Figure 65 highlights the relevance of this particular effect.

There was, at the time, no statutory requirement for an airline to have a Safety Management System. Nevertheless, the action of abolishing the Safety Department ought to have caused disquiet, at least. The CAA had been informed of this action, but made no inquiry as to the reason, or how the deficiency in safety oversight was to be made good (NZCAA, 1995). The CAA auditors were unaware that the Safety Department had been abolished (TAIC, 1995).

The recurring undercarriage defects, requiring regular use of the emergency system, were known to the Airworthiness Department of the CAA, but the implications as to the quality of maintenance were overlooked, and it appears that no-one saw fit to advise the operations side of the CAA. The auditors were not, therefore, alerted to look at what emergency procedures training the pilots might be getting.

The co-pilot's training records certified that he had been trained in undercarriage malfunction procedures (Ansett (NZ), (n.d. a)), but this was incorrect (Zotov, 2001). The erroneous entry in the co-pilot's training records was clearly a serious matter. It was discoverable on audit, but some prompt would have been needed for the auditors to review the records in sufficient depth to discover it.

However, the lack of simulator training was self-evident, and it would have been proper for the auditors to ask how the deficiency in training was being made good, particularly in regard to emergency and continuation training. Evidently they did not, and this raises questions about their background experience in airline operations.

With the exception of the original undercarriage design defect that set the accident sequence in motion, the core problems were all amenable to regulatory action. If the CAA had sought to compel the company to perform proper maintenance, train crews in emergency procedures, and re-instate its Safety Department, these actions might have been beyond Ansett (NZ)'s resources. Such action might then have resulted in suspension of the Operating Certificate, but in that case it would none-the-less have averted the deaths of passengers. This therefore raises the question of what the problems were in the CAA that prevented it from taking effective action.

Current Reality Tree: The Civil Aviation Authority

To consider why CAA oversight did not identify the weaknesses in Ansett that led to the accident, it is necessary to look at the CRT from the CAA perspective⁴⁴.

Prior to the formation of the CAA in 1990 its predecessor, the Civil Aviation Division (CAD) of the Ministry of Transport⁴⁵ had performed its function of the safety oversight of air transport by conducting surveillance in accordance with the ICAO Manual of Procedures for Operations Inspection, Certification and Continued Surveillance (Doc 8335 AN/879). However, the CAD was significantly understaffed for the work it was required to do, largely as a result of a Government policy of 'downsizing' ("Safety in the Sky", 1990). This resulted in severe criticism of the CAD by two Courts of Inquiry, set up to inquire into two air transport accidents (Carruthers, 1988, 1989). The amount and quality of surveillance performed was found to have fallen short of that required. Additionally, review of documentation by Division staff, prior to the accidents, would have had the potential to alert the airline inspectors of the shortcomings that led to those accidents. In 1990 the CAA sought an alternative to surveillance, which it recognised that it was unable to perform due to staff shortages.

Following the Skyferry Court of Inquiry (Carruthers, 1988), an independent review of civil aviation regulation and monitoring, the Swedavia Review, (Swedavia AB & McGregor and Company, 1988) recommended that the CAD needed a suite of monitoring tools, particularly surveillance of operations and auditing of documentation. The Swedavia Review argued that operators would act responsibly because it was in their interests to do so, so that a primary function of the CAD should be to ensure that operators had satisfactory systems in place that would ensure safe operation. When the CAA was formed, it decided to discard the surveillance role, and to confine itself to auditing (NZCAA, 1994). Further, such audits would be largely confined to review of safety system documentation (ibid, 'Audit Tools'); examination of outputs would be a minor function, since this would be 'surveillance' (see, for example, "CAA audits", 1995). There appears to have been little surveillance of Ansett prior to the Dash 8 accident (TAIC, 1995).

⁴⁴ For convenience in presentation, the activities of the CAA will be shown in a separate diagram, the linkages between the CAA and Ansett parts of the CRT being indicated by key letters in circles.

⁴⁵ There was a transient stage when the CAD was known as the Air Transport Division of the Ministry of Transport, but this is unimportant for the present study.

A further complication, introduced at about this time, was a Government philosophy of 'user pays'. Government bodies would not be funded from general taxation, but as far as possible, by those who benefited from the activities of those bodies. In the case of the CAA, aircraft operators were perceived to be the 'users', and were charged for CAA 'services' at a rate which was required to cover the costs of those services ("AIA conference report", 1994).

One consequence of the 'user pays' approach was that time spent on monitoring airline activities was charged at an hourly rate, and that rate was far in excess of the market rate for such activities. For example, clerical time was charged at \$133 per hour ("CAA funding", 1995). The aviation industry protested at the level of charges. In response to criticism, the CAA sought ways to minimise the time spent on auditing. In particular, since a significant proportion of audit costs came from time spent on preparation such as review of documents, the preliminary reviews were minimised.

The decision to (largely) confine audits to a review of documentation had a number of effects. Abnormal events were not covered by the review, so events which might have been precursors to more serious trouble were unknown to auditors. An audit which does not examine the actuality of operations by looking at the end-product cannot detect such abnormal events. Also, not all the actions required for safe operation are capable of being documented. The flexible reactions characterised by Weick and Sutcliffe (2001) as part of 'mindfulness' are essential to any high reliability organisation, but by their nature they cannot be documented: they are a part of the organisational culture. Additionally, an airline may not necessarily operate in accordance with its documentation: as Clausewitz (1874) said, the map is not the terrain. An audit which does not examine the actuality of operations by looking at the end-product cannot detect such non-conformance with the documentation (Arbon, Homer & Feeler, 1998). The consequences of lack of knowledge of real operations at Ansett were two-fold. Firstly, the auditors were unaware that, in the period before the accident, Ansett had abolished the position of Safety Manager, although Ansett stated that they had advised the CAA of the change (NZCAA, 1995). Had the auditors been aware of this, they would have been aware of a non-conformance with the documentation as they believed it to be. Also, they would have been prompted to

review risk management at Ansett, since a prime function of the Safety Department is risk management.

Secondly, the auditors were unaware of the history of undercarriage malfunctions in the Dash 8 fleet. Ansett had advised the Airworthiness section at CAA, who were 'monitoring' the situation but had not advised the auditors (TAIC, 1995). Since the auditors were unaware of the undercarriage malfunctions, they could not query the management of the associated risks, which might have led them to discover the absence of the Safety Manager. Awareness of the recurring undercarriage malfunctions could also have led them to query the ineffectiveness of engineering rectification of the failures, and the absence of effective training of pilots in what had become a recurring emergency.

The undesirable effects at the CAA are shown in Figure 66.

The undesirable effect 'Audits do not avert accidents' is the end-point of a sequence of undesirable effects relating to auditing. Those relating to this particular accident include:

- Auditors were unaware of the absence of a Safety Manager
- Auditors were unaware of deficient crew training
- Auditors were unaware of recurring malfunctions

And, arguably,

- CAA did not perform surveillance of airline operations.

These undesirable effects shown in Figure 66 are written in the present tense, which by convention is used in the Current Reality Tree.

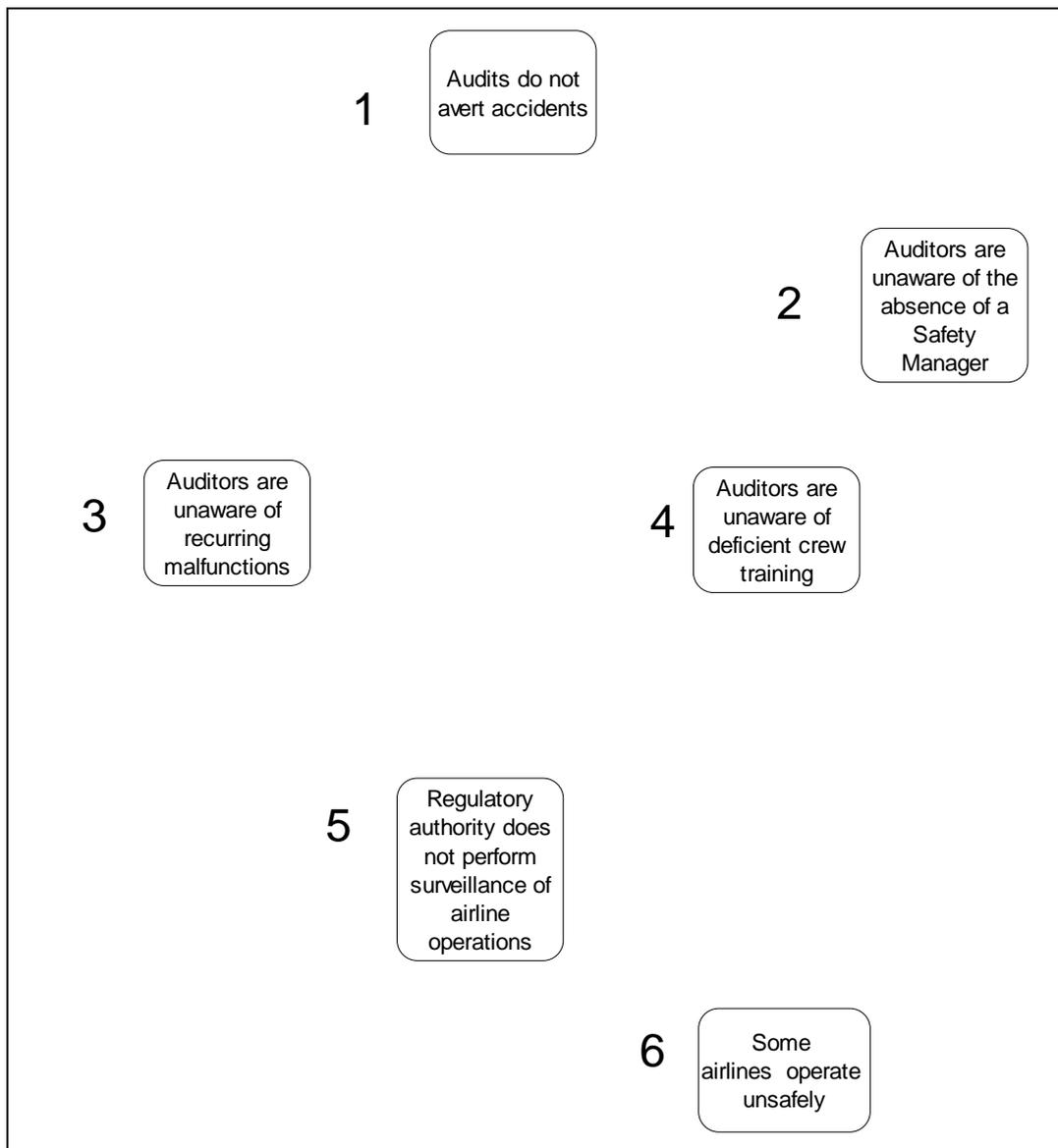


Figure 66. Undesirable effects at the CAA.

Key

1. Audits do not avert accidents
2. Auditors are unaware of the absence of a Safety Manager
3. Auditors are unaware of recurring malfunctions
4. Auditors are unaware of deficient crew training
5. Regulatory authority does not perform surveillance of airline operations
6. Some airlines operate unsafely

CAA auditing of airlines is one of the ways by which the regulatory authority can achieve safety oversight. Other components of oversight include surveillance (ICAO, 1995) and monitoring the effectiveness of an airline's Safety Management System. Audits alone are unlikely to be effective in informing the CAA of the safety health of an airline (Swedavia AB & McGregor and Company, 1988). The undesirable effects shown in Figure 66 stem from the decision to confine oversight activities to auditing alone, exacerbated by defining 'auditing' as 'determining that an organisation has a management system in place which will ensure compliance with relevant standards...' (TAIC, 1995). In practice, audits were largely confined to review of documentation (see, e.g., "CAA Audits", 1995; "Safety in the Sky", 1990). The CRT traces the linkages which demonstrate why this policy had adverse consequences.

Crew Training.

Consider, first, the deficient training of the crew in emergency procedures. Emergency training was not performed in accordance with the documentation, but auditing of the documentation, alone, could not detect the deficient training. The auditors were not prompted to review the training in undercarriage emergencies, even though these were a recurring problem (as discussed in the next section) and so the absence of training to handle a recurring emergency was not detected. (See Figure 67). (The numbers on the following diagrams refer to the key for Figure 73, 'CAA Performance').

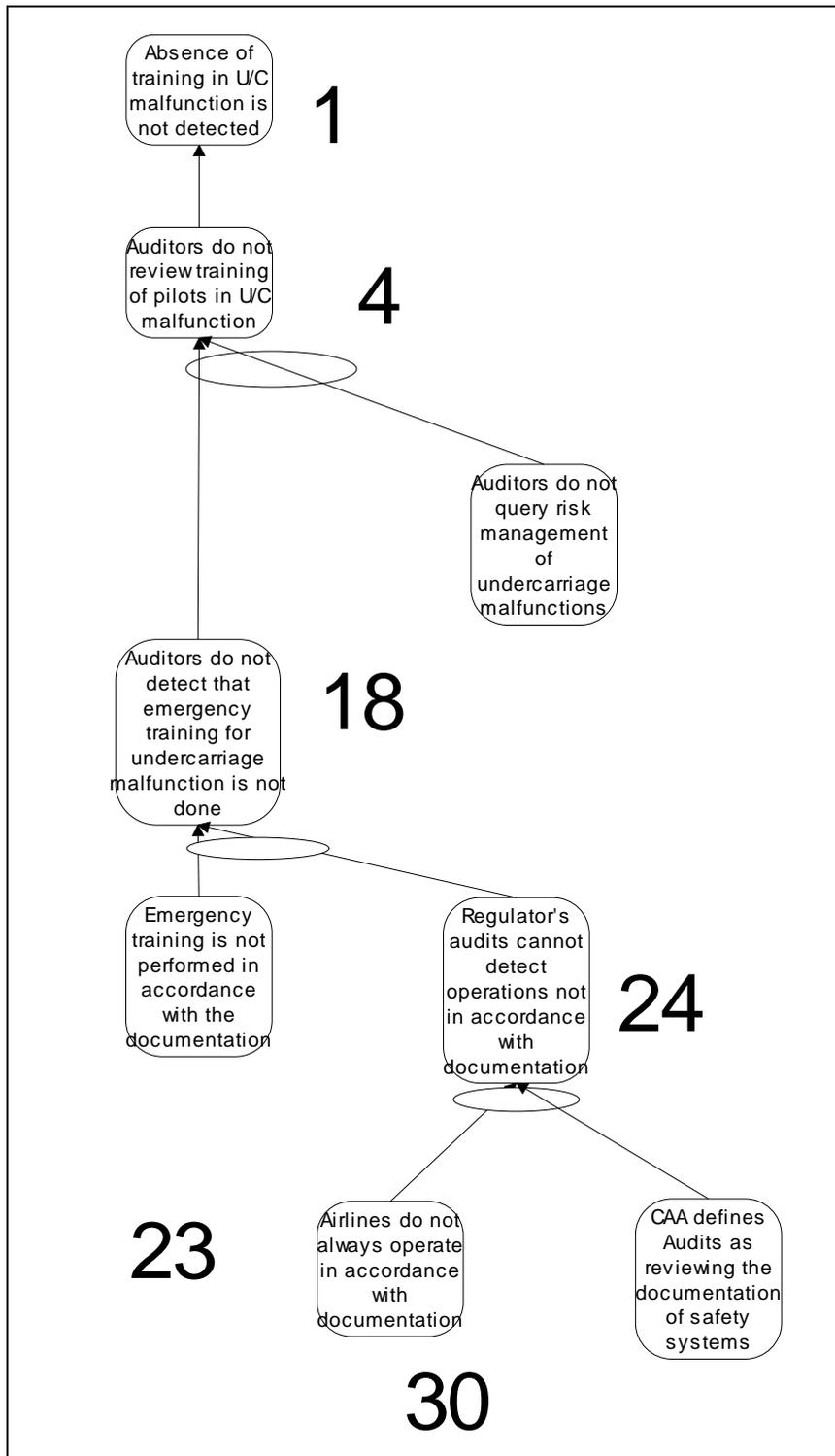


Figure 67. Knowledge of Crew Training.

Recurring events.

Abnormal events which occur in flight are noted in crew reports, not in the airline's procedural documentation available to the auditors before they commence an

audit. The auditors are therefore unaware of such events if they do not also review crew reports. Likewise, review of maintenance procedural documentation would not have alerted the auditors, since there were no applicable airworthiness directives referring to the engineering problem. The auditors did not examine physical reality by performing surveillance, which would have had at least some chance of observing defects recurring or being rectified. Absence of either review of crew or defect reports, or surveillance, meant that the auditors were unaware of the recurring undercarriage defects. Had they been aware, they might have inquired into the risk management of these events, e.g. what training the aircrew had received to deal with such events. Inquiry as to why the events recurred should have led the auditors to the deficient maintenance instruction which did not detail the required inspection (see Figure 68).

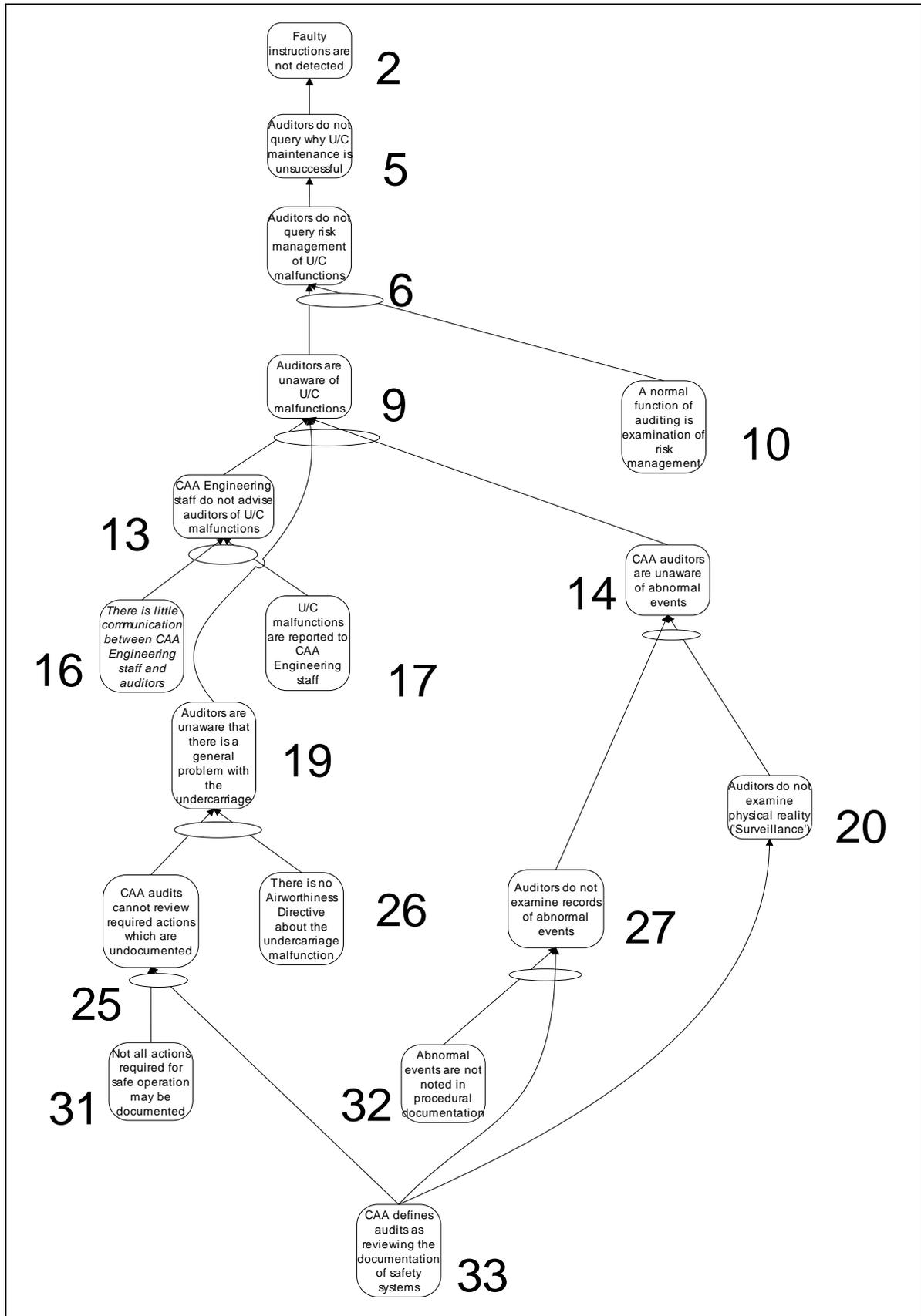


Figure 68. Knowledge of Recurring Events.

Risk Management.

Risk management is one function of the Safety Department. However, although the CAA had been advised that Ansett no longer had a Safety Manager, the CAA auditors did not know this (TAIC, 1995). Audit preparation should have alerted the auditors to the change, but pressure to minimise cost, and therefore time for such preparation (ibid., p. 56), led to deficient preparation, and the change went unnoticed. Surveillance should have brought the absence of the Safety Manager to the auditors' notice. In the event, the auditors were unaware of the change, and so of the absence of risk management. (See Figure 69).

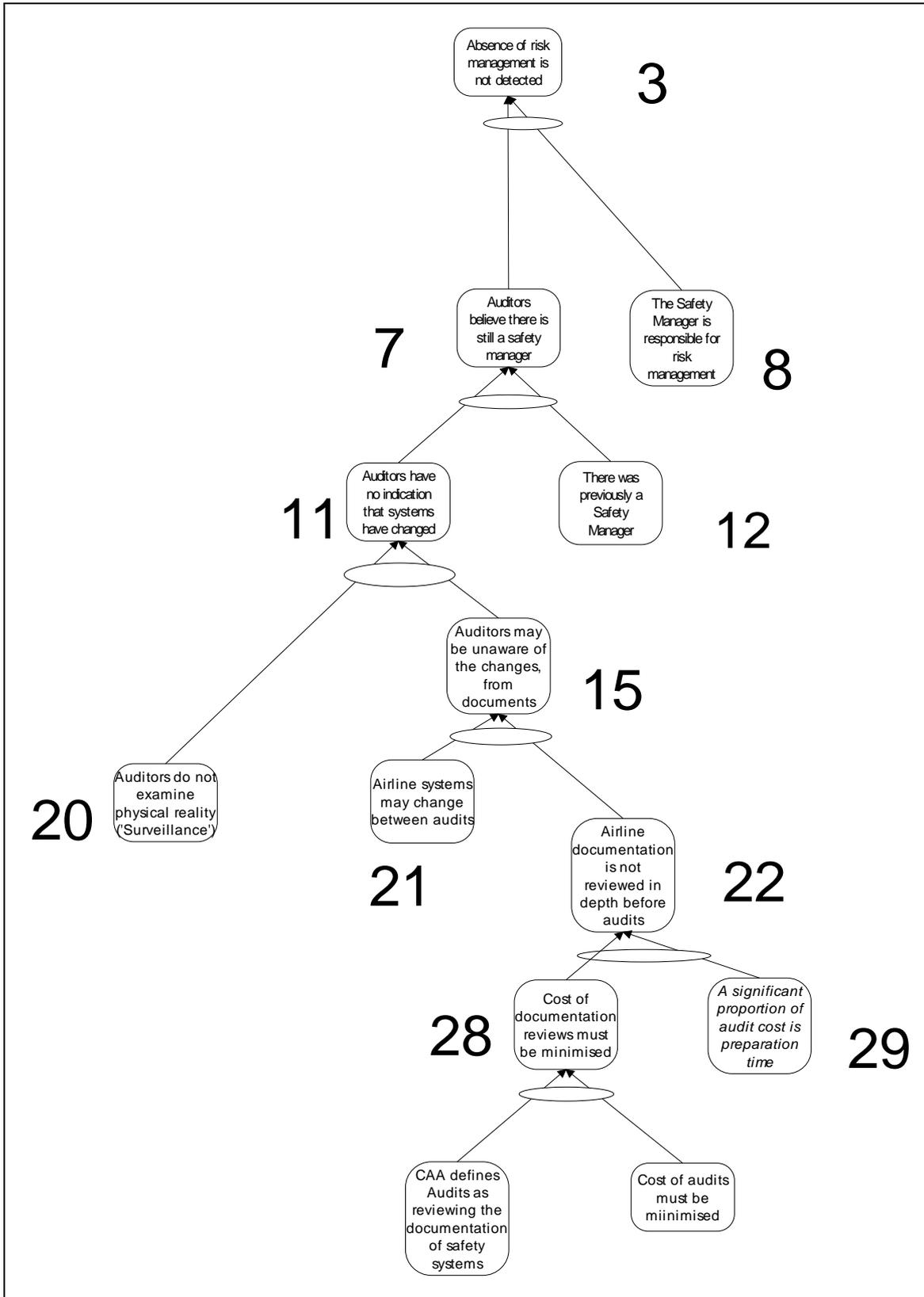


Figure 69. Knowledge of risk management.

The combined diagram (Figure 70) illustrates why audits alone could not keep the CAA informed as to the true state of the airline. Had the CAA been aware, possible corrective actions included

- Insisting that emergency training be performed
- Requiring correction of the defective maintenance instruction
- Requiring the Safety Manager position to be reinstated.

Collectively, these actions would have made the accident unlikely.

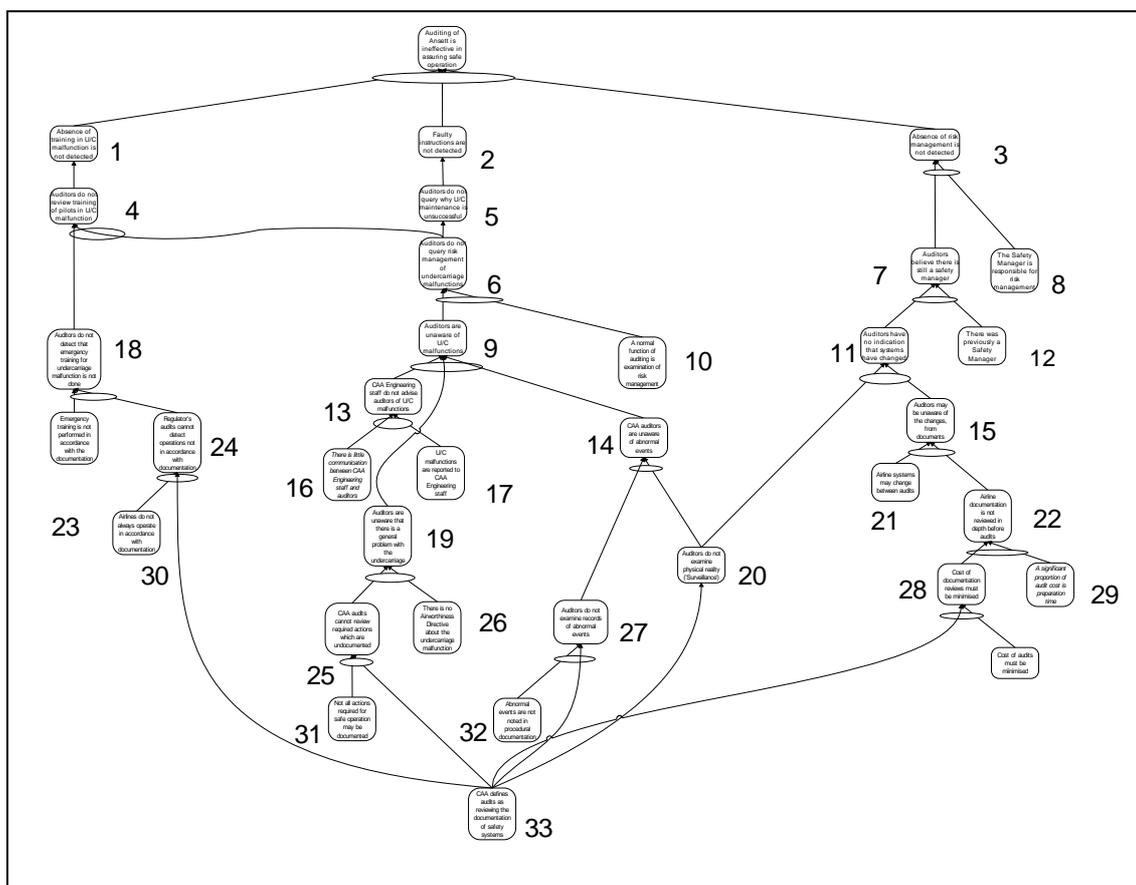


Figure 70. Combination of Figures 67, 68 and 69.

There are two common themes so far:

- The policy of not conducting surveillance, and
- Restricting ‘audits’ to examination of the airline’s documentation to ensure that systems were in place.

Both of these stemmed from the need to minimise costs. The relationship is shown in Figure 71. Surveillance to the level required by the ICAO Manual (ICAO, 1995) is resource intensive, and the CAA had insufficient staff who were suitably qualified and trained to conduct surveillance. The CAA and its predecessors had been criticised for inadequate surveillance, when a number of air transport accidents had been investigated (e.g. Carruthers, 1988, 1989). The CAA therefore sought an alternative to surveillance. An independent review (Swedavia AB & McGregor and Company, 1988) recommended a combination of audit and surveillance, but the CAA decided to conduct audits only.

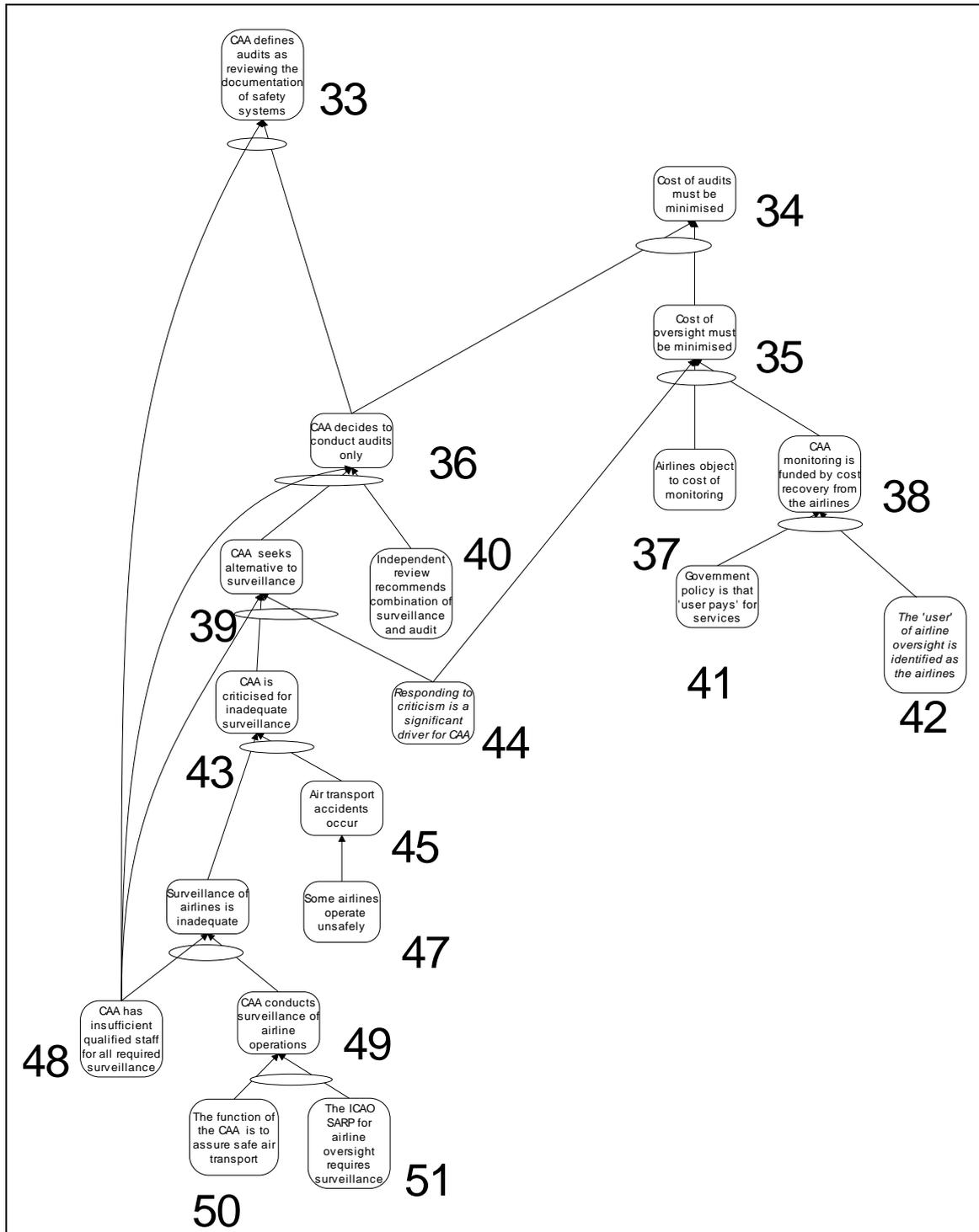


Figure 71. Audit Policy.

The cost pressures which prevented recruitment of suitably qualified staff for surveillance also bore on the audit process. It was Government policy that the users of services were to be charged for those services. The ‘users’ of audits were considered to be the airlines, who were charged fees based on the time that an audit took. There

was pressure to minimise fees, which resulted in reduced preparation time (TAIC, 1995).

All of the pressures leading to the CAA being unaware of the increasing potential for the Ansett accident can be seen to stem from the ‘double bind’ between safe performance and cost (Mumford, 2001). This double bind can be depicted as a Conflict Resolution Diagram, Figure 72.

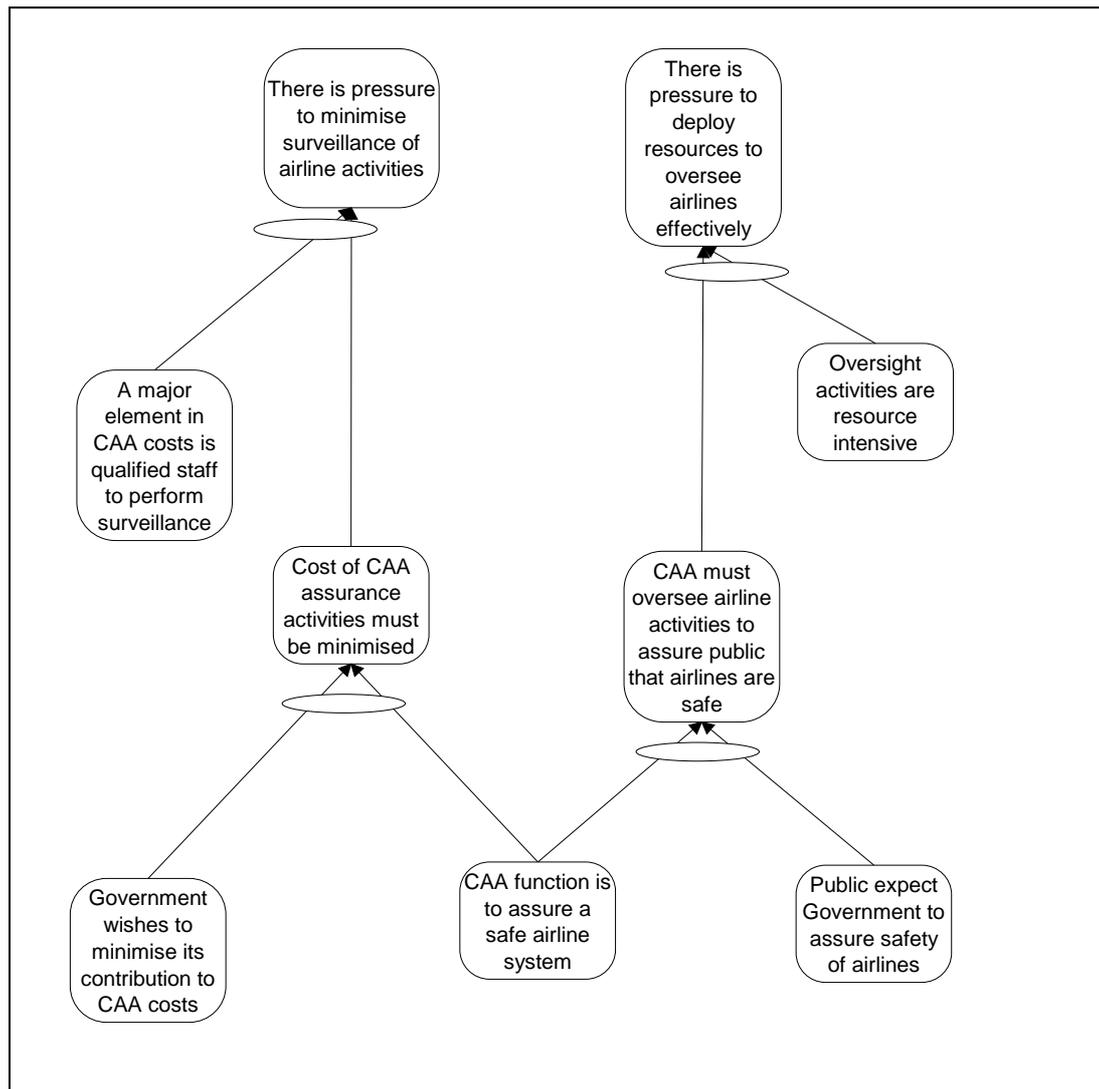


Figure 72. Safe Performance and Cost.

The diagrams relating to CAA performance can be combined, as shown in Figure 73.

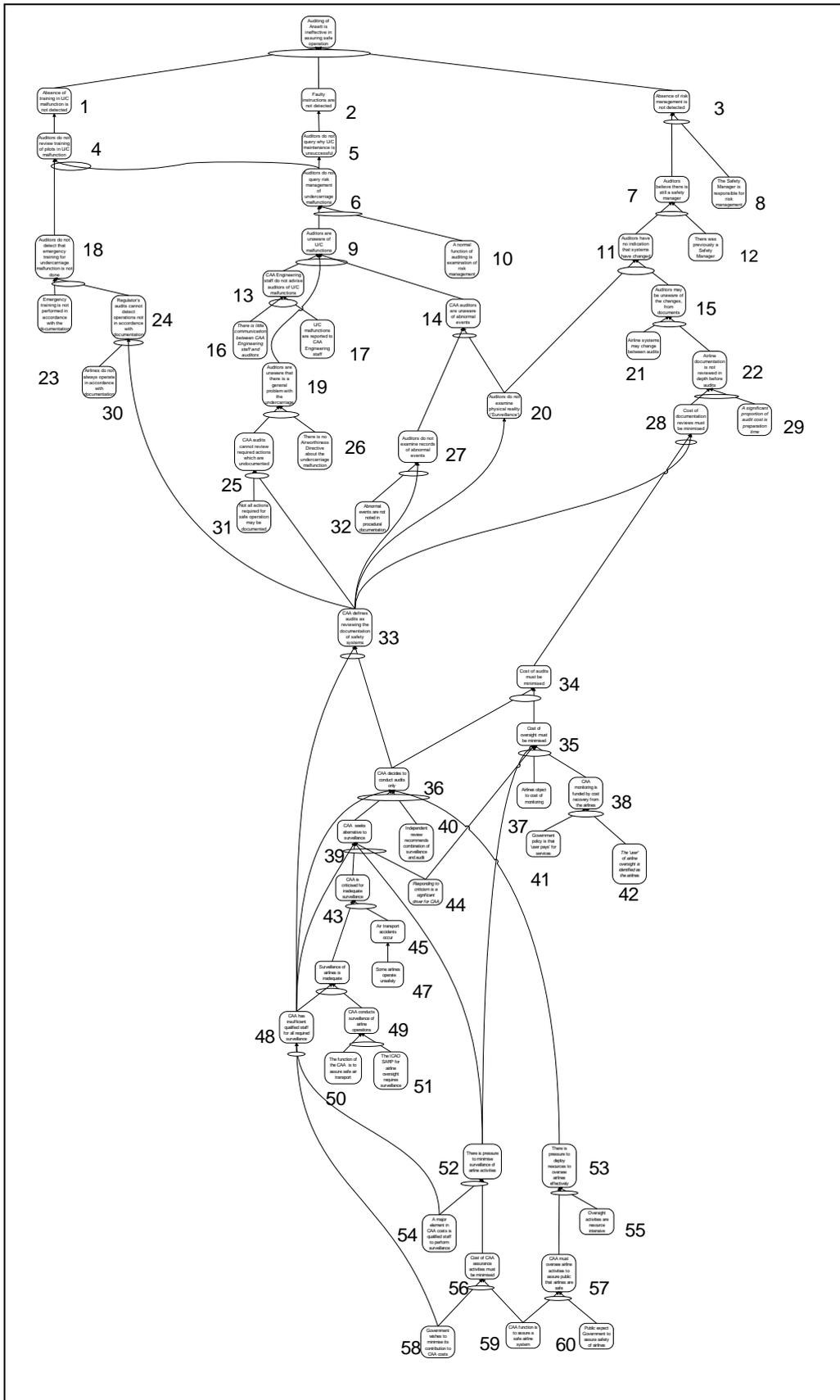


Figure 73. CAA Performance.

Key to Figure 73

1. Absence of training in undercarriage malfunction is not detected
2. Faulty instructions are not detected
3. Absence of risk management is not detected
4. Auditors do not review training of pilots in undercarriage malfunction
5. Auditors do not query why undercarriage maintenance is unsuccessful
6. Auditors do not query risk management of undercarriage malfunctions
7. Auditors believe there is still a Safety Manager
8. The Safety Manager is responsible for risk management
9. Auditors are unaware of undercarriage malfunctions
10. A normal function of auditing is examination of risk management
11. Auditors have no indication that systems have changed
12. There was previously a Safety Manager
13. CAA Engineering staff do not advise auditors of undercarriage malfunctions
14. Auditors do not examine records of abnormal events
15. Auditors may be unaware of changes, from documents
16. *There is little communication between CAA Engineering staff, and auditors*
17. Undercarriage malfunctions are reported to CAA Engineering staff
18. Auditors do not detect that emergency training for undercarriage malfunction is not done
19. Auditors are unaware that there is a general problem with the undercarriage
20. Auditors do not examine physical reality ("Surveillance" is not allowed)
21. Airline systems may change between audits
22. Airline documentation is not reviewed in depth between audits
23. Emergency training is not performed in accordance with the documentation
24. CAA Audits cannot detect operations not in accordance with documentation
25. CAA Audits cannot review required action which is undocumented
26. There is no Airworthiness Directive about the undercarriage malfunction
27. CAA Auditors are unaware of abnormal events
28. Cost of documentation reviews must be minimised
29. *A significant proportion of audit cost is preparation time*
30. Airlines do not always operate in accordance with documentation
31. Not all actions required for safe operation may be documented
32. Abnormal events are not noted in procedural documentation
33. CAA defines audits as reviewing the documentation of safety systems
34. Cost of audits must be minimised
35. Cost of oversight must be minimised
36. CAA decides to conduct audits only
37. Airlines object to the cost of CAA monitoring
38. CAA monitoring is funded by cost recovery from the airlines
39. CAA seeks alternative to surveillance
40. Independent review recommends combination of surveillance and audit
41. Government policy is that 'user pays' for services
42. *The 'user' of airline services is identified as the airlines*
43. CAA is criticised for inadequate surveillance
44. *Responding to criticism is a significant driver for the CAA*
45. Air transport accidents occur
46. Surveillance of airlines is inadequate
47. Some airlines operate unsafely
48. CAA has insufficient qualified staff for all required surveillance
49. CAA conducts surveillance of airline operations
50. The function of the CAA is to assure safe air transport
51. The ICAO SARP for airline oversight requires surveillance
52. There is pressure to minimise surveillance of airline activities
53. There is pressure to deploy resources to oversee airlines effectively
54. A major element in CAA oversight costs is qualified staff to perform surveillance
55. Oversight activities are resource intensive
56. Cost of CAA oversight activities must be minimised
57. CAA must oversee airline activities to assure the public that airlines are safe
58. Government wishes to minimise its contribution to CAA costs
59. CAA function is to assure a safe airline system
60. The public expects the Government to assure the safety of airlines

It could reasonably be expected that where an airline was under financial stress, it might attempt to minimise costs, perhaps to the detriment of safe performance. Ansett's actions in not buying replacement undercarriage parts, not training its crews in emergency procedures, and abolishing the Safety Manager position, can be construed as a response to financial pressures, as previously discussed. Therefore, it would be reasonable to increase the level of safety oversight of airlines under financial pressure. However, the CAA had been deprived of direct knowledge of airlines' financial positions. Previously, airlines had had to make regular financial returns ("Air Services Licensing Act", 1983) but this requirement was abolished as part of the reforms encompassed in the Civil Aviation Act (1990). The financial viability of airlines was considered to be a matter for market forces. The effect of the removal of financial information is shown in Figure 74.

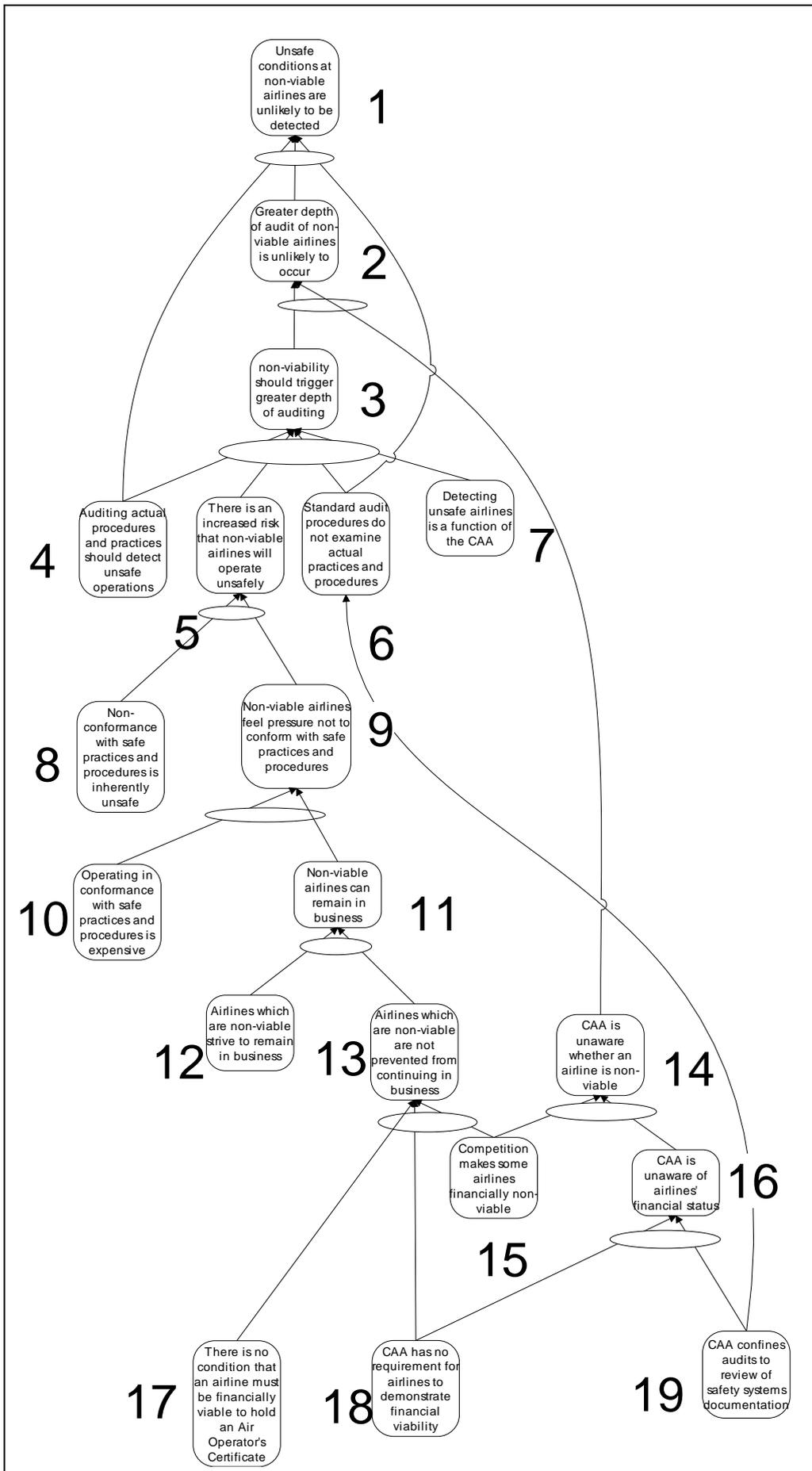


Figure 74. Lack of financial information

When Figure 74 is combined with Figure 73, the final Current Reality Tree from the perspective of the CAA is obtained (Figure 75). This CRT has been rearranged slightly (without altering the linkages) so that the core problems - again shown in red - are evident.

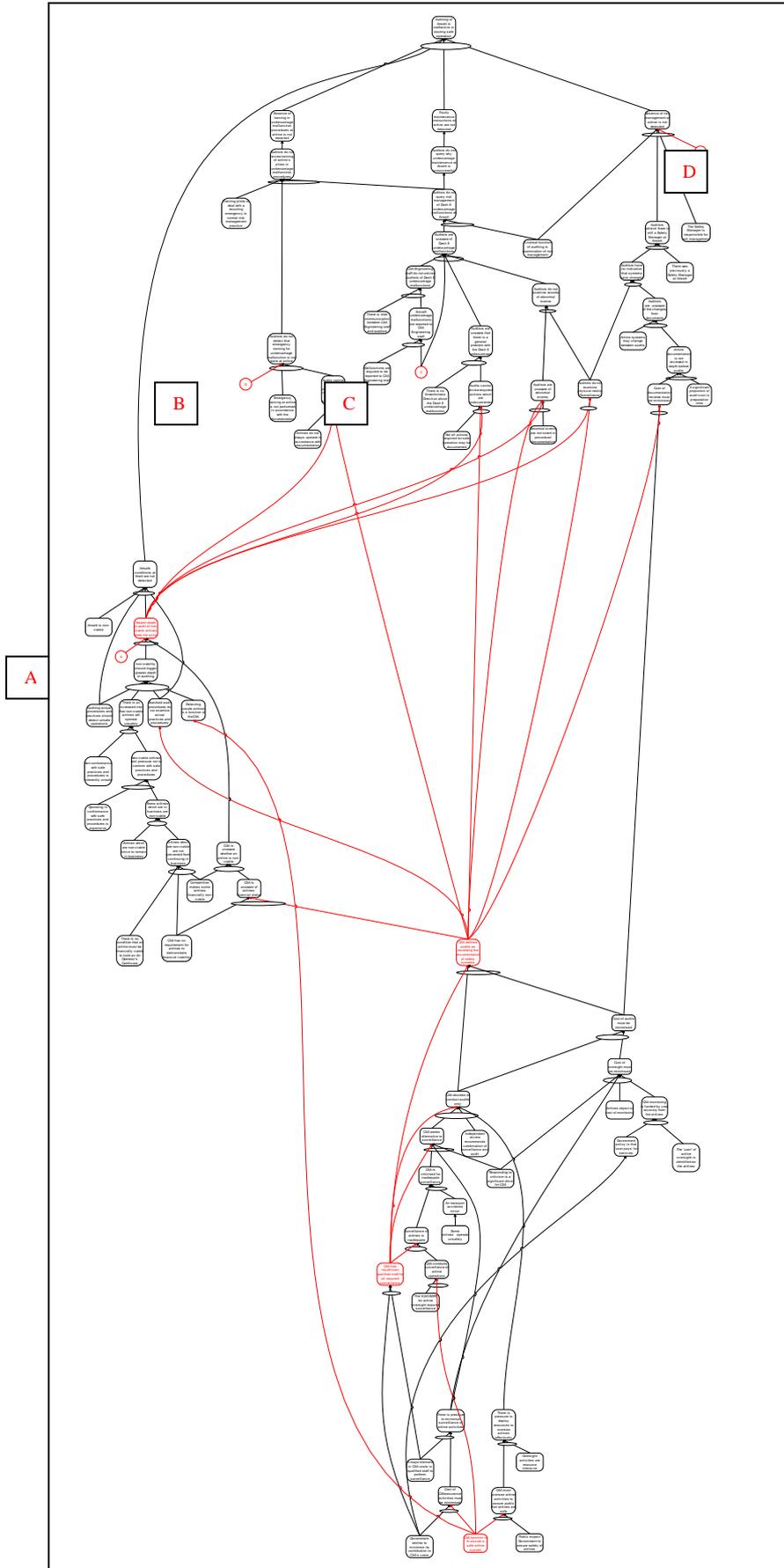


Figure 75. CRT from the CAA perspective.

As in the CRT from the Ansett perspective, core problems are highlighted:

- The CAA had insufficient qualified staff for all required surveillance;
- The CAA confined audits to review of the documentation of safety systems; and
- Non-viable airlines did not incur a greater depth of auditing.

The effects of the core problems and, in particular the decision to confine auditing to review of the documentation, are clear.

The insufficiency of staff at the CAA was a matter for appropriate funding, and getting a warning of the financial status of airlines might have required a change to the law. Neither of these was impossible, if an appropriate case had been made. However, the dominant problem was the definition of the oversight role as being confined to a review of the documentation. This was entirely a matter within the province of the CAA. It is relevant that ICAO defines this as a passive role; “The State is not in a good position to assess the adherence of industry to the regulations, other than by knowledge obtained fortuitously or in the course of accident or incident investigation. Such a system would not enable the State to exercise the necessary preventive and corrective responsibilities required by the Convention” (ICAO, 1999, p. A2-3).

Once again, although the CRT is only the first stage in the application of the TOC, it is possible to discern corrective actions. The Future Reality Trees, derived from the Current Reality Trees, will be considered next.

The Future Reality Tree

Whereas the Current Reality Tree shows undesirable effects in the present system, the Future Reality Tree (FRT) shows the system as one would like it to be. The FRT serves a number of purposes:

1. It provides a means of testing ideas for improvement, to see whether they will indeed do what is hoped, and whether there are unforeseen effects that would not be wanted. It acts as a simulator in which these ideas can be tried, before the expense of putting them into practice in reality (Dettmer, 1997).
2. It provides a safety net. The CRT or Conflict Resolution Diagrams (CRD)s may be imperfect: ‘As Goldratt has said, “It’s better to be approximately correct than precisely incorrect”’ (Dettmer, 1997, p. 195). If there are imperfections in the CRT or CRD(s), it is still possible to have an effective FRT, because the imperfections will come to light as ‘negative branches’, that is, undesirable outcomes from changes that may be introduced. These can be identified and removed.
3. The various injections needed to construct the FRT form the basis for subsequent Safety Recommendations.

One primary difference between the CRT and FRT, in this application of the Theory of Constraints methodology as an accident investigation tool, is the level of specificity. In the CRT, the action is traced from ‘this particular accident’ to the specific factors which caused it, tracing back to the more general problems which gave rise to those factors. For example, the undercarriage malfunction was one of a series of repeated undercarriage malfunctions, which arose from a particular faulty instruction by the Maintenance Manager, which may have arisen from excessive workload. The FRT, by contrast, must deal with more generic terms. It is totally improbable that this particular faulty instruction would recur at this particular company. However, it is virtually certain that problems of some sort will recur in some company. Their immediate cause is irrelevant for the purpose of considering what to do about them: what is necessary is that crews are trained to deal with

foreseeable problems, so that the aircraft will not be jeopardised, and that the recurrence is spotted so that the underlying problem (such as the faulty instruction) can be identified and fixed. It is for this reason that it is necessary to be able to express effects in general terms, such as ‘problems recur’.

There are various ways to move from the CRT to the FRT:

- It may be possible to discover a core conflict at the very base of the CRT. Either it may be evident on inspection, or it may be possible to discover a common factor underlying several core problems. In this case it could be possible to find a solution to the core conflict, using a Conflict Resolution Diagram (CRD). If this can be done, the FRT is generated by linkages from the injection which broke the basic assumption, to the various desirable effects which it is wished to achieve (Goldratt, 1998). The FRT, in this instance, may bear little resemblance to the CRT, because the CRT itself is no longer valid. This reflects reality: resolution of a fundamental conflict may require a complete restructuring of the business in order to take advantage of the new opportunities available.
- It may be possible to address a number of core problems, using CRDs to generate ideas for solving the underlying problems, and then construct a FRT, similar in layout to the CRT, but achieving desirable effects. In this instance the FRT may be rather similar in layout to the CRT, because the underlying structure of the business may not change very much (Dettmer, 1997). For example, an airline is likely to have maintenance, flight operations and training departments, regardless of improvements in financial management.
- A third approach is to attempt to transform the CRT, by rewriting the various undesirable effects as desirable effects, adding appropriate injections required to bring the changes about (Dettmer, 1997). Like the previous approach, this is based on the idea that the underlying structure is unlikely to change much.

The first two methods were tried, for the purpose of generating a FRT from the Ansett CRT. They were unsuccessful, for a reason that is obvious in hindsight. The usual objective in applying the Theory of Constraints is to bring about an improvement in the company which is experiencing undesirable effects. In the case of

Ansett, all the undesirable effects stemmed from financial constraints, and in particular the impossibility of competing head-on with the established airline, Air New Zealand. In trying to use conventional methods to construct the FRT, solutions generated were aimed at solving Ansett's financial problems. For example, while start-up full service airlines have been almost universally unsuccessful, the history of low-cost start-ups contains its share of successes (Williams, 2002). A reasonable solution for Ansett could have been to seek a low-cost niche market in which Air New Zealand, as an established full-service airline, might have been unable or unwilling to compete.

However, while this might have resolved Ansett's financial woes (and could well have been a useful exercise for Ansett to perform), it does not meet the requirements of a system intended to generate safety recommendations, for two reasons:

- Both the investigative and regulatory authorities are Government bodies, and it would be improper for them to act in a way intended to give one airline a competitive advantage. Besides, such advice might not be well-received by the airline.
- The solution is not generic. It is highly unlikely that Ansett would have another CFIT accident resulting from undercarriage malfunction, but it is quite possible that some airline would suffer a CFIT accident as a result of crew distraction. It is to the general problem that recommendations are best directed.

Accordingly, the third method was adopted for the construction of the Ansett FRT, and the earlier attempts will not be discussed further.

The FRT for the CAA, by contrast, could be constructed in the classical fashion of seeking to address a core conflict at the base of the CRT. In the first place, there is no inhibition about seeking to improve a Government body. Secondly, there is no need to seek a generic solution, because there is only one such body in the country. And thirdly, inspection of the CRT shows that there is indeed such a core conflict evident in the way in which the CAA is funded.

Using these two different approaches, it will be shown that useful recommendations can be derived from the injections needed to construct the two FRTs.

Construction of the Ansett Future Reality Tree

The method adopted was to replace each of the non-commercial undesirable effects in the Ansett CRT with the opposing desirable effect. For example,

“Crews get no training on newly-introduced procedures” is replaced with

“Crews are trained on newly-introduced procedures”.

1. Flight Crew Training

In order to illustrate the transformation process, the question of crew training can be examined. In the CRT, the undesirable effects are:

- Crews are not trained to handle an undercarriage latch malfunction
- Crews are not trained on the new approach
- Crews get no simulator training.

These statements are transformed, in the FRT, to:

- Crews are trained to handle foreseeable emergencies
- Crews are trained on newly-introduced procedures
- Crews get emergency, CRM and recurrent training on the simulator, despite the cost involved.

The first iteration of this implementation is shown in Figure 76. (For clarity, the entity ‘pilots must be trained to operate the aircraft’, entity number 12, has been moved onto this diagram).

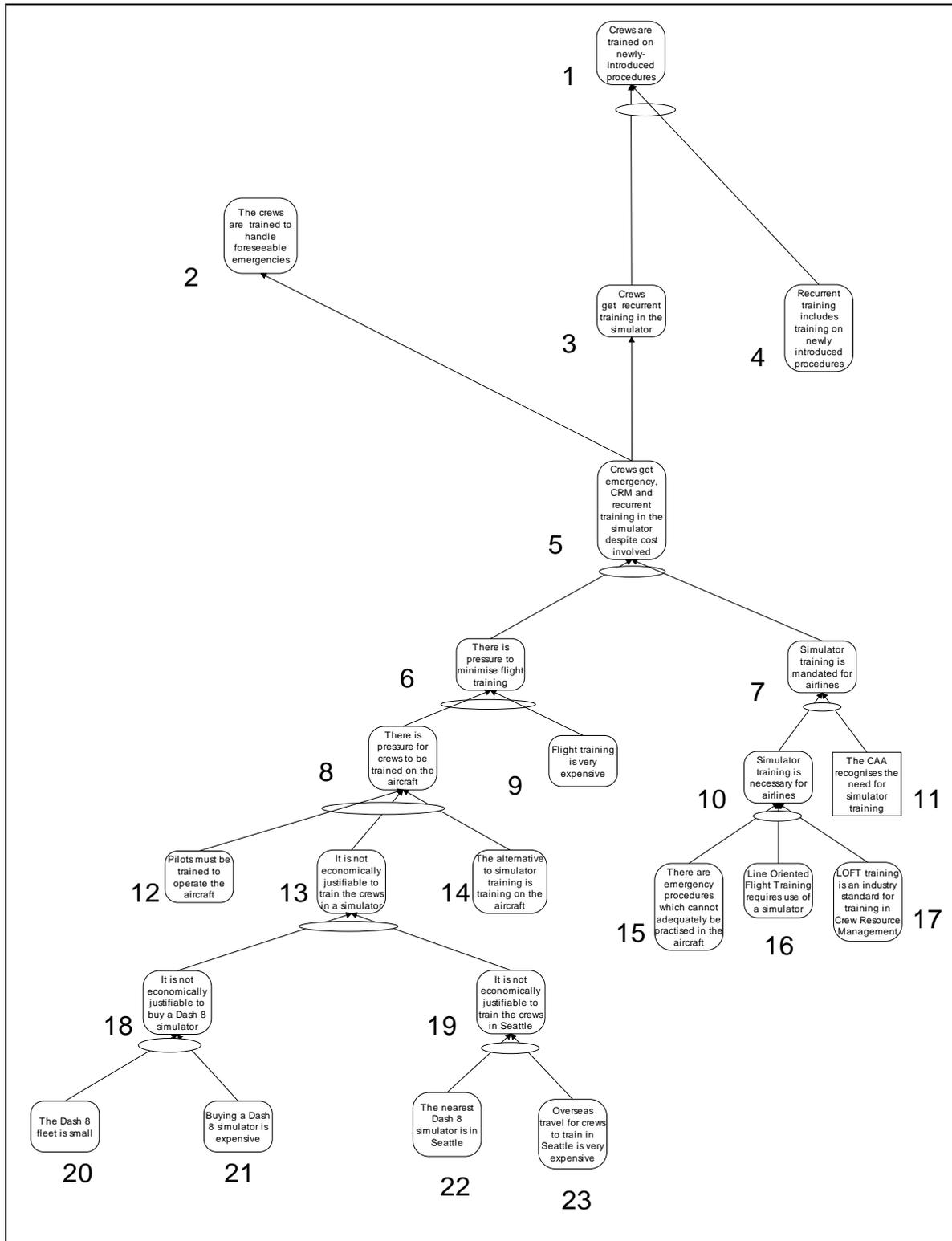


Figure 76. Crew training.

Key

1. Crews are trained on newly-introduced procedures
2. The crews are trained to handle foreseeable emergencies
3. Crews get recurrent training in the simulator
4. Recurrent training includes training on newly introduced procedures
5. Crews get emergency, CRM and recurrent training in the simulator despite cost involved
6. There is pressure to minimise flight training
7. Simulator training is mandated for airlines
8. There is pressure for crews to be trained on the aircraft
9. Flight training is very expensive
10. Simulator training is necessary for airlines
11. The CAA recognises the need for simulator training
12. Pilots must be trained to operate the aircraft
13. It is not economically justifiable to train the crews in a simulator
14. The alternative to simulator training is training on the aircraft
15. There are emergency procedures which cannot adequately be practised in the aircraft
16. Line Oriented Flight Training requires use of a simulator
17. LOFT training is an industry standard for training in Crew Resource Management
18. It is not economically justifiable to buy a Dash 8 simulator
19. It is not economically justifiable to train the crews in Seattle
20. The Dash 8 fleet is small
21. Buying a Dash 8 simulator is expensive
22. The nearest Dash 8 simulator is in Seattle
23. Overseas travel for crews to train in Seattle is very expensive

Merely because it would be very nice were these changed conditions so, does not necessarily make them so. Injections⁴⁶ are needed to ensure that these desirable effects will come about in reality. The group leading to ‘There is pressure to minimise flight training’ is unchanged. All of these statements are, and will continue to be, valid. How, then, is proper crew training to be achieved? Ansett’s response, after the accident, that training on the aircraft is satisfactory (Ansett (NZ), 1995) demonstrates the need for prescriptive action by the CAA. The group at the lower right demonstrates the need for simulator training of airline crews. The injection (in the square box) is that the CAA recognises the need for simulator training. Detailed

⁴⁶ The term ‘injection’ is particular to the Theory of Constraints. In psychological literature, an ‘injection’ is referred to as an ‘intervention’.

scrutiny of Figure 76 leads to a second iteration, shown at Figure 77. This forms Sector 1 of the FRT.

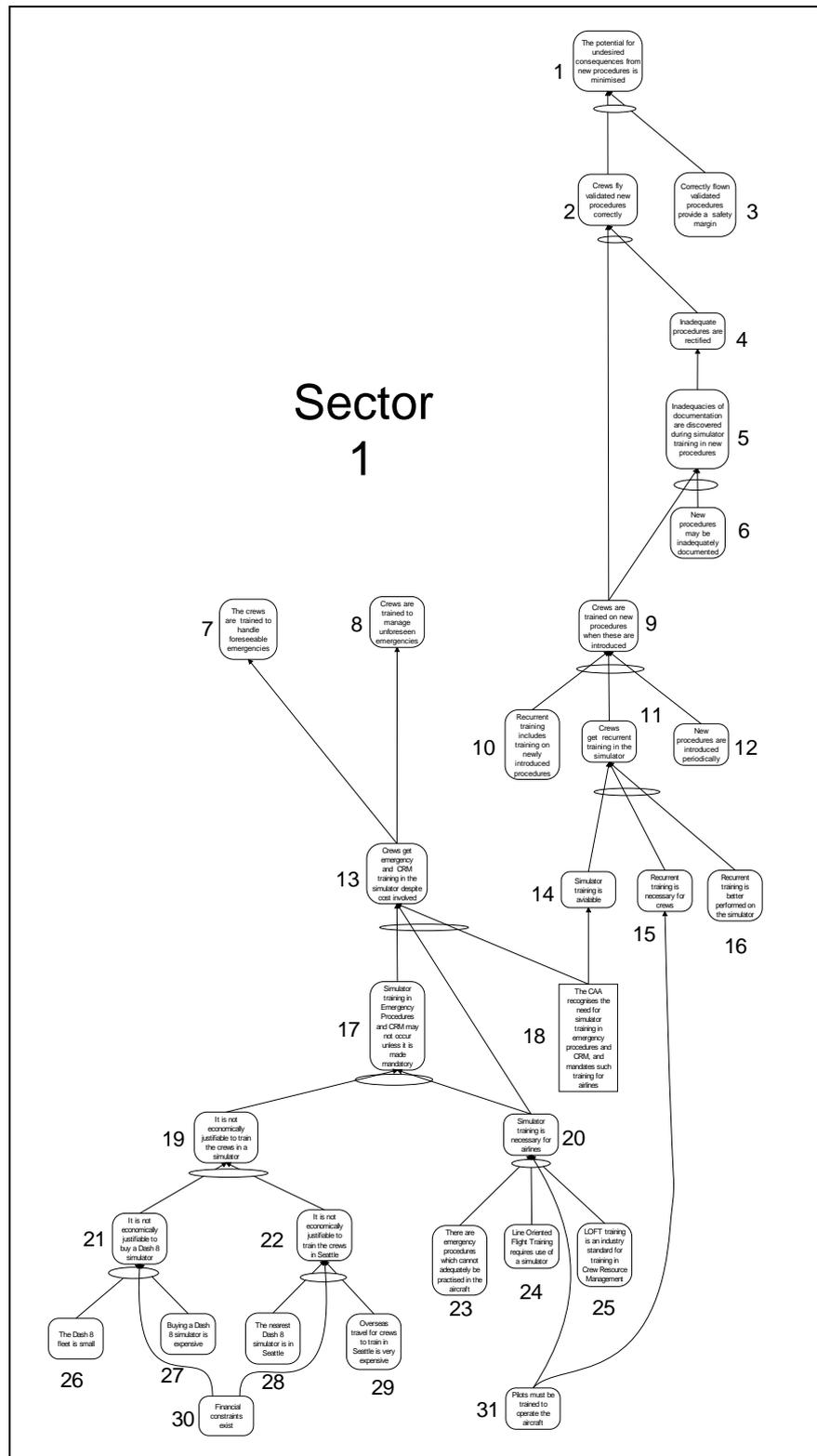


Figure 77. FRT: Training (Sector 1)

Key

1. The potential for undesired consequences from new procedures is minimised
2. Crews fly validated new procedures correctly
3. Correctly flown validated procedures provide a safety margin
4. Inadequate procedures are rectified
5. Inadequacies of documentation are discovered during simulator training in new procedures
6. New procedures may be inadequately documented
7. The crews are trained to handle foreseeable emergencies
8. Crews are trained to manage unforeseen emergencies
9. Crews are trained on new procedures when these are introduced
10. Recurrent training includes training on newly introduced procedures
11. Crews get recurrent training in the simulator
12. New procedures are introduced periodically
13. Crews get emergency and CRM training in the simulator despite cost involved
14. Simulator training is available
15. Recurrent training is necessary for crews
16. Recurrent training is better performed on the simulator
17. Simulator training in Emergency Procedures and CRM may not occur unless it is made mandatory
18. The CAA recognises the need for simulator training in emergency procedures and CRM and mandates such training for airlines
19. It is not economically justifiable to train the crews in a simulator
20. Simulator training is necessary for airlines
21. It is not economically justifiable to buy a Dash 8 simulator
22. It is not economically justifiable to train the crews in Seattle
23. There are emergency procedures which cannot adequately be practised in the aircraft
24. Line Oriented Flight Training requires use of a simulator
25. LOFT training is an industry standard for training in Crew Resource Management
26. The Dash 8 fleet is small
27. Buying a Dash 8 simulator is expensive
28. The nearest Dash 8 simulator is in Seattle
29. Overseas travel for crews to train in Seattle is very expensive
30. Financial constraints exist
31. Pilots must be trained to operate the aircraft

2. Safety management

The absence of a Safety Manager was central to several of the core problems in the Ansett CRT. There are five identified core problems in the CRT⁴⁷:

⁴⁷ The criterion used in defining a core problem was that it should have the maximum number of effect lines radiating from it; the maximum number of effect lines found in the Ansett CRT was four, and there were five such core problems. Subsequently, on combining the Ansett and CAA CRTs, linkages

1. Costs in all departments must be reduced to a minimum
2. The undercarriage latch does not tolerate wear
3. The Engineering Department decides that undercarriage malfunctions have no safety implication
4. Undercarriage malfunctions recur
5. No individual is responsible for safety oversight and risk management.

1. Cost Reduction

Cost reduction is a particular aspect of the question ‘How can Ansett move towards profitability?’ As already discussed, such commercial matters are beyond the purview of either the investigators or the regulatory authority, and will not be considered further here.

2. Undercarriage Latch Design

The design deficiency in the undercarriage latch was at the root of this accident, because had it not existed, the accident would not have occurred. However, one cannot legislate against design deficiencies: human errors are inevitable. Naturally, had the Engineering department decided to accept the manufacturer’s offer of replacement components at a heavily discounted price, the problem would have disappeared, but the Engineers believed that they were complying with Company policy in saving money where possible and they made an internal policy decision, not subject to outside review, that such an economy had no safety effects. This policy decision will be considered next. The problem of the design defect, per se, needs no further consideration.

3. Engineering Safety Review

In deciding not to purchase the replacement parts, the Engineers held a review in their department to consider whether there were any safety implications. They concluded that there were not, because the pilots could always lower the undercarriage using the emergency mechanism (Ansett (NZ), 1993a). The procedure

between the CRTs were found to increase the maximum to five, in three cases. However, all of the effects with four or five effect lines radiating from them were used in this analysis of core problems.

to do this involved depressurising the undercarriage hydraulic system by opening a flap in the cockpit roof, withdrawing the undercarriage latch by pulling a cable accessed by the flap (allowing the undercarriage to fall down under gravity) then raising a flap beside the co-pilot's seat, inserting a lever and moving the lever to reapply hydraulic pressure. (This last action was irreversible in flight).

Requiring the crews to use the emergency system to perform a routine operation removed one stage of the safety system. Also, this requirement assumed that the pilots were trained in this somewhat lengthy procedure, and would seldom if ever make a mistake in using it.

There was no external review of this decision, either by Flight Operations, whose crews were directly affected by it, or by any other department. Nor was there any requirement that it should be reviewed outside the Engineering Department.

4. Recurrent malfunctions

Recurring problems will inevitably occur from time to time; what is necessary is that the recurrence should be noted, and the cause found. Detecting the recurrence of problems is a specific function of a Safety Manager (ICAO, 1984). Once the recurrence has been noted, it should be brought to the attention of the responsible manager (in this case the Maintenance Manager) for diagnosis and correction.

Since the Maintenance Manager was aware of exactly what the mechanical problem was, the fault lay in the implementation of his instructions, and simple inquiry would have brought to light the ambiguity of those instructions. This ambiguity could have been corrected with ease. If mechanical rectification had then proved too difficult (and manual grinding of a hard chromed surface, attempted at one time (Ansett (NZ), 1993c) would have been a somewhat dubious procedure) then purchase of replacement parts would have been seen to have been a priority. Thus, the proper performance of the Safety Manager's function would have removed a core problem in the potentiation of this accident.

5. Safety oversight and risk management

Ansett had previously had a Safety Manager, but as already discussed, the position had been abolished two years before the accident (TAIC, 1995), p. 49.). The inference is that the position was abolished to save money. Other explanations are possible, such as personal conflict, but the abolition of the position was in line with the requirement to save money in all departments. The effect of abolishing the position was that no individual was responsible for safety oversight and risk management. In theory, this was one of the duties of the CEO, under the general duty of care. In practice, safety oversight and risk management are specialised functions which require both experience and training (see for example the outline of training suggested in the ICAO: Accident Prevention Manual (ICAO, 1984, pp. 72-79) and it is general practice to have a Safety Department, headed by a Safety Manager. While there could be other alternatives, such as a high level committee from all departments headed by the CEO, none of these were implemented by Ansett. In any case, ICAO advises that there should be an independent company safety officer, reporting directly to the highest level of management (ICAO, 1984). This view is reflected in guidance to airline operators by the UK Civil Aviation Authority (UKCAA, 2002), who consider this best practice, and in pending Australian legislation (Civil Aviation Safety Regulation 119 (in draft)). A Conflict Resolution Diagram (CRD) can be used to surface the assumptions behind Ansett's action in abolishing the Safety Manager position.

Conflict Resolution Diagram Formation

A CRD is a 'necessity' diagram, as opposed to the CRT and FRT, which are 'sufficiency' diagrams. That is, it shows things which are necessary, but not necessarily of themselves sufficient to bring about the effects shown. One way of forming it is by writing an undesirable effect, and below it the preferred opposite, on the right hand side of the diagram (by convention). Then the CRD is formed from the right-hand side. (Figure 78).

Then the important need which gives rise to the undesirable effect is sought, and also the need which would be satisfied by the desired opposite effect. Finally, the common goal which gives rise to each of the needs is sought. The conflict

(‘lightning’) arrow indicates that ‘we can’t have both’, either because resources are limited, or because of mutual exclusivity.

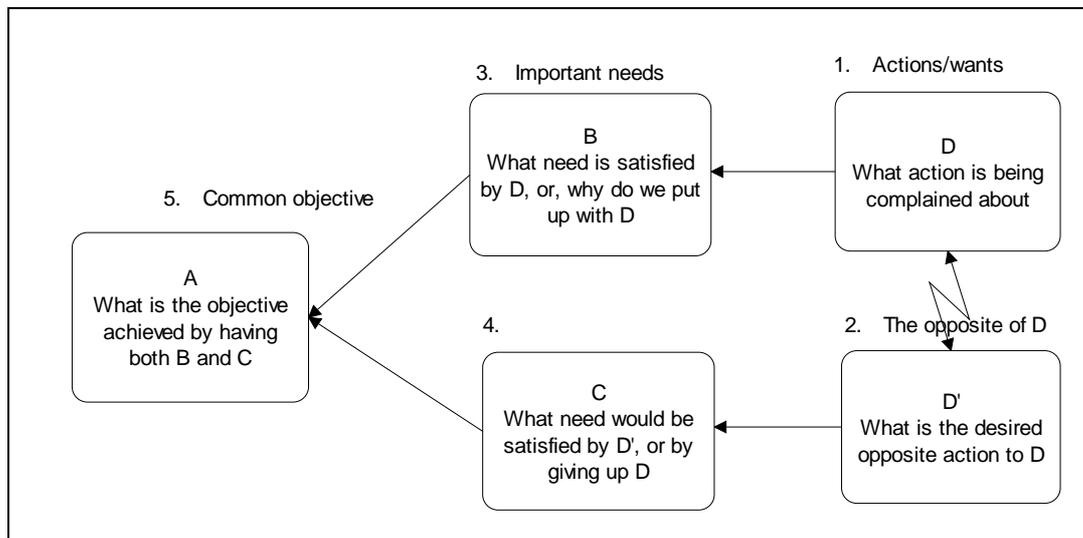


Figure 78. Forming the CRD from an undesirable effect. Source: Goldratt, A.Y (1998). *The Jonah Programme*. New Haven, CT: Avraham Goldratt Institute.

The CRD is read from the left hand side:

“In order to have A we need B, and in order to have B we must have D”

“In order to have A we need C, and in order to have C we must have D’. And we can’t have both D and D’.”

The rationale for ‘we must’ or ‘in direct conflict with’ comes from underlying assumptions. “The presence of an arrow in [any TOC] diagram indicates the existence of hidden, underlying assumptions about the relationship between elements... of the diagram” (Dettmer, 1997, p. 131). Such assumptions, which may be untested, need to be challenged. They may never have been valid, or may have become invalid in a changed environment. (There is a parallel with *latent failure* (Johnson, 1980), where policies that were once valid may have become inadequate because of changed circumstances). The object of the CRD is to surface underlying assumptions, so that those which are invalid can be identified.

An injection is a change initiated for the purpose of breaking a conflict or solving a problem. It may be either an action, or a desired condition (the necessary actions to achieve the desired condition being developed later). Even valid

assumptions, which are impeding the conflict resolution, can be invalidated by an injection.

While not all conflicts are bi-polar – there may be three or more interacting elements – the CRD permits partitioning into manageable pieces, dealing with complexity two elements at a time.

This procedure can be applied to the abolition of the Safety Manager position (Figure 79).

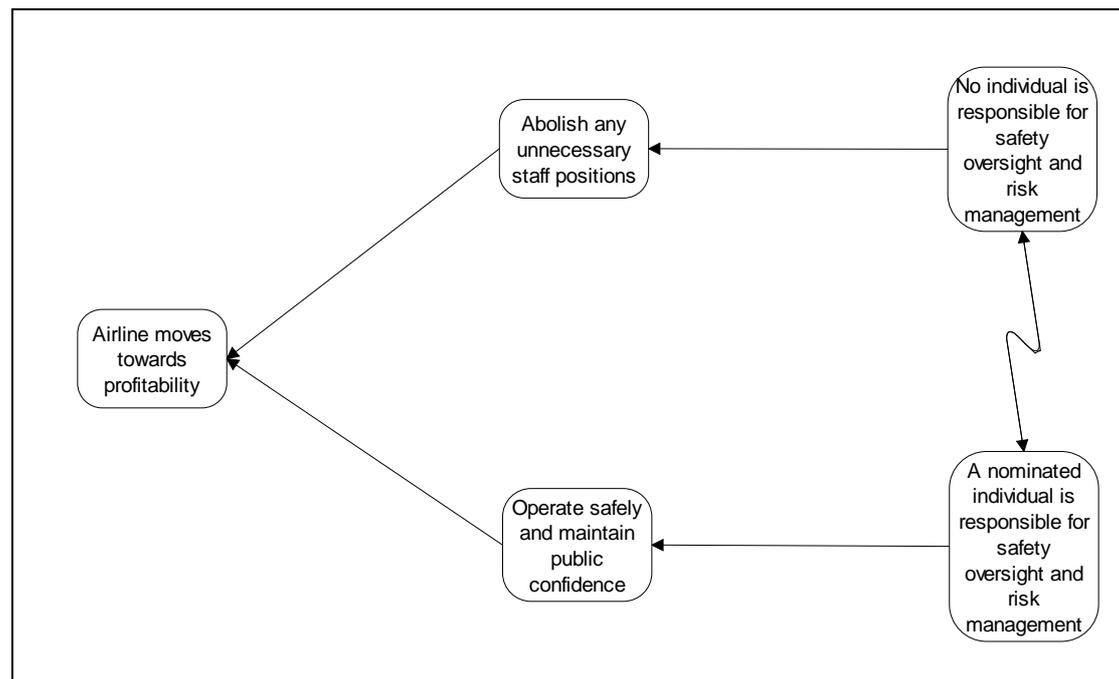


Figure 79. Conflict Resolution Diagram: Safety Manager position.

The absence of an individual responsible for safety oversight and risk management has been shown (in the CRT) to lead to a variety of undesirable effects, including unawareness by the Engineers that the undercarriage malfunctions were recurring more and more frequently, the lack of perception by the Engineers that there was a safety connotation to undercarriage malfunctions, and the absence of risk mitigation by the Training and Flight Operations Departments in the face of recurring undercarriage malfunctions. The need which gave rise to the undesirable effect appears to have been the desire to eliminate unnecessary positions, so that the goal of moving towards profitability could be achieved. The need which would have been satisfied by having a Safety Manager was the need to perform safety management

functions, in order to operate safely and maintain public confidence. The common goal was to move towards profitability.

Each of the arrows in the CRD conceals assumptions, which may now be surfaced for examination.

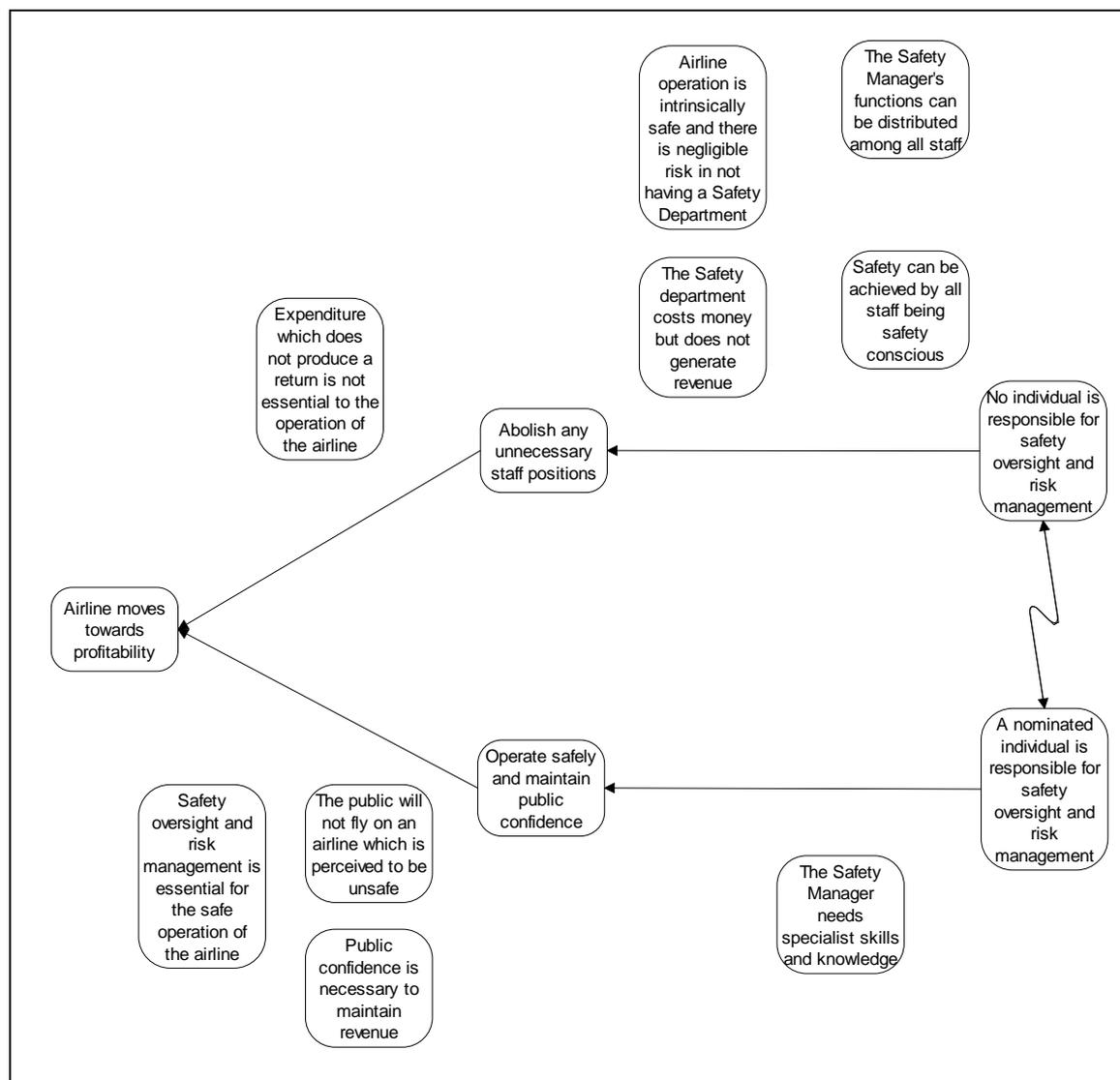


Figure 80. Assumptions in the Safety Manager CRD.

Some of the assumptions indicated by the arrows in Figure 4 have been inserted in Figure 80⁴⁸. For example, in order to eliminate expenditure which does not

⁴⁸ These assumptions are those likely to have been made at the time. Some are inferred from actions (such as abolishing the Safety Manager position), others are generally true (such as the relation between public confidence and revenue), and where possible they are supported by evidence (for example, the Chairman's requirement to cut costs). Where such an analysis is performed a priori, or in the course of an accident investigation, the assumptions would be validated as part of the analysis.

produce a return, all unnecessary positions must be abolished; the Safety Manager position is unnecessary because its functions can be spread over other functions.

When the assumptions are set out in this way, their validity can be examined.

Considering first the lower part of the diagram, the need for the Safety Manager to have specialist skills and knowledge has already been established. The more general proposition, that safety oversight and risk management is essential for safe operation, might seem self-evident, were it not that Ansett, a major airline, did not consider it so. However, the fact that ICAO had published its Accident Prevention Manual in 1984 (ICAO, 1984) some 10 years before the accident, stipulating the need for safety management, indicates that the idea was not novel. The weight of authority in favour of safety management is now overwhelming, as already discussed, but even before the accident, the idea should not have been a matter of serious dispute.

Is it valid to say that expenditure which does not produce a return is not essential to the operation of the airline? That depends, in part, on the timeframe being considered. If the proposition was reworded 'expenditure which *never* produces...' it might well be considered valid. However, some expenditure generally considered essential produces a return only in the long term, and then if successful, the only return may be that nothing untoward happens. An example of this is simulator training for aircrew. In the simulator it is possible to train for emergencies which cannot safely be practised in the aircraft, and the return is that when confronted by such an emergency during operations, the aircrew is more likely to handle it effectively. Such benefits are difficult to quantify in accounting terms, but they are nonetheless real. Suppose, in this example, the aircrew do not handle the emergency successfully and an accident results. The loss of public confidence following an accident can result in the demise of the airline (for example, the ValuJet accident (NTSB, 1997; Sakata, 2003)). The assumption that expenditure which does not produce a return is not essential to the operation of the airline would only be valid if the term 'return' was appropriately qualified.

It is undoubtedly true that an airline whose aircraft have mishaps⁴⁹ is likely to be perceived as unsafe, especially if fatalities occur, and that the public will not fly with an airline perceived to be unsafe – the example of the ValuJet disaster makes this point (NTSB, 1997; Sakata, 2003)⁵⁰.

The assumption that the Safety Manager functions can be achieved by all staff being safety conscious does not stand up to examination, since it is most unlikely that the staff would have the specialist skills required. Besides, some of the functions, such as confidential reporting of incidents, require that the Safety Department be seen to be separate from operational departments.

Considering now the proposition that safety can be achieved by all staff being safety conscious ('safety is everybody's concern'), there is no dispute that everyone being safety conscious is highly desirable. But this is not the same thing as proper safety management. Individuals, without guidance, could not be expected to take on such extra roles as ensuring that there was independent evaluation of cost-saving proposals, and establishing communication between departments when independent evaluation showed that a proposal by one department might have safety implications for another. And it would be most unlikely to find, within an airline, individuals with the necessary skills in, say, incident investigation to take on a part of the Safety Manager role. The assumptions that either general safety consciousness could make the position redundant, or that the various functions could be shared out among airline staff without specialist training (Ansett (NZ), 1993b) are therefore invalid.

The idea that airline operations are intrinsically safe is part of air transport mythology. While such operations have a generally good safety record, this has been achieved primarily by attention to all the things that might go wrong, and providing training or other assurance against them. The Safety Department, which provides

⁴⁹ The term 'accident' has defined meanings in aviation, but some incidents coming within these official definitions might not fall within what the public means by an accident. In this thesis, the term 'defect' refers to some mechanical malfunction, while an 'incident' is something less than a mishap because it is correctly handled by the crew. An undercarriage latch that sticks is a defect; an undercarriage leg which does not extend on command is an incident. A mishap encompasses anything likely to attract the attention of the news media: the Qantas overrun at Bangkok (ATSB, 2001) would be termed a mishap, even though no-one was injured thereby.

⁵⁰ ValuJet's load factor declined from 60% in April 1996 to 39% in June, after the crash.

oversight of such safety operations, justifies its existence by the things that do not go wrong: difficult to quantify, but no more to be abandoned than a fire insurance policy.

While the assumptions across the lower half of the conflict diagram are valid, those across the top are unequivocally invalid. Action is therefore required to ensure that the Safety Manager position is filled, and that the Safety Manager functions effectively.

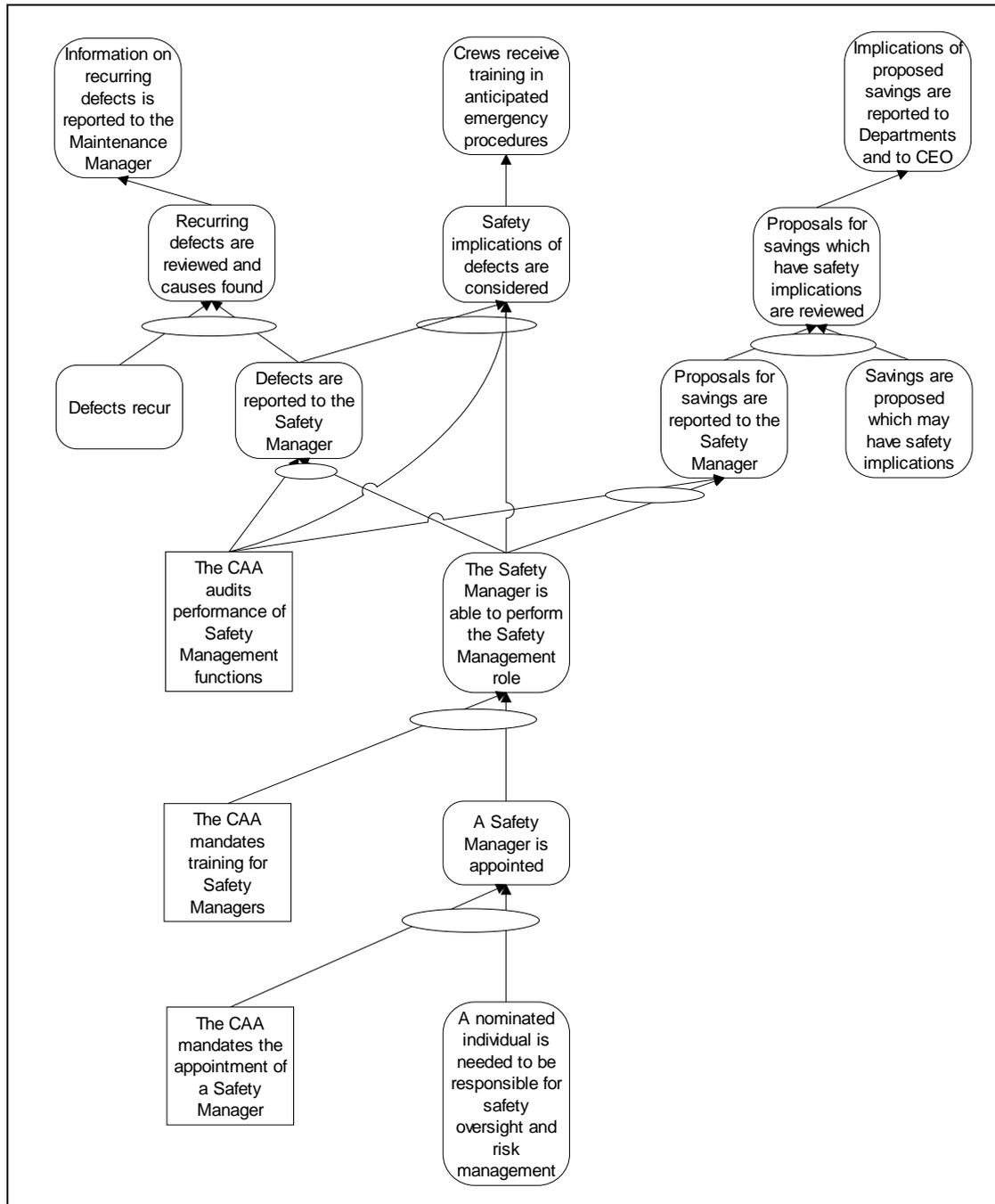


Figure 81. Future Reality Tree: Safety Manager functions.

A first iteration of the section of the FRT dealing with Safety Management is shown in Figure 81.

While it would be unlikely that Ansett would have been tempted to abolish its Safety Department again, there could be no guarantee that another airline might not be tempted to do so⁵¹. In the long term, education and publicity as to the need for a Safety Department might be the answer, but the immediate solution should come from the CAA in the form of a Regulation. Likewise, proper training for the Safety Manager should be mandated.

Where the Safety Manager is properly trained, normal performance of the Safety Manager's functions should have detected the factors which led to the Dash 8 accident, before it occurred. Detection of recurring problems is one such function (ICAO, 1984). Consideration of the implications of not purchasing the modified undercarriage parts should have led to their purchase (with trivial extra expenditure). Review of the performance of these functions, by CAA Auditors, should assure their proper performance (see Figure 80).

Furthermore, if there was some delay in rectifying the undercarriages, ensuring that crews were trained in the emergency procedure, and enforcing a requirement for a climb to a safe altitude in the event of malfunction on approach to land – both perfectly normal procedures, and within the purview of the Safety Manager – would have avoided any possibility of closure with terrain while the emergency was being sorted out. More generally, the safety implications of any defect not yet rectified should be considered, and appropriate emergency procedure training put in place.

Detailed scrutiny of Figure 81 led to a second iteration shown at Figure 82, which forms Sector 2 of the completed FRT.

⁵¹ In 2005, Helmreich advised that two major American airlines, under financial stress, had abolished their Safety Departments (R.L. Helmreich, personal communication, 2005).

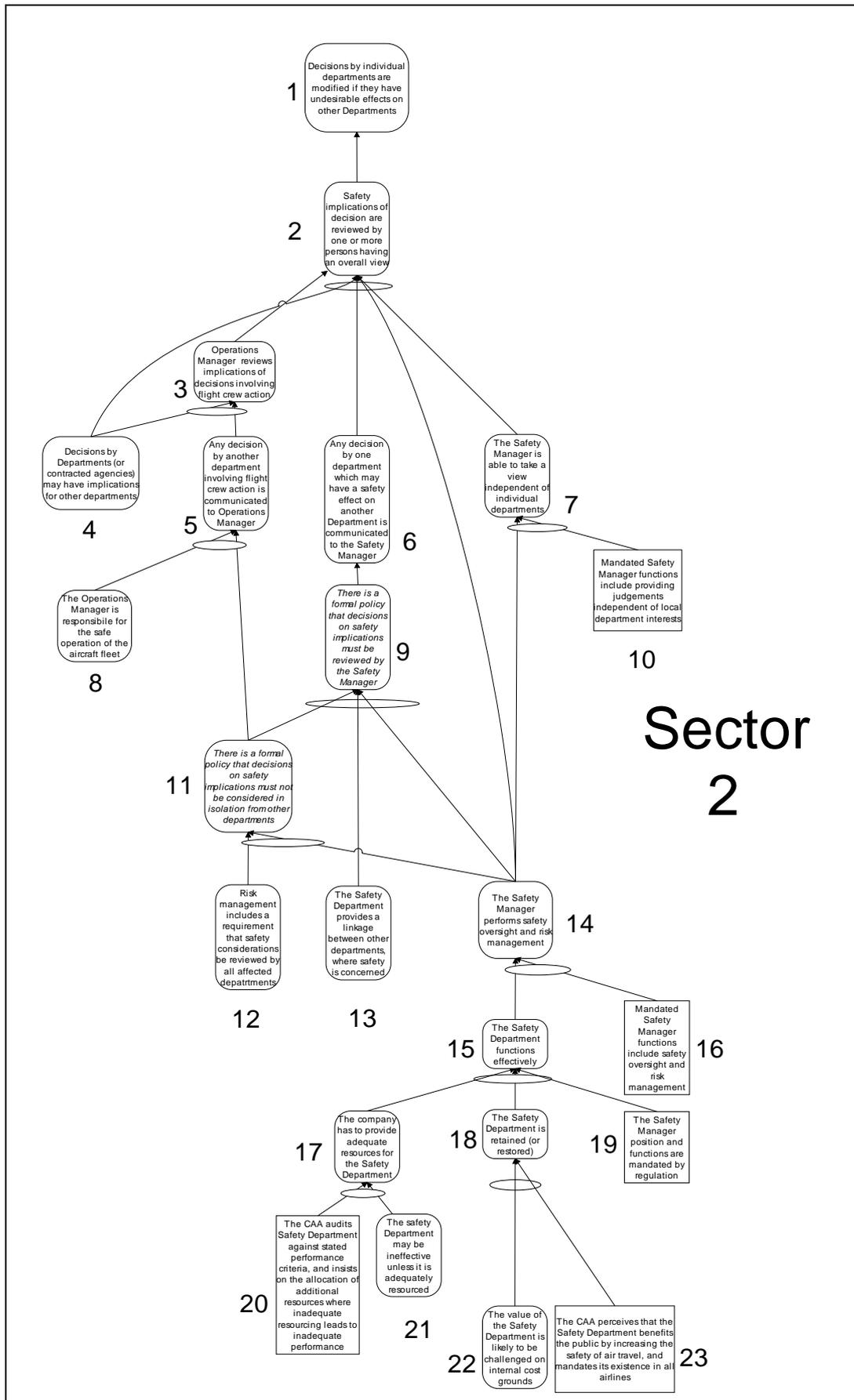


Figure 82. FRT: Safety Management System (Sector 2).

Key

1. Decisions by individual departments are modified if they have undesirable effects on other Departments
2. Safety implications of decision are reviewed by one or more persons having an overall view
3. Operations Manager reviews implications of decision involving flight crew action
4. Decisions by Departments (or contracted agencies) may have implications for other departments
5. Any decision by another department involving flight crew action is communicated to Operations Manager
6. Any decision by one department which may have a safety effect on another Department is communicated to the Safety Manager
7. The Safety Manager is able to take a view independent of individual departments
8. Operations Manager is responsible for the safe operation of the aircraft fleet
9. There is a formal policy that decisions on safety implications must be reviewed by the Safety Manager
10. Mandated Safety Manager functions include providing judgements independent of local departmental interests
11. There is a formal policy that decisions on safety implications must not be considered in isolation from other departments
12. Risk management includes a requirement that safety considerations are reviewed by all affected Departments
13. The Safety Department provides a linkage between other departments, where safety is concerned
14. The Safety Manager performs safety oversight and risk management
15. The Safety Department functions effectively
16. Mandated Safety Manager functions include safety oversight and risk management
17. The company has to provide adequate resources for the Safety Department
18. The Safety Department is retained (or restored)
19. The Safety Manager position and functions are mandated by regulation
20. The CAA audits Safety Department against stated performance criteria, and insists on the allocation of additional resources where inadequate resourcing leads to inadequate performance
21. The Safety Department will be ineffective unless it is adequately resourced
22. The value of the Safety Department is likely to be challenged on internal cost grounds
23. The CAA perceives that the Safety Department benefits the public by increasing the safety of air travel, and mandates its existence in all airlines

The remaining sectors of the CRT are transformed in a similar fashion, to generate the complete FRT:

- Figure 83 shows Sector 3, Maintenance
- Figure 84 shows Sector 4, Pressures
- Figure 85 shows Sector 5, Distraction
- Figure 86 shows Ground Proximity Warning System.

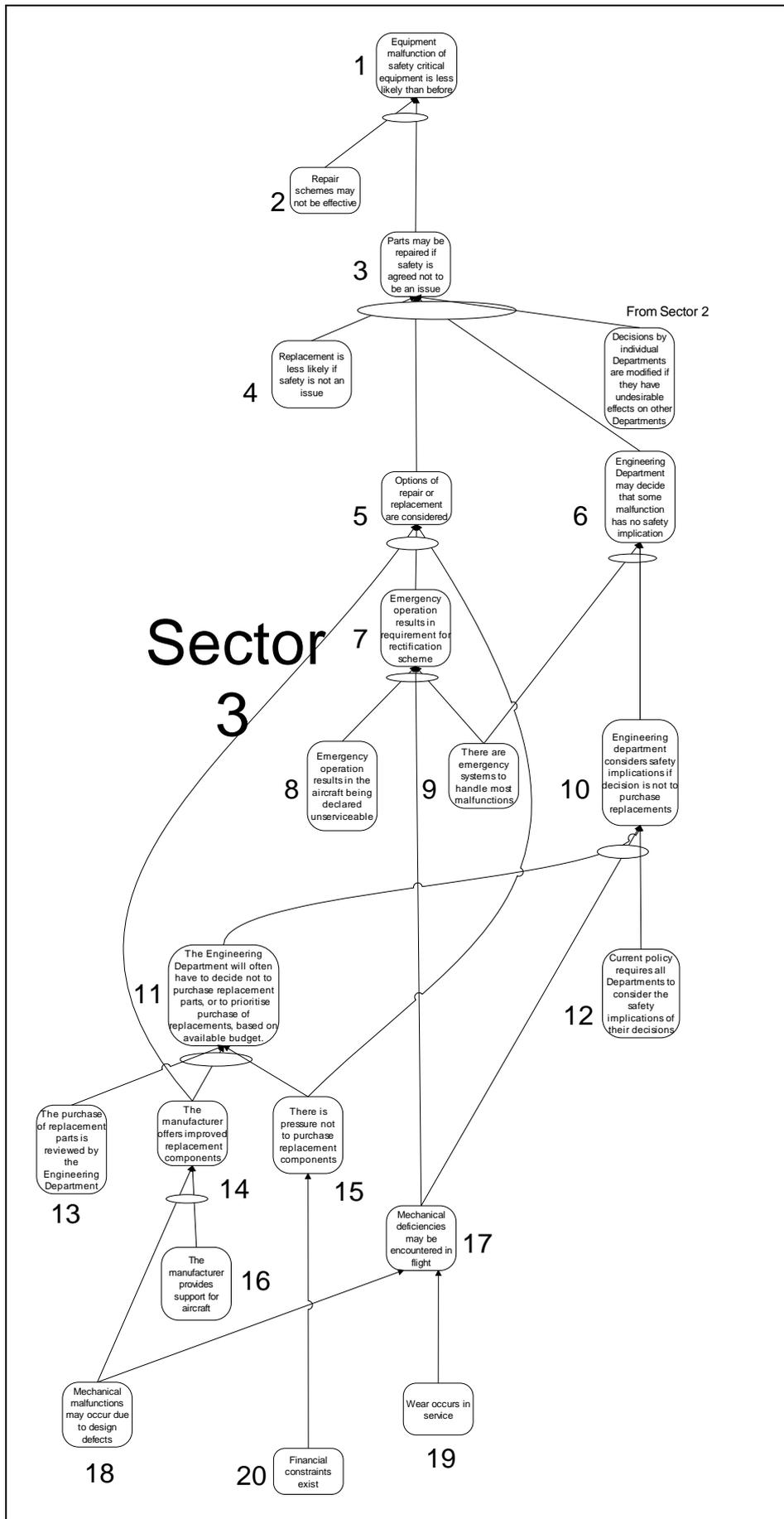


Figure 83. FRT: Maintenance (Sector 3).

Key

1. Malfunction of safety critical equipment is less likely than before
2. Repair schemes may not be effective
3. Parts may be repaired if safety is agreed not to be an issue
4. Replacement is less likely if safety is not an issue
5. Options of repair or replacement are considered
6. Engineering Department may decide that some malfunction has no safety implication
7. Emergency operation results in requirement for rectification scheme
8. Emergency operation results in the aircraft being declared unserviceable
9. There are emergency systems to handle most malfunctions
10. Engineering department considers safety implications if decision is not to purchase replacements
11. The Engineering Department will often have to decide not to purchase replacement parts, or to prioritise purchase of replacements, based on available budget
12. Current policy requires all Departments to consider the safety implications of their decisions
13. The purchase of replacement parts is reviewed by the Engineering Department
14. The manufacturer offers improved replacement components
15. There is pressure not to purchase replacement components
16. The manufacturer provides support for aircraft
17. Mechanical deficiencies may be encountered in flight
18. Mechanical malfunctions may occur due to design defects
19. Wear occurs in service
20. Financial constraints exist

From Sector 2: Decisions by individual Departments are modified if they have undesirable effects on other Departments

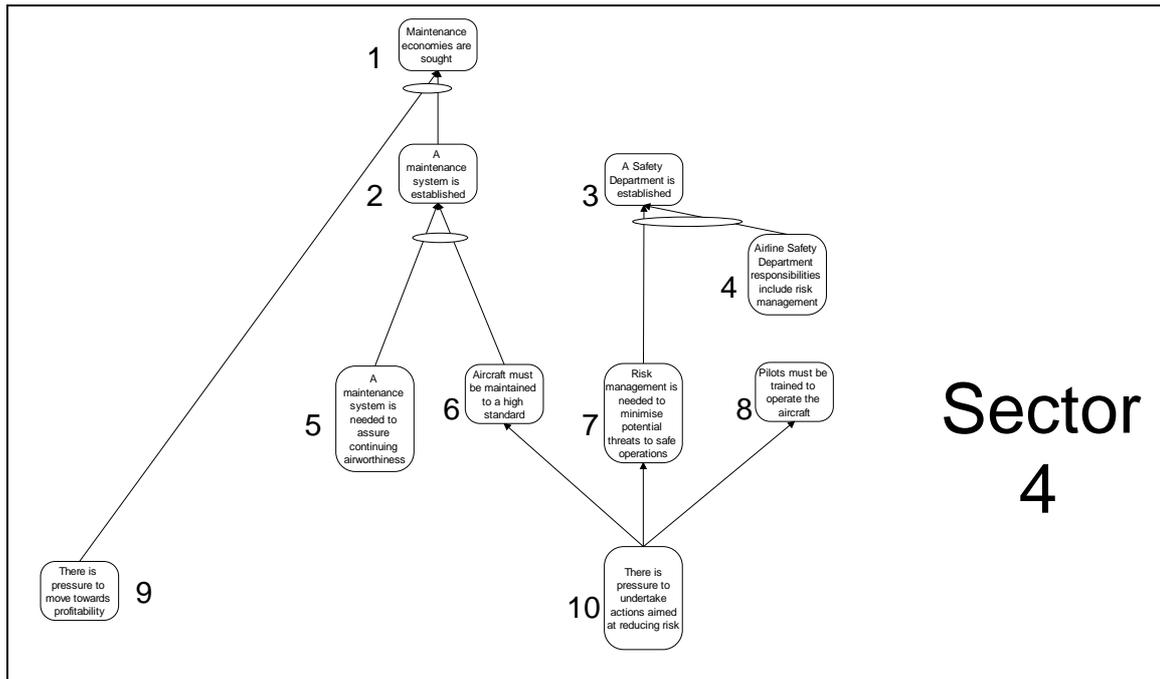


Figure 84. FRT: Pressures (Sector 4).

Key

1. Maintenance economies are sought
2. A maintenance system is established
3. A Safety Department is established
4. Airline Safety Department responsibilities include risk management
5. A maintenance system is needed to assure continuing airworthiness
6. Aircraft must be maintained to a high standard
7. Risk management is needed to minimise potential threats to safe operations
8. Pilots must be trained to operate the aircraft
9. There is pressure to move towards profitability
10. There is pressure to undertake actions aimed at reducing risk

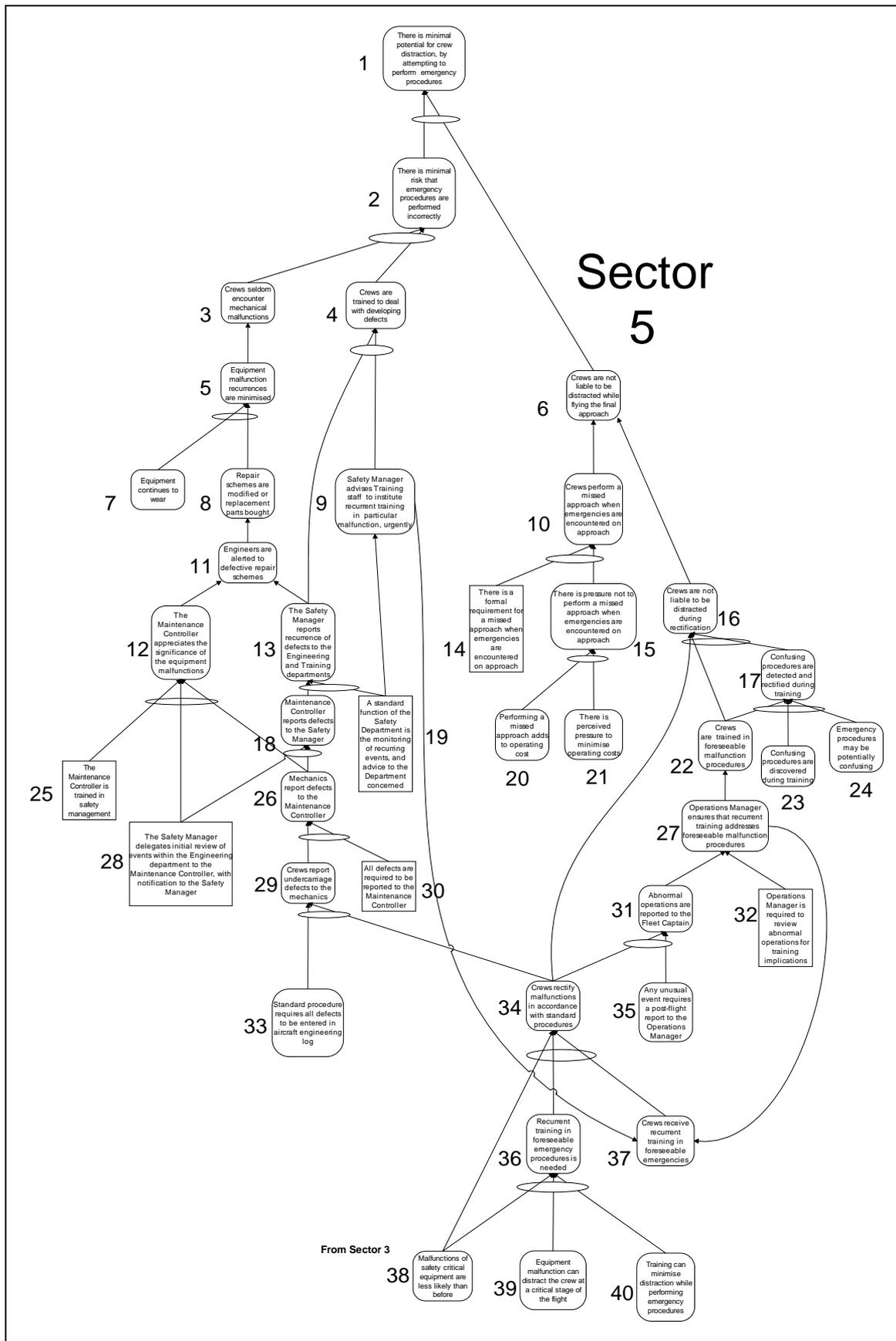


Figure 85. Distraction (Sector 5).

Key

1. There is minimal potential for crew distraction, by attempting to perform emergency procedures
2. There is minimal risk that emergency procedures are performed incorrectly
3. Crews seldom encounter mechanical malfunctions
4. Crews are trained to deal with developing defects
5. Equipment malfunctions seldom recur
6. Crews are not liable to be distracted while flying the final approach
7. Equipment continues to wear
8. Repair schemes are modified or replacement parts bought
9. Safety Manager advises Training staff to institute recurrent training in particular malfunction, urgently
10. Crews perform a missed approach when emergencies are encountered on approach
11. Engineers are alerted to defective repair schemes
12. The Maintenance Controller appreciates the significance of the equipment malfunctions
13. The Safety Manager reports recurrence of defects to the Engineering and Training Departments
14. There is a formal requirement for a missed approach when emergencies are encountered on approach
15. There is pressure not to perform a missed approach when emergencies are encountered on approach
16. Crews are not liable to be distracted during rectification
17. Confusing procedures are detected and rectified during training
18. Maintenance Controller reports defects to the Safety Manager
19. A standard function of the Safety Department is the monitoring of recurring events, and advice to the Department concerned
20. Performing a missed approach adds to operating cost
21. There is perceived pressure to minimise operating costs
22. Crews are trained in foreseeable malfunction procedures
23. Confusing procedures are discovered during training
24. Emergency procedures may be potentially confusing
25. The Maintenance Controller is trained in safety management
26. Mechanics report defects to the Maintenance Controller
27. Operations Manager ensures that recurrent training addresses foreseeable malfunction procedures
28. The Safety Manager delegates initial review of events within the Engineering department to the Maintenance Controller, with notification to the Safety Manager
29. Crews report defects to the mechanics
30. All defects are required to be reported to the Maintenance Controller
31. Abnormal operations are reported to the Fleet Captain
32. Operations Manager is required to review abnormal operations for training implications
33. Standard procedure requires all defects to be entered in aircraft engineering log
34. Crews rectify malfunctions in accordance with standard procedures
35. Any unusual event requires a post-flight report to the Operations Manager
36. Recurrent training in foreseeable emergency procedures is needed
37. Crews receive recurrent training in foreseeable emergencies
38. Malfunctions of key critical equipment are less likely than before
39. Equipment malfunction can distract the crew at a critical stage of the flight
40. Training can minimise distraction while performing emergency procedures

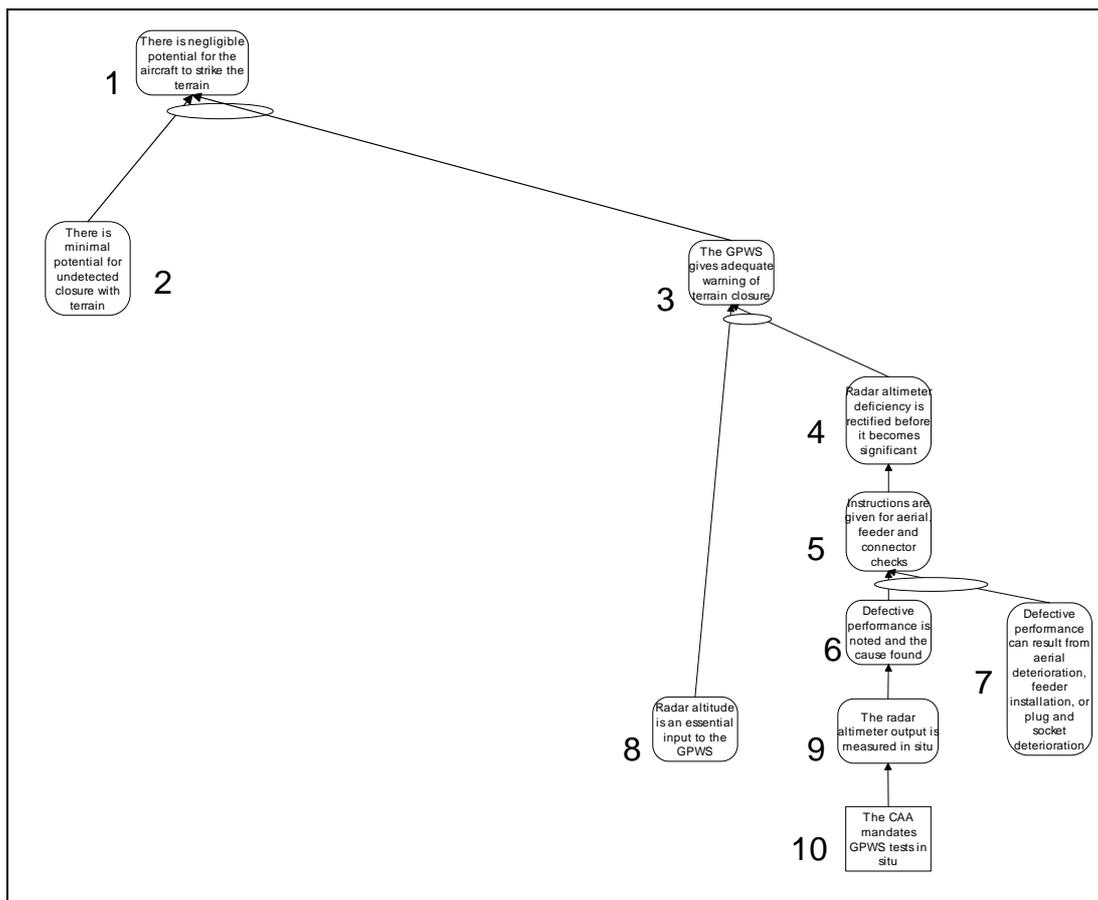


Figure 86. FRT: Ground Proximity Warning System.

Key

1. There is no potential for the aircraft to strike the terrain
2. There is minimal potential for undetected closure with terrain
3. The GPWS gives adequate warning of terrain closure
4. Radar altimeter deficiency is rectified before it becomes significant
5. Instructions are given for aerial, feeder and connector checks
6. Defective performance is noted and the cause found
7. Defective performance can result from aerial deterioration, feeder installation, or plug and socket deterioration
8. Radar altitude is an essential input to the GPWS
9. The radar altimeter output is measured in situ
10. The CAA mandates GPWS tests in situ

The complete Ansett FRT is shown at Figure 87. The contents of the individual sectors are unchanged; the diagram is intended to show the way in which the sectors link together to form the complete FRT.

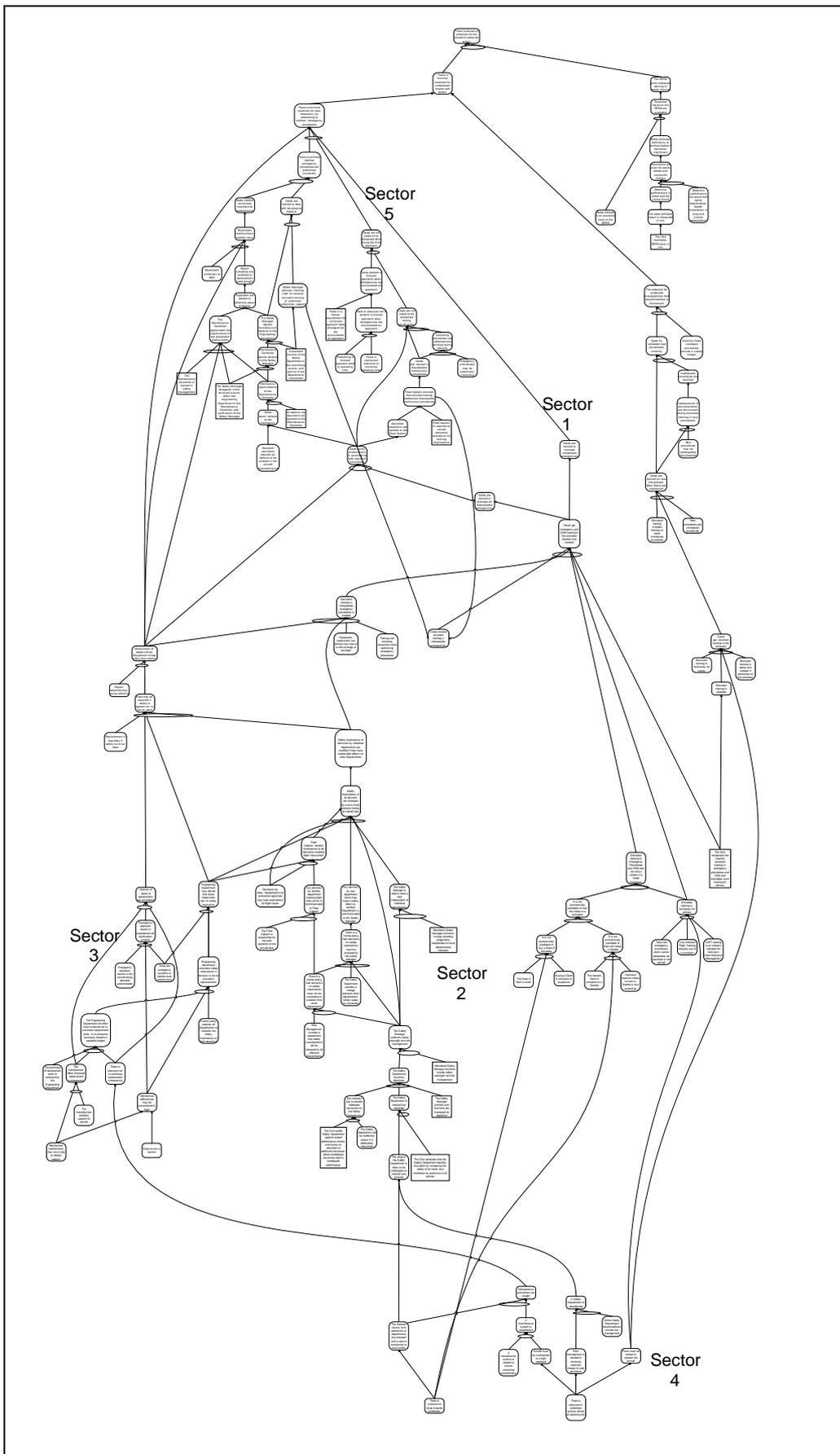


Figure 87. Ansett FRT

Additive Effects

The conjunction of two effect lines without a logical and denotes an additive effect. For example, in Sector 5 the entity

“Engineers are alerted to the defective repair scheme”

is fed by both

“The Safety Manager reports recurring defects to the Engineering department”, and by

“The Maintenance Controller appreciates the significance of equipment malfunctions”.

Either on its own would suffice. The double linkage indicates a back-up system – a highly desirable state of affairs whereby, if one system fails for some reason, the alternative system ensures that overall performance is unaffected. Here, both the reporting system through the Maintenance Controller, and the occurrence monitoring by the Safety Department, should detect a recurring defect. As both would notify the Engineering Department, an omission by either alone would have no adverse effect.

Positive reinforcement

Finally, it is desirable to generate feedback loops to provide positive reinforcement, to ensure that the planned changes do not ‘run out of steam’. A desirable output is fed back into the FRT at an earlier (lower) stage, so that it amplifies or reinforces an earlier desirable effect (Dettmer, 1997). It may be necessary to add an injection to make this possible. Schematically, the process is shown in Figure 88.

The flow in the feedback loop is against the implicit timebase, and so appears to go back in time. Strictly, the elements inside the loop should be repeated upwards ad infinitum. (This difficulty can be handled by Petri Nets, which was one of the reasons they were formerly advocated by Johnson, Wright, & McCarthy, 1995).

However, the downward loop is a convenient shorthand notation, and is standard usage in the literature of the Theory of Constraints (see, for example, Dettmer, 1997). (The effects from the downward loop are not read on the first pass through that point).

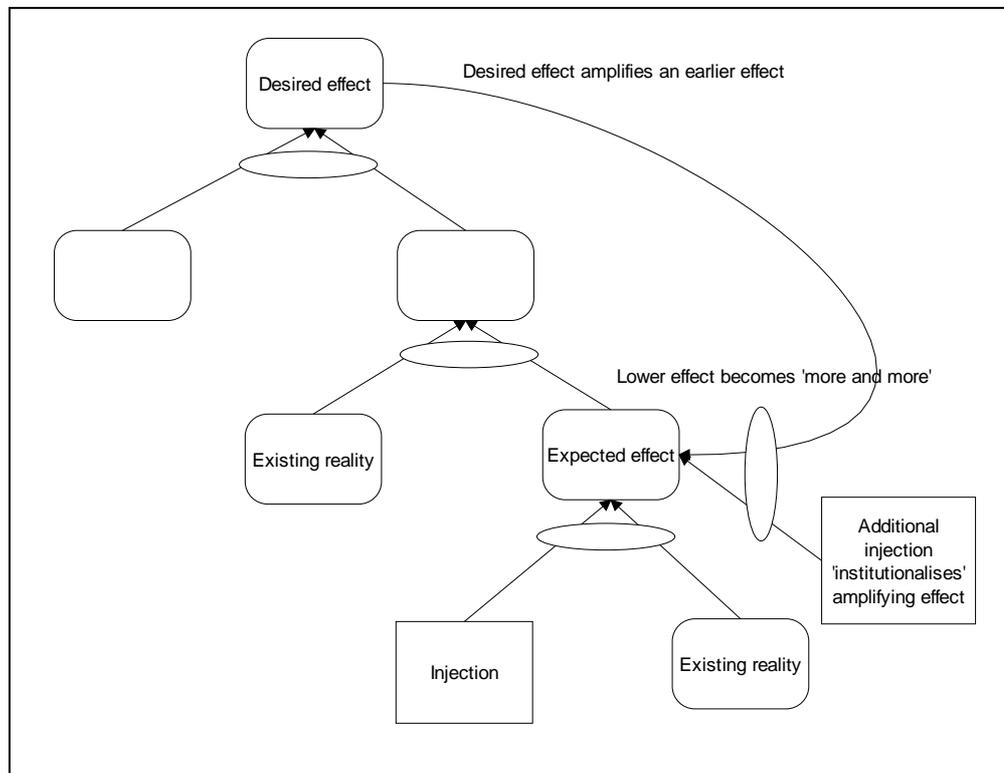


Figure 88. Positive reinforcing loop. (Source: Dettmer, H. W. (1997). *Goldratt's theory of constraints: A systems approach to continuous improvement*. Milwaukee: Quality Press).

Positive reinforcement loops can be drawn from the handling of incidents by maintenance and flight crews. Incidents are required to be reported to the Safety Department, so that lessons can be learnt, but in order for this to happen, personnel need to be assured that they will not be blamed for an innocent action or omission which has had an adverse outcome. This is variously referred to as a ‘no blame’ or ‘just’ culture within the company⁵² (Reason, 1997), and the required injection is “A no-blame culture is introduced”. The feedback will return to “Incidents are investigated” (by the Safety Department or Maintenance Controller, as appropriate). These positive reinforcement loops are shown in Figure 87.

⁵² A ‘no blame’ culture requires that someone who makes an error or commits a violation, and subsequently reports it, will not be penalised, while a ‘just’ culture requires that there shall be no penalty for an action that is neither negligent nor intentional.

Negative Branch Reservations

In order to remove undesirable effects, injections – that is, changes – have been made. While the injections have been examined to see that they can bring about the removal of undesirable effects, there is the possibility that the changes may introduce new undesirable effects. The linkages which lead from injections to such new undesired effects are known as Negative Branches (Dettmer, 1997), and it is necessary to ‘trim’ these branches, either by choosing a different injection in the first place, or by a further injection which will nullify the undesired side effects.

The procedure is to examine each injection in turn, asking what, beside the desired effect, could also result from the injection. (It is also possible that negative branches might originate from the desired effects generated by injections).

The generation of undesirable effects by injections is a separate consideration from examination of obstacles to implementation. These are matters for the implementation process, the Prerequisite Tree and Transition Tree, should such obstacles be anticipated. However, while the injections are being reviewed, it will be convenient to note possible difficulties in implementation, for later analysis.

The Injections in the Ansett FRT

The injections in the Ansett FRT are listed in Table 2. Some, expanded in the FRT for clarity, have been grouped in Table 2. An example is the grouping of the various functions of the Safety Manager.

It is recognised that implementing some injections might have an adverse effect on Ansett’s financial situation – for example, having a requirement for simulator training. However, this is not a direct concern for either the accident investigators or the CAA, whose concern is with the safety of operations, not their commercial viability. Deterioration of Ansett’s financial position would only be relevant insofar as it put the company under even more pressure to minimise safety activities in order to attempt to survive. Where this possibility is foreseen, it will be necessary to take additional measures to ensure that no reduction in safety occurs; that is, that the negative branches are trimmed. This could take the form of increased safety oversight by the CAA, as discussed in the next section.

Table 2. Ansett FRT, Injections and reservations.

Injection	Negative Branch Reservation	Implementation Reservation	Remarks
The CAA perceives that the Safety Department benefits the public by increasing the safety of air travel, and mandates its existence in all airlines		The Safety Department may be ineffective if the Safety Manager lacks the right personality, experience and training	Further injections needed: The Safety Manager must be an "approved person". (Recommendation to the CAA)
The CAA audits the Safety Department against stated performance criteria, and insists on allocation of additional resources where inadequate resourcing is disclosed			
The Safety Manager position and functions are mandated by regulation	The cost of a Safety Department will put an additional financial burden on the airline, which may try to cut corners in other areas		Further monitoring by CAA will be needed to prevent short-cuts
The CAA recognises the need for simulator training in emergency procedures and Crew Resource Management, and mandates such training for all airlines	<p>The cost of simulator training will put an additional financial burden on the airline, which may try to cut corners in other areas</p> <p>Simulator training may be skimped (e.g. no Line Oriented Flight Training, which is expensive in simulator time)</p>	Current doctrine is that airlines are the proper judges of what is safe, so persuading the CAA to act may be difficult	<p>The accident has demonstrated that airline judgement may be faulty, and prescriptive action is called for (Formal Recommendation to CAA) (See Maurino, 1998, in Helmreich & Merritt, 1998).</p> <p>Further monitoring by CAA will be needed to prevent short-cuts</p> <p>More detailed surveillance by CAA will be needed</p>
The Maintenance Controller is trained in safety management	Minor adverse financial effect		<p>Addressed by Safety Case requirement</p> <p>(See CAA Injections)</p>
The Safety Manager delegates initial review of events within the Engineering Department to the Maintenance Controller, with notification to the Safety Manager			All defects are required to be reported to the Maintenance Controller
There is a formal requirement for a missed approach when emergencies are encountered on approach	Minor adverse financial effect		<p>Addressed by Safety Case requirement</p> <p>(Supra)</p>
The Operations Manager is required to review abnormal operations for training implications			
The CAA mandates GPWS tests in situ	Minor adverse financial effect		Global problem: will require regulatory action by CAA

In general, Safety Recommendations are directed to the CAA since, as already discussed, recommendations to Ansett might be ineffective in view of the company's financial situation.

The CAA Future Reality Tree

The classical approach to construction of a Future Reality Tree (FRT) is to seek to address the core conflict at or near the base of the Current Reality Tree (CRT). This approach was ineffective when constructing the Ansett FRT, because Ansett's problems stemmed from its financial problems. It was not open to Government bodies, such as the accident investigation authority or the CAA, to address these problems. Accordingly, the alternative approach, of transforming the CRT piecemeal, was successfully adopted to address the safety problems alone.

In the case of the CAA FRT, this restriction does not prevail. If, to address the CAA's performance problems, it was necessary to address the financial problems which gave rise to them, this would be perfectly permissible. The CRT discloses a number of core problems:

- Greater depth of audit of non-viable airlines does not occur
- CAA defines audits as reviewing the documentation of systems
- CAA has insufficient qualified staff for all required surveillance

However, it is worth attempting to address the conflict at the base of the CRT. If this can be resolved, the undesirable effects above it may disappear.

The CRT originates in a clear-cut conflict:

- There is pressure to minimise surveillance of airline activities, and
- There is pressure to deploy resources effectively, but
- The CAA cannot meet both of these requirements

And since *all* of the other undesirable effects stem from this fundamental conflict, it may be possible to clear all the difficulties which the CAA had in performing effective oversight of airline safety, by resolving this conflict. This approach is what Goldratt (1987) has termed an 'evaporating cloud'.

The base of the CRT is shown in Figure 89.

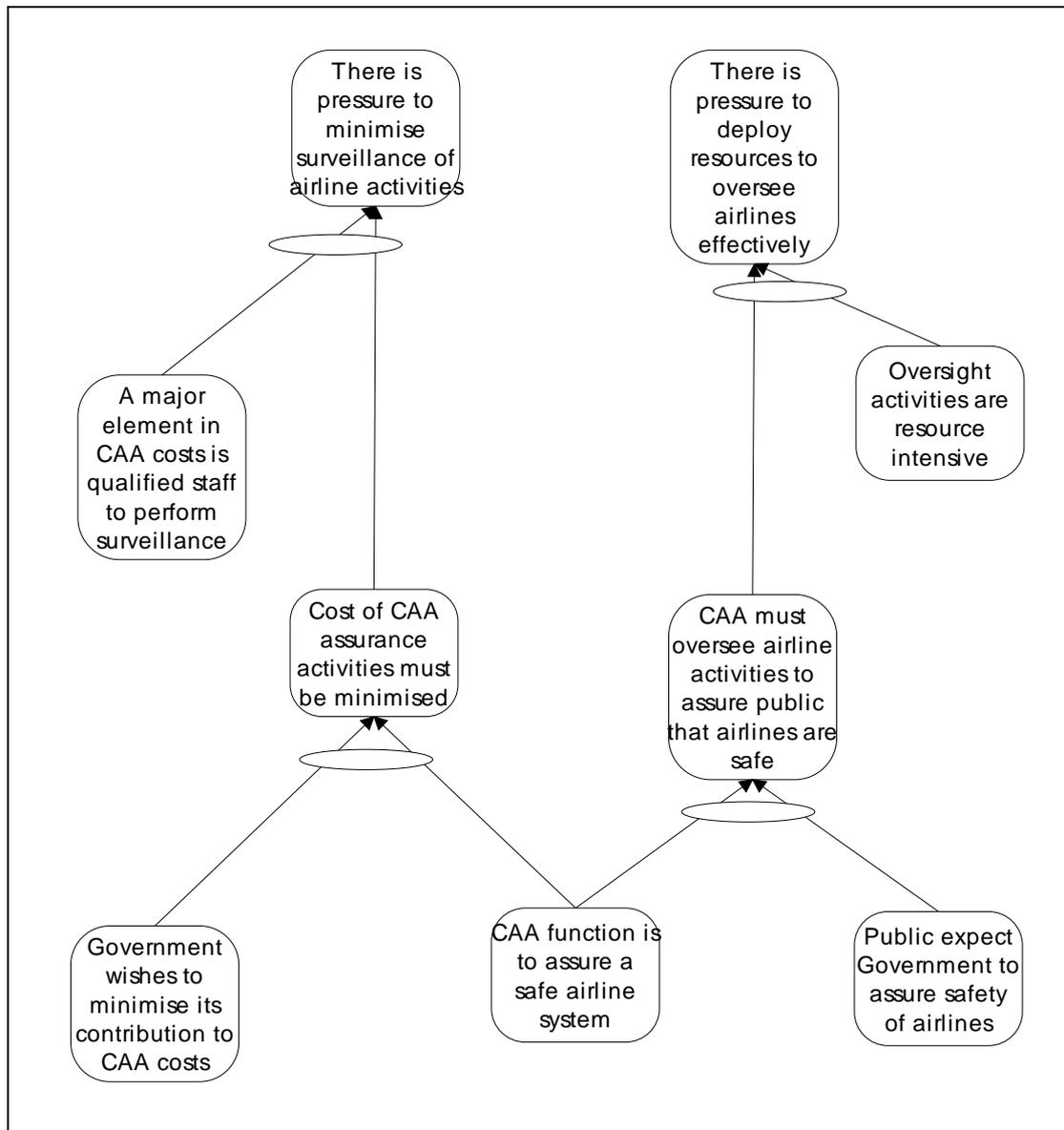


Figure 89. The core conflict at the base of the CAA CRT

It could be argued that additional sufficiency is needed, such as ‘*Effective* oversight activities are resource intensive’, ‘There is pressure to deploy *more* resources...’, but these do not affect the subsequent analysis. This illustrates Dettmer’s point that the FRT acts as a safety net where there are deficiencies in the CRT (Dettmer, 1997).

The core conflict can be re-drawn as a Conflict Resolution Diagram (CRD) as shown in Figure 90. This figure also shows the assumptions which underlie the arrows (Dettmer, 1997).

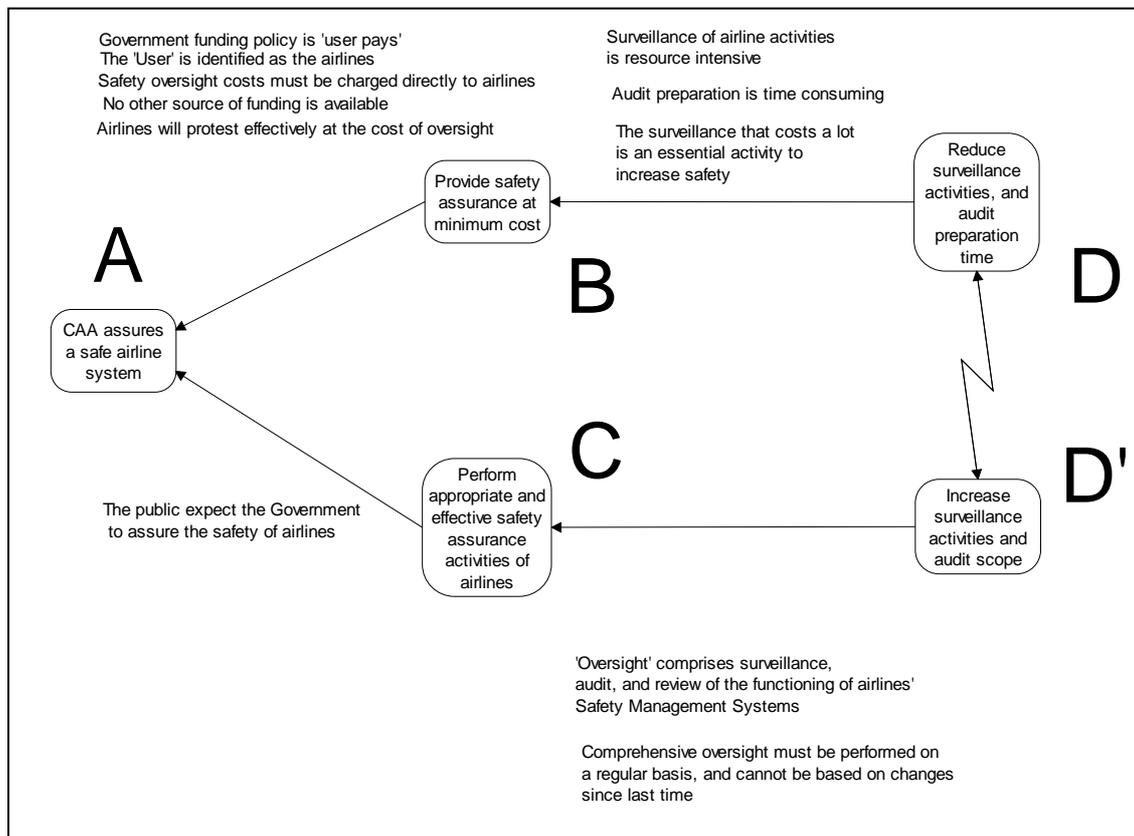


Figure 90. Conflict Resolution Diagram from CAA CRT.

Surveillance of airline activities requires a sizeable staff of highly qualified Inspectors (ICAO, 1995), and audit preparation requires a thorough review of the airline's manuals which takes appreciable time. The assumptions B-D are therefore valid. Likewise, the activities required for safety oversight (C-D) are well established (ICAO, 1999, 1995; Swedavia AB & McGregor and Company, 1988; Flight Safety Foundation, 1998). Public expectation that the Government will assure airline safety (A-C) has been demonstrated by requirements for Inquiries after a disaster (see, for example, the Erebus Royal Commission, Mahon, 1981). If the assumptions at A-B are valid, the CAA's dilemma is clear: it is required to do those things necessary to assure airline safety, but must remain within funding constraints dictated by airline pressure. It cannot do both effectively.

The assumptions to be addressed, therefore, are those at A-B:

- The Government's funding policy is 'user pays'
- The 'user' is identified as the airlines
- Safety oversight must be charged directly to airlines
- No other source of funding is available
- Airlines will protest effectively at the cost of oversight.

There is no question that the Government required CAA activities to be charged to the user of those activities, and the Government was adamant that it would not pay for the safety of airline operations ("AIA Conference Report," 1994). Where these costs were passed to airlines it is not surprising that protests should result, and given the constitution of the CAA Board which contained representatives from the aviation industry, those protests were likely to be effective (see, for example, "CAA Board Appointments," 1994). However, the identification of the 'user' of CAA 'services' as the airlines themselves is open to challenge.

It was the public expectation, that the Government would assure the safety of air travel, that gave rise to existence of the CAA. (This expectation was a world-wide phenomenon, which led in part to the Chicago Convention (ICAO, 2000): the safety of aviation is a significant function of ICAO). The public, as travellers, were the beneficiaries of the CAA's activities. Accordingly, the public could be seen as the 'users'. A feasible means of payment could be a small levy per ticket, as previously used to fund the activities of the Air Services Licensing Authority ("Air Services Licensing Act," 1983). The charge would be so small, in proportion to the cost of an air ticket, as to be virtually unnoticeable, and therefore unlikely to excite protest⁵³.

Since there is a feasible alternative source of funding for the CAA, the assumptions at A-B that safety oversight must be charged to airlines, and no alternative funding is available, are not valid. The conflict (D-D') is therefore broken:

⁵³ Figures needed to determine the levy which would have been needed in 1994 are not readily available. Current figures in Australia in 2004 are 93.8 million passenger tickets (single sector); operating cost of the Civil Aviation Safety Authority (CASA) is \$114 million: a charge of \$2 per ticket would adequately fund the Authority's operating costs. The costs of the NZCAA could be expected to be roughly proportional to those of the Australian CASA.

it is possible to deploy all resources to oversee airlines effectively, within potential alternative funding.

In the CRT, the core conflict feeds to the limitation in what can be done ('audit is defined as review of airlines' documentation to assure that safe systems are in place') which in turn feeds to all the factors depriving the CAA of 'mindfulness' (Weick & Sutcliffe, 2001) such as 'audits cannot detect operations which are not in accordance with the documentation'. These factors, collectively, were the reason that 'auditing Ansett is ineffective in assuring safe operation'. With the basic conflict resolved by a funding mechanism which should provide sufficient funding for the CAA to operate effectively, it should be possible to identify high-risk operations, and take action to forestall many airline accidents.

The FRT from the CAA perspective is constructed somewhat differently from the Ansett FRT, because the performance improvement sought is more generic. It is not just accidents similar to that which happened to the Dash 8 that are to be averted, but all the airline accidents which can be averted by proper safety oversight. Additionally, it is not practicable merely to reverse undesirable effects in the CAA CRT as the basis for the FRT, since the fundamental injection – that adequate funding is available – completely collapses the CRT. It is therefore necessary to build the FRT ab initio, from the basic premises that adequate funding is available, and all necessary oversight means can be used.

The FRT is constructed from a number of clusters:

- A. Funding is not a constraint on safety oversight
- B. Oversight comprises surveillance, auditing and safety management review
- C. Non-viability of airlines triggers greater depth of auditing
- D. CAA is aware of deficiencies in airline operations.

These clusters are shown separately in Figures 91 - 94, and the complete FRT is shown at Figure 95.

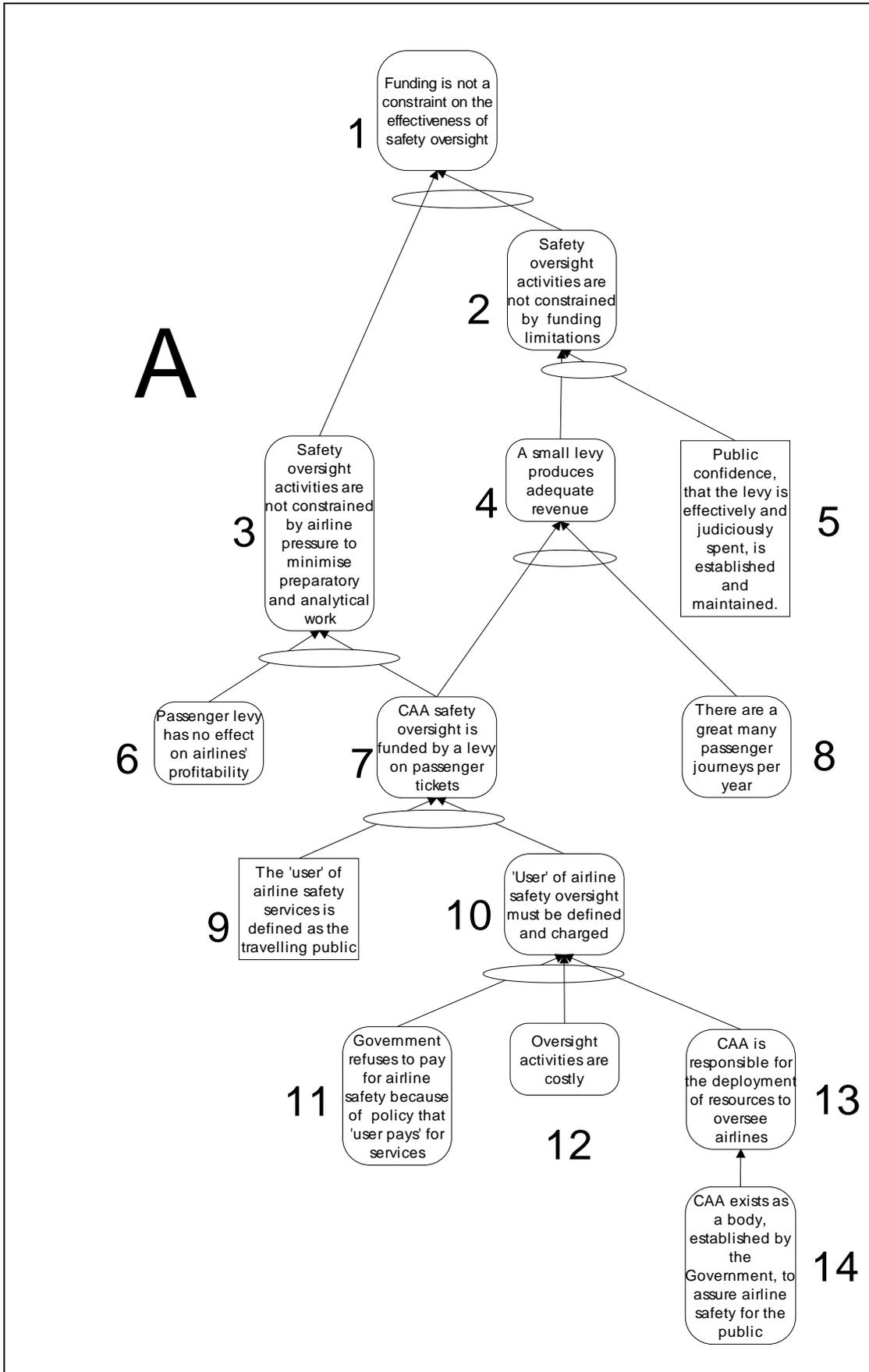


Figure 91. Funding is not a constraint on safety oversight.

Key

1. Funding is not a constraint on the effectiveness of safety oversight
2. Safety oversight activities are not constrained by funding limitations
3. Safety oversight activities are not constrained by airline pressure to minimise preparatory and analytical work
4. A small levy produces adequate revenue
5. Public confidence that the levy is effectively and judiciously spent is established and maintained.
6. Passenger levy has no effect on airlines' profitability
7. CAA safety oversight is funded by a levy on passenger tickets
8. There are a great many passenger journeys per year
9. The 'user' of airline safety services is defined as the travelling public
10. 'User' of airline safety oversight must be defined and charged
11. Government refuses to pay for safety oversight because of policy that 'user pays' for services
12. Oversight activities are costly
13. CAA is responsible for the deployment of resources to oversee airlines
14. CAA exists as a body, established by the Government, to assure airline safety for the public

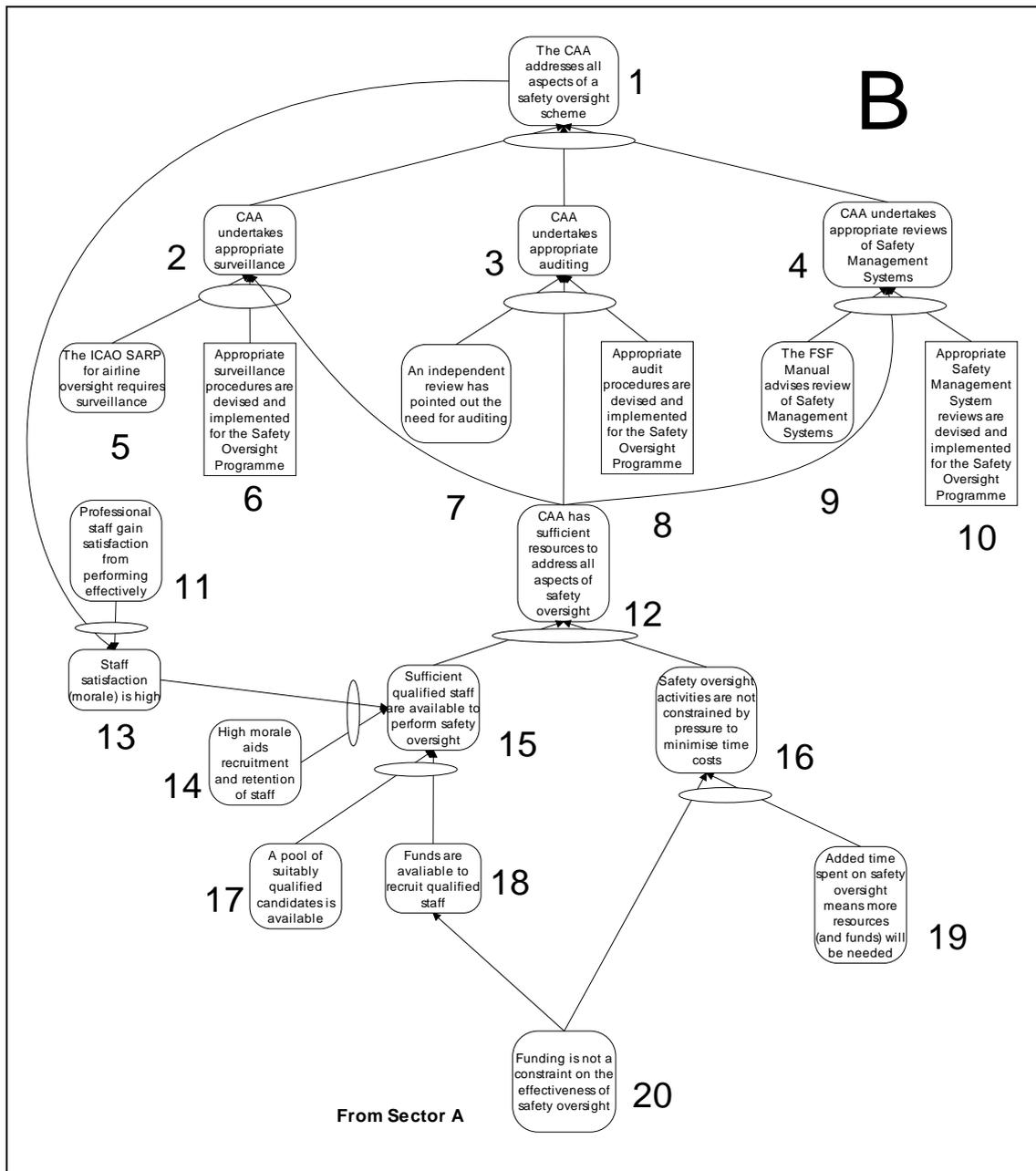


Figure 92. Oversight comprises surveillance, auditing and safety management review.

Key

1. The CAA addresses all aspects of a safety oversight scheme
2. CAA undertakes appropriate surveillance
3. CAA undertakes appropriate auditing
4. CAA undertakes appropriate reviews of Safety Management Systems
5. The ICAO SARP for airline oversight requires surveillance
6. Appropriate surveillance procedures are devised and implemented for the Safety Oversight Programme
7. An independent review has pointed out the need for auditing
8. Appropriate audit procedures are devised and implemented for the Safety Oversight Programme
9. The FSF Manual advises review of Safety Management Systems
10. Appropriate Safety Management System reviews are devised and implemented for the Safety Oversight Programme
11. Professional staff gain satisfaction from performing effectively
12. CAA has sufficient resources to address all aspects of safety oversight
13. Staff satisfaction (morale) is high
14. High morale aids recruitment and retention of staff
15. Sufficient qualified staff are available to perform safety oversight
16. Safety oversight activities are not constrained by pressure to minimise time costs
17. A pool of suitably qualified candidates is available
18. Funds are available to recruit qualified staff
19. Added time spent on safety oversight means more resources (and funds) will be needed
20. Funding is not a constraint on the effectiveness of safety oversight

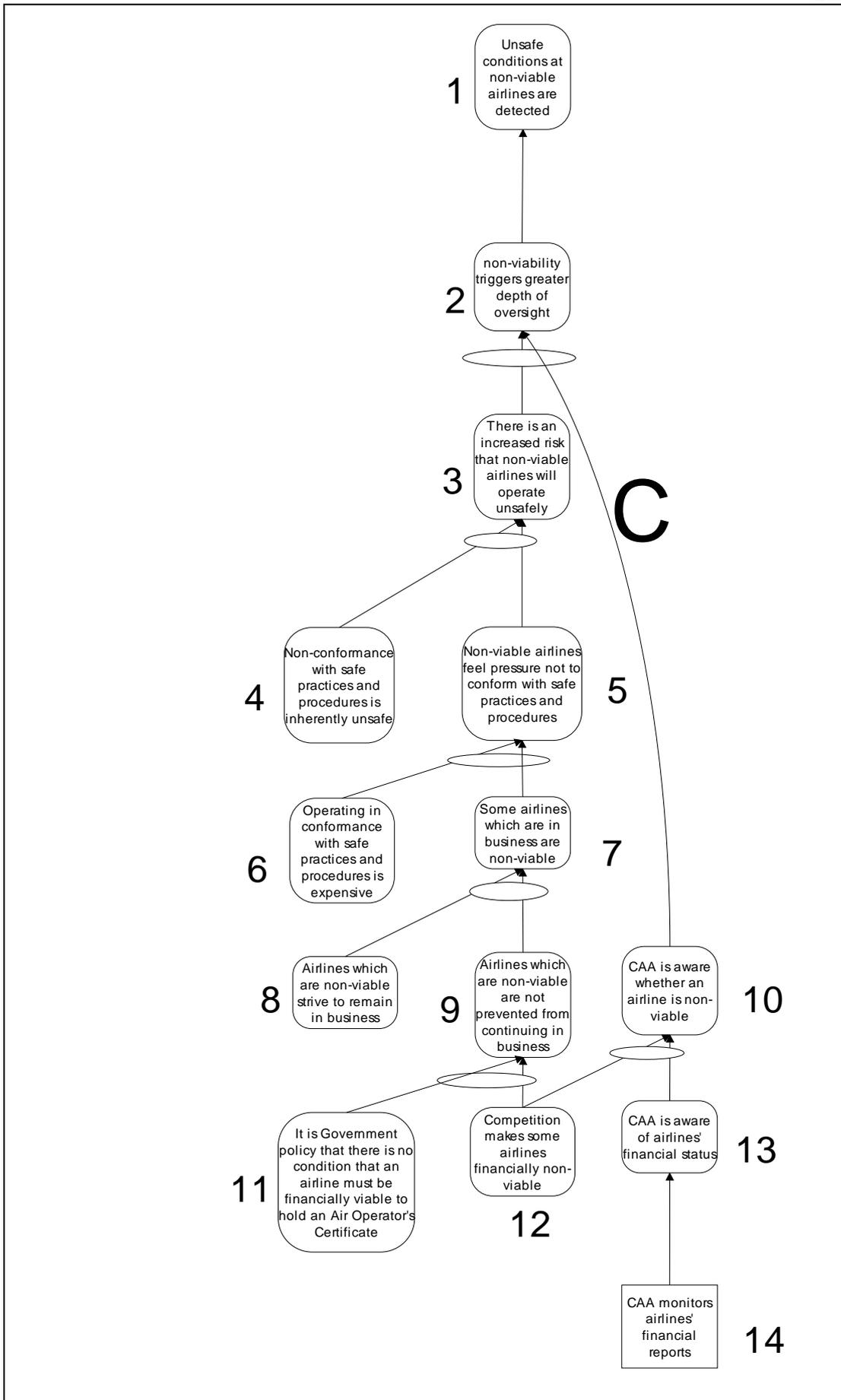


Figure 93. Non-viability of airlines triggers greater depth of oversight

Key

1. Unsafe conditions at non-viable airlines are detected
2. non-viability triggers greater depth of oversight
3. There is an increased risk that non-viable airlines will operate unsafely
4. Non-conformance with safe practices and procedures is inherently unsafe
5. Non-viable airlines feel pressure not to conform with safe practices and procedures
6. Operating in conformance with safe practices and procedures is expensive
7. Some airlines which are in business are non-viable
8. Airlines which are non-viable strive to remain in business
9. Airlines which are non-viable are not prevented from continuing in business
10. CAA is aware whether an airline is non-viable
11. It is Government policy that there is no condition that an airline must be financially viable to hold an Air Operator's Certificate
12. Competition makes some airlines financially non-viable
13. CAA is aware of airlines' financial status
14. CAA monitors airlines' financial reports

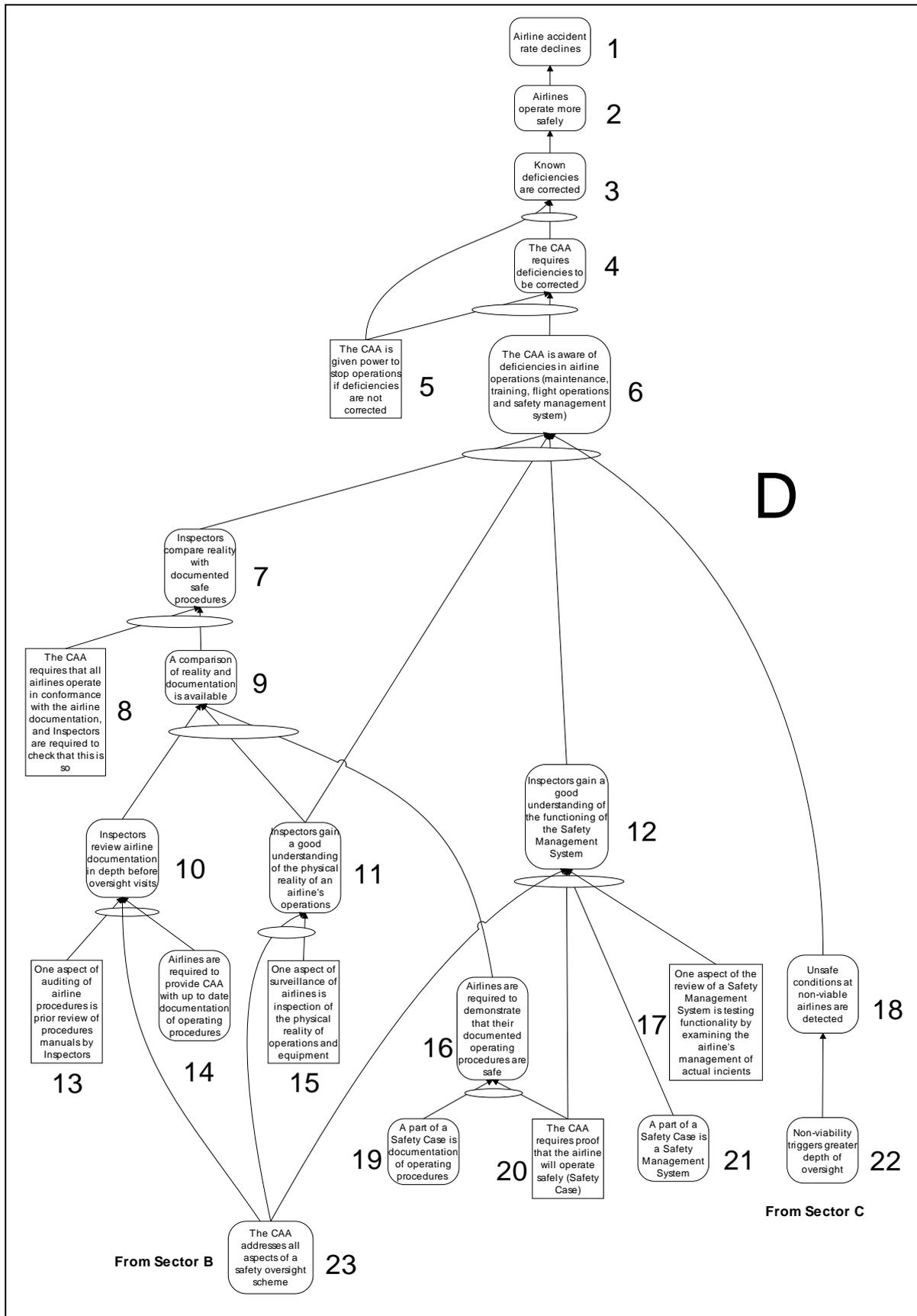


Figure 94. CAA is aware of deficiencies in airline operations.

Key

1. Airline accident rate declines
2. Airlines operate more safely
3. Known deficiencies are corrected
4. The CAA requires deficiencies to be corrected
5. The CAA is given power to stop operations if deficiencies are not corrected
6. The CAA is aware of deficiencies in airline operations (maintenance, training, flight operations and safety management system)
7. Inspectors compare reality with documented safe procedures
8. The CAA requires that all airlines operate in conformance with the airline documentation, and Inspectors are required to check that this is so
9. A comparison of reality and documentation is available
10. Inspectors review airline documentation in depth before oversight visits
11. Inspectors gain a good understanding of the physical reality of an airline's operations
12. Inspectors gain a good understanding of the functioning of the Safety Management System
13. One aspect of auditing of airline procedures is prior review of procedures manuals by Inspectors
14. Airlines are required to provide CAA with up to date documentation of operating procedures
15. One aspect of surveillance of airlines is inspection of the physical reality of operations and equipment
16. Airlines are required to demonstrate that their documented operating procedures are safe
17. One aspect of the review of a Safety Management System is testing functionality by examining the airline's management of actual incidents
18. Unsafe conditions at non-viable airlines are detected
19. A part of a Safety Case is documentation of operating procedures
20. The CAA requires proof that the airline will operate safely (Safety Case)
21. A part of a Safety Case is a Safety Management System
22. Non-viability triggers greater depth of oversight
23. The CAA addresses all aspects of a safety oversight scheme

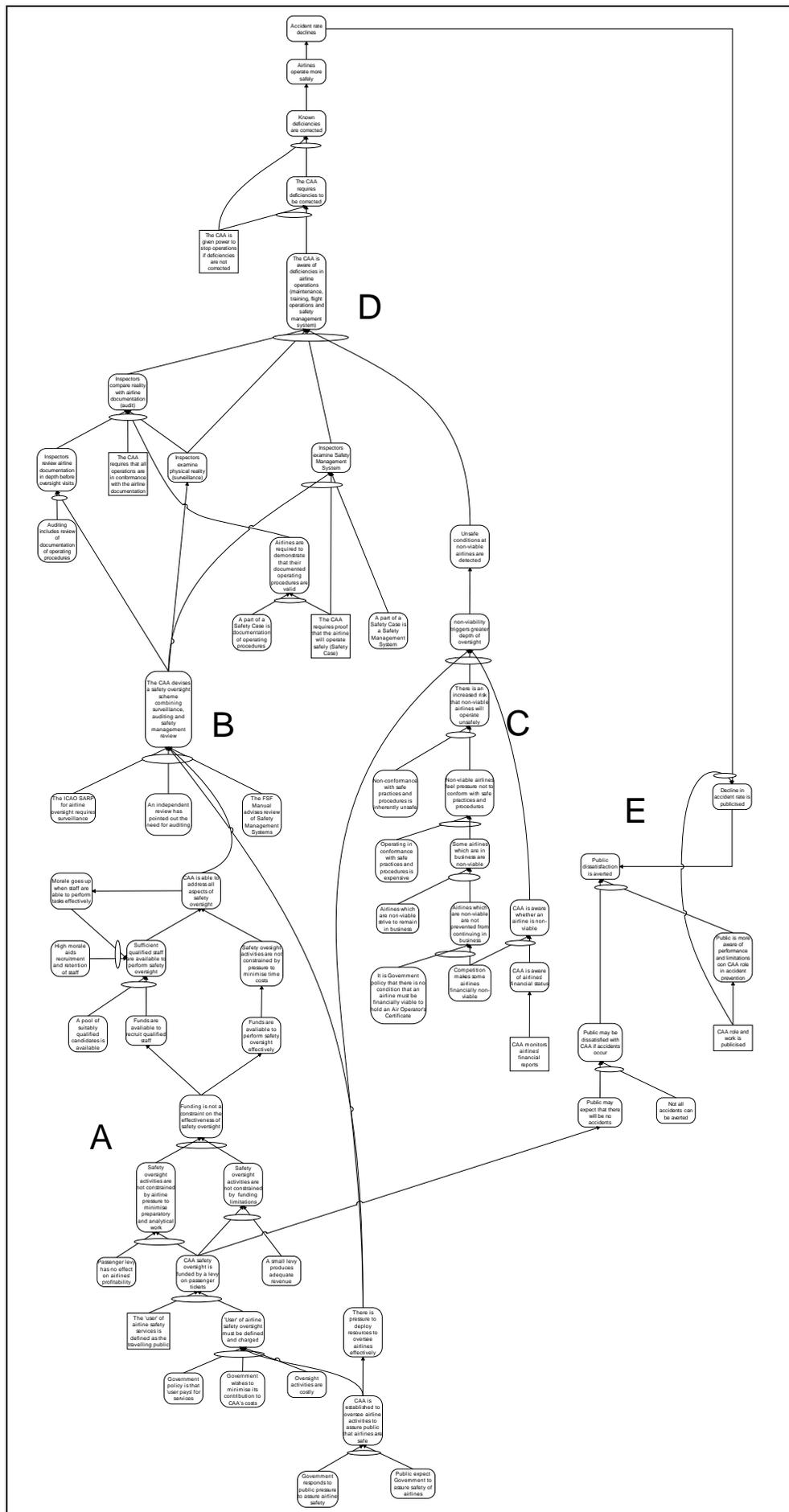


Figure 95. CAA Future Reality Tree

Figure 94 also addresses a potential ‘negative branch’, that is, a potential undesirable effect arising from an otherwise beneficial injection. Imposing a safety charge on the public could give rise to the perception that the CAA is able to ensure that all airlines are absolutely safe. The CAA cannot do this: it can increase safety by reducing risk, but there is always the possibility that something unforeseen could lead to disaster. If an accident is not to give rise to unwarranted criticism of the CAA, it is necessary that the public understands the CAA’s function, be aware of its success (as shown by a reducing rate of accidents and incidents) and be aware of the limitations of what can be done. This negative branch and response is shown in Figure 96.

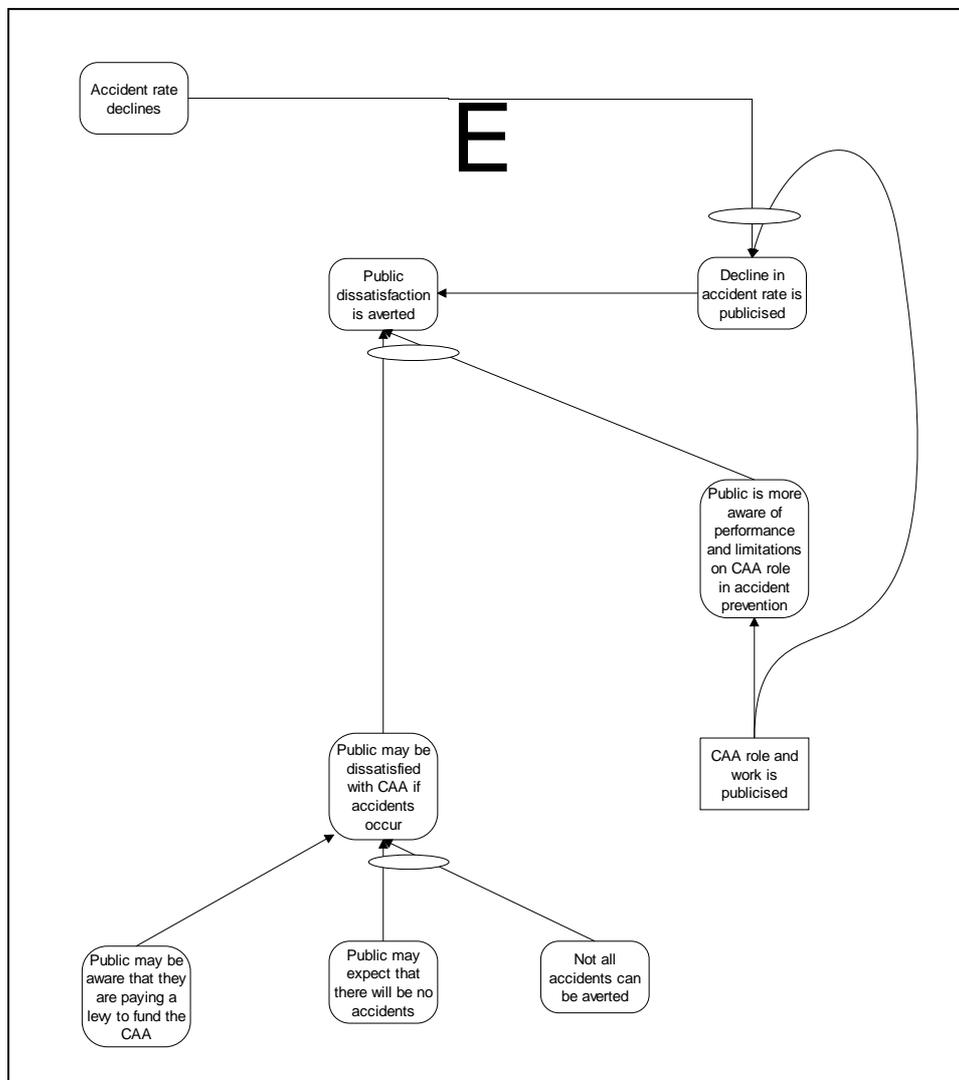


Figure 96. Negative Branch: public perception of CAA performance.

Apart from the fundamental injection that ‘The user of CAA services is defined as the travelling public’, there are a number of other required injections, as shown by the square boxes in Figure 94. These are:

- A Safety Case is required⁵⁴
- The CAA requires that all operations are acceptably documented, and conducted in conformance with the airline’s documentation
- The CAA has power to stop an airline operating, if identified deficiencies are not remedied
- The CAA monitors airlines’ financial reports, and
- The CAA’s role and work is publicised.

Negative Branch Reservations

In the same way as was done with the Ansett FRT, the injections in the CAA FRT must be scrutinised for negative branch reservations. The injections, with negative branch and implementation reservations, are listed in Table 3 below. Only two of these injections require further comment:

- Power to stop an airline operating: This would require express legislation, since the power to suspend an Operating Certificate exists only to prevent an unsafe operation, and mere non-conformance with documentation might not be held, in Court, to demonstrate that the operation was manifestly unsafe. To demonstrate this to politicians, the CAA would need to show them that, in operating outside its documentation, the airline was in breach of its Safety Case, that is, the airline’s own statement of how it was going to conduct its operations safely. In so doing, the airline had departed from known safe ground, and should immediately return to its documented procedures, and an effective sanction was required to ensure that this happened. The CAA might well need to consider a Prerequisite Tree, to produce a case for such legislation, but this is not a matter for the Investigating authority.

⁵⁴ A Safety Case is documentation showing how the company is going to conduct its business safely. A Safety Management System is part of a Safety Case (DITR, 2003).

- Monitoring financial reports: Current doctrine is that this should not be an interest of the CAA, as market forces would ensure that only viable airlines survived. This doctrine overlooks the known propensity for airlines under financial stress to seek economies which may reduce the margin of safety (see, for example, Dekker, 2004). The Ansett accident indicates the value of financial information as an alerting tool, and the information is readily available. The Recommendation needs to be couched in these terms, so as to persuade the CAA to change its practice.

Table 3. CAA FRT: injections and reservations

Injection	Negative Branch reservation	Implementation reservation	Remarks
The user of CAA services is defined as the travelling public			Within CAA's purview
A Safety Case is required	Novel approach for civil aviation		Within CAA's purview. Already widely required in other hazardous industries in other countries
The CAA requires that all operations are acceptably documented, and conducted in conformance with the airline's documentation			Amplification of existing requirement
The CAA has power to stop an airline operating, if identified deficiencies are not remedied	May require additional legislation	May need to demonstrate to politicians that additional powers are required	Departure from the Safety Case is, of itself, unsafe. CAA needs to be able to stop an operation without having to demonstrate that it is unsafe, in the particular case.
The CAA monitors airline's financial reports	Contrary to current doctrine	Could be obtained from reports to Companies Office, or through financial monitoring agencies	CAA may need to be persuaded of the need to change its doctrine: financial stress is an indicator that there may be unsafe operations
The CAA's role and work is publicised			Extension of existing role, in countering adverse comment. Implements requirement that there be public confidence that funds are effectively and judiciously spent
Appropriate safety oversight procedures are devised and implemented		Increase in staffing levels will be needed	Safety Oversight includes surveillance, auditing, and review of the airline's Safety Management System.

Safety Recommendations

The injections form the basis of the Safety Recommendations. As discussed earlier, recommendations to Ansett are seen as being ineffective, in that Ansett might not have the financial resources to implement them. Accordingly, the recommendations are directed to the CAA, and come in two forms:

- Recommendations derived from the Ansett FRT refer to changes which the CAA should make in order that airlines will operate more safely
- Recommendations derived from the CAA FRT refer to changes in the CAA's methods of operating, in order that it may conduct the safety oversight of airlines more effectively.

The purpose of the FRT is to show how improvements may be made. It can be seen as a simulator, in which proposed changes can be examined for effectiveness, and checked for adverse effects which might arise. It can also highlight implementation difficulties, requiring further analysis.

One objective of this case study was to see whether the information from an accident could be put in the form required for analysis by the methodology of the Theory of Constraints. That this could be achieved has been demonstrated by the first part, the Current Reality Tree. The Current Reality Tree showed that there were a few areas which could profitably be addressed, and gave an indication of the changes that might be needed. These areas were examined by Conflict Resolution Diagrams, which aimed to surface hidden assumptions, so that they could be investigated. Changes might then be possible to invalidate assumptions and so break the conflict; alternatively, some assumptions might be found to be already invalid.

The ideas generated by the Conflict Resolution Diagrams were then used to generate Future Reality Trees. These tested the ideas, and showed where further injections might be needed to make the ideas work.

Safety Recommendations which have been through this process are thus tested, as far as is possible before actually putting them into force, and are likely to be practicable and effective. The Safety Recommendations are:

To the CAA, in respect of airline safety:

1. Safety Management:

- a. The CAA perceives that the Safety Department benefits the public by increasing the safety of air travel, and mandates its existence in all airlines
- b. The Safety Manager position and functions are mandated by regulation
- c. The Safety Manager must be an “approved person”
- d. The CAA audits the Safety Department against stated performance criteria
- e. The Maintenance Controller is trained in safety management, and initial review of events within the Engineering Department is delegated to him, with notification to the Safety Manager
- f. Airlines have a formal policy that decisions on safety implications by one Department must not be considered in isolation from other Departments.

2. Simulator Training

The CAA recognises the need for simulator training in emergency procedures and Crew Resource Management, and mandates its use in airlines.

3. Abnormal Operations

- a. Operations Managers are required to review abnormal operations, for training implications
- b. Airlines have a formal requirement for a missed approach when emergencies are encountered on approach.

4. Ground Proximity Warning Systems

Radar altimeters related to Ground Proximity Warning Systems are tested in situ.

To the CAA, in respect of its own operations:

1. Funding

The user of CAA services is defined as the travelling public.

2. Safety Management

- a. A Safety Case is required for airline operations
- b. The CAA requires that all operations are acceptably documented, and conducted in conformance with the airline's documentation, and Inspectors are required to check that this is so
- c. The CAA seeks power to stop an airline operating, if identified deficiencies are not remedied.

3. Safety Oversight

- a. Appropriate safety oversight procedures are designed and implemented, including surveillance, auditing, and review of Safety Management Systems
- b. The CAA monitors airline's financial reports.

4. Public Relations

The CAA's role and work is publicised.

There are four sets of recommendations, generic in nature, addressing airline operations, and four sets dealing with improvements to the CAA's safety oversight. The official Report had 15 recommendations to Ansett, and six recommendations to the CAA. However, the principal difference between the recommendations derived from the TOC analysis and those in the official report is in the nature of the recommendations. In the official report, some were matters of detail (for example, "Enhance the opportunity for the Flight Safety Coordinator to attend international flight safety conferences and seminars" (TAIC 1995, p. 94)). Many were related to 'this accident' and 'this airline'. But 'this accident' is unlikely to happen again in any event, while the chance of Ansett (NZ) having another 'Controlled Flight Into

Terrain' accident related to undercarriage malfunction is negligibly small. More generally, the Safety Recommendations in the official report deal largely with undesirable effects rather than the deeper core problems giving rise to those undesirable effects. For example, it is recommended that the CAA consider performing surveillance, but the underlying funding problem is not addressed.

The ability to seek out and resolve core problems is a distinguishing advantage of the TOC methodology. The recommendations arising from the Theory of Constraints analysis deal with the underlying systemic factors which gave rise to the accident, and the recommendations are generic. They relate to all airline operations, rather than to the specific accident being analysed.

The recommendations from the TOC methodology are different in kind from those derived from the earlier formal analyses, performed as part of this case study, Multilinear Events Sequencing and Why-Because Analysis. MES gave rise to a recommendation on fuel tank inerting. MES is about 'what happened', and this is an intervention related to 'what happened' – an outer wing panel was blown off by a fuel-air explosion, and the ensuing inverted impact caused fatalities and injuries. WBA is about the specific causality of the accident, and WBA gave rise to recommendations relating to causality – 'why it happened' – on specific matters:

- The early start to the crew roster, leading to fatigue
- The confusing approach plate, leading to the high rate of descent inbound to Palmerston North
- The painted radio altimeter radome, leading to corrosion of the aerial and inadequate performance of the Ground Proximity Warning System
- The abolition of the Safety Department

The advantages of the 'multi-framing' approach (Mabin & Davies, 2003), using a number of analytical methodologies to achieve different perspectives, is apparent.

Discussion of the Theory of Constraints Study

The Current Reality Trees

In the construction of the Current Reality Trees (CRTs), two departures from normal practice were found helpful:

1. The CRT was commenced by arraying the undesirable effects in chronological order, and the CRT has an implicit timebase. This is a natural consequence of the understanding that an accident is a sequence of events and conditions, as demonstrated by Multilinear Events Sequencing (MES) and Why-Because Analysis (WBA). Whereas undesirable effects in a process plant might conveniently be arrayed by physical position, time is the natural variable in an accident. As with WBA, discussed earlier, having a timebase facilitates chronological validation, and also the presentation of an explanation of an accident. In reality, any CRT has an implicit timebase, since it uses 'precede-follow' logic, so making the timebase explicit is not a radical departure.
2. The concept of potentiation, discussed previously at p. 220, is new. While the lower stages of the Ansett CRT use necessary and sufficient connections between entities, in the ultimate stages this is not possible. The linkage between the underlying conditions and the accident shows that the accident was likely, but it was not inevitable, without more. The additional factors – low cloud and an undercarriage malfunction – would normally have been benign. Low cloud is quite normal, and an undercarriage malfunction ought not to have resulted in continued descent until impact with the terrain. However, these entities had been potentiated by the preceding conditions, and the random factor – the undercarriage malfunction occurring as the aircraft reached the correct glidepath – tipped the scales from potential to actuality. The concept of potentiation offers an answer to the question of why the accident had not happened before, even though all of the underlying conditions were in place for the preceding undercarriage malfunction incidents. This is important, because otherwise that question will cast doubt on the validity of the explanation of the accident.

The Future Reality Trees

The construction of the Ansett Future Reality Tree (FRT) required several attempts. Difficulties were experienced because it was found that the remedies being generated related to the Company's goals and structure. This would be a normal product of the analysis of undesirable effects within a company, but was inappropriate to the objects of the case study. The case study sought to discover whether the TOC analysis could be used to generate effective safety recommendations: the perspective therefore was that of the accident investigation authority. As a Government body, it would be inappropriate for the authority to instruct Ansett on what its goals should be. Further, Ansett's problems were fundamentally lack of finance, and a law change a few years before the accident (Civil Aviation Act, 1990) had removed oversight of the financial state of the company from the Civil Aviation Authority, and by implication, from the considerations of the accident investigators. While it might be appropriate for there to be recommendations to the Government that this legislation needed re-examination, in the interim the question of what type of airline Ansett should be was not open for discussion.

Attempts to generate the FRT by addressing the core problem at the base of the CRT having been ineffective, it was necessary to adopt an alternative procedure, of transforming the CRT, in so far as non-financial matters were concerned. This was successful, but resulted in an unusual feature. A FRT should have no undesirable effects in it: all should have been addressed, so that only desirable effects remain. However, in the Ansett FRT, the financial matters are unchanged.

Undesirable effects would, in any case, remain in a FRT generated from an accident investigation, because some things are not amenable to change. Inadequate design, and errors by operational staff, are not going to go away: like gravity, errors are always with us. What is needed is that they should be detected before lasting harm occurs, and mitigated in some way. In order to show how these detection and mitigation processes can work, it is necessary for the FRT to contain the undesirable effects which generate the need for mitigation. This is a necessary departure from the conventional structure of a FRT.

The CAA FRT, by contrast, responded to a conventional approach. The core problem at the base of the CRT was addressed with a Conflict Resolution Diagram, a false assumption was located, and it was found that by eliminating this false assumption, the CAA could perform all of the functions necessary for effective safety oversight.

Applicability

Had the methods discussed in this chapter been available to those involved in the accident sequence, there is a reasonable possibility that the build-up of undesirable effects could have been foreseen. It was not necessary for there to have been an accident, before a Current Reality Tree and/or Future Reality Tree could be constructed. There would then have been the opportunity to modify policies, measures and behaviours to avoid the undesirable effects, and so the accident could have been averted.

Starting right at the beginning, constructing a Future Reality Tree for airline competition would have shown the Government that, while predatory pricing was permitted, competition between a newcomer and the existing major airline was unlikely to produce lasting benefits. It would then have been possible to debar predatory pricing, as a necessary preliminary to introducing a competitive regime. It would be proper for the investigating authority to recommend that such a change be considered.

The effects of the various economies that Ansett proposed (particularly the abolition of the Safety Manager position) could have been examined in advance. This would not have made the airline any more viable, but would have provided a powerful argument for addressing operating strategy before the disaster, notwithstanding the sunk capital in maintenance facilities, terminal buildings and so on.

From the CAA's perspective, analysis of the effects of constraining audits to review of systems documentation could have illustrated the potential inability of such auditing to disclose various types of problems. Other methods of oversight could have been added to the auditors' toolbox, such as surveillance in accordance with the ICAO

Manual (ICAO, 1995), so that weaknesses in airlines could be detected and addressed before a major accident occurred.

The accident investigators would have benefited by the use of the Current Reality Tree as a formal analytical technique during the investigation, by their attention being drawn to information that might otherwise be overlooked (e.g. the need to discover whether the radar altimeter radome drain was in fact blocked). And the generation of Safety Recommendations would be focussed by the need to generate a Future Reality Tree in which the existing undesirable effects did not occur. For example, the need to ensure that an airline could not abolish the Safety Manager position, without managing the impact, could lead to the requirement for a new regulation making such a position mandatory.

Safety Recommendations

The base of the CRT suggests that given the state of commercial law, which had no prohibition on predatory pricing practices, there was limited likelihood that Ansett (NZ) could ever operate profitably. It need not have taken an accident to make this point – an argument for the construction of a Future Reality Tree as a means of decision-making. But the corollary is that there might have been little point in the investigating authority making safety recommendations to the airline. The implementation of safety recommendations almost invariably costs money, and there was a limited prospect of Ansett (NZ) generating the necessary revenue. Only if Ansett Australia was prepared to continue subsidising New Zealand travellers indefinitely could the airline find the funds to make safety improvements. Alternatively, the Government could have used taxpayers' funds to assure travellers' safety, but the Government was adamant that it would not do so ("AIA conference report", 1994).

The alternative to making recommendations to Ansett (NZ) was for the investigating authority to demonstrate the latent failures to the Civil Aviation Authority (CAA). It would then have been open to the CAA to direct that Ansett address these failures. If Ansett was unable to do so, that would have provided grounds for suspension of the airline's Operating Certificate. Further, the knowledge

that such latent failures had occurred should have been grounds for increased safety oversight by the CAA.

Summary

The purpose of this section of the case study was to see whether it was possible to put the information from an accident into the form required for analysis by the methods used in the Theory of Constraints. If so, then it should be possible to use that change mechanism to remove the undesirable effects from aviation operations, i.e. to make effective Safety Recommendations. It was found possible to take the information from lower levels of analysis – Multilinear Events Sequencing and Why-Because Analysis – and put it into the appropriate format for analysis by the Theory of Constraints methodology. As predicted by the Theory of Constraints, core problems were identifiable, so enabling corrective action to be focussed where it could be effective. The only modifications to the usual format that were found necessary were the use of an explicit chronological order in constructing the Current Reality Tree, and the concept of potentiation.

The construction of the logic trees proved straightforward; the method of forming individual segments and aggregating them was successful. The process of finding additional information, where gaps in the logic tree showed the need, proved time-consuming, as it is in an investigation of any sort. The construction of the CRTs was an iterative process, with retrospective amendments to the individual segments being required, as the developing CRT showed the need for changes – generally the need for additional sufficiency, but sometimes also, testing showed that the original linkages were not logically sound. It would be highly desirable to be able to link diagrams so that changes in one were reflected in changes to others as appropriate. Such linkage was not a function of the graphics programs available to the author, and retrospective amendment proved time-consuming. (The need for updating the earlier stages comes from the need to present the tree to the reader in stages, rather than the somewhat bewildering apparent complexity of the final product).

Overall, the construction of a CRT and the ensuing FRT can be seen to be a powerful analytical tool, both in averting accidents *ab initio*, and in making recommendations to avoid recurrence.

Chapter 8: Comparison of Methodologies

Bases for Comparison

The usefulness of the various analytical methodologies for the investigation of aircraft accidents, which have been examined in this thesis, can be considered under a number of headings:

- The comprehensibility of the resulting report of the investigation,
- The internal validity of the resulting report, i.e. the correctness of the conclusions drawn from the evidence, and
- The insights which the investigators gained from the analysis, and the likely usefulness of the recommendations derived therefrom.

In this case study, an official report generated using traditional intuitive methods has been examined, and formal analyses using the same data which was available to the official investigators were performed using Multilinear Events Sequencing (MES), Why-Because Analysis (WBA), and the Theory of Constraints (TOC). Comprehensibility and internal validity will be considered briefly, but the main points of comparison will be the insights gained by each method, and the Safety Recommendations which were or could have been generated.

Comprehensibility

A report is of little value unless it can be readily understood by those who could take action to remedy the deficiencies the report discloses, and unless it is sufficiently persuasive that action is indeed taken. The difficulty of writing and understanding the official report, which is written in the standard ICAO format, has been discussed in Chapter 5, dealing with the generation of the Multilinear Events Sequence. The comment by Johnson et al. (1995), that writing is essentially serial while in an accident events take place in parallel, is well illustrated by the official report, in which its authors found it difficult to describe the approach sequence. In section 1.1 (History of the Flight) there is no mention of the fact that the aircraft was high above the approach path on completing the turn onto final approach (the information is available at 1.8.19 and Figure 3, radar data, but attracts no comment).

Nor is the Captain's briefing for the approach reported, though it is available at Appendix C, Cockpit Voice Recorder. Since the high start to the final approach led to the high rate of descent which intersected terrain short of the runway, and since the Captain's briefing led to the high completion of the turn onto final approach, these were relevant factors in understanding the flight and accident.

The three formal methods examined do not suffer from difficulty in presenting parallel sequences of events and conditions, since they lend themselves to explanation by leading the reader through the graphs of events and conditions. Chapter 5 (MES) shows that there were in reality parallel strands in progress during the final approach, and it is necessary to understand these in order to have a good picture of the accident sequence.

Not only is the official report not easy to follow, but as will be shown, it was evidently unpersuasive in the important area of CAA monitoring of the airline.

Internal validity

In a purely written report, it is possible to cover lack of knowledge by general statements, such as

“The aircraft had yawed to the right as a result of impact forces, and after lofting some 60m across a gully it struck the hillside again” (1.12.15, p. 36).

This statement overlooks the fuel air explosion in the starboard wing, the subsequent departure of the starboard outer panel, and the consequent roll into an inverted attitude prior to the impact across the gully, as discussed in Chapter 5. Had the investigators been using a formal methodology, the lack of knowledge would have been shown by blanks on the flow charts, and they would have been alerted to the need to gather further information. Lack of validity may lead to incorrect (or no) recommendations being made: in this case, a recommendation on fuel tank inerting, to prevent explosions, would have been relevant. Equally importantly, if flaws in internal validity come to light after the report has been published, they detract from the credibility of the report as a whole. The ability to demonstrate the internal validity of an investigation which has used formal methodology is an important advantage over traditional intuitive analysis.

Insights from the analyses

A principle measure of usefulness of the various analytical methods is a comparison of the insights which the investigators gained from the analysis, and the likely usefulness of the recommendations derived therefrom. The insights and recommendations from the various methods of analysis will be examined in turn, starting with the official report and then taking the formal methods in order of increasing abstraction (MES, WBA and TOC) since that is the order in which it is suggested that the suite of formal methods should be applied. While the traditional method is considered first, some of the comments about its limitations derive from the various formal analyses, and will be cross-referenced to those later sections.

Official Investigation

The insights from the official investigation are encapsulated in the Findings, the Causal Factors, and the Safety Recommendations. These are set out below.

Findings

Some of the Findings set out in Section 3 of the official report are routine, such as

“The flight crew were properly licensed and fit to conduct the flight”, and

“The aircraft had a valid C of A and Maintenance Release”.

While necessary, these do not add greatly to the information about the accident, and will not be considered further. Altogether, there are 50 Findings listed; those that are material to this study are:

- 3.2 The Captain and First Officer had completed the company’s normal Dash 8 type conversion training and checking successfully.
- 3.3 Although the Captain and First Officer were experienced pilots, the Captain was not experienced as a Captain, nor was the First Officer experienced as a co-pilot, in a two-pilot crew.

- 3.7 The failure of the undercarriage to extend normally, which occurred during the aircraft's instrument approach to Palmerston North, was probably due to the wear on the right main undercarriage uplock latch.
- 3.8 The extent of wear on the uplock latch as determined after the accident exceeded the Messier-Dowty limits referred to in Temporary Revision SUP-383 to the Manufacturer's Maintenance Programme issued in November 1994.
- 3.11 The operator's initial decision not to modify the aircraft's undercarriage should not have jeopardised the safety of the aircraft significantly.
- 3.12 The operator's original decision not to modify the aircraft's undercarriage should have been promulgated to Dash 8 crews and to Ansett New Zealand's Flight Safety Coordinator.
- 3.13 The operator did not take the optimum steps to ensure that Dash 8 crews could deal with any malfunction of the undercarriage system safely in the light of the Dash 8 aircraft's history of the main undercarriage not extending normally.
- 3.14 The necessity to lower the right main undercarriage using the alternate gear extension procedure should not have endangered the aircraft on its approach to Palmerston North.
- 3.15 The operator's QRH checklists need to be improved to ensure standardisation in reference to similar procedures and to avoid the potential for the reader to confuse similar nomenclature on lines in close proximity.
- 3.16 The Captain had briefed for the instrument approach correctly and flew the approach track properly.

- 3.17 The aircraft was allowed, inadvertently, to descend below the instrument approach profile and below step limits until the aircraft collided with high terrain.
- 3.18 The Captain did not apply sufficient engine power to intercept and maintain the approach profile during the later stages of the instrument approach to Palmerston North Aerodrome.
- 3.21 The absence of a company standard operating procedure for the crew to discontinue an approach while they dealt with an abnormal situation may have influenced the Captain's decision to implement the alternate gear extension procedure while continuing with the approach.
- 3.22 The breakdown in monitoring the aircraft's altitude during the approach was contributed to by each pilot having a different understanding of his responsibilities in this respect in the event of an abnormal situation arising.
- 3.24 The breakdown in monitoring the aircraft's altitude during the approach to Palmerston North was unlikely to have been due primarily to any fatigue resulting from the pilots' early start for duty.
- 3.28 The cause of the GPWS failure to give adequate warning was not established.
- 3.35 Air Traffic advice that the minimum altitude for Ansett Flight 703 on the 14 DME arc was 6000 feet was ambiguous.
- 3.37 The key members of the operator's flight safety organisation would have benefited from formal training in flight safety and accident prevention.
- 3.41 The CAA's audit staff numbers were not adequate to ensure that Ansett New Zealand operated to the standards with which it had undertaken to comply.

- 3.42 The CAA's auditing might have detected weaknesses in the operator's procedures if it had carried out check flights during its auditing in the period leading up to the accident.

Causal Factors

The investigation identified the following causal factors:

Crew

- 3.51.1 The Captain did not ensure the aircraft's engine power was adjusted correctly for the aircraft to intercept and maintain the approach profile.
- 3.51.2 The Captain's lack of attention to, and/or misperception of, the aircraft's altitude during the approach.
- 3.51.3 The pilots' diversion from the primary task of flying the aircraft and ensuring its safety, by their endeavours to correct an undercarriage malfunction.
- 3.51.4 The Captain's perseverance with his decision to attempt to get the undercarriage lowered without discontinuing the instrument approach in which he was engaged when the situation arose.
- 3.51.5 The absence of a requirement for cross-monitoring of the aircraft's altitude while executing the QRH "Alternate Gear Extension" procedure.
- 3.51.6 The First Officer not executing the QRH procedure in the correct sequence, which distracted the Captain.

Systems

- 3.51.7 The inadequate warning given by the GPWS.

Contributory Factors

The report also listed a number of contributory factors; it did not describe how these were distinguished from causal factors.

Operator

- 3.52.1 The operator not ensuring its pilots were aware of the recurring undercarriage malfunction.
- 3.52.2 The limitations of knowledge-based CRM training for Dash 8 pilots.
- 3.52.3 The operator's checklist for alternate gear extension which held the potential to be difficult to follow sequentially.
- 3.52.4 The operator's requirement to configure the undercarriage down earlier than normal on the approach.

Weather

- 3.52.5 The existence of a significant orographic downdraught on the lee side of the ranges beneath the aircraft's flight path.

Systems

- 3.52.6 The failure of the right undercarriage leg to extend normally when selected "down".

Civil Aviation Authority

- 3.52.7 The CAA's lack of audit staff to detect the weaknesses in the operator's standard operating procedures during its audits.
- 3.52.8 The absence of check flights by qualified CAA auditors to supplement their scheduled route checks.

Safety Recommendations (pp. 93-101)

There were 26 Safety Recommendations, summarised below:

Ansett (NZ)

- 4.1.1 Pilots to practice alternate gear extension, under supervision.
- 4.1.2 Instruction to be issued that when an abnormality occurs in IMC on approach, the aircraft is to climb to a safe altitude until the abnormality has been corrected.
- 4.1.3 Advise pilots of the potential for distraction when a system abnormality occurs, if a need to give assistance develops.
- 4.1.4 Ensure that the Flight Safety Coordinator has input from management, operations and engineering staff on which to base an accident prevention programme.
- 4.1.5 Flight Safety Coordinator should attend international conferences and seminars.
- 4.1.6 Make CRM training more realistic, by use of simulators or otherwise.
- 4.1.7 Review QRH undercarriage emergency checklists in order to eliminate confusion.
- 4.1.8 Embody modifications to eliminate nuisance warnings from the GPWS.
- 4.1.9 – 4.1.12 (Modifications to approach procedures; not directly connected with the accident).
- 4.1.13 Consider use of Flight Director and autopilot on non-precision approaches, to alleviate pilot workload.
- 4.1.14 Issue instructions to Flight Attendants that are specific to type, and emphasise the sterile cockpit concept and the need for them to be seated as soon as possible after the signal to do so.
- 4.1.15 Remove obstacles to fitting Cockpit Voice Recorders.

Civil Aviation Authority

- 4.2.1 and 4.2.4 Review the adequacy of audit staff numbers, and increase numbers to achieve planned audits.
- 4.2.2 Improve the indication of first aid kits and fire extinguishers.
- 4.2.3 Investigate improvements to Electronic Locator Transmitter aerials.
- 4.2.5 and 4.2.6 Perform check flights as well as audits.

Airways Corporation [Air Traffic Control]

- 4.3.1 Investigate the introduction of a Minimum Safe Altitude Warning System.
- 4.3.2 Enable provision of radar data to Search and Rescue.
- 4.3.3 Review terminology for use with DME Arc approaches.

Transport Canada

- 4.4.1 Determine the reason for the inadequate GPWS warning.

New Zealand Airline Pilots' Association

- 4.5.1 Negotiate the removal of the impediment to installing CVRs in Ansett aircraft.

Commentary on the insights in the official investigation report.

Causation.

While the report contains details of the company structure and operation, very little is reflected in the Findings. There is only one item relating directly to company operation (3.37: formal training would be desirable for key members of the flight safety organisation). A few matters are referred to by implication:

- Communications and decision-making (3.12: the decision not to modify the undercarriage should have been promulgated to flight crews and the Flight Safety Coordinator)
- Procedures (3.21: lack of requirement to discontinue an approach; 3.15: defective checklists need improvement).

However, the defective undercarriage latch is not considered to have endangered the aircraft (3.14), and the causal factors (3.51.1-6) relate to failings by the crew during the final approach. In other words the report adheres to the concept of proximate cause, which gave rise to so much controversy after the Erebus disaster (Mahon, 1981; OAAI, 1980; Vette, 1997). There is mention of inadequate check lists (3.52.2), limited CRM training (3.52.3), and inadequate auditing by the CAA (3.41, 3.42, 3.52.7, 3.52.8) but these are relegated to ‘contributory factors’.

‘Contributory factors’ are not defined. If any factor is necessary to the occurrence of the accident, then its removal would have averted the accident. By definition, it is causal (Lewis, 1973, 1986). As Mahon (1981) showed, remoteness is no bar to causality.

The nominated causal factors, with their string of pilot ‘failures’, amount to a finding of professional negligence against the pilots, notwithstanding the disclaimer on the inside front cover of the report, that ‘it is inappropriate that reports should be used to assign fault or liability’. This view that the pilots had been negligent was taken by the Police, who brought a charge of manslaughter against the captain (“R. v Sotheran”, 2001).

Safety Recommendations

Since the investigators considered that various errors by the pilots, such as not setting the correct engine power (3.51.1) caused the accident, it might be expected that the main thrust of the Safety Recommendations would be directed to assuring that pilots would not err in the same way in future. However, the only recommendations to this end are issuing an instruction to climb (4.1.2) and, perhaps, more realistic CRM training (4.1.6). The other pilot-oriented recommendations (training in undercarriage extension, 4.1.1, and reviewing the undercarriage checklist, 4.1.7) are too specific to

be of general value. Recommendations directed to averting a recurrence of this particular accident are unlikely to be useful, because it is unlikely in the extreme that Ansett will have another CFIT accident due to undercarriage malfunction.

Where the recommendations are more generic, such as the instruction to climb on encountering an abnormality (4.1.2), they are still confined to Ansett; they will be conveyed to other airlines only by chance. They would be more useful if presented in generic terms, and directed to all airlines.

The principal recommendations to the CAA concern staff numbers and auditing concepts. However, they do not address the underlying difficulties of funding which brought these problems about, and drew less-than-helpful responses from the Director of Civil Aviation (pp. 99-100):

- “The CAA does not accept that its auditors or audit numbers were in any way germane to the accident”
- “The CAA can accept [the recommendation to conduct flight checks] only to the extent that it does not cut across the operator’s clear responsibility to train and supervise its own employees. Check flights of individual flight crew by the CAA would be an example of a very detailed sample of the effectiveness of an airline’s own training system and would be relatively infrequent, while surveillance of the airline’s own checking of flight crew... would be the more common level of audit”

In general, the official Safety Recommendations deal largely with undesirable effects, rather than the deeper core problems giving rise to these undesirable effects.

Survivability.

The accident was survivable, due to the long ground slide, freedom from obstacles, and the low vertical impact forces. The pilots and most of the passengers survived, but some of the survivors were seriously injured. There was the potential to discover why some survived unscathed, while others were injured or killed: this might have led to ways of improving survivability overall. While there is some discussion in

the report, there are no conclusions or recommendations, other than that the Flight Attendant should have been strapped in (4.1.14). This recommendation was of doubtful value, considering that the Flight Attendant had, quite properly, passed the observation of a passenger about the undercarriage position to the pilots, and was then explaining the situation to the passenger when the impact occurred.

Internal Validity.

- The Finding that the First Officer had completed the company's normal Dash 8 conversion training and checking successfully (3.2) is contradicted by available evidence that his training record was falsified in respect of emergency procedures. This will be discussed in 'Why-Because Analysis' (WBA), later in this chapter
- The Finding that the breakdown in monitoring the aircraft's altitude "was unlikely to have been primarily due to... fatigue" (3.24) amounts to sophistry. The evidence shows clearly that fatigue is likely to have been a factor (see WBA, post). To say that something is not a primary cause is to suppose that there is such a thing as a primary cause, as opposed to a secondary cause. As the discussion of formal analytical methods has shown, such a distinction is not valid. A more useful finding would have been that fatigue was probably a causal factor in the accident.
- The Finding that the Captain briefed the approach correctly is invalid, since the stated requirement to hold 4600 feet at the commencement of the approach was wrong (descent to 3000 feet was permissible): refer to the discussion of WBA, later in this chapter.

Such invalid findings detract from the credibility of the official Report.

Multilinear Events Sequencing

Multilinear Events Sequencing (MES) is entirely concrete, in that it considers only the actions by the various ‘actors’ (which may include machines). Active voice should be used exclusively, in order that the actions shall be able to be visualised clearly. The end product is a set of parallel timelines for the various actors, showing how their actions interact. Not only does MES enable visualisation of the accident sequence, but it shows clearly where there is inadequate information, because there are blanks on the graph where there should be actions. It thus prompts the investigators to gather the additional information needed, or to examine data whose significance might not otherwise be appreciated. Both of these functions were evident in this case study.

The accident sequence after initial ground contact

The initial impact was relatively light. After a slight touch, the starboard wingtip, engine and main fuselage touched the ground and the aircraft rebounded (official report, Figure 5). According to the official report,

“The aircraft had yawed to the right as a result of impact forces, and after lofting some 60m across a gully it struck the hillside again” (1.12.15, p. 36).

This does not explain how the starboard outer wing panel came to be in the bottom of the gully (Figure 5). Nor does it explain the ‘flash fire’. The strike on the starboard wing tip was insufficient to remove the outer wing panel by in-plane bending, and the impact of the engine on the ground would, if anything, have overloaded the wing root, not the outer panel. The answer, as demonstrated in Chapter 5, is that the impact initiated a fuel-air explosion in the starboard wing fuel tank, which blew off the outer panel. The precise initiation mechanism is not available, since the airline was permitted to destroy the wreckage before this question could be answered.

Survivability

The point that there was a fuel-air explosion, rather than a ‘flash fire’, is not merely academic, because it bears on the next question, that of survivability. For

example, how did the pilots come to suffer head injuries (1.13.8, p. 39)? They were strapped firmly in their seats, and could not have been flexed far enough forward by impact forces to strike the instrument panels or control columns with their heads. The answer is shown in the upper photograph on p. 4 of the report: lack of occupiable space. The cockpit roof struck the heads of the pilots. Naturally, it would not do this unaided, and in Chapter 5 it is shown that the crush line, clearly visible in the photograph, proves that the aircraft struck the ground inverted. The inverted impact also explains the way the passengers' seats broke adrift (they were loaded from a direction which was not a design consideration), the death of the flight attendant (she was also struck on the head by the cabin roof), the ejection of seats (Table 1, p. 38 of the report) and the injuries to passengers, not from 'rocking significantly during the impact sequence' (1.13.4, p. 37) but from the sudden arrest of the high rate of roll, approximately 180 degrees per second: refer Chapter 5.

The inverted impact explains why the port wing, with undercarriage extended, showed no sign of ground contact by the undercarriage or the underside of the wing (photograph, p. 2 of the official report). The detail photograph of the wheel shown in Chapter 5 (which was the port wheel) shows that it had no mud on it. This is not consistent with the port wing breaking away from the fuselage in an upright impact (1.13.1 - 2, p.37). There is other corroborating evidence of the inverted impact detailed in Chapter 5.

Thus MES gives a 'mental movie' of the accident sequence very different to that which can be gleaned from the official report, and one which can be validated from corroborating physical evidence. It follows that much of the medical information in section 1.13 of the official report is based on an incorrect appreciation of the impact sequence, and is therefore of little value in considering improvements to survivability. By contrast, the MES analysis shows that most if not all the injuries came about because of the explosion in the starboard wing, the loss of the wing, subsequent rapid roll and inverted impact.

Safety Recommendation from MES

Accordingly, an appropriate Safety Recommendation would deal with preventing such an explosion, i.e. inerting the fuel tanks with a non-combustible gas

so that combustion could not occur. Inerting fuel tanks has been on the American National Transportation Safety Board's 'most wanted' list (NTSB, 1990, 2004b, 2004c) since 1997, after the TWA 800 accident in which a Boeing 747 suffered a catastrophic fuel tank explosion over the Atlantic Ocean (NTSB, 2000). In December 2004, this item was still listed as "progressing slowly" (NTSB, 2004c). At the time of the issue of the official report on the Ansett Dash 8 accident, this issue was highly topical, and a Safety Recommendation would have added weight to the efforts of the American National Transportation Safety Board, to get some progress in inerting aircraft fuel tanks.

Why-Because Analysis

Why-Because Analysis (WBA) is designed to analyse causation. It is more abstract than MES, because in addition to events, it also considers conditions, some of which may be initiated and terminated by events, but others of which may be of long standing. The insights from WBA could be expected to be different from those derived from MES, as MES is designed to determine *what* happened, as opposed to *why* it happened. Also, the more abstract nature of WBA lends itself to going further back into organisational factors than MES: such factors as a Boardroom decision would be difficult to depict in an analysis limited to events.

WBA lends itself to the sort of backtracking advocated by Reason (1991), from the accident itself to the underlying latent failures. The insights gained from the WBA case study will therefore be presented in this order, starting with the accident.

The Final Approach

Considering the flight path of the aircraft, the first question is why should the Captain (who was the handling pilot) have had to initiate a high rate of descent? The answer lay in the confusing design of the instrument approach chart. The aircraft arrived at the end of the arc around the airfield at the correct height (so previous uncertainty as to height on the arc was immaterial) but the Captain stopped the descent at a height appropriate to the holding pattern which was outside the arc, when he could have descended steadily during the turn onto the final approach.

Having set a high rate of descent to intercept the normal glideslope, why did the Captain not stabilise the descent at normal rate when reaching the glideslope? And why did the First Officer not alert him to the continued descent? The answer here was the conjunction of a continuing condition (descent at high rate) and a stochastic event (failure of the undercarriage), the event occurring at about the time that the aircraft reached the normal glideslope. (MES is not able to detect such an occurrence, because of the prohibition on inclusion of conditions). It is probable that the Captain subsequently mis-read his altimeter for a significant period of time – again, a condition, and not amenable to discovery by MES. Neither of these points is addressed in the official report.

The defective design of the checklist helped to distract the First Officer, but he should have been familiar with the procedure for manual undercarriage extension (and so less susceptible to error), and in any case the defective design should have come to light during training. Investigation into why these things should be so led to the discovery of the falsification of the First Officer's training records: he had never been trained in emergency procedures.

There was more than adequate evidence in the official report that the pilots were fatigued:

- The 0300 start to the duty period, which would have required the crew to wake at about 0130. This would have resulted in a very short sleep period the night before
- The First Officer's recorded comment (p. 114) "Oh gee, excuse me, I'm tired"
- The catalogue of 10 attentional slips and memory lapses in the period immediately before the accident (pp. 77, 78).

Why did the Ground Proximity Warning System give inadequate warning? Having eliminated deficiencies in the various components of the GPWS, including the radar altimeter, and peculiarities which might have resulted from the terrain profile and nearby ground-based radio aerials, that which remains must be the truth (Conan Doyle, 1987). That which remained was the severe corrosion of the radar altimeter aerial, which attenuated the height signal on which the GPWS depended. The

corrosion was observed by the official investigators, but its significance was not appreciated: formal analysis brought its significance to light, and would have brought about a significant Safety Recommendation, discussed later in the TOC section.

Engineering

Absent the undercarriage failure, the accident would not have occurred. The failure was therefore a causal factor. The failure was due to a faulty maintenance instruction, which led to an existing defect remaining uncorrected. Also, no-one in the Engineering Department realised that undercarriage failures were happening more and more often – a sure sign of wear.

Safety Management

Lack of training in a recurring emergency situation, lack of realisation that the undercarriage was deteriorating, and that maintenance instructions were faulty, suggests that ‘no-one was minding the shop’. This pointed to an absence of monitoring and risk management, which are functions of the Safety Department. But these functions were not being performed because the position of Safety Manager had been abolished. The official investigators realised that the position had been replaced by a part-time ‘Safety Coordinator’ with limited functions, but did not appreciate the central part that the change played in the accident causation. This is shown in the Why-Because Graph, where the many lines of causation radiating from the Safety Management function characterise the absence of the Safety Manager as a core problem.

The WBA could, in principle, be taken further, to question what lay behind the abolition of the Safety Manager position, but absence of information on this point (due to the Company deciding to settle out of court before the information was obtained) provided a barrier.

Backtracking

The WBA could be extended to investigate the ineffectiveness of monitoring of the airline by the CAA, which gave no warning of the impending disaster. Likewise, Air Traffic Control and approach procedure design could have been considered. However, the analysis of matters affecting the Company suffices to

demonstrate the effectiveness of the method. It has been possible to back-track from the final stages before impact with the terrain, through such matters as design of the instrument approach chart, inadequate maintenance instructions and lack of pilot training, to the abolition of the Safety Manager position.

Causality

Some of these features (such as the faulty design of the instrument approach chart) were not discovered at all by the official investigation; others (such as the abolition of the Safety Manager position) were observed, but their significance as causal factors was not appreciated. In general, too, the matters examined by WBA are different in kind from those examined by MES: these two formal analytical methods are complementary.

A major point of difference between the official report and the WBA analysis is the number of causal factors. In the official report there were just six causal factors, and all concerned 'failures' by the pilots. The WBA revealed a multitude of causal factors, all of them necessary for the accident to happen. Very few were related to the pilots' actions or inactions: in general they related to underlying factors such as maintenance or training, or to Company structure (the abolition of the Safety Manager position).

The different view of causality puts the pilots' part in the accident in a very different light. Far from being negligent, with non-existent monitoring and Crew Resource Management (CRM) skills, the Captain assigned the flying task to himself so that the First Officer could attend to the emergency (necessary because the emergency controls could only be reached by the First Officer). Subsequently he monitored the First Officer's actions, and detected the error in the emergency action sequence. These actions could be regarded as good CRM.

The decision to attempt to correct the undercarriage failure while continuing the approach was in accordance with the company's (unofficial) procedure, sanctioned by the Operations Manager, and undoubtedly known among the pilots of the very small Dash 8 fleet. In short, the pilots were doing exactly what the Company expected them to do.

The accident causation can be traced back to policy decisions – engineering economies, training economies, and removal of the monitoring function provided by the Safety Manager.

Safety Recommendations from WBA

WBA can generate recommendations relating to causality – ‘why it happened’ – on specific matters, such as:

- The confusing approach plate and checklist, leading to a recommendation for continuation training
- The painted radar altimeter radome, leading to some means of testing the GPWS
- The early start to the crew roster
- Mandating the existence of a Safety Department

These are different in kind from recommendations derived from MES. MES gave rise to a recommendation on fuel tank inerting, which is an intervention based on ‘what happened’ – a wing was blown off by a fuel-air explosion.

While the designation of the abolition of the Safety Manager position as a core problem shows that a recommendation made in this area would have a wide impact, it may not be usual for WBA to highlight core problems in this way. (See, for example, the WB Graph of the Cali disaster in Gerdsmeyer et al., 1997). In general, a WBA will discover many causal factors, all of them necessary to the occurrence of the accident. Unless core problems are discovered, WBA may give little clue as to which of the many causal factors it would be profitable to address.

The discovery of core problems, and the effective elimination of undesirable effects, is the province of the Theory of Constraints (TOC), which will be examined next.

Theory of Constraints

The TOC methodology starts with listing the various undesirable effects which have been discovered during prior analysis, such as MES and WBA. The logical

linkages between these undesirable effects are then sought, and a network of interacting conditions, the Current Reality Tree (CRT), is generated. The TOC postulates that there will be a single underlying core conflict which gives rise to most or all of the undesirable effects observed, and eliminating this core conflict will also remove the undesirable effects. Attention can therefore be focussed on the major corrective action, rather than being spread over attempts to deal with the undesirable effects individually. In reality, a number of core problems may be found, but the principle remains the same.

From the CRT, a Future Realty Tree (FRT) is generated. 'Injections' (interventions to remove the conflicts which have set up the core problems) transform the undesirable effects into the opposite, desirable effects. Additional injections may be required in the course of implementation of the required changes. The injections, being the means for bringing about desired changes, are the basis for the Safety Recommendations.

Two CRTs and corresponding FRTs were generated in the course of this study: one set for the Company, and one for the Civil Aviation Authority.

Insights into the Problems at Ansett (NZ) from TOC

Ansett was set up as a full-service airline in opposition to the established carrier, Air New Zealand. Air New Zealand set out to preserve its market, and was well able to do so by aggressive price cutting, cross-subsidised from its profitable international operation. The result was that Ansett (NZ) never made a profit ("Ansett loss announcement", 1995), and came under pressure from its Australian parent company to become profitable. The solution which Ansett adopted was to seek savings across all departments (*ibid.*), since any price cuts to attempt to increase market share would simply be matched by Air New Zealand.

The company's policy appears to have been reflected in the actions of the staff. The Engineering Department decided that replacement parts to remedy a defect in the undercarriage were too expensive. The Training Department appear to have decided that it was not necessary to teach pilots emergency procedures; certainly the

First Officer on the accident flight had never practiced, or even been shown, the emergency procedure for lowering the undercarriage.

The decision to abolish the Safety Manager position was most likely also a cost-cutting exercise, though this could not be verified from the available evidence. It removed the Company's principle source of 'mindfulness' (Weick & Sutcliffe, 2001). The opportunity to monitor the undercarriage defects, the pilot training programme, and the interaction between the two, was lost. The net result was that crews were increasingly exposed to an emergency condition in which they were not trained, and the Company's implicit policy of attempting to correct the condition while continuing the approach gave them no protection.

The failure of the GPWS, though probably caused in this instance by the paint on the radar altimeter aerial radome, was a generic problem which was unlikely to have come to light in any airline, given contemporary testing methods. A general Airworthiness Directive is needed, to ensure that deterioration of the radar altimeter performance for any reason can be detected and rectified in good time.

Safety Recommendations from TOC: Ansett FRT

The Safety Recommendations in respect of Ansett's structure and performance are directed to the CAA rather than to the Company, because in view of the Company's financial situation, it would probably be necessary for the CAA to enforce appropriate actions. It would be possible for the Company itself to generate actions directed to improving its financial performance, but it would not be appropriate for either the investigators or the CAA to make such recommendations.

It is highly improbable that Ansett would have another CFIT accident involving undercarriage malfunction. Safety Recommendations should therefore be generic, addressing foreseeable problems both at Ansett and at other airlines.

Since the problems at Ansett centred around the absence of a Safety Department, a high priority must be to ensure that no airline could make a decision to abolish its Safety Department in future. Likewise, there need to be requirements for simulator training for aircrew. Also, there need to be requirements, probably best written into the Operations Manual, dealing with communications between

departments. While it had no doubt previously seemed unnecessary to mandate a go-around when an emergency was encountered on approach, this accident has shown that this, too needs to be specified.

The following Safety Recommendations were generated by the TOC analysis:

To the CAA, in respect of airline safety:

1. Safety Management:

- a. The CAA perceives that the Safety Department benefits the public by increasing the safety of air travel, and mandates its existence in all airlines
- b. The Safety Manager position and functions are mandated by regulation
- c. The Safety Manager must be an “approved person”
- d. The CAA audits the Safety Department against stated performance criteria
- e. The Maintenance Controller is trained in safety management, and initial review of events within the Engineering Department is delegated to him, with notification to the Safety Manager
- f. Airlines have a formal policy that decisions on safety implications by one Department must not be considered in isolation from other Departments

2. Simulator Training

The CAA recognises the need for simulator training in emergency procedures and Crew Resource Management, and mandates its use in airlines

3. Abnormal Operations

- a. Operations Managers are required to review abnormal operations, for training implications
- b. Airlines have a formal requirement for a missed approach when emergencies are encountered on approach

4. Ground Proximity Warning Systems

Radar altimeters related to Ground Proximity Warning Systems are tested in situ.

Insight into the Problems at the CAA, from TOC

The core problem which sits at the centre of the CAA CRT, like a spider in its web, is the policy decision to restrict audits primarily to a review of documentation. This decision had resulted from a long-term problem of insufficient qualified staff to perform all the oversight activities that might be desirable, and this in turn stemmed from inadequate funding. The CAA interpreted the general Government policy of ‘user pays’ to mean that it had to charge the airlines for safety oversight. The airlines were reluctant to pay for this, so it was also CAA policy that safety oversight had to be ‘cost-effective’. In practice, this meant that preparation for audits was minimal.

Absence of surveillance of airline operations, and lack of review of the airlines’ own safety management systems, meant that the CAA deprived itself of mindfulness in important respects. It did not really know what went on during flight operations; its auditors did not even know that the Safety Manager position had been abolished. The accident caught the CAA completely by surprise. However, had the CAA known what was really going on, this accident with its many precursor events ought to have been readily averted. Accordingly, Safety Recommendations to the CAA are directed to ensuring that it can achieve mindfulness.

Safety Recommendations from TOC: CAA FRT

The TOC analysis enables the CAA to break its mindset that funding for safety oversight had to come from the airlines. By redefining the ‘user’ as the travelling public, a small levy on tickets would have fallen within Government guidelines. This would have provided adequate funding for all the safety oversight activities necessary to achieve mindfulness. Accordingly, the principal Safety Recommendations concern CAA funding, recruitment of qualified staff, and the various activities that the CAA ought to undertake.

The following Safety Recommendations were generated by the TOC analysis:

To the CAA, in respect of its own operations:

1. Funding

The user of CAA services is defined as the travelling public

2. Safety Management

- a. A Safety Case is required for airline operations
- b. The CAA requires that all operations are acceptably documented, and conducted in conformance with the airline's documentation, and Inspectors are required to check that this is so
- c. The CAA seeks power to stop an airline operating, if identified deficiencies are not remedied

3. Safety Oversight

- a. Appropriate safety oversight procedures are designed and implemented, including surveillance, auditing, and review of Safety Management Systems
- b. The CAA monitors airline's financial reports

4. Public Relations

The CAA's role and work is publicised.

The recommendations arising from the TOC analysis deal with underlying systemic factors which potentiated the accident, and are generic: they relate to all airlines or CAA operations, rather than to the specific accident being analysed.

System Safety Concepts

Reason's 'Swiss cheese' analogy, wherein an accident is considered to happen when weaknesses in various parts of the system coincide, does not appear to fit the structure of this accident. There was very little that could be construed as defence in depth, although the defective GPWS was a failed defence. Stretching a point, the abolition of the Safety Manager position could be seen as removing a defence, but these two weaknesses do not look very much like the alignment of holes in slices of Swiss cheese. It may be that attempting to force the facts of an accident to fit some a priori concept is not very productive. While the core problems identified may be seen as latent failures, it is difficult to see how Reason's comparison with pathogens in a body is helpful. A better analogy might be that the core problems are like tumours,

spreading their tentacles through the body, and triggering more tumours: like tumours, the core problems need to be excised if the body is to survive.

An alternative analogy (D. Harris, personal communication, 2003) would be to consider the company as a supposedly fail-safe engineering system. In a fail-safe system, the primary structure normally carries the load, but there is a secondary structure to carry the load should the primary structure fail. There must also be a warning system to indicate that the primary system has failed, so that it can be repaired. In this accident, the primary structure was the Engineering Department, which should have produced a serviceable aircraft for the pilots to fly. This system failed, and the aircraft was not serviceable. The warning system should have been the Safety Management system, but this had been abolished. The secondary structure was the pilots, who should have been able to cope with an undercarriage malfunction. Due to lack of training of the First Officer, the secondary structure failed. There was a further back-up structure, the GPWS, but unknown to anyone this had already failed.

However, the primary virtue of the TOC methodology is that it does not require any a priori concept of the accident structure. It represents the system as it is, regardless of any heuristic, and sets out to remove undesirable effects by making practicable changes. It then demonstrates that the proposed changes should indeed produce the results desired. In these characteristics, it is unique.

Summary of Comparisons

The official report has been shown to have weaknesses in terms of factual information, either not gathered, or not appreciated, or (as with the fatigue information) simply wrong. Its analysis of causation found that the pilots had been professionally negligent. This view resulted in the trial of the Captain for manslaughter, but the jury rejected the charge and he was found not guilty.

MES analysis resulted in a better understanding of the impact sequence, corroborated by factual information. This in turn resulted in a quite different understanding of the survivability of the accident, and an important safety

recommendation (inerting of fuel tanks) would have resulted. However, MES could not (and was not designed to) analyse systemic issues.

Compared with the official report, WBA resulted in a completely different understanding of causation, in which the crew played little part. Their actions were shown to be, in essence, what the Company required in the circumstances. An ill-judged change to Company structure, in the removal of the Safety Manager position, was shown to have been a core problem: there was no-one 'minding the shop'. This analysis was used in the passengers' action against the Company; the Company settled out of court. However, WBA may not usually indicate core problems, and if it does not, the large number of causative factors may result in difficulty in deciding which factors to address. This is the province of TOC analysis.

TOC analysis of this case (in reality, two related analyses of the Company and the CAA) showed that, in this case study at least, it was able to function as intended by showing the core problems. The injections needed to transform the CRT to a FRT form the basis of Safety Recommendations which should be effective, and these have been tested in the FRT. The small number of clusters of recommendations should focus attention on effective changes, rather than dispersing effort. Because managers are accustomed to working with flow charts, the case for the necessary changes should be readily understood.

The TOC analysis showed that the company's troubles were deep-rooted, and in the main stemmed from management decisions. However, until the last moment the accident was not inevitable: there had been ten precursor events, from which the outcome was benign. The difference in the case of the accident was a series of stochastic events: the Captain misunderstanding a new approach chart, the undercarriage malfunction occurring at about the time when the aircraft reached the desired glideslope, and the condition that the aircraft was and remained in cloud. This gives rise to the concept of *potentiation*. All the previous conditions such as faulty maintenance and lack of training potentiated the accident, but it was not inevitable until the stochastic factors flipped the system from 'unsafe' to 'accident sequence'. This concept may improve the understanding of causality, which appears to have troubled the official investigators.

None of this is to suggest that the official investigators were incompetent. They were respected Inspectors of Air Accidents, with many years of experience. What they lacked were the tools to analyse a complex accident.

Chapter 9: Discussion

Each of the chapters on the embedded case studies concluded with discussion of the appropriate element of the thesis. Those individual discussions were considered in Chapter 8, Comparison of Methodologies, and those matters are considered only briefly here. The embedded case studies will be put into the overall context under four headings:

1. The value of the formal analytical methods, as compared to the intuitive approach to analysis, and
2. The contribution that the Theory of Constraints methodology can make to accident investigation,
3. The relationship between the three formal methodologies considered, and
4. The benefits of a multi-framing approach to analysis.

Finally, lessons learnt from the work in this thesis will be adumbrated; in particular, ways in which the presentation of information could be improved.

The Value of the Formal Analytical Methods

It would appear to be a truism that, in order to learn lessons from an accident or incident, it is first necessary to understand what happened, though this is not universally accepted (Walker, 2003; Hollnagel 2001, 1999). The fallacy that useful safety recommendations can be made without first understanding the accident sequence is illustrated by the failure of the official investigation to disclose the inverted impact. The inverted impact was the reason for the severity of the injuries in what should, by a lucky circumstance of geography, have been a moderate and completely survivable impact sequence. Lack of understanding of the impact sequence prevented the official investigation from producing any useful recommendations to improve survivability, which in this case would have endorsed the NTSB's call for fuel tank inerting (NTSB 2004).

The understanding of parallel sequences and their interaction would have made only minor improvements to the official report in regard to the pre-impact

sequence of events. However, the official report was deficient in dealing with the post-impact sequence. Aside from the inverted impact, there are internal contradictions within the official report, and unsubstantiated assumptions such as the assumption that torsional forces could have split the cabin floor longitudinally.

Multilinear Events Sequencing

Multilinear Events Sequencing, by its insistence on finding logical linkages between events, has the potential to show where additional evidence needs to be sought, in order to make those linkages. Further, the disciplined use of language which MES requires prevents obfuscation from concealing lack of knowledge. Accordingly, had MES been used in the course of the official investigation, the deficiencies therein should have been brought to light while the information was still available to be gathered, to correct these deficiencies.

The MES rules stipulate that only events may be considered. However, in this case study where MES is being used as a means of depicting ‘what happened’, as an alternative to the present written presentation, it was found helpful to introduce some ‘conditions’ (in the sense of ‘a continuing state of affairs’). These conditions, being a departure from the strict rules of MES, have been indicated by flagged boxes. No disadvantage was found to arise from this innovation, which was found more convenient than alternatives such as a commentary line on the graph. Flagged boxes could also be used should other departures from the rules be desirable, such as the use of negatives where these have been established as facts.

Why-Because Analysis

The findings of causation in the official report amounted to findings of professional negligence against the pilots. This may have been the reason that Ansett initially sought to defend itself against claims by surviving passengers and the personal representatives of the deceased: if the pilots were held to blame, then the Company could not be blamed. Likewise, the Police sought to prosecute the pilots. The prosecution of the co-pilot was abandoned at an early stage, but the Captain was prosecuted for manslaughter.

As R. Howard (personal communication, 2004) has pointed out, application of ‘airmanship’ – which could be construed as ‘doing the right thing’ – would have resulted in the aircraft climbing to a safe height as soon as an emergency was encountered on the approach, and the potential accident would have been averted. However, this raises the question, ‘why did the pilots not initiate a climb to a safe altitude?’ Since the pilots can be assumed to have intended to land the aircraft safely, it is likely that they did not perceive a hazard in what they were doing. The alternative view is that they perceived a hazard in what they were doing but judged the risk acceptable. However, there are two objections to this proposition:

1. The crew are sitting at the front of the aircraft, and will be first to arrive at the scene of an accident. Failure to visualise the consequences of an impact with terrain may be a feature of some private flight accidents, especially where inexperienced pilots are involved, but airline pilots are much more experienced (in this case, about 7000 hours flying time) and are collectively risk averse.
2. If the crew perceived a hazard, and were proceeding in the knowledge that what they were doing was dangerous but the probability of impact was low, then anything which increased that probability (such as incorrect operation of the emergency system, leading to a requirement for further corrective action) could be expected to trigger a return to normal procedure, namely a go-around.

This suggests that, to the pilots, ‘airmanship’ meant correcting the problem which was presented to them, without disrupting the flight. There is evidence that there was a company culture of taking such corrective action.

The Why-Because Analysis shows that there were many causal factors, such as fatigue arising from the very early start of the working day and preceding disrupted sleep, lack of training, and deficient maintenance: all factors within the control of the company. The analysis also indicates that there was a lack of knowledge within the company of the way in which deficiencies were building up – ‘no-one minding the shop’ – and this pointed to the absence of a Safety Manager as a core problem underlying the accident.

When these matters were put to Ansett, the litigation with the passengers was settled out of court. The prosecution of the Captain for manslaughter resulted in a verdict of 'Not Guilty' (R. v Sotheran, 2001). Accordingly, it can be said that the findings of the official report as to causation were not accepted, either in civil or in criminal proceedings.

Like MES, WBA also has a function as an indicator of deficient information. For example, the official investigation did not disclose the reason for the aircraft being high above the glidepath after completion of the turn onto final approach. Since the confusing nature of the approach plate was not identified, there was no recommendation to improve the plate, or more to the point, to discover deficiencies in documentation before a critical event occurred. Had the pilots not been confused as to the minimum altitude once the final turn was commenced, the aircraft would have been established on the glidepath on completion of the turn, with normal approach power set, and the aircraft would not have deviated substantially from the glidepath while the crew rectified the undercarriage hang-up. Since, in the absence of the confusion induced by the approach plate, the accident would not have happened, the approach plate presentation was a causal factor, but the official report did not identify it as such. The WBA pointed to the need for further information, and the potentially confusing nature of the approach plate was discovered.

The WBA is incomplete, in that other strands of analysis are needed to address such questions as rostering policy, design of approach procedures, and ATC radar monitoring. Certainly, these points would have needed to be addressed if WBA was being used in the course of an official investigation. However, the purpose of this part of the case study was to demonstrate the methodology. Investigating the additional strands would have substantially increased the length of Chapter 6, without contributing further to understanding of the methodology or of its potential value to the investigation.

The only departure from accepted WBA methodology was the presentation of the WB Graph in chronological sequence. The idea was to improve its value in 'telling the story', again as an alternative to the present written format. No disadvantage was found to result from this departure. While it is desirable to arrange the WB Graph with minimal cross-over of lines, in order to perform a formal logical

validation, software is now available which can transform the graph from the format used in this thesis, to that required by logicians, and this transformation has been made successfully (P. Ladkin, personal communication, 2003).

The Theory of Constraints

Modern theories of accident causation (e.g. Reason, 1991; Helmreich, 1990) suggest that it is necessary to look past the immediate actors – those proximately involved – to the underlying conditions that have made them act in the way that they did. Where those conditions have been put in place by corporations, it would seem desirable to look at methods designed to analyse corporate activity. The Theory of Constraints is such a methodology, and since it uses similar flow-charting methods to MES and WBA, it could readily form part of a matching suite of analytical tools, should it prove useful.

The distinguishing feature of the TOC is its ability to identify a few core problems, which give rise to all the undesirable effects within a system. To be useful as a tool in analysing accidents, therefore, it is essential that when the various undesirable effects found during an investigation are analysed with the TOC, core problems should be identified. Further, since the TOC is a change mechanism, it should be able to identify effective changes – the Safety Recommendations, which are the real output of an investigation.

When the information from the case study, already analysed by MES and WBA, was used to generate a Current Reality Tree showing the system state at the time of the accident, clear core problems were identified. It was found helpful to construct separate CRTs for each of the main players: the airline, which should have had a safe system of working, and the NZCAA, whose oversight of the airline should have assured that the airline's system was safe. The two CRTs were linked, and could, if desired, have been shown as an integrated whole. However, lessons learned about airline safety, and embodied in the Ansett Future Reality Tree were only somewhat generic, relating as they do to particular types of potentially disruptive influences such as defective maintenance and inadequate crew training. By contrast, the CAA FRT is completely generic, dealing with such matters as how safety oversight should be

defined. For this reason, it appears that the CRT parts (which are the preliminary step towards the FRTs) could with advantage be kept separate.

While fewer Safety Recommendations were generated by the TOC methodology than those generated by the official investigation, the numerical difference was less than expected. The important difference was in the type of recommendations arising from each methodology. The recommendations arising from the official report related mainly to the CFIT accident at Ansett Airlines. Some were very specific, such as sending the Safety Coordinator to overseas conferences: no doubt worthy, but of uncertain impact on the safety of Ansett's operations, and of little benefit to other airlines. Other recommendations, such as that to the CAA to 'consider' flight inspection, were so imprecise as to permit an anodyne response without real action.

The recommendations generated by the TOC were, by design, generic. In the airline section, recommendations to the CAA were designed to avert all similar accidents at all airlines. The recommendations to the CAA in respect of its own operations showed it how to address its fundamental problem – funding – and how best to use its new-found freedom from excessive financial constraints.

The TOC analysis disclosed fundamental problems which were completely beyond the scope of the official report, the inadequate funding of the CAA being an example. While these problems remained unaddressed, the undesirable effects arising from them could recur in one form or another. It was therefore necessary to find and excise such 'tumours', in order to improve the safety of operations in the future.

The Relation Between the Three Formal Methodologies

While MES and WBA might be seen as competing methodologies, this case study has demonstrated that, in reality, they are complementary. This is because they operate at different levels of abstraction.

MES is concrete: it deals with events (almost) exclusively. It is intended to focus the investigator's attention on what happened, a very necessary focus in the early stages of an investigation. MES, or some similar time-line method, is an

essential in any investigation. The recommendations derived from MES analysis will also be concrete, by the nature of MES. In this case study, the recommendation derived was that fuel tank inerting should be pursued, to prevent fuel-air explosions.

In straightforward accidents it may be sufficient to know what happened, in which case MES alone would suffice. However, in more complex accidents the causation may be far from obvious, as demonstrated by the different understanding of causation shown in this case study, between the official report and the WB Analysis.

WBA, dealing with both events and conditions, is more abstract than MES, and its findings and recommendations are likewise more abstract. In this case study, the finding that the absence of the Safety Manager position allowed a variety of other undesirable effects to occur unchecked would lead to a recommendation that the position should be reinstated. Note that such a recommendation would be specific to Ansett, and indeed would probably be made to them. The question of how to ensure that such a recommendation produced practical effects is not addressed. How to produce results is not the function of WBA; that is the province of the TOC.

The TOC is still more abstract than WBA, since it deals (almost) exclusively with underlying conditions. In the Ansett case study, the problems both at Ansett and at the CAA are shown to derive from funding constraints. In the case of Ansett, those funding constraints could not be addressed by any action open to the investigators or the regulatory authority. Accordingly, leverage points higher in the tree were found and addressed. These gave rise to generic recommendations, such as 'The CAA mandates the existence of a Safety Department in all airlines'. In the case of the CAA itself, its funding problem was amenable to action, though the CAA had not realised it. With this fundamental problem addressed, the CAA could direct its attention to doing its job effectively.

Multi-Framing

Mabin and Davies (2003) have suggested that using several methodologies to address a problem can be advantageous. This case study illustrates the benefits of a multi-framing approach in the investigation of a complex accident. Each approach produces quite different recommendations, as well as providing a foundation for the

succeeding analyses. For example, the TOC would not lead to the discovery of the fuel-air explosion: the TOC analysis is too abstract to bring such matters to light. WBA might have done so, though there was no obvious prompt to consider the wing failure. However, the effect of abolishing the Safety Manager position was clearly evident from the WBA, but could not be discovered by MES.

The TOC analysis was prompted, by the WBA, to include the absence of the Safety Department, when this matter might not otherwise have been addressed. On the other hand, such matters as the false assumption underlying the CAA funding difficulty were readily discernable by TOC analysis, but might not have been addressed by WBA.

The different types of recommendations arising from the different levels of formal analysis illustrate the benefits of multi-framing, as advocated by Mabin & Davies (2003). None of the proposed analytical tools will suffice, on its own, in analysing a complex accident. In a simple case, it may be enough to know *what* happened, and MES will provide this knowledge. In a more complex case it will undoubtedly be necessary to understand *why* the accident came about, and WBA can analyse causality. This may be enough to generate the necessary corrective action. However, as this case study has shown, there will be complex accidents where knowing *why* is not enough. In order to find the necessary corrective actions, we need to understand and resolve the underlying conflicts which potentiated the accident, and for this we need the TOC. As Mabin & Davies (2003) have suggested, multi-framing gives more insights than can any one analytical method on its own. The use of a suite of logical tools appears to be the way to improve the quality of safety recommendations generated by an accident investigation.

In summary, the three formal methodologies studied form a complementary suite of analytical tools of progressively increasing abstraction. The more complex the accident, the higher is the level of abstraction that may be needed to understand it and devise effective remedies. Multi-framing is beneficial both in prompting examination of various points at progressively higher levels of abstraction, and in producing a variety of insights which might not be achieved by any one method alone.

Comprehensibility of Reports

It was expected that the logical presentation of data would lead to a more readable report than the scattered arrangement of information in the standard ICAO format. However, the presentation of the graphs poses some difficulty. When these were constructed for analytical purposes, some of them were quite large (e.g., 3 x 2, A3 sheets) and these cannot be reduced legibly to a normal-sized page. Hence the format adopted in this thesis was devised, where the detail of sections is shown legibly on the graph where possible, or by key where that cannot be achieved, and then an overall diagram shows the linkage between sections. However, the real problem is the amount of detail being shown on the graphs. This detail is needed to provide sufficiency, for a lay audience. Were the presentation to be made solely to a professional aviation audience, it would be possible to use 'long arrows', that is, the detail between rather widely spaced boxes could be taken as read. For example, in the Skyferry accident (Carruthers, 1988) the immediate detail before the accident could probably be reduced to

'Heavy ice accretion \wedge autopilot height lock engaged \sim > stall and spin'.

For a lay audience, it might be necessary to point out that ice both increases drag and decreases lift; attempting to maintain height causes the airspeed to reduce and the nose-up attitude to increase; the airflow over the wing will ultimately break down; the aircraft will then stall and the nose will drop; with a propeller-driven aircraft under power, the aircraft will yaw at the stall; and yaw at the stall will result in asymmetric lift causing a spin.

It will thus be seen that the graphs needed to explain the analysis to a professional audience could be significantly simplified. They would then be easier to produce in legible form, and easier to follow. Since an accident report is primarily for use by professional readers, it might be that the simpler version is all that is needed. The full version could be available for reference, should supporting detail be required.

Conclusion

This case study sought answers to three questions:

1. Could the application of the methodology of the Theory of Constraints, to the data from an accident investigation, discover underlying core problems? If so,
2. Can the Theory of Constraints methodology generate improvements (i.e. Safety Recommendations) likely to be more effective than those generated by traditional analytical methods? If so,
3. Whether the use of a suite of formal tools is likely to bring about an improvement in the effectiveness of accident investigation.

The answer to the first question is yes. The information from the accident chosen could be put into Current Reality Trees, depicting the situation that led to the accident. The accident chosen for the case study was not selected on the basis of its apparent suitability for this method of analysis, but because much more detailed information was available than is generally the case. There is no evident reason why the information from any other accident should not be put into the form of a Current Reality Tree. The Current Reality Trees from this accident show that a few core problems were at the root of the many undesirable effects disclosed by the investigation.

The answer to the second question has also been shown to be yes. Conflict Resolution Diagrams indicated ways to address the deep-seated conflicts which set up the core problems. The injections necessary to break these core problems, as demonstrated in the Future Reality Trees, provide the clusters of Safety Recommendations which invalidate the underlying conflicts, and ensure the implementation of the necessary changes. The Future Reality Tree demonstrated that those Safety Recommendations should be effective in averting similar accidents, not only at the airline involved, but at other airlines in general. By contrast, as discussed below, the Safety Recommendations from the official investigation were of limited utility.

Thirdly, it has been shown that the multiple perspectives arising from the use of a suite of methodologies gives a broader insight into the accident than could be obtained by any one method used on its own.

The official investigation of this accident was performed by a group of very experienced investigators, using traditional intuitive methods of analysis. The examination of the same data that was available to the official investigators, but using formal methods of analysis, has shown that the official investigation was in some instances wrong in its observations (by omission, and by inaccurate observation). Some of the conclusions in the official report were also incorrect. In some areas, Safety Recommendations were not made where they could have been, and some recommendations that were made were unlikely to avert future accidents.

This is not to say that the official investigators were incompetent, but that they lacked the tools with which to gather and understand the available information. The suite of formal analytical methods used in this case study provides suitable tools, and their use should improve the quality of future accident investigations.

Implications for the TOC Field

The purpose of the study did not include developments in the TOC field expressly, but three matters became evident.

1. Firstly, the TOC graphs have generally been considered to be in the nature of a snapshot: production volume of components and sub-assemblies is improved; in another part of the works a bottleneck is encountered, and downstream there are inadequate supplies. These are treated as concurrent effects, and indeed they may well be. However, these are causal trees, and proceed-follow logic dictates that the CRT and FRT have an implicit time-base. If A caused B, then A necessarily preceded B. In an accident, or indeed an incident in any dynamic environment, the time-base is explicit. We talk of 'events sequencing'. Using this concept proved to have advantages both in the initial layout of the CRT (since position along the time-line was usually easy to establish) and in testing the logic. It might be advantageous if the use of an explicit time-base was made general.
2. Second, the limitation of the sorts of recommendations that could properly be made by an official investigating agency caused some difficulties in applying TOC methodology. The FRT is normally used

to enable a company to improve its commercial performance. In the case of accident investigations, that would not be proper, yet those were the sorts of recommendations coming from the usual methods, such as seeking underlying problems by generating particular conflict diagrams and seeking to generalise them. When this difficulty became apparent, it was necessary to revert to the older method of seeking to transform the CRT by injections to remove the undesirable safety effects. It was then possible to ignore the commercial changes which might be made, but which were 'off limits' to a Government agency. The resulting FRT did not conform to the standard requirement that there should be no remaining Undesirable Effects, since undesirable commercial effects remained. Indeed, this is part of a more general truth, since some undesirable effects can never be eliminated: design error, for example, will always be with us, and what is important is that our systems should acknowledge this and be able to deal with it before a disaster results.

3. In the TOC literature, the definitions of core problems are arbitrary. The definition of core problems in this thesis, as those problems from which the maximum number of effect lines radiate, is new and provides a rational basis for selection.

Implications for the Practice of Air Accident Investigation

The primary implication for the practice of air accident investigation is that conventional (informal) methods of analysis are demonstrably unsatisfactory. When applied in this case by very experienced investigators, they resulted in

- Information being missed or misinterpreted
- Important recommendations not being made (for example, fuel tank inerting and GPWS testing), and
- Logical failures which ascribed to the pilots improper motivation which could not be substantiated.

The underlying corporate effects – the 'backtracking' advocated by Reason (1991) – were not identified. It is doubtful if any of the recommendations could have had any

effect beyond the immediate confines of Ansett (NZ). The case study shows that the use of a formal suite of tools could generate recommendations likely to improve safety in airlines generally. However, in order to use formal logical tools, it is necessary that investigators be trained in logical analysis. This represents a radical departure from traditional training methods, which deal with physical techniques such as fracture analysis, and are largely apprenticeship based.

Limitations

This study has not established generality. While the present author reached the conclusions about this particular accident using the stated methods, it is possible that the author could have come to the same conclusion regardless of the methods used. Alternatively, other investigators using these methods might have come to other conclusions. However, it was not the intention of this study to establish generality: the object was exploratory – *could* the proposed methodology produce useful results. Further study to establish generality would be highly desirable.

Further Study

No major obstacles were encountered in applying the methodology of the Theory of Constraints to the facts of the case, and there is no reason to suppose that this methodology is not generally applicable. However, the external validity would be enhanced by testing on at least one other accident, and desirably by other investigators trying it in the field in the course of an accident investigation.

There are very few accidents which have been officially reported where the depth of information available is such as to permit retrospective analysis of the kind used in this case study. One accident which does appear to fit the requirements is the Air Ontario F 28 accident at Dryden, investigated by the Moshansky Commission of Inquiry (Moshansky, 1992). A retrospective analysis of this accident could improve confidence in the generalisability of the conclusions drawn from the present study. In addition, the author is seeking to persuade investigators to try these formal analytical methods in the course of an investigation.

The complexity of an accident, as presented in a CRT, may be daunting to readers. Rasmussen's (1997) Accimaps, which seek to map the cultural factors underlying accidents, appear to be a different representation of the same things. The TOC seeks to find underlying policies, measures and behaviours behind core problems, and these are the visible manifestations of culture. The difficulty with Accimaps is in proving the logic, but they are not complex, and are therefore relatively simple for readers to follow. By contrast, a CRT is complex and more difficult for a reader to follow, but it can be exactly validated. If it could be shown (perhaps by analysing the same accident using both methodologies) that the two were congruent, then the Accimap could be validated by construction of a CRT, and the results could be presented using the Accimap.

References

- AAIB. (1988). *Report on the accident to Boeing 737-236 G-BGJL at Manchester Airport on 22 August 1985* (Aircraft Accident Report No. 8/88). London: HMSO.
- ACRC. (1996). *Controlled flight into terrain, American Airlines Flight 965, Boeing 757-223, N651AA, near Cali, Colombia, December 20 1995*. (Aircraft accident report): Aeronautica Civil of the Republic of Colombia.
- Agnew, N. M., Ford, K. M., & Hayes, P. J. (1997). Expertise in context: Personally constructed, socially selected, and reality-relevant? In P.J. Feltovitch, K.M. Ford & R. R. Hoffman (Eds.), *Expertise in context* (pp. 219-244). Cambridge, Massachusetts: MIT Press.
- AIA Conference Report. (1994). *New Zealand Wings*, September 1994, 14.
- AIB. (1976). *DC-10 (series 10) aircraft TC-JAV, near Orly (translation from the French BIA report)*. (Aircraft Accident Report No. 8/76). London: HMSO.
- Air Services Licensing Act (1983).
- Ammerman, J. W. (1998). *The root cause analysis handbook*. New York, NY: Quality Resources.
- Ansett (NZ). (1992). Ansett Technical Instruction. Christchurch: Ansett (NZ) Engineering department.
- Ansett (NZ). (1993a). *Ansett Defect Investigation Report* (Defect Investigation Report No. 33/93). Christchurch: Ansett (NZ).
- Ansett (NZ). (1993b). *Ansett New Zealand Flight Operations Policy Manual* (Vol. Section 6 - Flight Safety Programmes). Christchurch: Ansett (NZ).
- Ansett (NZ). (1993c). *Maintenance log, ZK-NEY*. Christchurch: Ansett (NZ) Maintenance.
- Ansett (NZ). (1994a). *Ansett Service Information Evaluation And Action Record* (Note of Action No. SBB-32-98). Christchurch: Ansett (NZ) Engineering Department.
- Ansett (NZ). (1994b). Memorandum. Christchurch: Ansett (NZ).
- Ansett (NZ). (1995). *Post Accident Review* (Memorandum). Christchurch: Ansett (NZ).
- Ansett (NZ). (1996). Memorandum. Christchurch: Ansett (NZ).
- Ansett (NZ). ((n.d. a)). DHC-8 Line Training File, First Officer Brown. Christchurch: Ansett (NZ).
- Ansett (NZ). ((n.d. b)). DHC-8 Line Training File, Captain Sotheran. Christchurch: Ansett (NZ).
- Ansett (NZ). ((n.d. c)). *Ansett Post-Accident Review, Engineering Report*. Christchurch: Ansett (NZ) Engineering Department.
- Ansett announcement. (1994). *New Zealand Wings*, October 1994, 4.
- Ansett Captain. (1988). *General Flight Report* (Undercarriage malfunction). Christchurch: Ansett (NZ).
- Ansett Captain. (1993). *General Flight Report* (Undercarriage malfunction). Christchurch: Ansett (NZ).
- Ansett Captain. (1994). *General Flight Report* (Undercarriage malfunction). Christchurch: Ansett (NZ).
- Ansett Captain. (1995). *General Flight Report* (Undercarriage malfunction). Christchurch: Ansett (NZ).
- Ansett Loss Announcement. (1995). *New Zealand Wings*, January 1995, 4.

- Arbon, E. R., Homer, L., & Feeler, R. A. (1998). *The practice of aviation safety* (2nd ed.). Alexandria, VA: Flight safety Foundation.
- ATSB. (2001). *Boeing 747-438, VH-OJH, Bangkok, Thailand, 23 September 1999* (Investigation Report No. 199904538). Canberra: Australian Transport Safety Bureau.
- Benner, L. (1975). Accident investigations: Multilinear event sequencing methods. *Journal of Safety Research*, 7(2) (June), 67-73.
- Benner, L. (1994). *Ten multilinear event sequencing guides*. Sterling, Va.: ISASI.
- Bennett, J. (1988). *Events and their names*. Oxford: Oxford University Press.
- Berliner, D. C. (1994). The wonder of exemplary performances. In J.N. Mangieri & C.C. Block (Eds.), *Creating powerful thinking in teachers and students* (pp. 161-186). Fort Worth: Harcourt Brace College Publishers.
- Boeing. (1985). *Statistical summary of commercial jet aircraft accidents, worldwide operations, 1959-1984*. Seattle: Boeing Commercial Aeroplane Company.
- Bombardier. (1994). Bombardier.
- Bombardier. ((n.d.)). All Operator Message: Bombardier.
- Bramorski, T., M. Madan, et al. (1997). "Application of the Theory of Constraints in Banks." *Bankers Magazine* Vol. 180(No. 1): 53-59.
- CAA audits. (1995). *New Zealand Wings*, April 1995, 12.
- CAA board appointments. (1994). *New Zealand Wings*, March 1994, 12.
- CAA funding. (1995). *New Zealand Wings*, April 1995, 2.
- Carruthers, D. J. (1988). *Report of a Court of Inquiry under the Civil Aviation (Accident Investigation) Regulations 1978 involving Outdoor Aviation Limited Cessna ZK-SFB near Haumuri Bluffs, Kaikoura Coast on 27 November 1987*. Wellington: Government printer.
- Carruthers, D. J. (1989). *Report of a Court of Inquiry under the Civil Aviation (Accident Investigation) Regulations 1978 involving Foxpine Air Charter Limited which occurred in the Ahu Ahu Valley, near Wanganui on 12 May 1988*. Wellington: Government Printer.
- Charles, M. (1991). *Selling the product of the human factors investigation*. Paper presented at the 22nd International Seminar of the International Society of Air Safety Investigators.
- Chivell, W. C. (2003). *Finding of inquest (Coroner's inquest)*. Adelaide: Coroner's Court.
- Civil Aviation Act. (1990).
- Clausewitz, C. v. (1874). *On war* (J. J. Graham, Trans.).
- Conan Doyle, A. T. (1987). *Sherlock Holmes: The Long Stories*. Leicester: Galley Press.
- Congress, U. S. (1974). *Oversight Hearings on the DC-10 Aircraft Committee* (Senate Oversight Committee Report). Washington: United States Congress.
- Dawson, D., A. Feyer, et al. (2001). *Fatigue expert group: options for regulatory approach to fatigue of drivers of heavy vehicles in Australia and New Zealand*. Canberra, Department of Transport and Regional Services.
- Dekker, S. W. A. (2004). Why we need new accident models. *Human factors and aerospace safety*, 4(1), 1-18.
- Deming, W. E. (1993). *The new economics for industry, government and education*. Cambridge, Massachusetts, MIT Centre for Advanced Engineering Study.
- Dettmer, H. W. (1997). *Goldratt's theory of constraints: A systems approach to continuous improvement*. Milwaukee: Quality Press.

- Dettmer, H. W. (1998). *Breaking the constraints to world-class performance*. Milwaukee, American Society for Quality.
- Dinges, D. F. (1995). *Performance effects of fatigue*. Paper presented at the Fatigue Symposium.
- DITR. (2003, 17 October 2003). Introduction to the safety case concept. Retrieved 4 August 2004, 2004, from <http://www.industry.gov.au/content/itritnet/cmscontent.cfm?objectID=84DD4268-9C12-4309-B46A5721BD194650>
- DOE. (1999). *Accident investigation workbook*. Washington, DC: Department of Energy.
- Ericsson, K. A. (1996). The acquisition of expert performance: An introduction to some of the issues. In K. A. Ericsson (Ed.), *The road to excellence: the acquisition of expert performance in the arts, sciences, sports and games* (pp. 1-50). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Ferry, T. S. (1988). *Modern accident investigation and analysis*. New York, NY: John Wiley and Sons.
- Filotas, L. (1991). *Improbable cause*. Toronto: McClelland-Bantam.
- Fine, W. T. (1976). A management approach in accident prevention. Silver Spring, MD: Surface Naval Weapons Centre.
- Fleming, J. G. (1992). *The law of torts* (8th ed.). Sydney: The Law Book Company Ltd.
- Flight Safety Foundation. (1998). *The practice of aviation safety - observations from flight safety foundation safety audits* (Second ed.): Flight Safety Foundation.
- Garner, K. M. and R. N. Bailey (1992). *Using constraint management to reduce congestion in a fracture clinic: preliminary analysis*. Wellington, New Zealand, DSIR Physical Sciences Applied mathematics group.
- Gemmell, I. (1995). *Observations and recommendations of Ansett New Zealand's flight operations* (Post-accident review). Christchurch: Ansett (NZ).
- Gerdsmeier, T., Ladkin, P. B., & Loer, K. (1997). *Analysing the Cali accident with a WB-Graph*. Paper presented at the First Workshop On Human Error And Systems Development., Glasgow.
- Gertman, D. I. & Blackman, H.S. (1994). *Human reliability and safety analysis data handbook*. New York, NY: John Wiley and Sons.
- Gibb, G., & de Landre, J. (2002). *Applying Reason to safety investigation: BHP Billiton's ICAM*. Paper presented at the Human Error, Safety and System Development, University of Newcastle, NSW.
- Gibson, J. J. (1961). Contribution of experimental psychology to formulation of the problem of safety. *Behavioural approaches to accident research*.
- Goldratt, A. Y. (1998). *The Jonah Program*. New Haven, CT: Avraham Y. Goldratt Institute.
- Goldratt, E. M. (1984). *The goal*. Great Barrington, MA: The North River Press.
- Goldratt, E. M. (1987). Laying the foundation. *The Theory of Constraints Journal*, 1(2), 1-20.
- Goldratt, E. M. (1990a). *The haystack syndrome: Sifting information from the data ocean*. Croton-on-Hudson: The North River Press.
- Goldratt, E. M. (1990b). *What is this thing called the theory of constraints and how should it be implemented*. Croton-on-Hudson: The North River Press.
- Goldratt, E. M. (1994). *It's not luck*. Great Barrington, MA: The North River Press.
- Haddon, W. (1973). "Energy damage and ten countermeasure strategies." *Human factors* 15(4): 355-366.

- Hale, A. R., L. H. J. Goossens, et al. (2004). Managing safety barriers and controls at the workplace. *Probabilistic Safety Assessment & Management*. C. Spitzer, U. Schmocker and V. N. Dang. Berlin, Springer Verlag: 608 – 613.
- Harrison, Y. & Horn, J.A. (2000). The impact of sleep deprivation on decision making: A review. *Journal Of Experimental Psychology: Applied*, (6), 230-249.
- Helmreich, R. L. (1990). Human factors aspects of the air Ontario crash at Dryden, Ontario. In V. P. Moshansky (Ed.), *Final Report Of The Commission of Inquiry Into the Air Ontario Crash at Dryden, Ontario*. Ottawa: Minister of Supply and Services.
- Helmreich, R. L., & Merritt, A. C. (1998). *Culture at work in aviation and medicine*. Aldershot: Ashgate.
- Helmreich, R. L. & Merritt, A.C. (2000). Safety and error management: The role of crew resource management. In B. J. Hayward and A.R.Lowe (Eds.), *Aviation resource management* (Vol. 1, pp. 107-120). Aldershot: Ashgate.
- Hendrick, K. & Benner, L. (1987). *Investigating accidents with step*. New York: Marcel Dekker.
- Hendrick, K. M., Benner, L., & Lawton, R. (1987, April 27-30, 1987). A *methodological approach to the search for indirect (human) events related to mishaps*. Paper presented at the 4th International Symposium on Aviation Psychology, Columbus, OH.
- Hill, S. G., Harbour, J. L., Sullivan, C., & Hallbert, B. P. (1990). Examining human-system interactions: The HSYS methodology., *Human Factors Society 34th annual meeting* (pp. 1186 - 1194). EG&G Idaho, Idaho Falls, Indiana.
- Hills, B. (1989). *Blue murder - two thousand doomed to die*. Melbourne: Sun Macmillan.
- Hinnenburg, P. A., W. Lynch, et al. (1996). *Lean logistics*. APICS Constraints Management Symposium and Technical Exhibit, American Production and Inventory Control Society.
- Hirschfeld, A. H., & Behan, R. C. (1963). The accident process. *Journal of the American Medical Association*, 186(October), 193-199.
- Hoehl, M., & Ladkin, P. B. (1997). *Analysing the 1993 Warsaw accident with a WB-Graph*. (Technical Report No. RVS-Occ-97-09). Bielefeld: RVS Group, University of Bielefeld.
- Hollnagel, E. (1999). *Accidents and Barriers*. Les Valenciennes, Valenciennes, Presses Universitaires de Valenciennes.
- Hollnagel, E. (2001). *Barrier Analysis and Accident Prevention*. Human and Organisational Risk Management Workshop, NASA Ames Research Centre, Human factors and technology division.
- ICAO. (1970). *Manual of aircraft accident investigation*. Montreal: International Civil Aviation Organisation.
- ICAO. (1984). *Accident prevention manual* (1st ed.). Montreal: International Civil Aviation Organisation.
- ICAO. (1993). *Procedures for air navigation services - aircraft operations (PANSOPS)* (Vol. Volume 1: Flight Procedures; Volume 2: Construction of Visual and Instrument Flight Procedures). Ottawa: International Civil Aviation Organisation.
- ICAO. (1994). *Aircraft accident investigation: Annex 13 to the convention on international civil aviation* (8th ed.). Montreal: International Civil Aviation Organisation.

- ICAO. (1995). *Manual of procedures for operations inspection, certification and continued surveillance* (4th ed.). Montreal: International Civil Aviation Organisation.
- ICAO. (1999). *The establishment and management of a state's safety oversight system* (First ed.). Montreal: International Civil Aviation Organisation.
- ICAO. (2000). *Convention on International Civil Aviation* (8th ed.). Montreal: International Civil Aviation Organisation.
- Johnson, C. W., Wright, P. C., & McCarthy, J. C. (1995). Using a formal language to support natural language in accident reports. *Ergonomics*, 38, 1264-1282.
- Johnson, C. W. & Botting, R.M. (1999). Using Reason's model of organisational accidents in formalising accident reports. *Cognition, Technology and Work*, 1999(1), 107-118.
- Johnson, W. G. (1973). *MORT, the management oversight and risk tree*. Washington: Atomic Energy Commission.
- Johnson, W. G. (1975). MORT: The management oversight and risk tree. *Journal of Safety Research*, 7(1), 4-15.
- Johnson, W. G. (1980). *MORT: Safety assurance systems*. New York: Marcel Dekker.
- Kryger, H., Roth, T., & Dement, W.G. (1998). *Principles and practice of sleep medicine* (3rd ed.): Saunders.
- L'Estrange, C. H. N. (1995). *The Erebus inquiry: A tragic miscarriage of justice*. Takapuna: The Air Safety League of New Zealand.
- Ladkin, P. B. (1996). *Formalism helps in describing accidents*. Bielefeld: University of Bielefeld.
- Ladkin, P. B. (1999). *A quick introduction to Why-Because Analysis*. Bielefeld: University of Bielefeld.
- Ladkin, P. B., & Loer, K. (1998). *Why-Because Analysis: Formal reasoning about incidents*. Bielefeld: University of Bielefeld.
- Lewis, D. (1973). Causation. *Journal of Philosophy*, 70, 556-567.
- Lewis, D. (1986). Causal explanation. In *Philosophical papers* (Vol. 2, pp. 214-240). Oxford: Oxford University Press.
- Mabin, V., & Balderstone, S. (1998). *A bibliographic review of the Theory Of Constraints*. Wellington: Victoria University.
- Mabin, V. J., & Balderstone, S. J. (2003, Jan 15-16 2003). *The performance of the theory of constraints: A review of published reports of Theory Of Constraints applications*. Paper presented at the Theory of Constraints Conference 2003: Profiting from strategic constraint management, Kuala Lumpur.
- Mabin, V. J., & Davies, J. (2002). *Framing an ethical dilemma: a case for questioning identity*. Paper presented at the Western Decision Sciences Institute 31st Annual Meeting, Las Vegas.
- Mabin, V. J., & Davies, J. (2003). Framework for understanding the complementary nature of TOC frames: Insights from the product mix dilemma. *International Journal of Production Research* (Special issue on Constraints Management), 1-20.
- Mahon, P. T. (1981). *Report of the Royal Commission to inquire into the crash on Mount Erebus, Antarctica of a DC-10 aircraft operated by Air New Zealand Limited*. Wellington: Government Printer.
- Maldutis, J. (2004). Legacy airlines: Woolly mammoths or their own saviours? *Aviation Week And Space Technology*, 22 March 2004, 160, 66.
- Maurino, D. (1998). Foreword. In *Culture at work in aviation and medicine*. Aldershot: Ashgate.

- Maurino, D. E. (1999). *Implementing safety recommendations: An international report*. Paper presented at the International Seminar of the International Society of Air Safety Investigators, Boston, Mass.
- Maurino, D. E., Reason, J., Johnston, N., & Lee, R. B. (1995). *Beyond aviation human factors*. Aldershot: Ashgate.
- McDonnell. (1979). *The DCc-10: A special report*: McDonnell Douglas Corporation.
- Messier Dowty. (1995). *Ansett New Zealand accident investigation of uplock assembly* (Technical Memorandum No. DS-611): Messier Dowty.
- Mill, J. S. (1873). *A system of logic* (8th ed.). London: Longmans.
- Miller, C. O. (1991). *Down with probable cause*. Paper presented at the 22nd International Seminar of the International Society of Air Safety Investigators, Canberra.
- Miller, C. O. (1999). *Resolving the problem of action failure*. Paper presented at the International Seminar of the International Society of Air Safety Investigators, Boston, Mass.
- Moray, N. (1994). Error reduction as a systems problem. In M. S. Bogner (Ed.), *Human error in medicine* (pp. 67-91). Hillsdale: Lawrence Erlbaum.
- Morgan, J. (2001, 11 May 2001). Corroded aerial possible cause of warning fault. *The Dominion*, p. 7.
- Moshansky, V. P. (1992). *Commission of Inquiry into the Air Ontario crash at Dryden, Ontario: Final report*. Ottawa: Minister of Supply and Services.
- Mumford, E. (2001). Deadly risks in juggling. *Weekend Herald*, August 25, 2001, p. C 12.
- Munson, S. (1999). *Assessment of accident investigation methods for wildland firefighting incidents by case study method*. Unpublished Masters thesis, University of Montana.
- NTSB. (1973). *American Airlines Flight 96, Douglas DC-10(series 10) aircraft N103AA, Windsor, Ontario*. (Aircraft Accident Report No. NTSB AAR-73/2). Washington, DC: National Transportation Safety Board.
- NTSB. (1979). *American Airlines Inc. Dc-10-10, N110AA, Chicago O'Hare International Airport, Chicago, Illinois, May 25 1979* (Aircraft accident report No. NTSB-AAR-79-17). Washington, DC: National Transportation Safety Board.
- NTSB. (1988a). *Continental Airlines Inc., Flight 1713, McDonnell Douglas DC-9-14, N626TX, Stapleton International Airport, Denver, Colorado, November 15, 1987* (Aircraft Accident Report No. NTSB AAR-88-09). Washington, DC: National Transportation Safety Board.
- NTSB. (1988b). *Northwest Airlines Inc., McDonnell Douglas DC-9-82, N312RC, Detroit Metropolitan Wayne County Airport, Romulus, Michigan, August 16, 1987* (Aircraft Accident Report No. NTSB AAR-88-05). Washington, DC: National Transportation Safety Board.
- NTSB. (1989). *Delta Airlines Inc., Boeing 737-232, N473DA, Dallas Fort Worth International Airport, Texas, August 31 1988* (Aircraft Accident Report No. NTSB AAR-889-04). Washington, DC: National Transportation Safety Board.
- NTSB. (1990). Original "most wanted" list of transportation safety improvements as adopted September 1990. Retrieved 8 December, 2004, from www.nts.gov/recs/mostwanted/original_list.htm
- NTSB. (1991). *Ryan International Airlines DC-9-15, N565PC. Loss of control on take off. Cleveland Hopkins International Airport, Cleveland, Ohio, February*

- 17 1991 (Aircraft Accident Report No. NTSB AAR-91-09). Washington, DC: National Transportation Safety Board.
- NTSB. (1994). *Uncontrolled collision with terrain, American International Airways Flight 808, Douglas DC-8-61, N814CK, US Naval Air Station Guantanamo Bay, Cuba, August 18 1993* (Aircraft Accident report No. NTSB/AAR-94/04). Washington, DC: National transportation Safety Board.
- NTSB. (1997). *In-flight fire and impact with terrain: ValuJet Airlines, Flight 592 DC-9-32, N904VJ; Everglades, Near Miami, Florida. May 11 1996* (Aircraft Accident Report No. NTSB No AAR-97/06). Washington: National Transportation Safety Board.
- NTSB. (2000). *Inflight breakup over the Atlantic Ocean, Trans World Airlines Flight 800, Boeing 747-131, N 93119, near East Moriches, New York, July 1996* (Aircraft Accident Report No. AAR-00/03). Washington, DC: National Transportation Safety Board.
- NTSB. (2004a). Fedex landing crash in Tallahassee. Washington, DC: National Transportation Safety Board.
- NTSB. (2004b). Modifications to "most wanted" list of transportation safety improvements, after September 1990. Retrieved 8 December 2004, 2004, from www.nts.gov/recs/mostwanted/modifications_made_since_1990.htm
- NTSB. (2004c). Most wanted transportation safety improvements, aviation issues area. Retrieved 8 December 2004, 2004, from www.nts.gov/recs/mostwanted/aviation_issues.htm
- NZCAA. (1994). *Safety audit training* (4th ed.). Lower Hutt: New Zealand Civil Aviation Authority.
- Network Rail (2005). *Consultation on capacity study for East Coast main line*. London, Network Rail.
- Noreen, E., D. Smith, et al. (1995). *The Theory of Constraints and its implications for management accounting*. Great Barrington, MA, North River Press.
- NZCAA. (1995). Lower Hutt: New Zealand Civil Aviation Authority.
- O'Hare, D. (1990). Pilots' perception of risks and hazards in general aviation. *Aviation, Space and Environmental Medicine*, 61(7), 599-603.
- O'Hare, D. (1994). Latent failure and human error. *New Zealand Flight Safety*, 94, 4-7.
- O'Hare, D., Wiggins, M., Batt, R., & Morrison, D. (1994). Cognitive failure analysis for aircraft accident investigation. *Ergonomics*, 37(11), 1855-1870.
- O'Hare, D. (2002). "The 'Wheel of Misfortune': a taxonomic approach to human factors in accident investigation and analysis in aviation and other complex systems." *Ergonomics* 43(12): 2001-2019.
- OAAI. (1980). *Air New Zealand McDonnell Douglas DC-10-30 ZK-NZP Ross Island, Antarctica* (Aircraft accident report No. 79-139). Wellington: Government Printer.
- OAAI. (1983). *Pterodactyl Ascender ZK-FCB, Upper Waitohi, Canterbury Province* (Aircraft Accident Brief No. 83-041). Wellington: Office of Air Accidents Investigation.
- OAAI. (1984a). *Civil aircraft accidents 1984: Published reports* (Consolidated Air Accident Reports). Wellington: Office of Air Accidents Investigation.
- OAAI. (1984b). *Pterodactyl Ascender II +2 Microlight, ZK-FJK Near Pongakawa, South Auckland Province* (Aircraft Accident Report No. 84-109). Wellington: Office of Air Accidents Investigation.

- OAAI. (1985a). *Cessna 402b ZK-EHT Near Arrowsmith Point, Tory Channel, Marlborough Province* (Aircraft Accident Report No. 85-084). Wellington: Office of Air Accidents Investigation.
- OAAI. (1985b). *Pterodactyl Ascender, ZK-EWR Near Blenheim, Marlborough Province* (Aircraft Accident Report No. 85-024). Wellington: Office of Air Accidents Investigation.
- OAAI. (1988). *Pterodactyl Ascender Microlight ZK-FIY Near Rakaia, Canterbury Province* (Aircraft Accident Report No. 88-025). Wellington: Office of Air Accidents Investigation.
- Palmer, D. J., Stough, L. M., Burdenski, T. K., & Gonzales, M. (2005). Identifying teacher expertise: An examination of researchers' decision making. *Educational Psychologist, 40*(1), 13-25.
- Perrow, C. (1984). *Normal accidents*. New York: Basic Books.
- Petersen, J. (2005). Countermeasures and barriers. Roskilde, Technical University of Denmark.
- Presidential Commission (1986). *Report of the Presidential Commission on the space shuttle accident*. Washington.
- Purvis, J. W. (1998). *The Boeing safety strategy - reducing the worldwide accident rate*. Paper presented at the 29th International Seminar of the International Society of Air Safety Investigators, Barcelona.
- R v Sotheran (High Court, Palmerston North 2001).
- RAE. (1954). *Report on Comet accident investigation*. London: HMSO.
- RLC Engineering Group (2004). *Theory of Constraints at Callender*. Ballasalla, IOM, RLC Engineering Group Limited.
- Rasmussen, J. (1980). What can be learned from human error reports? In M. G. a. D. W. K.D. Duncan (Ed.), *Changes in working life*. New York: Wiley.
- Rasmussen, J. (1982). Human errors: a taxonomy for describing human malfunction in industrial installations. *Journal of occupational accidents, 4*, 311-315.
- Rasmussen, J. (1997). Risk management in a dynamic society: A modelling problem. *Safety Science, 27*(2/3), 183-213.
- Reason, J. (1990). *Human error*. Cambridge: Cambridge University Press.
- Reason, J. (1991). *Identifying the latent causes of aircraft accidents before and after the event*. Paper presented at the 22nd International seminar of the International Society of Air Safety Investigators.
- Reason, J. (1997). *Managing the risks of organisational accidents*. Aldershot: Ashgate.
- Reason, J. and A. Hobbs (2003). *Managing maintenance error*. Aldershot, Ashgate.
- Retstein, Z., R. Wilf-Miron, et al. (2002). "Management by constraints: considering patient volume when adding medical staff to the Emergency Department." *Israel Medical Association Journal Vol. 4*(March 2002).
- Rimson, I. J. (1998). *Investigating 'causes'*. Paper presented at the 29th International Seminar of the International Society of Air Safety Investigators, Barcelona.
- Rosekind, M. R. (1995). *Physiological considerations of fatigue*. Paper presented at the Fatigue Symposium, National Transportation Safety Board.
- Safety in the Sky (1990). [Television], *Frontline*. Wellington: TV One.
- Sakata, N. (2003). *Economic impact of airplane crash media coverage on airline business performance*. Unpublished manuscript, Washington, DC.
- Sheen, M. J. (1987). *MV Herald Of Free Enterprise* (Court of Inquiry No. 8074). London: Department of Transport.

- Stevens, R., Brook, P., Jackson, K., & Arnold, S. (1998). *Systems engineering: Coping with complexity*. Harlow: Pearson Education.
- Swedavia AB, & McGregor and Company. (1988). *Swedavia - McGregor Report*. Wellington.
- TAIC. (1992a). *Airmiss Incident Boeing 737-200 ZK-NAZ and Piper PA 38 ZK-PAH at Wellington* (Aircraft Accident Report No. 92-010). Wellington: Transport Accident Investigation Commission.
- TAIC. (1992b). *Pterodactyl Ascender 11+2, ZK-FKF, Manukau Harbour, 8 March 1992* (Aircraft accident report No. 92-007). Wellington: Transport Accident Investigation Commission.
- TAIC. (1995). *De Havilland DHC-8, ZK-NEY Controlled Flight Into Terrain near Palmerston North, 9 June 1995* (Aircraft Accident Report No. 95-011). Wellington: Transport Accident Investigation Commission.
- TAIC. (1996a). *Beech 65-A80-8800 Queen Air (Excalibur) ZK-TIK near Hamilton, 29 March 1995* (Aircraft Accident Report No. 95-004). Wellington: Transport Accident Investigation Commission.
- TAIC. (1996b). *Cessna Caravan, ZK-SFA, 10 Nm North-East of Blenheim, 29 January 1996* (Aircraft Accident Report No. 96-006). Wellington: Transport Accident Investigation Commission.
- Taylor, A. F. (1998). *Airworthiness requirements: Accidents investigation and safety recommendations*. Paper presented at the 29th International Seminar of the International Society of Air Safety Investigators, Barcelona.
- UKCAA. (2002). *Safety management systems for commercial air transport operations*. London: United Kingdom Civil Aviation Authority.
- USAAMRDL. (1971). *Crash survival design guide* (Technical report No. 71-22). Fort Eustis, VA: US Army Air Mobility Research and Development Laboratory.
- van Vuuren, W. (1998). *Organisational failure: An exploratory study in the steel industry and the medical domain*. Unpublished Doctoral Thesis, Eindhoven University of Technology, Eindhoven.
- Vette, A. G. (1997). *Impact Erebus* (Revised ed.). Auckland: Aviation Consultants.
- Vette, A. G. (1999). *Impact Erebus Two* (2nd ed.). Auckland: Aviation Consultants.
- Waldeck, T. A. (1997). *Unified system safety model*. Unpublished.
- Walker, M. (2003). *Reasoning with the Reason model*. Paper presented at the ANZSASI Regional Seminar 2003, Maroochydore.
- Weaver, D. A. (1973). TOR analysis: A diagnostic training tool. *American Society of Safety Engineers Journal* (June 1973), 24-29.
- Weick, K. E., & Sutcliffe, K. M. (2001). *Managing the unexpected: Assuring high performance in an age of complexity*. San Francisco: Jossey-Bass.
- Wiegmann, D. A., & Shappell, S. A. (1997). Human factors analysis of post-accident data: Applying theoretical taxonomies of human error. *International Journal of Aviation Psychology*.
- Williams, G. (2002). *Airline competition: Deregulation's mixed legacy*. Aldershot: Ashgate.
- Wood, R. H. (1997). *Aviation safety programs* (2 ed.). Englewood: Jeppesen.
- Wood, R. H., & Sweginnis, R. W. (1995). *Aircraft accident investigation*. Casper: Endeavour.
- Yin, R. K. (1994). *Case study research and design methods*. Thousand Oaks: Sage.
- Zotov, D. V. (1996). *Reporting human factors accidents*. Paper presented at the 27th International Seminar of the International Society of Air Safety Investigators, Auckland.

- Zotov, D. V. (1997a). Lessons from ZK-SFA. *New Zealand Wings, August, 1997*, 36-39.
- Zotov, D. V. (1997b). *Pilot error: Cognitive failure analysis*. Unpublished Masters, Massey, Palmerston North.
- Zotov, D. V. (1999). The role of accident investigation in general aviation. In D. O'Hare (Ed.), *Human performance in general aviation* (pp. 291-316). Aldershot: Ashgate.
- Zotov, D. V. (2000). *Applying scientific methodology to accident investigation*. Paper presented at the 31st International Seminar of the International Society of Air Safety Investigators, Bunratty, Ireland.
- Zotov, D. V. (2001, 1-3 June 2001). *Analysing the Ansett Dash 8 accident with a WB-Graph*. Paper presented at the International seminar of the Australia and New Zealand Societies of Air Safety Investigators, Cairns, Australia.

Annex A

Glossary

Organisations

AAIB	Air Accident Investigation Branch (United Kingdom). Formerly known as the Accident Investigation Branch, AIB
CAA	Civil Aviation Authority. (In this thesis, the New Zealand authority)
CTSB	Canadian Transport Safety Board
DOE	Department of Energy (United States)
FAA	Federal Aviation Authority (United States)
ICAO	International Civil Aviation Organisation
NTSB	National Transportation Safety Board (United States)
RAE	Royal Aeronautical Establishment (United Kingdom)
TAIC	Transport Accident Investigation Commission (New Zealand)
USAAMRDL	US Army Air Mobility Research and Development Laboratory

Equipment

CVR	Cockpit Voice Recorder
DME	Distance Measuring Equipment
FDR	Flight Data Recorder
VOR	Very high frequency O mnidirectional R adio range (Provides bearing from a ground station)
GPWS	Ground Proximity Warning System

QRH Quick Reference Handbook

Procedural

CRM Crew Resource Management Training

LOFT Line Oriented Flight Training

IMC Instrument Meteorological Conditions

PANSOPS Procedures for Air Navigation - Standard Operating Procedures

VMC Visual Meteorological Conditions

n. m. Nautical miles

Analytical

ECAN Events and Causal Factors Analysis

ELAN Event Link Analysis Network

CRD Conflict Resolution Diagram

CRT Current Reality Tree

FRT Future Reality Tree

MES Multilinear Events Sequencing

MORT Management Oversight Risk Tree

TOC Theory of Constraints

WBA Why Because Analysis

WBG Why Because Graph



Report 95-011

de Havilland DHC-8, ZK-NEY

controlled flight into terrain

near Palmerston North

9 June 1995

Abstract

At approximately 0922 hours on Friday 9 June 1995 a de Havilland DHC-8 aircraft, ZK-NEY, collided with the terrain some 16 km east of Palmerston North Aerodrome while carrying out an instrument approach. One crew member and three passengers lost their lives and two crew members and 12 passengers were seriously injured in the accident.

The causal factors were: the Captain not ensuring the aircraft intercepted and maintained the approach profile during the conduct of the non-precision instrument approach, the Captain's perseverance with his decision to get the undercarriage lowered without discontinuing the instrument approach, the Captain's distraction from the primary task of flying the aircraft safely during the First Officer's endeavours to correct an undercarriage malfunction, the First Officer not executing a Quick Reference Handbook procedure in the correct sequence, and the shortness of the ground proximity warning system warning.

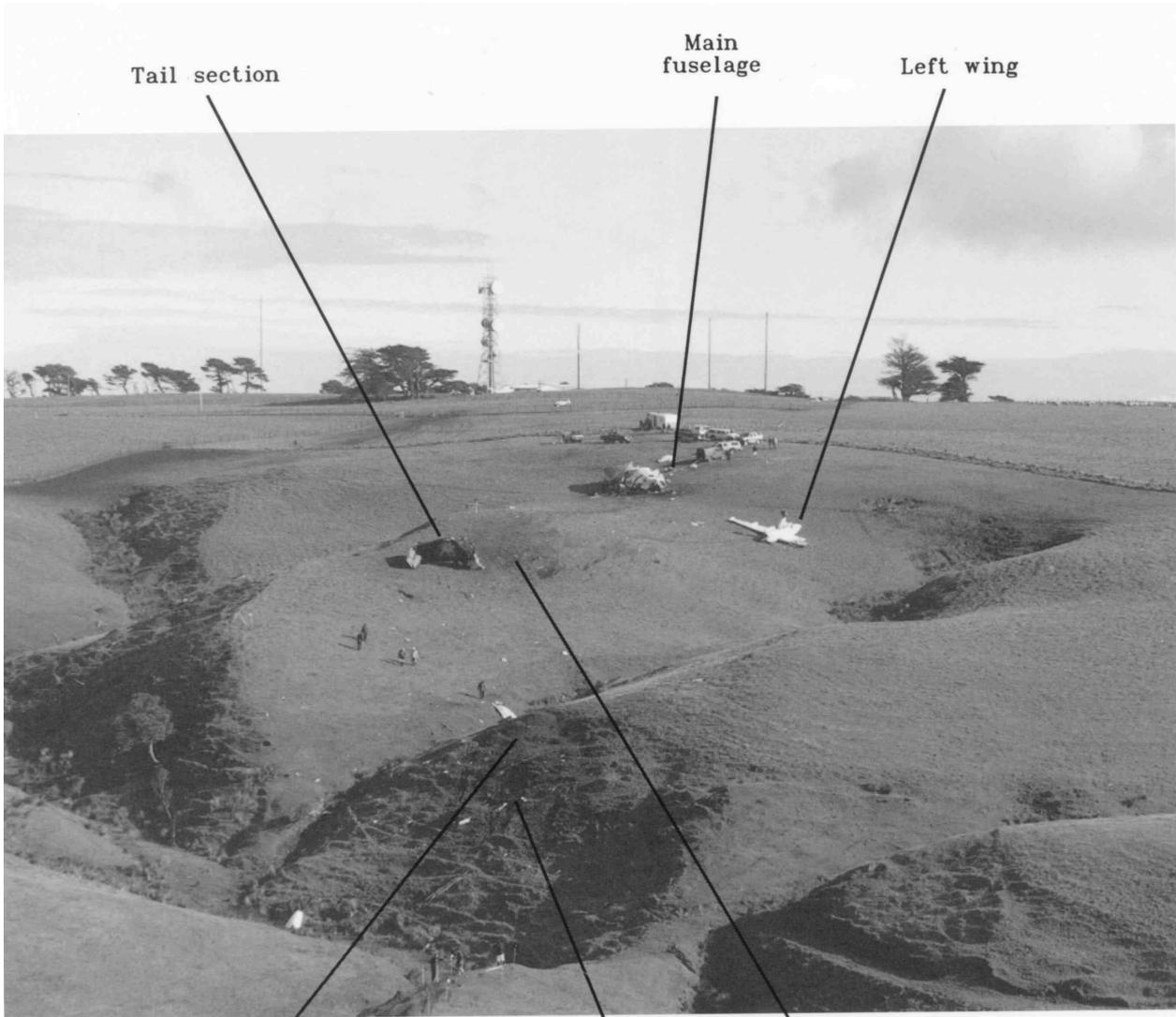
The safety issues discussed are: the need for pilots to continue to monitor the safe conduct of the flight while dealing with any non-normal system operation, the desirability of the Captain assuming manipulative control of the aircraft in the event of an abnormal situation arising, the efficacy of the operator's follow-up on their decision not to modify the aircraft's undercarriage, the efficacy of the operator's flight safety programme, the design of the Quick Reference Handbook checklists, the limitations of the knowledge-based crew resource management training, the Civil Aviation Authority's shortage of audit staff available to detect weaknesses in operating procedures during its audits, the standard of performance of the aircraft's ground proximity warning system, the completeness of the advice to passengers on the safety equipment carried in an aircraft and the implementation of a minimum safe altitude warning system for the Air Traffic Control radar.

The Transport Accident Investigation Commission is an independent Crown entity established to determine the circumstances and causes of accidents and incidents with a view to avoiding similar occurrences in the future. Accordingly it is inappropriate that reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The Commission may make recommendations to improve transport safety. The cost of implementing any recommendation must always be balanced against its benefits. Such analysis is a matter for the regulator and the industry.

These reports may be reprinted in whole or in part without charge, providing acknowledgement is made to the Transport Accident Investigation Commission.

Transport Accident Investigation Commission
P O Box 10-323, Wellington, New Zealand
Phone +64 4 473 3112 Fax +64 4 499 1510
E-mail: reports@taic.org.nz Web site: www.taic.org.nz



Tail section

Main fuselage

Left wing

Right wing

Initial impact

First major impact area

Second major impact area

Accident Site - General View

Table of Contents

1.	Factual Information		7
1.1	History of the flight		7
1.2	Injuries to persons		8
1.3	Damage to aircraft		8
1.4	Other damage		8
1.5	Personnel information		8
1.6	Aircraft information		10
1.7	Meteorological information		23
1.8	Aids to navigation		26
1.9	Communications		29
1.10	Aerodrome information		31
1.11	Flight recorders		31
1.12	Wreckage and impact information		33
1.13	Medical and pathological information		37
1.14	Fire		39
1.15	Survival aspects		40
1.16	Tests and research		44
1.17	Organisational and management information		49
1.18	Additional information		59
2.	Analysis		70
3.	Findings		89
4.	Safety Recommendations		93
Appendices			
Appendix A	DFDR Readouts		103
Appendix B	CFIT Checklist		105
Appendix C	Edited Extracts of CVR Transcript		109
	Glossary		133



ZK-NEY looking aft



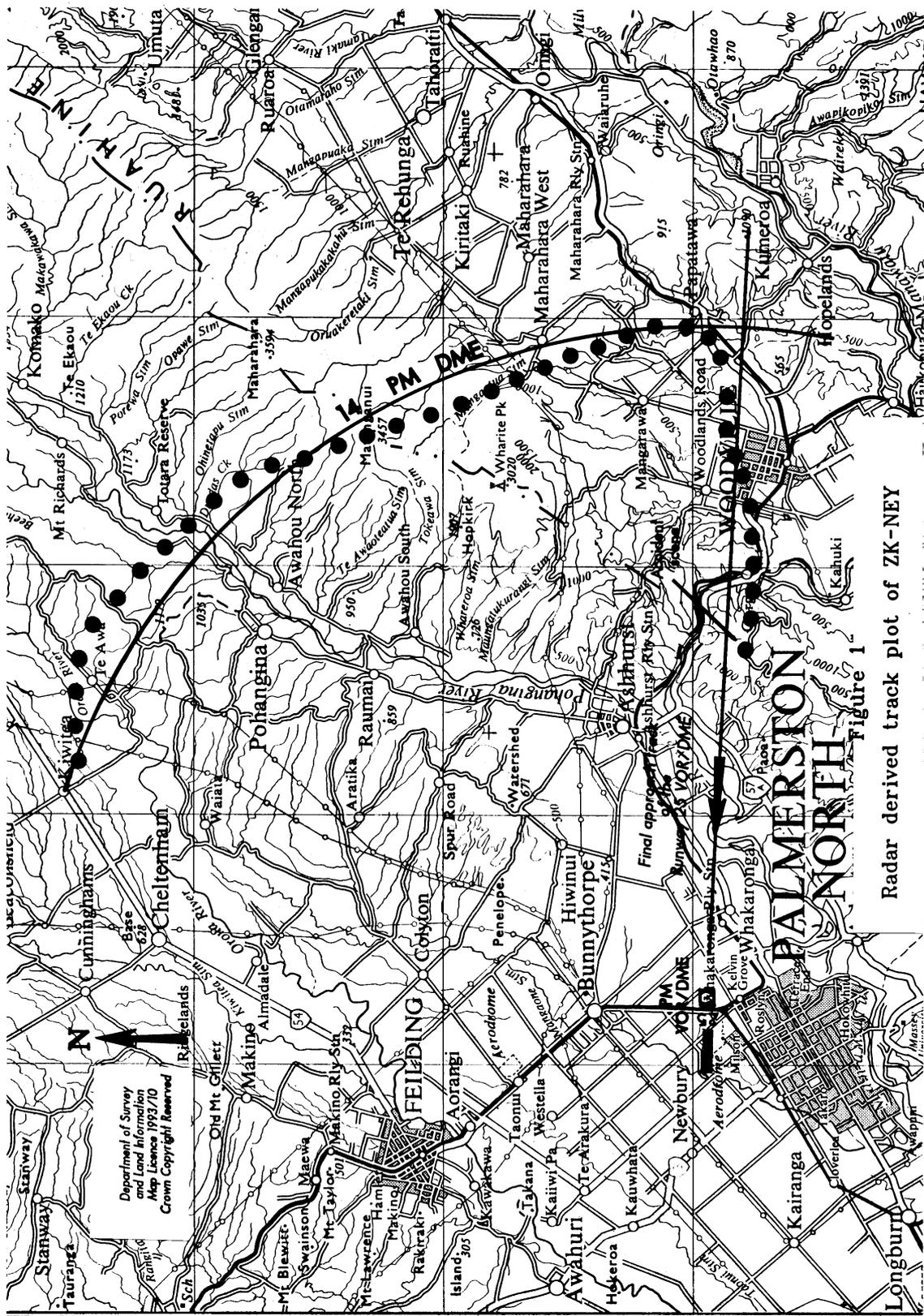
ZK-NEY right side

Transport Accident Investigation Commission

Aircraft Accident Report No. 95-011

Aircraft type, serial number and registration:	de Havilland DHC-8-102 ,055, ZK-NEY
Number and type of engines:	Two Pratt and Whitney PW-120A
Year of manufacture:	1986
Date and time:	9 June 1995, 0922 hours *
Location:	16 km east of Palmerston North Aerodrome Latitude: 40°20'S Longitude: 175°48'E
Operator:	Ansett New Zealand Limited
Type of flight:	Scheduled Air Transport, Passenger
Persons on board:	Crew: 3 Passengers: 18
Injuries:	Crew: 1 Fatal 2 Serious Passengers: 3 Fatal 12 Serious 3 Minor/none
Nature of damage:	Aircraft destroyed
Pilot-in-Command's Licence:	Airline Transport Pilot Licence (Aeroplane)
Pilot-in-Command's Age:	40
Pilot-in-Command's Total Flying Experience:	7765 hours (273 on type)
Investigator in Charge:	R Chippindale

* All times in this report are in NZST (UTC + 12 hours)



Radar derived track plot of ZK-NEY

Figure 1

Department of Survey and Land Information
Map Licence 1993/10
Crown Copyright Reserved

1. Factual Information

1.1 History of the flight

- 1.1.1 At 0817 hours on Friday 9 June 1995 ZK-NEY, a de Havilland DHC-8 (Dash 8) aircraft, departed Auckland as scheduled Ansett New Zealand Flight 703 bound for Palmerston North. Aboard were a crew of three and 18 passengers.
- 1.1.2 To the north of Palmerston North the pilots briefed themselves for a VOR/DME¹ approach to runway 07 which was the approach they preferred. Subsequently Air Traffic Control specified the VOR/DME approach for runway 25, due to departing traffic, and the pilots re-briefed for that instrument approach without further ado. The IMC involved flying in and out of stratiform cloud, but continuous cloud prevailed during most of the approach.
- 1.1.3 The aircraft was flown accurately to join the 14 nm DME arc (see Figure 1) and thence turned right and intercepted the final approach track of 250° M to the Palmerston North VOR. During the right turn, to intercept the inbound approach track, the aircraft's power levers were retarded to FLIGHT IDLE and shortly afterwards the First Officer advised the Captain "... 12 DME looking for 4000 (feet)". The final approach track was intercepted at approximately 13 DME and 4700 feet, and the First Officer advised Ohakea Control "Ansett 703" was "established inbound".
- 1.1.4 Just prior to 12 miles DME the Captain called "Gear down". The First Officer asked him to repeat what he had said and then responded "OK selected and on profile, ten - sorry hang on 10 DME we're looking for four thousand aren't we so - a fraction low". The Captain responded, "Check, and Flap 15". This was not acknowledged but the First Officer said, "Actually no, we're not, ten DME we're..... (The Captain whistled at this point) look at that". The Captain said, "I don't want that." and the First Officer responded, "No, that's not good is it, so she's not locked, so Alternate Landing Gear...?" The Captain acknowledged, "Alternate extension, you want to grab the QRH?" After the First Officer's "Yes", the Captain continued, "You want to whip through that one, see if we can get it out of the way before it's too late."
- 1.1.5 The Captain then stated, "I'll keep an eye on the aeroplane while you're doing that."
- 1.1.6 The First Officer located the appropriate "Landing Gear Malfunction Alternate Gear Extension" checklist in Ansett New Zealand's Quick Reference Handbook (QRH) and began reading it. He started with the first check on the list but the Captain told him to skip through some checks. The First Officer responded to this instruction and resumed reading and carrying out the necessary actions. It was the operator's policy that all items on the QRH checklists be actioned, or proceeded through, as directed by the Captain.
- 1.1.7 The First Officer carried out the checklist correctly up to and including the item:

L/G ALTERNATE RELEASE DOOR - OPEN FULLY & LEAVE OPEN

to which he commented "which it is." However he then continued "and insert this handle and operate until main gear locks, actually nose gear."

¹ For definition of abbreviations throughout, see the Glossary at the end of this report.

1.1.8 The correct sequence was:

L/G ALTERNATE RELEASE DOOR	OPEN FULLY & LEAVE OPEN
MAIN GEAR RELEASE HANDLE	PULL FULLY DOWN
L/G ALTERNATE EXTENSION DOOR	OPEN FULLY & LEAVE OPEN

Insert pump handle and operate until main landing gear locks down.....

1.1.9 The Captain noticed the First Officer's actions and advised "You're supposed to pull the handle..."

1.1.10 The First Officer then pulled the Main Gear Release Handle and had just finished saying, "Yeah that's pulled here we go.", when the GPWS's audio alarm sounded.

1.1.11 Between four and a half and four point eight seconds later the aircraft collided with the terrain.

1.1.12 One crew member and two passengers were killed during the impact sequence. Another passenger died 12 days later from burns received after he had escaped from the aircraft's cabin. He was waiting alongside the aircraft's right engine when an existing minor fire developed and engulfed him. Two crew members and 12 passengers suffered serious injuries and three passengers escaped with minor injuries.

1.2 Injuries to persons

1.2.1	Crew	Passengers	Others
Fatal	1	3	-
Serious	2	12	-
Minor/None	-	3	-

1.3 Damage to aircraft

1.3.1 The aircraft was destroyed.

1.4 Other damage

1.4.1 Three sheep were killed by the aircraft wreckage and an area of pasture was spoiled by the impact damage, fuel contamination and fire.

1.5 Personnel information

1.5.1	<i>Captain</i>	Male, aged 40 years
	Licence:	Airline Transport Pilot Licence (Aeroplane)
	Aircraft Ratings:	Boeing 737-200, BAe 146, DHC-8 and SA 227
	Medical Certificate:	Class 1, Valid until 17 May 1996
	Last Instrument Rating check:	7 January 1995
	Last Regulation 76 check:	13 March 1995

Last route check:	13 March 1995	
Flying experience:	Total all types:	7765 hours
	Total on type:	273 hours
	Total all types previous 90 days:	173 hours
	Total on type previous 90 days:	172 hours
Duty time:	5.2 hours	
Rest period before duty:	10 hours	

1.5.2 The Captain had been employed by Ansett New Zealand since April 1989, where he had flown 3740 hours on line operations as a First Officer on B737 and BAe 146 types up to 30 October 1994. Previous experience in two-pilot crew operations included 500 hours on Metroliner aircraft, of which 100 hours was in command. He had completed sessions of CRM Training at the Recurrent Training School on 9/10 September 1992, 16/17 March 1994, 1/2 November 1994 and 21 December 1994, and he had participated in five LOFT exercises as First Officer in the BAe 146 simulator flying as a First Officer in the right-hand seat.

1.5.3 He had no experience on the Dash 8 aircraft prior to October 1994. In preparation for his command of the Dash 8 he undertook and passed the conversion training for the type followed by 103 hours of command training with a training captain before his "check to line" on 13 March 1995. This included a base check on 11 March 1995 and line checks with different check and training Captains on 13 March and 14 May 1995. As a result his command and leadership ability was assessed as above average, and workload management and distraction avoidance as average.

1.5.4	<i>First Officer</i>	Male, aged 33 years
	Licence:	Airline Transport Pilot Licence (Aeroplane)
	Aircraft Ratings:	DHC-8, DHC-6, BN2, EMB-110 and B-200
	Medical Certificate:	Class 1, Valid until 29 August 1995
	Last Instrument Rating check:	20 November 1994
	Last Regulation 76 check:	30 April 1995
	Last route check:	30 April 1995
	ATPL issue Flight Test:	30 April 1995
	Flying experience:	Total all types: 6460 hours
		Total on type: 341 hours
		Total all types previous 90 days: 162 hours
		Total on type previous 90 days: 162 hours
	Duty time:	5.2 hours
	Rest period before duty:	More than 48 hours

1.5.5 The First Officer was employed by Ansett New Zealand in November 1994 after he had completed his Dash 8 ground course. For five years before that he had flown DHC-6, Britten-Norman BN2, Embraer 110 and Beech 200 types on airline passenger services in Papua New Guinea, logging 4000 hours predominantly on single pilot IFR operations. He had little two-pilot crew experience before joining Ansett. He had attended one four-hour session of Ansett New Zealand's CRM Training during his Dash 8 ground course.

1.6 Aircraft information

- 1.6.1 ZK-NEY was a de Havilland Canada DHC-8 (Dash 8) Series 102 Aircraft, Constructor's Number 055, which had been manufactured in Canada in 1986.
- 1.6.2 The aircraft was registered to Ansett New Zealand Limited in December 1986. It was issued with a temporary New Zealand Certificate of Airworthiness (C of A) to facilitate a ferry flight to New Zealand, and was subsequently granted a New Zealand C of A in the Standard Category in July 1987. This C of A was non-terminating provided the aircraft was maintained in accordance with the Ansett New Zealand Limited Engineering Procedures Manual and subsidiary Manuals authorised therein.
- 1.6.3 ZK-NEY entered service soon after its arrival in New Zealand. The aircraft had been maintained since that time by Ansett New Zealand Limited Engineering. A review of the Maintenance Log showed that all significant defects on ZK-NEY were recorded as having been investigated and rectified or deferred as appropriate, in conjunction with the airline's normal engineering procedure, prior to the occurrence of the accident. Relevant entries had been included in the Maintenance Status Section of the Maintenance Log carried on the aircraft. A six-monthly Maintenance Review was also carried out between 15 May and 18 May 1995.
- 1.6.4 The last Maintenance Release was issued on 19 May 1995, and was valid to 20 November 1995. On 6 June 1995 the Ansett New Zealand Limited Engineering Quality Assurance Manager completed an audit of this maintenance and considered it complied with the maintenance, modification and inspection requirements of the CAA and Ansett New Zealand Limited.
- 1.6.5 Routine overnight servicing was carried out on 8 June 1995 (the night before the accident). At this time, ZK-NEY had accumulated a total of 22 154 hours in service, and 24 976 cycles.
- 1.6.6 During this servicing period an investigation was made into a reported fuel seepage, within the right engine nacelle's tail cone, which had been observed when the aircraft was being refuelled earlier in the day. The seepage was only evident under the 45 psi (310 kPa) refuelling pressure. No seepage occurred under simulated "in flight" conditions. The reported discrepancy and deferral action, taken in accordance with the relevant provisions of the DHC-8 Maintenance Manual, were recorded in the aircraft's Maintenance Status Log.
- 1.6.7 Two Pratt and Whitney PW 120A engines were installed in ZK-NEY.
- The left engine was serial number PC-E120199. 18 926 hours and 21 495 cycles had been recorded for this engine since new.
- The right engine was serial number PC-E120206. 14 908 hours and 16 601 cycles had been recorded for this engine since new.
- 1.6.8 Hamilton Standard propellers, type 14SF-7 were fitted.
- The left propeller was serial number 870826 with 12 011 hours total time and 7974 hours recorded since overhaul.
- The right propeller was serial number 870521 with 8723 hours total time and 486 hours recorded since overhaul.
- 1.6.9 The propeller units comprised four blades of composite construction mounted on forged aluminium spars.

Undercarriage details

- 1.6.10 The Dash 8's undercarriage was a retractable tricycle-type incorporating air/oil shock struts with dual wheel assemblies fitted to each main undercarriage leg and the nosewheel leg.
- 1.6.11 The nose undercarriage was mounted in the front fuselage ahead of the flight deck area and retracted forward into the unpressurised nose section.
- 1.6.12 The left and right main undercarriage legs were attached to the respective engine nacelle structures. The main undercarriage retracted rearwards into wheel wells located in the nacelles.
- 1.6.13 Normal operation of the undercarriage utilised hydraulic power for retraction and extension. An undercarriage control panel located on the upper right of the central instrument panel incorporated a selector lever providing two positions - "UP" or "DOWN".
- 1.6.14 Positive mechanical locking of the main undercarriage was provided in the "UP" and "DOWN" positions. Indicators were provided to identify the position of the undercarriage and if the undercarriage doors were not in the correct position for the sequence selected. A non-cancellable audible warning device was provided to warn the flight crew if the undercarriage was not in a fully down and locked position when the engine power levers were retarded to a position suitable for landing and the airspeed was less than 130 knots indicated.
- 1.6.15 An alternative means of extending the main undercarriage was provided which involved mechanical actuation of the uplock to unlock the undercarriage legs thereby permitting a free-fall. Once the uplock was released the main undercarriage locking could be assisted by an independent hydraulic system operated by a hand pump located on the flight deck floor².
- 1.6.16 Each main undercarriage unit, when retracted, was completely enclosed within the nacelle by three doors. The main undercarriage door actuation was powered hydraulically and so controlled that the wheel bay and lower strut doors were closed when the undercarriage was fully down.
- 1.6.17 During main undercarriage extension a sequencing system opened the nacelle doors in the appropriate order and subsequently closed the rear and centre doors. The front doors remained open with the undercarriage in the "DOWN" position.

Relevant aspects of the undercarriage system

Extension

- 1.6.18 Normal extension of the undercarriage was initiated by a "DOWN" selection of the undercarriage control lever. The lever operated a switch to energise the down solenoid of the undercarriage selector valve. As soon as the down line was pressurised, the de-energised solenoid sequence valve directed hydraulic pressure to the open side of the rear and centre door actuator and the open side of the front door actuator was connected directly to the down hydraulic line. When the doors were 90% open, the mechanical sequence valve allowed full hydraulic flow to the main undercarriage actuators. When the uplock proximity sensors signalled the proximity switch electronic unit (PSEU) of a "far", or unlocked, condition, the PSEU turned on the red, "undercarriage unsafe", and amber, "undercarriage in transit" lights. When the down lock was made safely, the down lock proximity sensors signalled the PSEU of a "near" condition and the PSEU turned off the red, "unsafe", and amber, "undercarriage in transit" lights, and turned on the green, "undercarriage down and locked" lights. The PSEU via relays also energised the solenoid sequence valve which moved to the crossed port

² The Ansett New Zealand QRH required use of the hand pump as part of the alternate main gear lowering procedure.

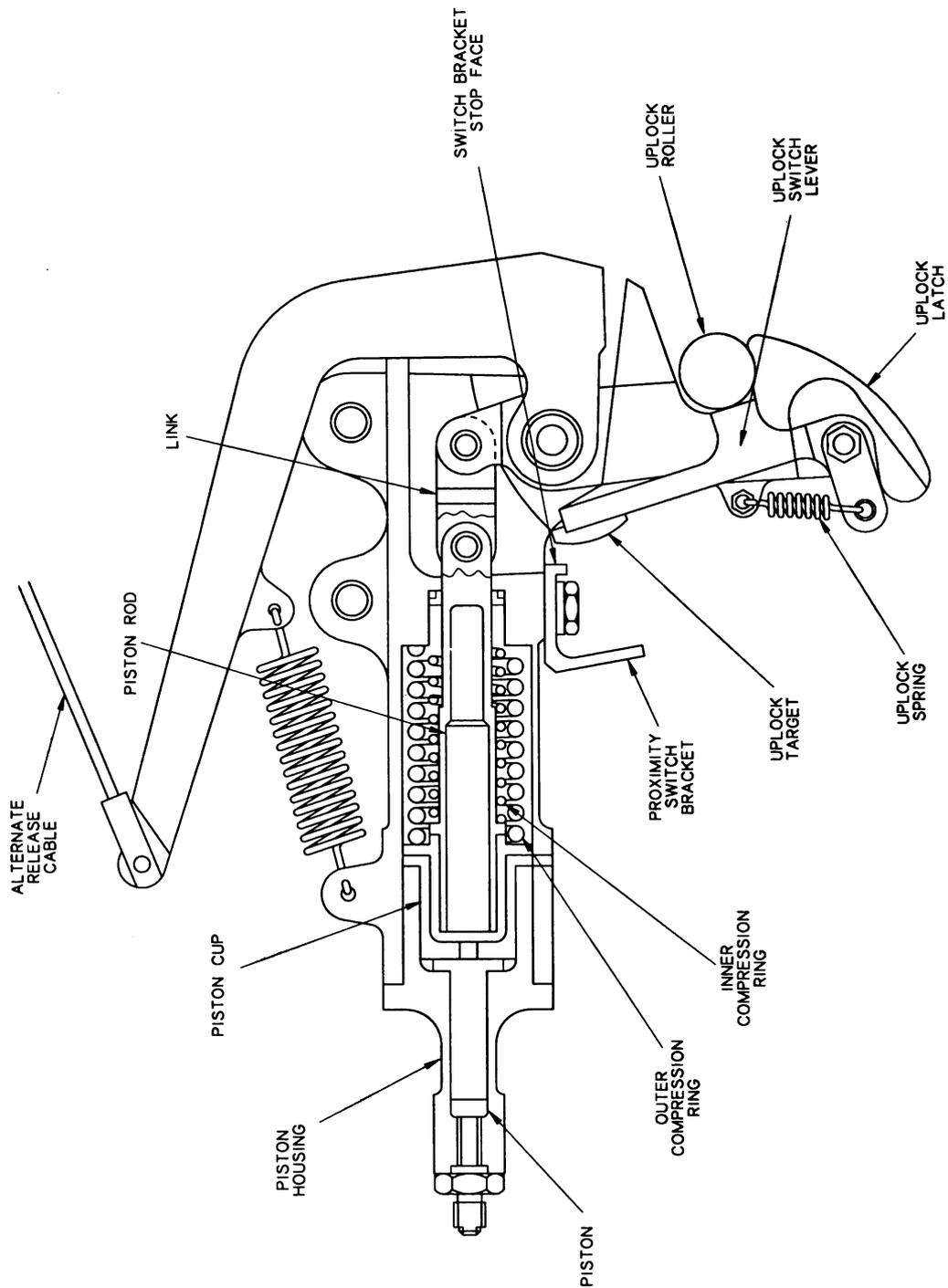


Figure 2
 Uplock assembly view
 (Not to scale)

configuration, connecting down hydraulic pressure to the “doors closed” side of both the rear and centre door actuator, and the front door actuator. The rear and centre doors would close but the front door would not, as hydraulic pressure was being applied to both sides of the actuator at that time and the differential piston area ensured it stayed in the “doors open” position.

Note: Normally the amber, “door advisory” lights would illuminate briefly at the completion of the extension cycle due to a transitory “undercarriage down and locked - doors open” condition.

Position indicators

1.6.19 Undercarriage position indicators comprised:

Three red undercarriage lights	- left, nose and right	Landing gear unsafe advisory lights
Three green undercarriage lights	- left, nose and right	Landing gear down and locked advisory lights
Three amber doors lights	- left, nose and right	Door open advisory lights
Two amber selector lever lights		

1.6.20 The red undercarriage lights indicated:

When the respective undercarriage position was not consistent with the selector lever’s selection.

When the undercarriage legs were not in either locked position.

1.6.21 Each of the green undercarriage lights would illuminate only if the respective undercarriage leg was down and locked.

1.6.22 The amber “transit” lights in the selector lever would indicate whenever an undercarriage position was not consistent with the lever selection.

1.6.23 All of the lights would be extinguished when the undercarriage legs were up and locked and the doors were closed.

Undercarriage ‘UP’ lock.

1.6.24 The main undercarriage uplocks fitted to the Dash 8 aircraft were designed to restrain the respective undercarriage leg in the retracted position under all flight conditions without the aid of hydraulic pressure. They comprised a latch assembly installed within the rear of the engine nacelle which engaged with a roller mounted on the undercarriage leg when the undercarriage was fully retracted, thus mechanically holding the undercarriage leg in the “UP” position. (See Figure 2.) With the uplock latches engaged and the forward, centre and aft doors closed, the solenoid selector valve was de-energised to isolate hydraulic pressure from the system.

1.6.25 In normal operation an actuator, attached to the latch assembly, activated hydraulically to release the undercarriage. However, in the event of non-release for any reason the latch was designed so that it could be operated manually by means of a system of cables connected to the Main Gear Release Handle. This handle was located in the flight deck overhead panel and was accessible most readily from the First Officer’s position.

1.6.26 When the Main Gear Release Handle was pulled, the cable system first released the main undercarriage forward centre and rear door uplocks, allowing spring tension to open the nacelle

doors, then disengaged the main undercarriage uplock latches from the leg mounted rollers, allowing the undercarriage legs to free-fall under their own weight.

1.6.27 After the uplocks were released by pulling the Main Gear Release Handle, it was normal for the main undercarriage to free-fall to the down and locked position. However, a hand pump assembly, connected to a separate hydraulic system, could be used to assist the locking of the main undercarriage if required.

1.6.28 The Ansett New Zealand QRH checklist 18A states:

Insert pump handle and operate until main landing gear locks down (LEFT & RIGHT green lights ON & L DOOR & R DOOR amber lights ON & movement becomes stiff),

whereas the Ansett New Zealand QRH checklist 14B states:

Operate hand pump until movement becomes stiff (LEFT AND RIGHT green and L DOOR & R DOOR amber lights ON).

1.6.29 The alternate undercarriage extension system incorporated a relatively light spring to resist the first part of the cable pull (releasing the nacelle door uplocks), and heavier spring tension over a longer travel resisting the second part of the pull (releasing the main undercarriage uplocks). Normally no undue effort was required to operate the undercarriage Alternate Main Gear Release System but it was necessary to pull the handle to its full extent (involving a cable extension of some 250 mm) to ensure that both actions had been achieved and the uplock latch had disengaged from the roller completely.

1.6.30 Although the Ansett New Zealand QRH and the DHC-8 Model 102 checklists each had “Pull fully down” as the action required, the manufacturer’s checklist continued:

check L Door and R Door amber door open and LEFT and RIGHT green gear locked down and advisory lights illuminate. Note: Gear release handle loads may exceed those experienced during practise sessions.

The Ansett New Zealand Dash 8 Pilot Engineering Manual included the following information: (Section 11 Landing Gear Page 12):

Both the main and nose gear uplock release handles are detented, i.e., pulling to the first detent releases the door uplocks; pulling the rest of the way releases the gear uplocks. The first detent is to facilitate opening the gear doors for ground servicing. During an alternate extension, the handles should be pulled as far as they will go in one motion.

1.6.31 Springs returned the Main Gear Release Handle to its original “stowed” position after it had been pulled.

Dash 8 main undercarriage uplock latch and roller modifications

- 1.6.32 The operational history of the Dash 8 involved instances of a failure of a main undercarriage leg to extend, or a significant delay in its extension, after the undercarriage had been selected down.
- 1.6.33 de Havilland Canada, the aircraft manufacturer, and Dowty Canada, the manufacturer of the undercarriage, had addressed the matter in Service Bulletins and had introduced various modifications over a period of years as a means of overcoming the problems encountered. An Airworthiness Directive (CF-89-03) had been issued by Transport Canada in relation to the matter.
- 1.6.34 ZK-NEY, and a sister aircraft ZK-NEZ, entered service with Ansett New Zealand Limited in late 1986 and early 1987 respectively.
- 1.6.35 Engineering records kept since that time relating to the operation of these aircraft listed those service difficulties, with the main undercarriage uplock latch assembly and the associated uplock roller, which had been reported, and summarised subsequent investigative and remedial action.

Historical summary - service bulletins and action taken

- 1.6.36 Service Bulletin SB8-32-58 Mod 8/0789 which was issued by de Havilland Canada (dated 20 November 1987) introduced:
- A re-profiled and hardened latch to overcome indenting.
- New bushes to prevent wear.
- A new proximity sensor mounting bracket and re-profiled target.
- 1.6.37 These modifications were embodied in ZK-NEZ on 26 October 1988, and ZK-NEY on 4 March 1989.
- 1.6.38 Service Bulletin SB8-32-74 Mod 8/0884 which was issued by de Havilland Canada (dated 30 September 1988) introduced a new roller (P/N 70765-5) with improved seals to prevent ingress of contaminants.
- 1.6.39 The improved rollers were fitted to ZK-NEY and ZK-NEZ in December 1993. (Earlier type rollers had remained in service subject to periodic inspections and an enhanced lubrication programme.)

- 1.6.40 Service Bulletin SBA8-32-79 (AD CF 89-03) which was issued by de Havilland Canada (dated 19 December 1988) introduced a re-profiled actuator body to prevent fouling of the target lever. The modification was embodied on ZK-NEY on 23 December 1988 and ZK-NEZ on 24 December 1988.
- 1.6.41 Airworthiness Directive CF-89-03 issued by Transport Canada, and effective from 30 June 1989, mandated compliance with the provisions of de Havilland Service Bulletin SBA8-32-79.
- 1.6.42 Service Bulletin SB8-32-98 Mod 8/1828 which was issued by de Havilland Canada dated 14 August 1992 introduced a re-designed uplock actuator assembly to overcome the problem of main undercarriage “hang-ups” due to failures of the original uplock to disengage after a normal “DOWN” selection. The new uplock unit was designed to minimise the hang-up problem and eliminate spurious indications that the main undercarriage had failed to lock down.
- 1.6.43 The manufacturer recommended compliance at the operator’s discretion. Cost was a factor taken into account by operators when considering the embodiment of this modification. The manufacturer offered operators a discount pricing system for the modification kits and the uplock actuator.
- 1.6.44 Ansett New Zealand Limited did not embody the modification at the time of its introduction. However, a Technical Instruction (TI 008-32-014) was raised by Ansett New Zealand Limited Engineering to include inspection of the existing uplock latch assemblies for indentation, and this was superseded by a requirement for repetitive inspections at 3000 hour intervals (TI 008-32-014A).
- 1.6.45 Ansett New Zealand Limited Engineering re-evaluated modification 8/1828 after a further undercarriage hang-up occurred in December 1993. The Quality and Technical Services Manager contacted the manufacturer on 30 March 1994 outlining Ansett New Zealand’s position and expressing concern. The manufacturer responded in April 1994 that the problems with the uplock actuator were well known and that they would consider offering a special discount pricing programme for the new uplocks as they had previously. Ansett New Zealand decided not to obtain modification 8/1828 at that time.
- 1.6.46 DHC-8 All Operator Message (AOM) 301 entitled “Main Landing Gear - Alternate Extension Difficulties” was promulgated by the manufacturer on 25 October 1994. The AOM discussed an occurrence in which the right main undercarriage on a DHC-8-300 aircraft failed to extend using the normal system. Use of the alternate extension system required more effort than anticipated because of a seized roller, and repeated attempts to release the undercarriage uplock. The AOM emphasised the need for operators to lubricate the roller properly and advised that the pilots were ultimately able to extend the right main undercarriage, using the alternate extension system, and the aircraft landed uneventfully.

- 1.6.47 The AOM also advised that pre-modification 8/1828 (SB8-32-98) or 8/1764 uplocks were sensitive to latch wear and that worn uplocks tended to show progressive operational problems which might start with a single main undercarriage releasing late or with a bang. If left uncorrected this might result in the affected main undercarriage failing to release using the normal system.
- 1.6.48 AOM 301 was received by Ansett New Zealand on 1 November 1994 and was distributed for information to Ansett New Zealand Engineering and Flight Operations.
- 1.6.49 Following a further review, Ansett New Zealand Limited Engineering issued a Technical Instruction in December 1994 to install the improved uplock actuator assembly in their Dash 8 fleet.
- 1.6.50 Stocks of the redesigned unit were limited and the aircraft manufacturer was unable to provide an immediate supply of the modification kits. As the modification remained optional (compliance subject to operator's discretion), no external requirement existed in respect of an installation date.
- 1.6.51 The majority of events involving failures of the main undercarriage to lower normally, and those which had occurred most recently on both of Ansett New Zealand's Dash 8 aircraft, had involved the left main undercarriage. Accordingly the left undercarriage assemblies received priority for embodying the modification as the redesigned units became available.
- 1.6.52 The left undercarriage of ZK-NEY was fitted with the modified uplock actuator on 16 April 1995 and the left undercarriage of ZK-NEZ modified similarly on 19 April 1995.
- 1.6.53 Redesigned units and modification kits to continue the upgrade programme, involving the right undercarriage of ZK-NEY and ZK-NEZ, had not been received by Ansett New Zealand Limited Engineering at the time of the accident involving ZK-NEY.

Brief details of reported main undercarriage lowering malfunctions and date

(The following table outlines the documented main undercarriage lowering malfunctions relating to Dash 8 aircraft ZK-NEY and ZK-NEZ since their introduction to service in New Zealand. Each notified malfunction was investigated by Ansett New Zealand Ltd Engineering.)

ZK-NEY		ZK-NEZ
1987	Nil	Nil
1988	Nil	Right undercarriage failed to lower normally Alternate extension used 22 Apr Left undercarriage failed to lower normally Alternate extension used 10 Aug Left undercarriage failed to lower normally Alternate extension used 15 Aug
1989	Nil	Nil
1990	Nil	Nil
1991	Nil	Nil
1992		
Left undercarriage slow to release	5 Jun	Nil
Right undercarriage slow to release	22 Jun	
1993		
Left undercarriage slow to release	10 May	Left undercarriage slow to release 7 Sep Right undercarriage failed to lower normally Alternate extension used 8 Dec
1994		
Left undercarriage slow to release	7 Sep	Left undercarriage failed to lower normally Alternate extension used 21 Mar
1995		
Left undercarriage very slow to release	18 Jan	Left undercarriage slow to release 24 Feb
Left undercarriage failed to lower normally Alternate extension used	8 Mar	Left undercarriage failed to lower normally Alternate extension used 13 Apr
Left undercarriage slow to release	8 Mar	

- 1.6.54 In all cases where the crew used the Alternate Extension procedure, a successful lowering of the affected undercarriage leg was achieved and the aircraft landed without further incident.
- 1.6.55 Details of the first occurrence on 22 April 1988, the occurrence on 8 December 1993, and the most recent occurrence on 13 April 1995, each relating to ZK-NEZ, were forwarded to the Airworthiness Section of the CAA.
- 1.6.56 The CAA was aware of the various measures taken by Ansett New Zealand Limited Engineering to investigate and rectify the problems experienced with the uplock latch assembly and uplock roller, and was aware of the Service Bulletins and modification programme recommended by the aircraft manufacturer.
- 1.6.57 In the circumstances CAA maintained a monitoring role. They saw no requirement for an Airworthiness Directive, or other direct action, concerning the undercarriage defects as reported or the rectification carried out or proposed by Ansett New Zealand Limited Engineering.

Weight and balance

- 1.6.58 The loadsheet for Flight ANZ 703 recorded a total of 18 passengers, classified as 16 adults, 1 child and 1 infant, together with 2 flight crew members and 1 flight attendant, a total of 21 persons on board.
- 1.6.59 Baggage weighing 232 kg was stowed in the aircraft's hold located at the rear of the passenger compartment.
- 1.6.60 The aircraft was refuelled at Auckland with 1172 litres of Jet A-1 turbine fuel providing a total fuel load on departure of 2000 kg.
- 1.6.61 The loadsheet indicated the actual take-off weight as 13 805 kg. Maximum take-off weight was 15 650 kg. The centre of gravity (CG) at take-off was shown as 21.4% of the mean aerodynamic chord (MAC).
- 1.6.62 The forward CG limit for ZK-NEY was specified as 15% MAC for weights up to 12 700 kg, varying linearly from 15% to 20% MAC from 12 700 kg up to 14 520 kg, and linearly from 20% to 21% MAC from 14 520 kg up to 15 650 kg.
- 1.6.63 The aft CG limit was 38% MAC for all weights.
- 1.6.64 The estimated all-up weight of the aircraft at the time of the accident was 13 305 kg. The CG was within the specified limits.

Ground proximity warning system

- 1.6.65 At the time of the accident there was no CAA requirement for New Zealand registered turboprop aircraft to be fitted with a GPWS.
- 1.6.66 The GPWS installation was basic to all production DHC-8 aircraft and was installed to meet the requirements of the FAA Operating Requirements FAR Part 121.360 - Ground Proximity Warning - Glide Slope Deviation Alerting System.

1.6.67 The aircraft was equipped with a Sundstrand GPWS Mark II Computer, date code 8621, serial number 5587, part number 965-0476-088, with modification status 16 incorporated. It was mounted in the radio equipment rack situated aft of the Captain's station. Inputs to the GPWS were from the:

radio altimeter (radio altitude and MDA setting),

(The radio altimeter was a Honeywell RT-300, part number 7001840-912, serial number 86051920. All applicable modifications in the series had been incorporated.)

air data computer (barometric altitude and mach/airspeed),

(Two Sperry AZ-810 air data computers were installed.)

glide slope receiver,

undercarriage and flap switches, and

flap override switch.

1.6.68 The GPWS computer function had six modes of operation:

Mode 1 - Excessive Sink Rate.

This mode had two unique boundaries, and advised the pilot if the rate of descent for a given altitude was excessive. If the outer boundary was penetrated a "Sink Rate" voice warning was given. If the inner boundary was penetrated a "Whoop Whoop Pull-Up" warning was given. The mode was independent of aircraft configuration.

Mode 2 - Excessive Closure Rate.

This mode's function involved airspeed, radio altitude, radio altitude rate, barometric altitude and aircraft configuration logic. The mode had an inner and outer boundary, and if the aircraft penetrated the outer boundary a "Terrain" voice warning was given twice. If the inner boundary was penetrated a "Whoop Whoop Pull-Up" voice warning was given. Time constant changes were made as a function of flap position and radio altitude. A flaps down condition initiated the mode 2B warning boundary envelope used during landing approach. The "Pull-Up" annunciation was replaced by "Terrain" for radio altitudes (heights) below 700 feet with undercarriage and flaps extended.

Mode 3 - Altitude Loss After Take-Off.

Mode 4A - Proximity To Terrain, Gear Up.

If the aircraft penetrated the envelope at speeds greater than 0.35 Mach with the undercarriage not down and locked a "Too Low Terrain" voice warning was given. If penetration was made at speeds below 0.35 Mach with the undercarriage not down and locked a "Too Low Gear" voice warning was given.

Mode 4B - Proximity To Terrain, Flaps Up.

This mode provided protection if the undercarriage was down and locked but the flaps were not in the landing position.

Mode 5 - Descent Below Glide slope.

This mode advised of descent below the glide path when carrying out an ILS approach.

Mode 6 - Descent Below Radio Altitude MDA.

This mode provided a voice alert if the aircraft passed through the MDA set on the radio altimeter.

- 1.6.69 At the time of the accident the aircraft was configured with the flaps in the “UP” position and the right main undercarriage was not “Down And Locked” and the undercarriage was thus sensed as “UP” by the GPWS. With the aircraft so configured, and carrying out a VOR/DME approach, a Mode 2 warning should have occurred. The replay of the CVR revealed that the GPWS gave a clear “Terrain, Whoop Whoop Pull-Up, Whoop Whoop Pull-Up” voice warning to the crew, commencing 4.5 to 4.8 seconds before impact with the terrain. Research has shown that an average pilot reaction time from hearing the GPWS warning to initiating a pull-up manoeuvre is 5.4 seconds.
- 1.6.70 The DFDR record showed that between 4.5 and 3.5 seconds before the end of the record the aircraft pitched down 2 degrees and the elevator up angle increased from 1.5 to 3.5 degrees. In the last 3.5 seconds the elevator position increased from approximately 3.5 degrees to 6 degrees up and the aircraft’s pitch angle increased from 0.18 degrees to 8 degrees. During this time the vertical G increased from 0.84 to an average value of 1.35 G, and the indicated airspeed increased to 149 knots before decaying to 143 knots at the last reading.
- 1.6.71 The GPWS computer had been maintained correctly by Ansett New Zealand, and its latest check was a 7000 hour Bench Check completed on 4 November 1994. The GPWS was a required part of the operator’s minimum equipment list for the aircraft.
- 1.6.72 Modifications 17 and 18 for the GPWS computer, as per the GPWS manufacturer’s Service Bulletin, had not been embodied. An AOM issued by the aircraft manufacturer in July 1993 indicated that Modification 17 was not approved for Dash 8 installation, pending evaluation. This restriction was lifted in a subsequent AOM issued in December 1993. This stated (in part):
- Mode 2 Warning Curve Reconfiguration (Mod 17) - Approved for Dash 8 Installation ... Sundstrand developed this change to address Mode 2A (closure rate - “TERRAIN TERRAIN”) nuisance warnings. de Havilland has reviewed the data and considers installation of the modified computer acceptable.
- 1.6.73 No Service Bulletin was issued by the aircraft manufacturer to require or recommend incorporation of Modification 17 or 18 in respect of the GPWS installation in the Dash 8, nor was there an Airworthiness Directive to this effect. The Modification 16 status of the GPWS Mk II computer in ZK-NEY at the time of the accident was in conformance with the applicable parts list/modification standard configuration for the DHC-8-102 aircraft type.
- 1.6.74 Modification 17 was developed by the GPWS manufacturer to eliminate, by reconfiguring the curves for the Mode 2 warning, many nuisance or unwanted warnings that could occur during an aircraft’s landing approach over rising terrain. Modification 18 was developed to be embodied with Modification 17 to eliminate the potential for shorts between comparator number two and the comparator, and between comparator number two and the monitor logic, after incorporating Modification 17.

1.6.75 According to the GPWS manufacturer, Modification 17 was “developed and recommended” for use on all aircraft, turbo-jet or turbo-prop, which were flying with Mk II GPWS equipment. The manufacturer also advised that to ensure notice of the availability of Modification 17 (and 18) reached beyond airline engineering and maintenance staff, a Service Information Letter (SIL) (August 30/1993 SIL: GPWS-MK 1, MK II, MK II No. 1) was sent to operators for the attention of “All Chief Pilots and all Flight Operations Managers” “recommending Mod 17 (SB20) to reduce unwanted warnings” and was “especially pertinent to Dash 8 operators who were reporting chronic nuisance warnings”.

1.6.76 The SIL dated August 30/93 included the following information:

SUBJECT: REDUCTION OF UNWANTED GPWS WARNINGS

This S.I.L is issued to provide operators with recommendations on reducing unwanted GPWS warnings.

Many airlines operate aircraft fitted with older generation GPWS equipment which can be susceptible to unwanted warnings. Improvements made over the past several years have been effective in reducing operationally induced GPWS warnings, especially those that occur during radar vectoring, holding patterns or initial approach. Actual airline experience and flight simulations have confirmed unwanted warning reductions of 60 percent and greater. Sundstrand makes the following recommendations for operators who want to incorporate these improvements into their present GPWS installations.

In relation to the GPWS Mark II computer it stated, in part:

Sundstrand considers the MK II - 088 as the minimum in warning requirements. Operators are encouraged to incorporate Mod 17 (SB 20) into these units as it was specifically designed to reduce unwanted warnings during radar vectoring.

1.6.77 The operator advised that they were aware of the availability of Modification 17 (and 18), but had not embodied either as the existing modification status was in accordance with the aircraft manufacturer’s required standard, and they believed the modification was not “recommended” for the Dash 8, but was developed for high speed aircraft, such as the Boeing 737, that would fly approaches at much higher speeds than the Dash 8.

1.6.78 The operator had instituted a system of configuring the aircraft early, for landing, by lowering the undercarriage and flap on the Palmerston North Runway 25 Approach, and on approaches to two other aerodromes, to minimise the occurrence of unwanted or nuisance warnings from the GPWS. The operator believed that the early configuration procedure improved the “utility” of the GPWS as it “reduced the potential for redundant/nuisance warnings which would by their very nature be not only distracting to the aircrew but also, by reason of being disregarded, have the potential to mislead aircrew when a “real” warning occurred.” In addition, the company believed early configuration was a prudent policy where terrain was a factor, as it relieved the crew of any systems selections that could have the potential to interfere with the pilots’ primary task of flight path monitoring during the approach and descent.

1.6.79 The adoption of such practices was successful in eliminating unwanted warnings because it altered the warning mode of the GPWS. In the case of Palmerston North Runway 25 VOR/DME Approach the Mode 1 Excessive descent rate alert “Sink Rate” would remain active but one of the limitations of the equipment, when the aircraft was configured to land, was that any potential Mode 2A warnings along the approach track were eliminated, Mode 2B was desensitised, and Mode 4 deactivated. The manufacturer of the GPWS advised that they did not approve of the practice of configuring an aircraft early for landing, with the flaps and undercarriage down, as a means of minimising the occurrence of nuisance warnings.

- 1.6.80 The manufacturer of the GPWS advised that, “by incorporating Modification 17, many nuisance warnings can be eliminated, with no need to configure for landing early, and with better GPWS performance for an inadvertent premature descent short of the runway.” By configuring the aircraft early, they said, “the effectiveness of the GPWS is significantly reduced for landing short situations, during non-precision approaches.”
- 1.6.81 The aircraft was in the clean configuration at the time of the accident, however, and a Mode 2A warning (Terrain Terrain Whoop Whoop Pull Up Whoop Whoop Pull Up) should have occurred approximately 17 seconds before the impact.
- 1.6.82 The normal approach procedure for the Dash-8 required the undercarriage to be selected at an altitude of 2000 feet and flap 15 at 1800 feet.

1.7 Meteorological information

- 1.7.1 An aftercast of the weather and comment on likely local small scale effects was provided by the Meteorological Service of New Zealand Limited.
- 1.7.2 On the morning of 9 June 1995 pressures were high to the north and north-west of New Zealand and a cold front was moving over the south of South Island. A strong west to north-west flow covered central New Zealand.
- 1.7.3 The upper winds over the southern half of North Island were south-west at 0600 hours and had veered westerly by 1200 hours, while increasing in strength. Any associated turbulence would have been light at the time of the accident.
- 1.7.4 Estimated winds over Palmerston North at 0900 hours were:

1000 feet	300°T/25 knots
2000 feet	290°T/30 knots
3000 feet	280°T/30 knots
5000 feet	270°T/30 knots
7000 feet	260°T/30 knots
- 1.7.5 A satellite picture made between 0934 and 0957 hours showed that most of southern North Island was covered in cloud. To the west of the ranges the cloud appeared to be stratiform, with a few embedded cumuliform clouds, while the cloud to the south-east of the ranges showed some poorly developed banding, parallel to the Tararua Range.
- 1.7.6 The air upstream of the Tararua Range was moist, and mainly light precipitation was reported at all observation points during the morning. Rain would have been heavier and more persistent over the ranges, due to orographic uplift. A convergence line brought heavier rain to the area after about 1200 hours. The Wellington weather radar showed scattered small echoes over the Manawatu at the time of the accident, increasing later that morning. While some shower activity occurred that morning, the radar did not indicate any large scale development which could have generated large convective downdraughts.
- 1.7.7 A computer simulation by the National Institute for Water and Atmosphere Research, using a simple hill model, suggested that an area of orographic downdraught would have been present on the lee side of the range, with a magnitude of 300 to 400 feet/minute. The final approach path of the aircraft would have passed through this area. Lee wave motion did not appear to be well developed at the time of the accident, however.

- 1.7.8 The pilot of another aircraft joining the Palmerston 25 VOR/DME approach from the south via the 14 DME arc, some six minutes after ZK-NEY, reported that flight conditions around the arc north of Woodville were VMC, but that the final approach from Woodville appeared to be continuous IMC. After holding at Woodville, he flew the final approach track in level flight at about 5000 feet at 0935 hours, before diverting from Palmerston North. There was a fresh westerly wind, but little or no turbulence was encountered.
- 1.7.9 Passengers on ZK-NEY reported that no significant turbulence was encountered on the aircraft's final approach.
- 1.7.10 The weather forecast supplied to the crew of ZK-NEY which was valid from 0520 to 1800 hours, included:

Briefing Statement:

An upper south-west flow covers the country. A weak front situated to the south-west of New Zealand is expected to move north-east to lie over central South Island by midday.

Turbulence:

Areas of occasional moderate turbulence below FL 100¹ about and east of South Island ranges.

CB: Nil

Ice: Areas occasional; moderate ice 9000 to FL 180 over South Island.

Route forecasts:

Winds:

Auckland/Palmerston North: 250°T/21 knots at FL 100³

Palmerston North/Wellington: 300°T/29 knots at FL 040³.

Aerodrome forecasts:

Palmerston North:

Surface wind: 340°T/10 knots

Visibility: 30 km

Cloud: 2 oktas cumulus 2000 feet, 4 oktas stratocumulus 3000 feet

becoming 0900 to 1200: 290°/20 gusting 30 knots

temporarily 1000 to 1600 hours: visibility 7000 m, rain showers, 5 oktas

cumulus 1200 feet

temporarily 1400 to 1800 hours: visibility 4000 m, rain, 4 oktas stratus 900 feet

2000 foot wind: 300°/15 knots

becoming 0900 to 1200 hours: 260°/30 knots

QNH minimum 1008, maximum 1017.

- 1.7.11 The 0900 hours METAR (aerodrome report) for Palmerston North was:

“Surface wind: 320°/15 knots

Visibility: 6000 m in rain

Cloud: 2 oktas stratus 800 feet, 3 oktas stratus 1200 feet

6 oktas stratocumulus 2000 feet

temperature 13°C, dew point (not stated)

QNH 1011.9.”

³ Although the forecast refers to FL (flight level) the transition level in New Zealand is FL 130.

- 1.7.12 The current Palmerston North automatic terminal information service (ATIS) broadcast at the time of the accident was “Foxtrot”. At 0857 hours the crew of ZK-NEY had advised Ohakea that they were in receipt of ATIS “Echo” and Ohakea Control confirmed that “Echo” was the correct information. At 0905 hours the current ATIS was changed to “Foxtrot” but this was not advised to ZK-NEY.
- 1.7.13 There was no requirement for ATC to pass on a change to the conditions broadcast by the ATIS unless they involved the conditions deteriorating below minima. The aircraft crew were given the amended QNH and would have been given any significant update on weather conditions when they contacted Palmerston Tower in the normal course of events.
- 1.7.14 The ATIS broadcast “Echo” for Palmerston North issued at 0830 hours included the following information:

Surface wind 290/15-20 knots
Visibility 20 km
Adjacent light rain
Cloud
 2 oktas at 800 feet
 3 oktas at 1200 feet
 4 oktas at 2500 feet
Temperature plus 13
2000 foot wind 280/15
QNH 1012

- 1.7.15 ATIS “Foxtrot” for Palmerston North issued at 0905 hours included the following information:

Surface wind 300/10-20 knots
Visibility 20 km reducing to 5000 m
Rain showers
Cloud
 2 oktas at 800 feet
 4 oktas at 1200 feet
 6 oktas at 2500 feet
Temperature plus 13
2000 foot wind 280/15
QNH 1011

- 1.7.16 A SPAR (special aerodrome report) for Palmerston North Aerodrome was issued at 0835 hours with the following information:

Cloud:
 2 oktas at 800 feet
 3 oktas at 1200 feet
 Patches lower.

- 1.7.17 A further SPAR for Palmerston North Aerodrome was issued at 0900 hours with the following information:

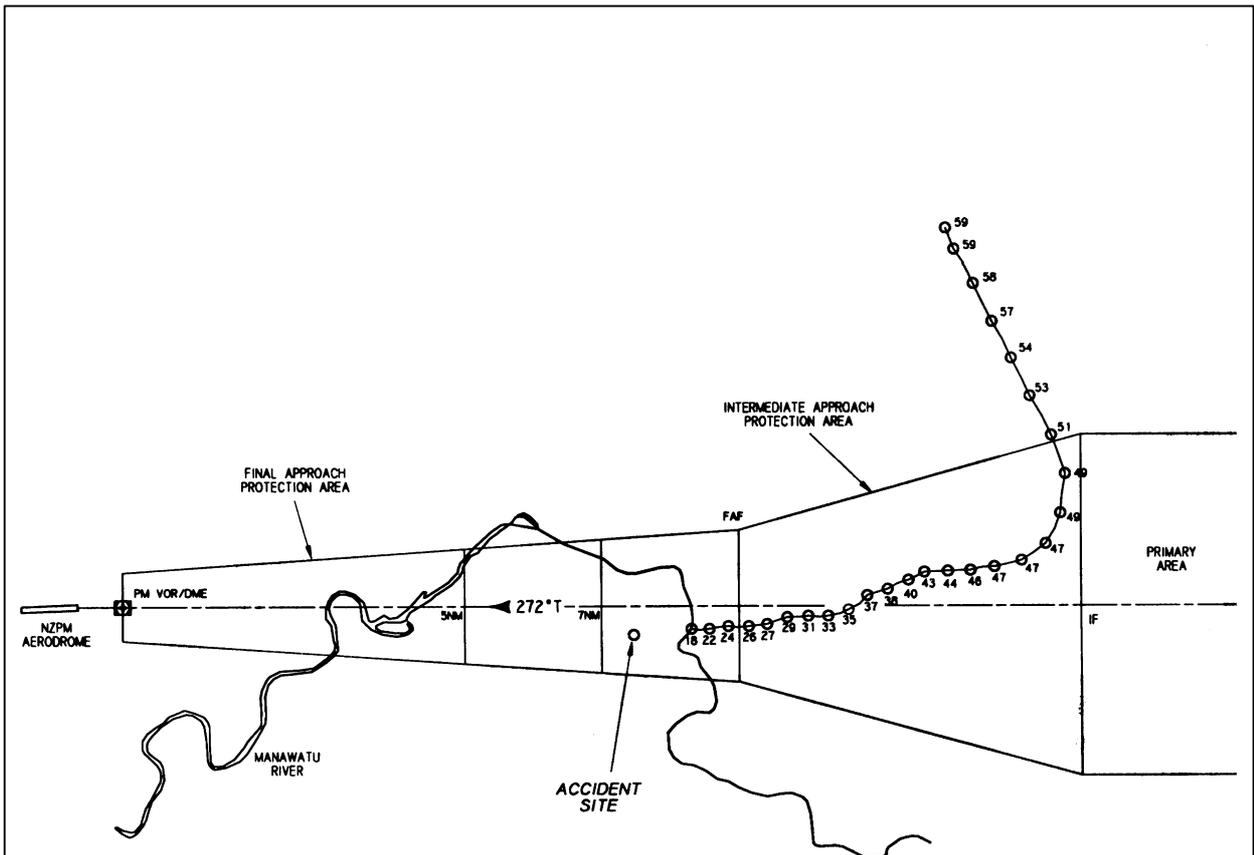
Visibility 20 km reduced to 5000m in rain showers
Cloud:
 2 oktas at 800 feet
 4 oktas at 1200 feet
 6 oktas at 2500 feet.

- 1.7.18 A comparison was made of the TAS values of ZK-NEY, derived from the DFDR data, over 70 seconds of descent on the final approach from 3200 to 1600 feet with the ground speed values for the same times from the ATC radar computer. This gave an average headwind experienced by the aircraft of approximately 30 knots.
- 1.7.19 A comparison was made between the rates of descent indicated by the DFDR and ATC radar records, and those expected by the manufacturer to result from the power settings used. This study, based on data for an aircraft in the configuration of ZK-NEY, indicated that a downdraft averaging some 410 feet per minute was encountered during the last four miles of the aircraft's approach.
- 1.7.20 During the last four miles the desired approach profile required a descent rate of 580 feet/minute. In still air average torque value of some 25 to 27% would have been required to maintain this profile and in the prevailing orographic downdraught conditions this would have increased to a requirement of some 37%. The average of the recorded engine torque for the period was approximately 20%.

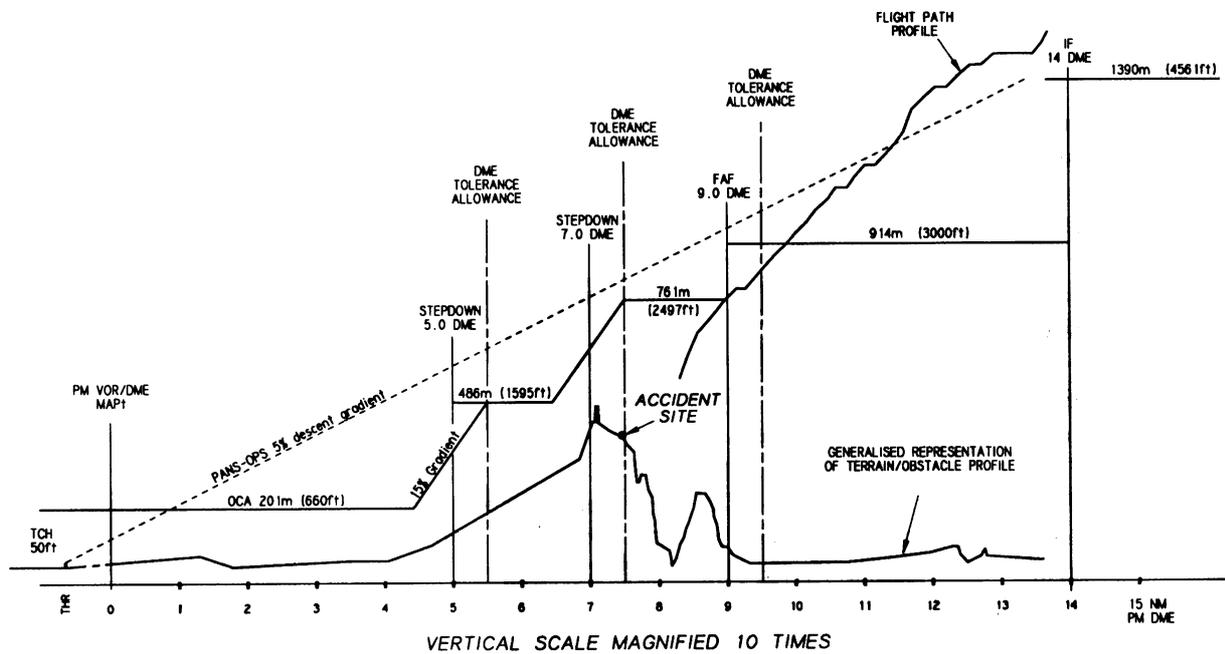
1.8 Aids to navigation

- 1.8.1 Palmerston North Aerodrome was equipped with an NDB, and a Doppler VOR with a co-sited DME. The instrument approach being flown by the crew of ZK-NEY required the use of the VOR and the DME.
- 1.8.2 These navigation aids were withdrawn from service shortly after the accident, as were the aerodrome lighting and communications facilities. All were investigated by the Airways Corporation and returned to service by them after being found to operate normally. The remote control and monitoring system fault logs recorded no defects or discontinuities during the hour surrounding the time of the accident.
- 1.8.3 A commissioning flight inspection in August 1993 found the VOR and DME to be operating satisfactorily. Routine inspections were due every 24 months thereafter. The last flight inspection on the NDB was carried out in November 1991, and recurrent flight inspections were not required, providing annual ground inspections demonstrated that it met the appropriate criteria.
- 1.8.4 Air Traffic Control Radar coverage was provided by primary surveillance radar sited at Wilson's Road, near Ohakea, by secondary surveillance radar at Ballance, 7 nm south-east of Palmerston North, and at Hawkins Hill, 73 nm south-west of Palmerston North.
- 1.8.5 On initial contact with Ohakea, Control Ansett 703 was cleared to descend from FL220 to FL130 when ready and told that they would be advised if "the 07 approach is available."
- 1.8.6 The aircraft was then cleared to 5000 feet with radar provided terrain clearance. Before the aircraft reached that altitude, however, the crew were instructed, "Ansett 703 stop descent at 6000 intercept the 14 DME arc for the VOR/DME approach to Runway 25." This instruction was accompanied by an apology for the approach to runway 07 not being available due to departing traffic.
- 1.8.7 Ohakea Control then instructed another aircraft which was approaching from Wellington to stop its descent at 5000 feet and to expect "the arc approach to runway 25."
- 1.8.8 Meanwhile the Captain acknowledged the instruction to stop the descent at 6000 feet and checked with the First Officer "and the MSA on that part of the arc is 5700?".

- 1.8.9 As they completed the “descent and approach” checklist the First Officer called, “Approaching the arc” which the Captain acknowledged with, “Check and on the arc fifty-seven hundred’s the minima?” The First Officer agreed.
- 1.8.10 At this time the Ohakea Controller advised the other aircraft, “Intercept the 14 DME arc for the VOR Approach Runway 25...” which received the response, “Intercept the 14 DME arc for the 25 approach...”.
- 1.8.11 The Captain of Ansett 703 then said to the First Officer, “You could set the minimum descent altitude.” The First Officer declined saying, “(the Controller) hasn’t cleared us for the approach yet though, has she, only cleared us to 6000?”
- 1.8.12 The Captain responded, “but once you are on the arc I think the procedure is to just set that thing to your minima.” The First Officer reiterated, “She didn’t clear us for the approach though. The Captain acknowledged, “No. I see what you mean.”
- 1.8.13 On his own initiative the First Officer queried Ohakea Control, “Just confirm we are to maintain 6000?” to which Ohakea responded, “Affirm minimum descent on the arc is 6000.”
- 1.8.14 This prompted the First Officer to remark, “... passing zero five zero we can go to forty-nine, or fifty hundred it is actually on the arc here.” The Captain agreed but added, “We won’t argue.”
- 1.8.15 Ansett 703 was then cleared for the VOR/DME Approach Runway 25 and given the Palmerston QNH of 1011 hPa.
- 1.8.16 Approach Control service to ZK-NEY was the responsibility of Ohakea Control. Normally, but not necessarily, they exercised radar control until the crew reported that they were established on the Palmerston North 25 Approach. This radar control was effected either by monitoring the aircraft’s own navigation, as with ZK-NEY, or by radar vectoring to ensure separation from any other aircraft was maintained. Although the RTF guard was transferred to Palmerston Tower when the aircraft reported they were established on the 25 Approach, Air Traffic Control service to the aircraft remained the responsibility of Ohakea Control until the aircraft reported “visual”.
- 1.8.17 The radar data was recorded at the Christchurch Air Traffic Control Centre. The recording of ZK-NEY was of good quality until it faded, probably because of masking as the aircraft descended close to high terrain. The last return was at about 8 DME, at 0922.11 hours, about half a nautical mile from the accident site.
- 1.8.18 The radar recording included Mode C data, identifying the aircraft and adding time and transponder altitude to each return.
- 1.8.19 The printout of the radar recording (see Figure 3) showed that the aircraft had descended around the 14 DME arc and had turned to intercept the final approach track normally at 5100 feet, at 0919.12 hours. On the final approach the aircraft was left of the specified track of 250° M to the VOR, being initially about one degree right of track, then crossing and maintaining about two degrees left of track to the last return. The Mode C altitude data showed a continuous descent through 2500 feet at 9 DME, to 1800 feet at the last return.
- 1.8.20 The study of the radar recording after the accident showed that the Mode C altitude data on the final approach, in conjunction with the aircraft’s position, could have enabled a radar controller to monitor the aircraft’s compliance with the instrument approach procedure while it was being carried out.



PLAN



PROFILE

Figure 3
Copy of simplified procedure design
with radar data overlaid

- 1.8.21 Because of the potential such monitoring had to alert the crew that their aircraft had descended below the minimum step-down altitudes of a VOR/DME approach, the applicable Air Traffic Control service procedures were investigated.
- 1.8.22 The primary purpose of providing an Air Traffic Control service was to prevent collisions between aircraft and to maintain an orderly flow of traffic.
- 1.8.23 When an aircraft reported it was established on the final approach of the instrument approach procedure, RTF guard was passed to Palmerston Tower for the purpose of updating the crew on the local weather and surface conditions. Until the aircraft was “visual”, responsibility for the provision of Air Traffic Control was retained by Ohakea Control but because the aircraft was then on a pilot-interpreted procedure the use of air traffic control radar was not necessary in order to exercise that control.
- 1.8.24 Palmerston Tower was not equipped with any radar facility, although the installation of a tower radar was planned at the time of the accident. The purpose of such a tower radar was to assist the Aerodrome Controller with flow control in his task of separating aircraft near the aerodrome which was done essentially by visual means.
- 1.8.25 While the radar system did generate enough data to monitor aircraft on instrument approaches, the Air Traffic Control system was not so tasked. This was because instrument approaches were pilot-interpreted procedures, with no requirement for radar control. Radar provided traffic separation for each aircraft until commencement of its approach, and it was transferred to Aerodrome Control once the aircraft reported “visual”.
- 1.8.26 Such monitoring, where practised overseas, generally dedicated one controller to each flight for the duration of its approach, and for that controller to have displayed the relevant approach chart for reference. Ohakea Control provided Approach Control to three different aerodromes, each with different approach procedures. The task of monitoring instrument approaches was thus not compatible with the normal task of controlling other aircraft (sometimes six or more) within a 30 nm radius for which the unit was established. To provide such monitoring would require a substantial increase of controllers and other resources.
- 1.8.27 A minimum safe altitude warning system (MSAW) has been designed for some ATC radar installations. The AIRCAT 2000 system purchased in 1991 by the Airways Corporation did not have such a system available at the time it was installed. The MSAW’s enhancement for the AIRCAT 2000 system is still in the developmental stage.
- 1.8.28 The Airways Corporation’s assessment of MSAW was that while it had potential to be useful in the future it had not reached the stage where it was sufficiently reliable. While they intend to review developments on a continuing basis, and to discuss options with the radar’s manufacturers and the CAA as they arise, they remained of the view that it is the pilot’s responsibility to monitor the aircraft’s altitude and they would need to determine the legal liability issues of accepting any responsibility for aircraft altitude monitoring before considering the implementation of such systems.

1.9 Communications

1.9.1 Radios

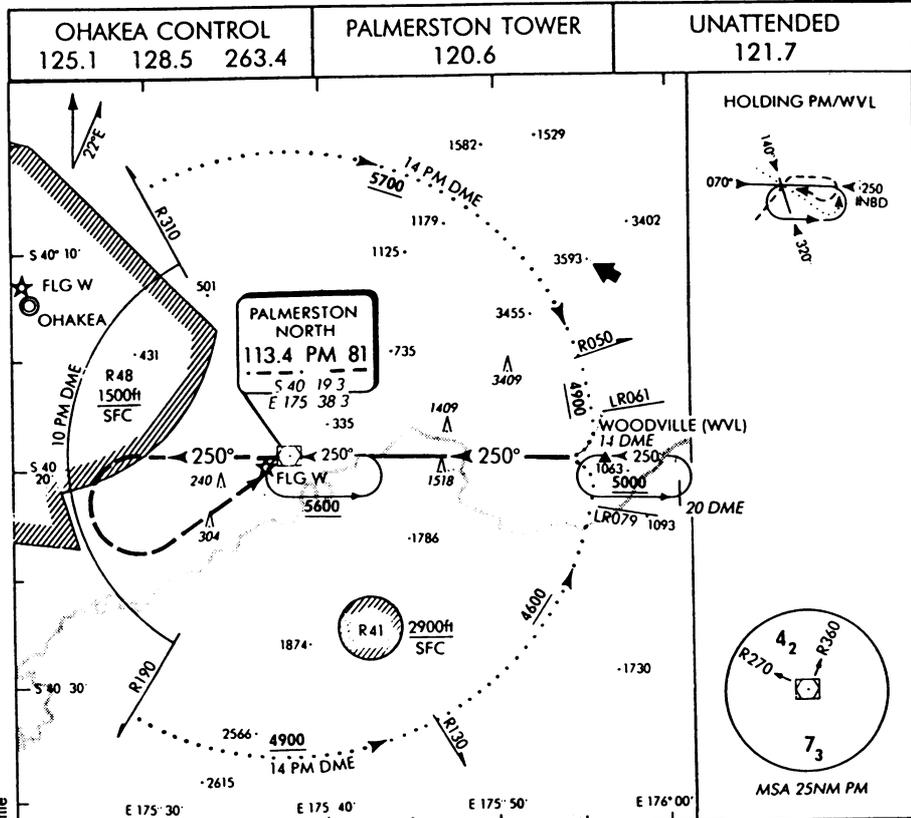
The aircraft was equipped with two King KTR908 VHF radios, VHF 1 and VHF 2. All communications were on VHF radio and were satisfactory. Air Traffic Service tape recordings of the frequencies used during the flight were available, and a transcript was produced by the Air Traffic Service for the Commission. At the time of the accident both VHF radios were selected to 120.6 MHz (Palmerston Tower).

PALMERSTON NORTH

VOR/DME RWY 25

ELEV 149

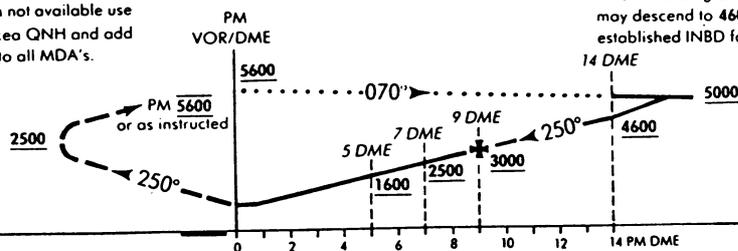
RWY 25 THR ELEV 148



Changes from 10NOV94: Profile

Use Palmerston North QNH
When not available use
Ohakea QNH and add
40h to all MDA's.

Aircraft holding at WOODVILLE
may descend to 4600 when
established INBD for APCH.



DME DIST	MAP	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Advisory Altitude 5%	MDA	690	990	1300	1600	1900	2210	2510	2820	3120	3420	3730	4030	4330	4640
Category		A			B			C			D				
VOR/DME		660 (511) - 2000						660 (511) - 2800							
Circling		660(511) - 2000			660(511) - 2800			960(811) - 4800			1320(1171) - 4800				

PALMERSTON NORTH

113.4 PM 81

VOR/DME RWY 25

2 MAR 95

© Airways Corporation of New Zealand Limited

- 1.9.2 The only RTF communications to and from the aircraft during the approach were between it and Ohakea Control.

1.10 Aerodrome information

- 1.10.1 Palmerston North is a public aerodrome located two nautical miles (3.7 km) north of Palmerston North City at an elevation of 149 feet amsl. It has a single tarmac runway 1522 m long, oriented 069/249 degrees magnetic. Runway 25 was the runway in use at the time of the accident.
- 1.10.2 The aerodrome is situated on the low-lying Manawatu Plain between the central North Island mountain ranges and the west coast 18 nm (33.3 km) away. The Manawatu Gorge, six nautical miles (11 km) east of the aerodrome, separates the Tararua and Ruahine Ranges which are oriented south-west/north-east. These ranges rise to about 5000 feet within 25 nm (46 km), but in the Manawatu Gorge area the terrain is generally up to about 1500 feet amsl. This area is designated mountainous terrain.
- 1.10.3 Palmerston North Control Zone/D extended from ground level up to 1500 feet around the aerodrome, and up to 2500 feet in the Manawatu Gorge area, out to nine nautical miles east of the DME. The accident occurred within this part of the Control Zone.
- 1.10.4 Ohakea Terminal Area/C, specified as transponder-mandatory airspace, extended above the Control Zone to 9500 feet.
- 1.10.5 Air Traffic Control services at the time of the accident were approach control and radar provided by Ohakea Control, and Aerodrome Control provided by Palmerston Tower.
- 1.10.6 The Palmerston North VOR/DME Runway 25 instrument approach procedure (Figure 4), was introduced in 1994. Before its introduction instrument approaches were oriented for Runway 07, requiring a circling approach if Runway 25 was in use. Increasing traffic density, with delays occurring between approaches for 07 and departures from 25 in IMC, led to its design.
- 1.10.7 It was designed as a straight-in procedure with DME stepdowns, to be used, principally, with a DME Arc initial approach segment, although an outbound initial approach with a procedure turn could be used.
- 1.10.8 Because of the high minimum safe altitudes over the mountainous terrain in the area, and the need to limit the steepness of the approach gradient to 5% in the final and intermediate segments, the procedure design did not provide a level intermediate segment for an aircraft to decelerate before commencing its descent on the final approach.
- 1.10.9 The procedure was designed by Airways Corporation and approved by CAA in 1993. The design (Figure 4) met the criteria of ICAO PANS-OPS Volume II.

1.11 Flight recorders

Cockpit voice recorder

- 1.11.1 The aircraft was equipped with a Fairchild model A100A CVR, serial number 51656, part number 93-A100-80, which was mounted aft of the aircraft's rear pressure bulkhead.

1.11.2 The CVR was of the nominal 30 minute duration, endless loop type. It recorded on four tracks, allocated as follows:

Track 1- Captain's "live" microphone and headset signals.

Track 2- Passenger Address system.

Track 3- Flight deck area microphone.

Track 4- First Officer's "live" microphone and headset signals.

1.11.3 The CVR was recovered from the aircraft at the accident site. The tape was undamaged and a satisfactory replay was obtained by the Australian Bureau of Air Safety Investigation (BASI). The audio quality of the CVR was good, and a full transcript was produced for the nominal thirty-minute duration of the recording.

1.11.4 The relevant extracts from the CVR transcript are shown in relation to the DFDR information in Appendix A.

Flight data recorder

1.11.5 The aircraft was fitted with a Lockheed model 209F Digital Flight Data Recorder (DFDR), serial number 3075, part number 10077A500, with a recording duration of 25 hours on Mylar magnetic tape, and a Teledyne flight data acquisition unit (FDAU). The DFDR was mounted alongside the CVR, aft of the aircraft's rear pressure bulkhead.

1.11.6 A total of 25 parameters and eight discrete events were recorded. The parameters included:

pressure altitude,
computed airspeed,
magnetic heading,
flap position,
spoiler position, and
engine torque values (left and right).

The radio altimeter parameter was not recorded.

1.11.7 The DFDR was recovered from the aircraft at the accident site. The record was undamaged and a satisfactory readout and analysis was obtained using the BASI's FDR replay equipment. The readout quality was good, and a printout of the various parameters was produced.

1.11.8 Appendix A shows a plot of the aircraft's computed airspeed, altitude, magnetic heading, and engine torque values against a "real time"⁴ reference from the initial impact. The time reference used was the ATS audio recording of the VHF communications with Ohakea control⁵. The figure shows these plots commencing from 5792 feet as the aircraft passed the 050 radial from PM VOR, 256 seconds before impact with the terrain.

1.11.9 The record of the DFDR shows that the engine torque was reduced to flight idle at an altitude of about 4800 feet, some 13.5 miles DME from Palmerston North, and left at that setting until the First Officer called "on profile" just over a minute later. At this point the engine torque was increased to about 33% for twenty seconds before it was reduced again to 24% for 30 seconds then further to flight idle with a trickle increase back to 10% over the next 30 seconds after which the undercarriage warning horn sounded and the Captain increased the power to 35% at which value it remained until impact.

⁴ The DFDR plot has VHF1 and VHF2 discrettes. These were used to marry the CVR, DFDR and ATS audio recordings.

⁵ ATS audio and radar time injections have an ACNZ standard of plus or minus 10 seconds each.

New Zealand requirements for flight recorder installation in aircraft

CVR

- 1.11.10 At the time of the accident there was no CAA requirement for New Zealand registered aircraft to be fitted with a CVR.
- 1.11.11 The contract negotiated between Ansett New Zealand and NZALPA required in paragraph 4.3 “.....Cockpit voice recorders shall only be installed or operative when legally required to be installed in the aircraft by the State and enforced by legislation.”

DFDR

- 1.11.12 New Zealand Civil Airworthiness Requirements Airworthiness Standards, C4, paragraph 2.2 stated that:

Each turbine engined air transport aircraft with a maximum certified take-off weight greater than 5700 kg shall be fitted with an approved flight data recorder of non-ejectable type, unless the aircraft is a newly acquired aircraft being ferried to a base where a flight data recorder is to be fitted. The flight recorder shall be capable of recording against a time scale the following data:

Indicated airspeed

Indicated altitude

Magnetic heading

Vertical acceleration

Pitch attitude (if a suitable source is available to the aircraft).

1.12 Wreckage and impact information

- 1.12.1 The VOR/DME Runway 25 Approach to Palmerston North Aerodrome crossed a low range of hills lying between Woodville to the east and the Manawatu Plain. On the eastern side of the hills the lower slopes are steep with bush-clad faces interspersed with many short gullies and longer creeks, blending into typically undulating rough hill country pasture at a higher level. The western hillsides comprise relatively gentle slopes of open grazing land descending to the Manawatu River.
- 1.12.2 ZK-NEY collided with the upper slope of the hills on the eastern side some 740 m east of a microwave tower while flying the approach path 8 nm (15 km) from the threshold of runway 25 at Palmerston North Aerodrome.
- 1.12.3 The accident occurred on private farmland which was divided by post and wire fences for grazing. The various areas involved in the impact sequence and the pieces of wreckage were all located in one large hillside paddock. (See Figure 5.) The paddock included two gullies and intersecting spurs of high ground rising toward the hilltop. The principal impact zones and general wreckage trail followed an uphill pattern over open grassland, although items of wreckage were distributed into gullies during the accident sequence.

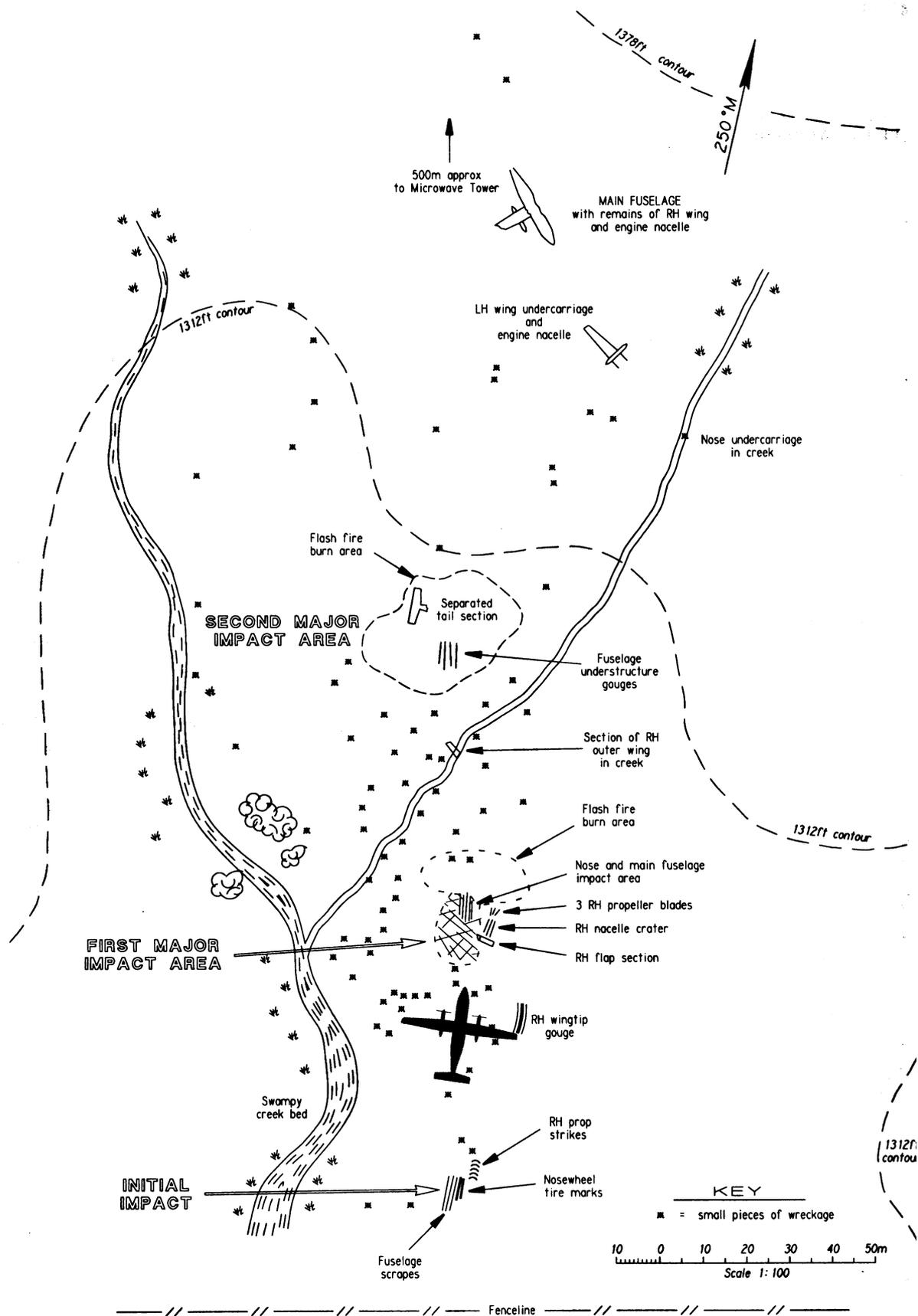


Figure 5
Impact and wreckage diagram

- 1.12.4 The initial ground impact occurred as the nosewheel of ZK-NEY contacted a gently rising grassy knoll which had an overall up-slope of about 5°. The aircraft was approximately level laterally at the time.
- 1.12.5 Scrape marks extending over a distance of nine metres, paint flecks and small items of debris from the fuselage skin showed that the underside of the aircraft struck the knoll subsequently.
- 1.12.6 The limited extent, and shallow scoring of the short cropped grass, indicated that the fuselage ground contact in this area was brief and involved little structural distortion. The alignment of the score marks showed the aircraft to have been tracking on 253° M.
- 1.12.7 The surveyed elevation of the initial impact point was 1272 feet amsl.
- 1.12.8 The ground dropped away steeply to the left of the knoll, allowing the aircraft's left wing and engine assembly, including the fully extended and locked down left main undercarriage, to clear the terrain.
- 1.12.9 The ground to the right of the knoll sloped upwards. The smooth grass surface retained a series of well-defined slash marks, which had been produced by the right propeller, about 100 mm in depth and 1050 mm apart. In normal circumstances the aircraft's propellers would have been rotating at 900 rpm at this stage of the approach. At 900 rpm the distance between the propeller slashes was consistent with a ground speed, at initial ground contact, of 122 knots.
- 1.12.10 As a consequence of the ground strike, the majority of items recovered at the commencement of the wreckage trail were widely scattered fragments from the tips and outer portions of the right propeller blades.
- 1.12.11 The grass in the location where the right main undercarriage, had it been extended, would have made ground contact, was undisturbed. The absence of any tyre marks, which in the case of the nose undercarriage ground contact were clear and unmistakable, established that the right main undercarriage had either been held up by the uplock or had not descended far enough for the wheels to strike the ground. The normal ground clearance of the propeller tips with the main wheels on the ground is 37 inches (940 mm).
- 1.12.12 While the impact forces at the point of first ground contact were light, the brief rolling contact of the nosewheels on the upsloping knoll probably resulted in a positive fuselage pitch change and assisted in deflecting the aircraft's flight path upwards. Consequently the aircraft continued for some 42 m on an ascending path of about 5° before the right wing tip gouged the soft earth of the nearby hillside for seven metres.
- 1.12.13 Approximately 28 m further on and 70 m beyond the grass knoll, the aircraft struck a terraced grass spur which had an upslope, in the impact area, of about 30°. The orientation of the spur was such that the major impact was absorbed by the aircraft's fuselage, right engine and right wing assembly. Three of the four already damaged right propeller blades detached from their hub and a four-metre-long section of the right outboard wing flap, together with smaller portions of other components from the lower fuselage and right side of the aircraft, were strewn over this impact area.
- 1.12.14 The subsequent scatter of assorted items of wreckage as the aircraft continued up the hillside, beyond this major impact area, showed that significant structural disruption and weakening had taken place, including the loss of integrity of the rear fuselage/tail assembly aft of the pressure bulkhead.

- 1.12.15 The aircraft had yawed to the right as a result of the impact forces, and after lofting some 60 m across a gully it struck the hillside again. During this second major impact, the tail section separated, and the entire left wing assembly, including the engine and extended left main undercarriage, broke away from the fuselage. The tail section fell onto the hillside approximately 140 m upslope from the initial impact point.
- 1.12.16 The left wing and engine assembly slid inverted along the hillside in the general direction of the aircraft's travel before coming to rest 200 m from the first point of ground contact.
- 1.12.17 The damaged fuselage section comprising the flight deck and cabin, with the remains of the right wing and right engine installation loosely attached, continued uphill until brought to rest against a bank on the hillside, having traversed a total distance of about 235 m from initial impact. The fuselage was slewed through some 150° and lay across the slope on a heading of 040°M partially rolled onto its left side, at an elevation of 1345 feet amsl.
- 1.12.18 Information from the aircraft's flight deck included the following:
- “The power levers were both fully forward. The condition levers were similarly forward, in the maximum propeller rpm position. However, the positions of these levers “as found” did not necessarily reflect their pre-impact configuration due to the extensive disruption which had occurred during the accident sequence.
- The flap selector lever was in the 0° detent. The pointer of the Flap Position Indicator, mounted in the instrument panel, indicated that the flaps were up.
- The Captain's and First Officer's altimeters provided a drum and pointer display of barometrically corrected altitude using information from the air data computer. The sub-scale of the Captain's altimeter, as found, was part way between 1011 hPa and 1010 hPa. The sub-scale of the First Officer's altimeter was set to 1010 hPa. Both altimeters, by drum and pointer, indicated 1260 feet. A failure flag was showing in front of each altitude counter.
- The standby 'barometric' altimeter sub-scale setting was 1011 hPa. The instrument's drum and pointer display read 1470 feet.
- The Captain's and First Officer's Static Source Selectors, which were located independently, were both selected to 'NORMAL'.
- 1.12.19 The undercarriage selector lever was selected fully 'DOWN'. The adjacent Selector Lever Lock Release knob was in its uppermost position.
- 1.12.20 Alternate undercarriage extension controls were located in the flight deck roof above the First Officer, and in the floor area to the left of the First Officer's seat. The overhead panels had sustained considerable disruption and the plastic trim surrounding the Landing Gear Alternate Release Door and the associated L/G Down Select Inhibit Switch had collapsed. The Inhibit Switch incorporated a hinged cover to guard, under normal circumstances, against inadvertent switch activation. The Inhibit Switch was found in the 'NORMAL' position with the guard closed over it; however, subsequent closure of the guard during the impact sequence would have moved the switch to the 'NORMAL' position and resulted in the 'as found' condition.
- 1.12.21 The Landing Gear Alternate Release Door was open and the Main Gear Uplock Release Handle was hanging down, exposing some 750 mm of the release operating cable, to which the handle was securely attached. Significant structural distortion affecting pulley locations and cable runs, and tensile overload failures of the cable installation caused by the aircraft break-up, rendered it impracticable to determine conclusively the pre-impact integrity of the cable release system. There was no evidence found to suggest that it was not capable of satisfactory operation.

- 1.12.22 The damage and disruption precluded determination as to whether the Main Gear Release Handle had been pulled in flight to the second ‘pulse’ (i.e.: sufficiently to manually disengage the uplock latch from the leg-mounted roller and allow the ‘hung’ right undercarriage leg to commence descending). However, the aft doors of the intact left engine nacelle were fully open, and damage to recovered portions of the aft doors from the right nacelle indicated that they were also open at impact. This confirmed that the alternate extension sequence had been activated to at least the first stage by the pulling of the uplock release handle. The uplock roller was not in the uplock latch on the right main undercarriage.
- 1.12.23 The Landing Gear Alternate Extension Door, located on the flight deck floor, was fully open. The socket of the hand pump assembly, accessible with the panel door open, was unobstructed. The pump handle was lying on the collapsed coaming adjacent to the flight deck window to the left of the Captain’s seat. The pump handle was normally stowed against the bulkhead behind the First Officer, its lower end located in a metal ‘cup’, and the upper end restrained by a short bungee cord. No damage had occurred to the cup or bungee retaining assembly, providing supportive evidence that the pump handle had been removed from its stowage prior to ground impact.

1.13 Medical and pathological information

Impact and injury characteristics

- 1.13.1 The aircraft flight deck and cabin received at least two major impacts with a large vertical deceleration and a deceleration along the longitudinal axis. The result of the impact forces threw the occupants forwards and downwards, injuring the crew and most of the passengers. Extensive damage was inflicted on a number of the passenger seat mountings but in the forward part of the cabin this did not result in the seats breaking free.
- 1.13.2 Both wings broke away from the fuselage, imposing major torsional forces on the fuselage in the areas adjoining seat rows 4 to 8 and significant lateral forces on the seats.
- 1.13.3 Prior to coming to rest the lower part of the fuselage structure failed and split longitudinally, resulting in a height difference of up to a metre between the right and left halves of the cabin floor.
- 1.13.4 The aircraft rocked significantly during the impact sequence causing many passengers to sustain substantial contacts between the fuselage, or other passengers, and their heads, shoulders, chests and arms.
- 1.13.5 During the initial vertical impacts, many of the mountings for the cabin ceiling and the baggage lockers failed, resulting in a partial collapse of the ceiling and lockers. Most of the disruption to the baggage lockers occurred in the wing root area.
- 1.13.6 Debris and some aircraft structure intruded into the cabin during the deformation of the fuselage. The greater localised forces in the wing root area transmitted through the seats resulted in a greater severity of injury to passengers seated in rows 5 to 9.
- 1.13.7 The relationship of injuries to the deformation of the aircraft’s seats and fuselage correlated accurately with the calculated forces of the impact sequence detailed above. (See Table 1.)

Seat	A	B	F	G
1	Unoccupied	Unoccupied	Unoccupied	Fatal injuries (unrestrained)
	SB: Missing. SS: Intact, base missing. Extensive bulkhead damage.	SB: Deformed	SB: OK SS: OK	SB: Deformed. SS: Deformed due to fuselage damage.
2	Fractured ankle.	Crush injuries to fingers	Unoccupied	Fracture lumbar spine and right shoulder
	SB: Minor damage. SS: Minor damage.	SB: Deformed laterally. SS: Broken off.	SB: Deformed. SS: Intact. Result of loose articles.	SB: Minor damage. SS: Intact
3	Minor facial injuries and neck strain	Unoccupied	Post accident burns	Chest injuries
	SB: Deformed. SS: Intact.	SB: Deformed. SS: Rear seat leg damaged by direct rear impact.	Seat ejected from aircraft	Seat ejected from aircraft.
4	Mild concussion	Unoccupied	Unoccupied	Broken collar bones, right shoulder and ribs
	SB: Intact. SS: Damaged at rear from impact.	SB: Intact. SS: Damaged at rear from impact.	SB: Missing. SS: Intact.	SB: Missing. SS: Intact
5	Unoccupied	Unoccupied	Unoccupied	Spinal injury
	SB: Intact. SS: Intact.	SB: Deformed	SB: Missing. SS: Minimal buckling.	SB: Deformed. SS: Buckled.
6	Chest injuries	Unoccupied	Unoccupied	Fatal back and head injuries
	SB: Damaged. SS: Broken free and severely damaged.	SB: Damaged. SS: Broken free and severely damaged.	SS: Broken at base and ejected from aircraft.	SS: Broken at base and ejected from aircraft.
7	Broken ankle and index finger	Fatal injuries, head neck and chest	Unoccupied	Unoccupied
	SB: Intact. SS: Broken high on legs.	SB: Intact. SS: Broken high on legs.	SB: Intact. SS: Intact. Uninhabitable space due to floor intrusion.	SB Deformed. SS: Lateral damage due to deformation of fuselage.
8	Neck and head injuries	Unoccupied	Unoccupied	Unoccupied
	SB: Deformed. SS: Broken at floor. Mounting indication major forward and lateral loadings.	SB: Deformed. SS: Broken at floor. Mounting indication major forward and lateral loadings.	SB: Severely damaged. SS: Intact.	SB: Severely damaged. SS: Intact.
9	Unoccupied	Unoccupied	Right fractured ribs	Bruising
	Parallelogram deformation indicating severe lateral impact.	Parallelogram deformation indicating severe lateral impact.	SB: Intact. SS: Intact.	SB: Deformed. SS: Intact.
10	Unoccupied	Unoccupied	Fractured lumber spine.	Fractured femora
	SB: Intact. SS: Intact	SB: Affected by rear bulkhead damage. SS: Some arm rest damage and minor seat deformation.	SB: Affected by rear bulkhead damage. SS: Minor deformation.	SS: Severe deformation from fuselage damage. SS: Similar.

Table 1 Key: SB = seat back, SS = seat support
Relationship of injuries to cabin occupants with seat damage and seat position

- 1.13.8 Most of the occupants' injuries, including those of the crew, were to the head, neck and chest. Passengers' injuries to the lower limbs from impact with the seat in front of them were minor, suggesting there was relatively little flailing.
- 1.13.9 Many of the head and facial injuries were sustained early in the impact sequence when restrained seat occupants were thrown forward onto the back of the seat immediately in front of them. These injuries often caused minor concussion which in some passengers caused a brief period of unconsciousness or confusion; this together with exit obstruction or entrapment, delayed emergency exit from the aircraft onto the hillside after the aircraft came to rest.
- 1.13.10 Some injuries were caused by contact with loose and penetrating objects entering the cabin area normally occupied by passengers and crew.
- 1.13.11 Both of the pilots remained conscious but were incapacitated by serious head injuries.
- 1.13.12 The flight attendant was leaning over the back of seat 1G facing rearwards at the time of the impact and was thrown to the floor sustaining fatal injuries to her head. The Flight Attendant's rearward facing seat was adjacent to the front left exit door facing seats 1A and 1B.
- 1.13.13 The other two immediate fatalities involved passengers seated in the rear mid-section of the aircraft. One was thrown, in his seat, onto another seat two rows forward, sustaining major chest injuries. The other died from chest injuries sustained while still restrained, due to additional localised impact loads from seat dislodgement.
- 1.13.14 The latter two fatalities were due to impact forces, well in excess of the survival design parameters, sustained either due to direct injury or through seat mounting failure.
- 1.13.15 One further fatality occurred involving a passenger who, while waiting outside the aircraft, became enveloped in a small, short-lived fire which erupted at the rear of the right engine nacelle. He survived initially but died 12 days later in hospital from extensive burns.

1.14 Fire

- 1.14.1 Post-impact fire had occurred in a number of areas during the accident sequence.
- 1.14.2 Following the aircraft's initial contact with a grassed knoll the right wingtip gouged into the adjacent hillside and the fuselage and right engine then struck the slope.
- 1.14.3 The progressive rapid disruption of the right wing outboard structure released a large volume of fuel from the right tank, and scorching of the grass over a widespread portion of the impact zone indicated that a flash fire had ensued.
- 1.14.4 Of the sources of ignition, the most likely was an exposed flame from the right engine exhaust ducting which sustained major damage and disruption at impact. Burn marks and sooting on items of wreckage scattered in this area and beyond suggested that in addition to the overall effect of a transitory fireball due to the ignition of misted fuel, small isolated pockets of puddled fuel had ignited and had burned for a longer period.
- 1.14.5 The aircraft's vertical and horizontal tail surfaces were sooted in a manner consistent with the occurrence of a similar brief flash fire in the area of the second major impact further up the hillside where the already weakened empennage and left wing and engine assembly separated from the fuselage structure. It was also likely that some sooting and fire damage resulted from immediate or subsequent burning of fuel droplets deposited on the tail surfaces when the right wing fuel tank was first ruptured.

- 1.14.6 The impact sequence was such that the left wing broke away from the fuselage in the region of the centre section. The left fuel tank bay located outboard of the engine nacelle sustained minimal damage resulting in only a minor leak. A considerable quantity of fuel remained in the left tank until the aircraft wreckage was removed from the accident site three days after the accident. Fuel from the left tank did not contribute to the fire. There was no significant sooting or fire damage on the separated left wing and engine, indicating that the effect of the flash fires at the major impact locations was confined to the right side and rear of the aircraft.
- 1.14.7 Survivor reports indicated that after the fuselage had come to rest a small and non-threatening fire was observed burning on the right side of the aircraft. The broken centre section and inboard portion of the right wing, although almost detached from the fuselage, still lay across it. The right engine nacelle and remaining structure of the outboard wing had collapsed onto the ground. Due to the angle at which the wreckage was lying it was likely that residual fuel was pooled in the vicinity of, and beneath, the rear of the right nacelle.
- 1.14.8 The exhaust duct had separated from the rear of the right engine. The fire which persisted in this area may have been sustained due to the proximity of the damaged engine and its hot section component parts.
- 1.14.9 After a number of survivors had made their way from the aircraft, the existing fire flared up suddenly in an explosive manner engulfing an extended area. Although it diminished in intensity quickly, it was this intense and unexpected conflagration that trapped and enveloped a nearby passenger.
- 1.14.10 Site examination and the evidence of survivors indicated that, with the exception of the fire adjacent to the aircraft fuselage, other outbreaks of fire which occurred during the impact sequence were relatively short-lived, and self-extinguished.
- 1.14.11 No attempt was made by the survivors to use the on board portable fire extinguishers on the small fire in the right wing area.
- 1.14.12 Rescue activities, undertaken approximately one hour after the accident, did not involve fire suppression as the fire in the right engine nacelle area had burnt out.

1.15 Survival aspects

Rescue operations

- 1.15.1 At 0926 hours Palmerston Tower alerted the Police, the Airport Rescue Fire Service, the New Zealand Fire Service and Palmerston North Hospital, that a Dash 8 aircraft had gone missing during an instrument approach to Palmerston North Aerodrome. This action followed unsuccessful attempts by the Tower and Ohakea Control to contact Ansett 703, and after confirming with Ohakea Control that the aircraft had disappeared from radar.
- 1.15.2 The emergency services notified by the Police included the Fire Service, ambulance, Civil Defence, the Palmerston North Airport Disaster Team, the Airport Rescue Fire Service, the Airport Medical Officer, Palmerston North Hospital, and the rescue helicopters.
- 1.15.3 As the exact location of the aircraft was not known, the emergency services were instructed to assemble together at a specific point and await further instructions. Nine ambulances, each with a crew of two, responded. The Fire Service dispatched three appliances, a command vehicle and a tanker, and the Police sent 30 personnel. The Airport Rescue Fire Service also provided a vehicle and personnel.
- 1.15.4 The search was centred initially on a position equating to four nautical miles final for runway 25, which was where the Ohakea Air Traffic Controller involved thought the aircraft was most likely

to be. A ground search by Police and rescue vehicles was augmented by a helicopter from Palmerston North at 0939 hours, and a second helicopter from Hastings at 1000 hours.

- 1.15.5 A few minutes after the accident, a passenger from the aircraft used his portable cellular telephone to make an emergency call to the Police, reporting that the aircraft had “crashed” in a paddock with no road access. The Palmerston Surface Movements Controller then made telephone contact with the passenger and was able to ascertain the condition of the survivors: that they were on a grassy hill top and in cloud with limited visibility and their position was indeterminable. He gave them advice on survival strategy while the search progressed, and also obtained a description of the only significant feature visible in their vicinity, which was a large stock pen.
- 1.15.6 From telephone inquiries of local farmers, the probable access road to this stock pen was discovered and ground vehicles were directed to it. The controller also got the passenger to report to him when the sound of a helicopter was heard. This information was relayed to the helicopters by RTF, thus narrowing their search area to some extent. The effectiveness of this process was reduced by the presence of two helicopters between which the passenger could not differentiate.
- 1.15.7 The two helicopters were instructed to search initially on the Ashhurst side of the Manawatu Gorge and then the Woodville side of the gorge. The helicopters searched both visually for the aircraft and electronically for its ELT.
- 1.15.8 One helicopter had been searching visually at low level, below the cloud base and hence below the accident site, while the other searched electronically at altitude, in or above cloud. When they were both able to receive the weak ELT signal on their homing equipment, and were in mutual visual contact, the pilots were able to track to the ELT by hover-taxiing over the hilly terrain, in cloud and poor visibility. Despite the flying conditions the wreckage was located at approximately 1019 hours.
- 1.15.9 Police and paramedic personnel on the helicopters were off-loaded near the wreckage, and both helicopters then flew to Palmerston North Hospital to collect medical staff and return them to the scene. Four further helicopters had been instructed to assist and arrived at the site to help with the evacuation of the injured, and for general transportation. The ground vehicles arrived a few minutes later.
- 1.15.10 Treatment and rescue of the aircraft’s occupants began without further delay.
- 1.15.11 At 1022 hours a road block was established at Hall Block Road and a medical trailer proceeded up this road to the scene. A command post was established on the crest of a hill near the accident site at approximately 1039 hours. On arrival at the road block the Airport Medical Officer assisted the ambulance staff before proceeding to the site.
- 1.15.12 A doctor on site assisted with the triaging of the injured, and the survivors were transported by helicopter to the ambulances stationed near the road block or were flown direct to Palmerston North Hospital. Some of the more seriously injured were transported by helicopter to Wellington Hospital. The first survivor arrived at Palmerston North Hospital by helicopter at about 1100 hours and the last survivor arrived by road ambulance at 1207 hours.
- 1.15.13 Further assistance was provided by the Army. The Salvation Army and members of other volunteer organisations who arrived at the scene during the proceedings also offered their assistance. A contingency force at RNZAF Base Ohakea was put on standby at the request of



Figure 6a
View of passenger cabin looking aft



Figure 6b
View of flight deck

the Airport Medical Officer and was stood down when the last of the survivors had been removed from the accident scene.

- 1.15.14 The deceased were removed from the scene by 1500 hours.
- 1.15.15 A Victim Support Group was mobilised by the Police and sent to Palmerston North Aerodrome and the Palmerston North Hospital to assist as required.
- 1.15.16 The Air Traffic Control Radar recording, when subsequently studied, showed information which had the potential to assist with the search for the aircraft after the accident, had it been available quickly. Because of this, the necessary procedure to obtain a playback of the recording was investigated.
- 1.15.17 When a request for a playback of current radar data was made, the first step was to switch from the active computer to a standby computer, which occupied a minimum of five minutes. The recorded data, in eight files, then had to be down loaded from the hard disc storage to a tape. The tape then had to be searched on a playback machine to find the appropriate data.
- 1.15.18 The normal minimum time required before a radar recording could be studied to assay the data was about 40 minutes, but could be up to 1 hour 40 minutes, and at least 15 minutes extra would then be required to find the relevant information and notify the RCC.
- 1.15.19 The Airways Corporation did not have an early radar recording search arranged as part of their standard response system, but facilities and personnel were generally available to accomplish this should it be requested.

Post accident survival factors

- 1.15.20 The limited involvement of the fuselage in the post-impact fire increased the post-impact survivability. Apart from the short-lived fire which occurred in the area of the right engine, most of the spilt fuel was consumed in two flash fires early in the impact sequence. Significant delays in effecting emergency egress were experienced by some passengers because of seat dislodgements and an accumulation of debris in the cabin. (Figures 6a and 6b.)
- 1.15.21 The door at seat 1G was opened by the impact forces and the window exits at seats 4A and 4G were also used as exits as was the large opening caused by the failure in the left wing root area. The large opening also enhanced the light level in the interior of the cabin, despite the overcast sky and fog conditions.
- 1.15.22 Exit from the aircraft was impeded by debris from loose seats, and by the collapse of the roof section in the mid-cabin area. This situation resulted in some passengers being trapped in the aircraft for 30 to 60 minutes after the accident.
- 1.15.23 The shelter of the fuselage probably protected some of the more seriously injured from exposure to the weather and consequential hypothermia.
- 1.15.24 As the initial concussed and dazed state of the more able survivors wore off, some became active in caring for the more seriously injured. At least one looked for a first aid kit but the lack of a clear indication of its existence prevented it being found. Others helped extricate the remaining individuals trapped in the wreckage and located items to act as insulation from the chilling wind and rain. Aircraft insulation and scattered clothing were gathered for this purpose.

Survivability

- 1.15.25 The energy absorbed by the aircraft structure and the extended stopping distance made the impact survivable.
- 1.15.26 In most cases the energy absorbing collapse of the seat supports which permitted continued restraint of seat occupants in the front and rear cabin also promoted survival. Seating design and mountings in these areas performed in excess of the normal design parameters. Seat structure and mounting failures resulted from additional laterally transmitted forces associated with the failure of the structure in the wing root area. More injuries would have occurred due to the longitudinal split in the fuselage had seats 4F to 8F been occupied.
- 1.15.27 Despite failure of the internal roof trim and overhead baggage locker mountings throughout the fuselage the lockers remained latched, reducing the potential for injuries from loose objects. Although the habitable spaces in the forward cabin were reduced to the survivable minimum, serious injuries were avoided in this area.
- 1.15.28 The hostile weather conditions on the exposed hillside caused considerable distress to the surviving passengers. Once the post-accident fire had died out and the area had been made safe, it would have been appropriate to use the cabin area for shelter, had any longer delays in rescue been experienced. In this case lack of shelter did not affect the survival rate.
- 1.15.29 The aircraft's two first aid kits were stowed in a locker located in the forward right cabin area. Their location was indicated by a small green cross. Their existence was not mentioned during the passenger safety briefing nor on the safety briefing card. Neither was located by the survivors or those who came to assist in the rescue of the occupants subsequently.
- 1.15.30 Many members of the public are trained in, and would have been able to administer, first aid given the appropriate equipment. Aircraft first aid kits were available but their locations were not marked clearly. The need for discretion in marking the location of these kits has been minimised since the removal of narcotics from them post 1987 reduced the risk of their theft.

1.16 Tests and research

The undercarriage

- 1.16.1 Following the accident the right main undercarriage uplock assembly and the associated roller from the right undercarriage leg were transported to Canada by the Investigator from the Transportation Safety Board of Canada who participated in the site investigation as the Canadian Accredited Representative.
- 1.16.2 The latch sub-assembly, part number 10812-11, had serial number DCL067. The uplock assembly, part number 10800-109, had serial number DCL 099/85/88 Mod SB 32-50.
- 1.16.3 The manufacturer's records indicated that the latch, part number 10802-7, manufactured by Messier-Dowty Incorporated, Canada, was fitted new to the uplock assembly in 1988. Satisfactory acceptance test results were achieved on the unit at this time, and in 1989 when it was tested following incorporation of Modification SB 32-50.
- 1.16.4 To accommodate the removal of in-service wear, the Messier-Dowty Component Maintenance Manual (CMM) permitted the re-profiling of the latch a maximum of five times, each 'rework' repair being identified by a letter/number code.

- 1.16.5 The latch had last been reworked by Messier-Dowty during May 1993 in accordance with the specifications in the CMM for a third repair, and was designated CRS 85-84-3. Messier-Dowty had issued a Maintenance Release tag following this repair indicating the latch sub-assembly was acceptable for service and reverted to zero hours total time.
- 1.16.6 Ansett New Zealand Limited Engineering had received the latch sub-assembly from Messier-Dowty as an exchange unit. It was installed on ZK-NEY on 4 September 1993 and had sustained a total of 5507 cycles prior to the accident.
- 1.16.7 No work had been carried out on the latch during this period of service but it had been subject to regular inspection as required by the aircraft's maintenance schedule. It had last been inspected on 2 May 1995 and had been assessed serviceable. The roller assembly had also been inspected and lubricated, and the uplock assembly as a whole inspected and assessed as serviceable at that time. Normally the roller assembly was lubricated every 400 hours. On the night prior to the accident it had accumulated 277 hours since the last servicing.
- 1.16.8 Inspection of the uplock latch on 2 May 1995 had been carried out in compliance with de Havilland Dash 8 - 100 Systems Maintenance Programme Task # 32 3006 which specified a visual inspection of the Main Landing Gear uplock actuator. In addition, on this date, Task # 32 1007 had been completed. This task called for inspection of the Main Landing Gear Lock Mechanism for condition and wear, and involved inspection of the uplock latch assembly in accordance with Ansett New Zealand Limited Engineering Technical Instruction TI 008 - 32 - 014A. The TI referred to the potential for wear in the latch to result in an undercarriage hang-up, and required "inspection of the latch assembly for evidence of wear particularly in the latch detent area where the uplock roller sits". If excessive wear was found the latch assembly was to be repaired or replaced. No dimensional limits in respect of the wear pattern resulting from roller contact on the latch surface were specified in the TI. Engineering staff, however, were accustomed to inspecting the latch detent area regularly and assessing the extent of wear by sight and touch.
- 1.16.9 The manufacturer routinely updated the maintenance programme, and had issued a Temporary Revision SUP-383 in November 1994. This Revision added the following note to the procedure for Task # 32 3006.

Visual inspection of MLG Uplock Actuator.

NOTE: For Pre Mod 8/1764 and Pre Mod 8/1828 aircraft, look for wear on uplock latch where roller engages (refer to PSM 1 - 8 - 6 Component Maintenance Manual, Chapter 32, Dowty 32 - 30 -04 for wear limits).

- 1.16.10 There was no compliance date associated with the Temporary Revision, nor indication of urgency, or safety implication, in regard to its incorporation in the maintenance programme. The manufacturer did not draw operators' attention to the issue of the Temporary Revision and its contents, by means of an AOM, safety alert, or other method normally employed if important safety information was distributed.
- 1.16.11 The Temporary Revision was received in Ansett New Zealand's Technical Library in December 1994. However, the engineering planning section did not action the Revision until 2 May 1995 due to the build-up of a backlog of amendments as a result of staff changes. The modification kits had been on order for some time, and two units had already been installed (see paragraph 1.6.52) which led the maintenance planning team to state on 2 May 1995 that no action was required in relation to the Revision. The Note providing a reference for wear limits was thus not included in the written task procedure for inspections, after that date, on the pre-modification latches.

1.16.12 Messier-Dowty examined the uplock assembly, latch, and roller, and subjected relevant components to tests. The examination and tests were carried out under the supervision of the Transportation Safety Board of Canada's Accredited Representative.

1.16.13 Results of the examination and tests were summarised as follows:

The uplock assembly in its fire and impact damaged condition was subjected to a partial Acceptance Test procedure:

- a) The testing involved verification of the hydraulic pressure required to unlock the mechanism, and recording of the load required to operate the manual release.

The hydraulic pressure to release the uplock was found to be 2000 psi/1850 psi (dependent on aft/fwd adjustments).

The acceptance range was 550-1050 psi (aft adjustment) and 400-900 psi (fwd adjustment).

The Manual alternate extension system operated satisfactorily at 64 and 40 pound of pull (aft/fwd adjustments). Normal unlocking force for Emergency Extension ranged from 5 to 22 pound (for both aft and fwd adjustments).

- b) The uplock latch Part No. 10802-7 was subjected to a profile check on a co-ordinate measuring machine. A wear pattern on the latch surface where the roller makes contact was found to have a width of 0.195 to 0.220 inches (4.95 to 5.59 mm) and a depth of 0.006 inches (0.152 mm).

CMM 32-30-04 Temp Rev. 32-1 dated 1 November 1994 provided inspection criteria for surface wear on the latch. The wear-band width was stated as indicative of the depth of wear. Maximum allowable wear-band width was shown as 0.125 inches (3.18 mm).

The fire damaged condition of the uplock latch prevented the metallurgical laboratory from determining the inter relationship of indentations and wear. The laboratory reported 'Damage marks could be caused by both wear and crash damage'.

- c) The rigging of the uplock target, relative to the proximity switch bracket stop face, and relative to the proximity switch, was found to be incorrect.
- d) Metallurgical tests to determine the hardness of the uplock latch and the uplock lever were inconclusive. Hardness readings varied to the extent that they were considered invalid due to the effects of the fire on the mechanical properties of the parts.

Messier-Dowty presented the following conclusions:

- (i) Heat damage to the seals, lined bushings, 'O' rings and internal springs of the uplock assembly meant that the actual pressures and loads measured in the post-accident tests may not have accurately represented the 'in-flight' loads and pressures. However Messier-Dowty's experience with previous uplocks indicated that the wear on the latch would have prevented the uplock assembly from passing the relevant acceptance test procedure.
- (ii) The extent of wear on the latch exceeded the limits published in Messier-Dowty CMM 32-30-04 Temp Rev 32-1. Based on the manufacturer's

experience, the wear condition, as determined, was sufficient to have prevented release of the undercarriage leg using the normal undercarriage extension procedure. It would not however have prevented manual/alternate release.

- (iii) The 'mis-rigged' condition of the target and proximity switch would not have affected the function of the uplock assembly. However, it may have provided the crew with an erroneous (or intermittent) flight deck indication. It also provided an explanation for the condition of the uplock lever which was found to be bent.
- (iv) Metallurgical testing of the uplock latch and uplock lever was inconclusive.
- (v) Modifications and repairs to the uplock assembly had been performed correctly. It had passed earlier acceptance tests satisfactorily.

The GPWS computer

- 1.16.14 The Sundstrand GPWS computer was recovered undamaged from the aircraft and was taken to the manufacturer for testing and analysis.
- 1.16.15 A bench test showed that the computer was operative and a complete production Acceptance Test Procedure (ATP) showed that the computer was serviceable and completely within all production specifications. The tray for the computer and the connector were intact and serviceable. The rear pins showed that the system had been programmed for normal air transport operation.
- 1.16.16 The DFDR did not record the radio altitude, so for simulation purposes this parameter was derived from a terrain profile along the aircraft's apparent track. By subtracting the terrain profile from the DFDR altitude, a pseudo radio altitude was constructed. While errors will exist, experience has shown that the radio altitude for a normal functioning system would have matched within 10 % of the derived values.
- 1.16.17 A flight parameter table applicable for GPWS simulation test purposes for the last two minutes of flight (undercarriage up, flap up) was constructed from the DFDR parameters. Time was constructed in conjunction with the ground speed readout from the radar plot, and the pseudo radio altitude used. These were formatted into engineering units onto a 3.5 inch disc, and a number of separate simulations were performed:

A Personal Computer flight animation programme was used to compile the flight parameter data and the GPWS alert/warning times calculated and displayed. The first warning, "Terrain! Terrain!", was shown visually 15 seconds before impact.

A Virtual Addressing Extended (VAX) simulation was run independently from the above flight parameter table, and it showed the first "Terrain" warning starting at 17.5 seconds before impact. Another Mark II GPWS modified in accordance with the latest Service Bulletin instructions showed the same result.

A laboratory test using the Batch Orientated System Simulation (BOSS) equipment was also carried out. Aircraft signals formatted to represent actual signals that the GPWS computer would have seen, during the period leading up to the accident, were compiled and the actual subject computer and a reference Mark II computer, to the same modification status, were run. Identical warnings were received from both computers and the first warning, measured by stopwatch, occurred 18 seconds before impact. A Mark II computer modified to the latest status was also operated with the same result.

Tests were also run on all three simulations with the “Flap Override” switch activated to give a flap down indication to the GPWS computer. The three results were the same with a “Too Low, Terrain” warning occurring at 500 feet radio altitude and 13 to 14 seconds before impact.

- 1.16.18 Simulation tests were performed using a track slightly north of the determined track in an attempt to match the actual GPWS warning as recorded on the CVR. The first warning by simulation occurred some 18 seconds from impact, and neither the “flap override” nor an “undercarriage down” discrete would duplicate the warning.
- 1.16.19 Using the BOSS simulation, the radio altimeter validity was interrupted at some 20 seconds from impact to simulate sudden loss of radio altimeter tracking where the terrain was rapidly changing. This did give, under the right interrupt conditions, a “Terrain, Whoop Whoop Pull-Up” warning, just before impact.
- 1.16.20 A concern that the undercarriage alternate extension procedures may have affected the normal undercarriage “Down And Locked” signal to the GPWS received the following response from the aircraft’s manufacturer:

The GPWS system receives a landing gear ‘down and locked’ signal from the Proximity Switch Electronic Unit (PSEU), which in turn receives real time output from proximity switches on the landing gear. All 3 landing gear have to be in a down and locked position before a down and locked signal is sent from the PSEU to the GPWS.

The Landing Gear inhibit switch removes 28 volts from the down solenoid of the landing gear selector valve, and does not have any effect on the PSEU output signal to the GPWS.

Neither the main ‘Landing Gear Alternate Release’ door nor the ‘Main Landing Gear Release’ handle (both located in the flight deck roof) affect the PSEU output signal to the GPWS.

The Captain’s altimeter

- 1.16.21 On 16 February 1996 the Captain wrote to the Commission. In that letter he mentioned his recollection of the altimeter jumping “I think from 2800 to 1800 feet”. The Captain’s altimeter was not damaged in the accident so it was tested functionally from 30 000 feet to sea level. The test showed a linear indication throughout the altitude range in accordance with normal serviceability requirements.
- 1.16.22 The test was not in itself conclusive. The disruption to the aircraft during the impact sequence rendered it impracticable to confirm with certainty that no malfunction had occurred within the system supplying data to the Captain’s altimeter.
- 1.16.23 The aircraft was equipped, however, with an independent “standby” altimeter for reference and cross-check, in addition to the Captain’s and First Officer’s altimeters.
- 1.16.24 The altitude alert light was also examined. It showed no indication which would assist in determining whether it was on or off at the time of the aircraft’s major impact with the terrain. The filament was undamaged.

1.17 Organisational and management information

Ansett New Zealand Limited

Background

- 1.17.1 Ansett New Zealand Limited adopted the operating practices of Ansett Australia at the inception of the airline. Operating manuals and general operating procedures were intended to be aligned as closely as practicable apart from variations for the New Zealand operating environment and specific aircraft types. The common approach was not imposed but shared. Senior Ansett New Zealand operational staff participated in the Ansett Australia Flight Operation Group meetings.
- 1.17.2 The original Flight Training and Safety Manager was responsible for introducing the company CRM programme into the recurrent training syllabus. He complemented this with his interest and experience in wider safety issues.
- 1.17.3 Neither the original Flight Training and Safety Manager nor any of his successors had undergone formal accident prevention or flight safety training.
- 1.17.4 The fundamental change in flight safety management procedure occurred in June 1993 as a result of a review of the former flight safety programme, as conducted by the erstwhile Safety Manager. Following the Safety Manager's return to full-time line flying, the operator decided that a flight safety effort reliant on one individual did not provide a clear view of the safety of the Ansett New Zealand operation. The operator resolved to ensure the flight safety information that was captured was not reduced by any "reticence of line crews to share issues with management".
- 1.17.5 The aircraft crew members were encouraged to submit reports of anything which they considered might lead to a degradation in the safety of their operation. The intention was that the operator's flight safety infrastructure should respond to these reports positively to prevent such incidents leading to accidents.
- 1.17.6 Concurrently they decided to "enhance (their) ability to react to line generated reports by data basing, trending and circulating (these) to managers who were able to make the necessary changes".
- 1.17.7 The operator stated in relation to these changes:

This effort was supported by a co-ordinator to provide another avenue of comment for crews, and the necessary bypass to the Chief Executive.

The overriding thrust was to involve all managers in Flight Safety.

The responsibilities and authority of the Flight Safety Co-ordinator exceed those of the earlier regime...and results in a more timely resolution of potential issues. Previous reliance on (a) large Flight Safety Panel dealing with events was not wholly effective. The close integration of CRM training with (the) Safety Role has been deliberately continued.

The position of Flight Safety Co-ordinator was not a replacement for the earlier position identified as the Flight Training and Safety Manager. It was a new position supporting a re-designed programme based on a General Flight Reporting System involving two management positions with the overriding policy that all managers were required to assume responsibility for the issues presented to them.

This had the effect of providing a dedicated Flight Safety thrust independent of the training bias of the earlier position.

- 1.17.8 Those charged with the implementation of flight safety by the company did not receive the training, exposure to overseas safety conferences or international collaboration on safety to the extent evident in many larger airlines.
- 1.17.9 The Ansett New Zealand Flight Operations Policy Manual, Section 6 - Flight Safety Programme, dated June 1993, was produced as a current document. It stated inter alia:

The Flight Safety Programme within Ansett New Zealand is established by the provision of all those systems necessary to support Airline Operations.

The programme utilises the principles of observation, reporting, analysis and action as a part of normal day to day operations.

Each and every operative within the division is responsible for applying common-sense flight safety principles to each and every activity.

External flight safety experience is contemplated by Airline membership of key Flight Safety Organisations.

Flight Safety trends, developments or deficiencies are monitored by the Regional Flight Managers who will ensure that expeditious and proactive interface with appropriate Managers occur.

The Flight Safety Co-ordinator may where he thinks fit, report directly to the Chief Executive Officer.

2 RESPONSIBILITY

A. Chief Executive Officer

The Chief Executive Officer is responsible for the provision of appropriate systems supporting a proactive flight safety programme.

B. Manager Flight Operations

The Manager Flight Operations (MFO) is responsible to the CEO for the managing, planning and those systems in support of Safe Airline Operations.

C. Regional Flight Managers

The Regional Flight Managers are responsible to the MFO for the establishment and control of systems necessary to achieve observation, reporting and analysis of Flight Safety issues and shall ensure that significant observations and deficiencies are communicated to the appropriate Manager for action and then recorded as closed or open.

D. Flight Safety Panel

A Flight Safety Panel shall be constituted by the Flight Safety Co-ordinator as required to analyse those flight safety matters not closed by management action and make such recommendations considered necessary.

E. Flight Safety Co-ordinator

The Flight Safety Co-ordinator will co-ordinate the activities of the Flight Safety Panel, co-opting such expertise as is from time to time required to resolve Flight Safety issues and where he thinks fit will report the findings of the Flight Safety Panel to the Chief Executive Officer.

The Flight Safety Co-ordinator shall have access to all records relating to Flight Safety and may investigate any matter he/she considers necessary with a view to monitoring the effectiveness of the Flight Safety Programme.

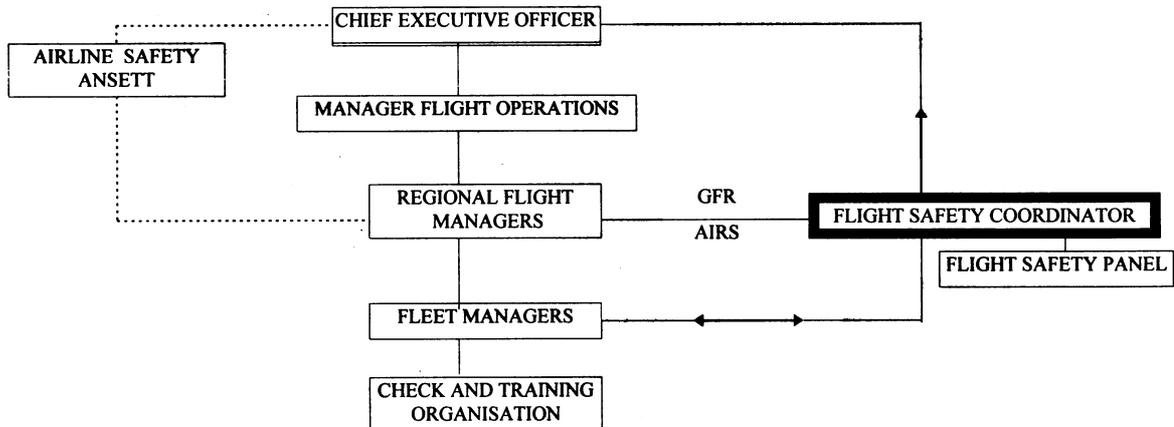
Monitoring the Flight Safety Programme may include:

- Review of General Flight Report trends
- Consideration of Line Pilot input
- Review of Internal Audit Reports

The Flight Safety Co-ordinator will review externally sourced flight safety references and make any information considered relevant available for general interest of aircrew.

- 1.17.10 The Flight Safety Co-ordinator had accumulated some 15 000 flying hours including 8000 hours instructing time. He had been a Captain on the operator's DHC-7, Boeing 737, DHC-8 and BAe 146 aircraft and was a training Captain at the time of the accident. He had both A and D Category Instructor Ratings and had completed courses in Instruction Technique. He saw his role as monitoring rather than managing Flight Safety. He had not undergone any course specifically relating to Flight Safety or Accident Prevention.
- 1.17.11 He considered he had the resources necessary to conduct an effective CRM programme as a facilitator of the Ansett Australia CRM programme and apart from some adverse comment on the technical quality of the copied videos and slides considered the feedback from crews was favourable.
- 1.17.12 He shared an office with the Regional Flight Manager Christchurch but did not receive any General Flight Reports (GFRs) or Air Incident Reports unless the Regional Flight Managers considered them worthy of his attention. He was able to, and did from time to time, review the data base of the GFRs, to monitor trends and oversee the system if the Regional Flight Managers were absent.
- 1.17.13 Ansett New Zealand Limited Engineering copied their Defect Investigation Reports to the Regional Managers.
- 1.17.14 The Flight Safety Co-ordinator was not privy to the company management's decision not to modify the Dash 8 aircraft undercarriage uplocks or to any policy decisions made which could have a bearing on flight safety.
- 1.17.15 Ansett New Zealand's membership of "key flight safety organisations" was limited to membership of the New Zealand Airline Flight Safety Committee. Ansett Australia was a member of the Flight Safety Foundation.
- 1.17.16 Ansett New Zealand received some incidental feedback from Ansett Australia's membership of this international flight safety organisation in that each of their pilots received Ansett Australia's quarterly flight safety magazine "On Course", and the Flight Safety Co-ordinator attended regular meetings with Ansett Australia's flight safety representatives. Although "On Course" listed incidents experienced by Ansett Australia it did not include reference to any experienced by Ansett New Zealand.
- 1.17.17 Ansett New Zealand described their flight safety programme as a "pro-actively reactive" organisation.

- 1.17.18 The Organisation Tree in the Ansett New Zealand Flight Operations Policy Manual, Section 2 Organisation, page 2, depicted the following diagram showing the FLIGHT SAFETY ORGANISATION.



FLIGHT SAFETY ORGANISATION May 1995

(Ref Ansett New Zealand Flight Operations Policy Manual Section 2, Page 2, May 1995)

- 1.17.19 The Engineering Management - Organisational Structure dated April 1995 showed no avenue for engineers to volunteer safety suggestions to the Flight Safety Panel.
- 1.17.20 Whereas the former flight safety panel met on a bi-monthly basis and involved representatives from most departments, the new concept involved only two permanent members (the Flight Safety Co-ordinator and one Regional Manager) and infrequent meetings, e.g. only once in the 12 months preceding the accident.
- 1.17.21 The panel could co-opt members from any department which it required to react to an identified problem but based its business on finding solutions to GFRs which raised matters not able to be dealt with by the Regional and Fleet Managers or to any individual item or trend which the Flight Safety Co-ordinator considered worthy of the panel's attention.
- 1.17.22 In lieu of the regular bi-monthly meetings of the Flight Safety Panel the system established was to respond to GFRs through a "conduit of information". The responsibility for this was that of the Regional Flight Managers who would then involve all relevant managers, including engineering and external divisions, to bring together the necessary information and personnel to address and solve the safety issue as soon as practicable "rather than to wait for up to 60 days for the next meeting of the Flight Safety Panel". Ansett New Zealand saw this system as having significant advantages over their former flight safety procedures.
- 1.17.23 The Flight Safety Co-ordinator was not aware of the details of an ICAO driven initiative to reduce the number of CFIT accidents and the associated publicity and the Checklist associated with this programme. This material was available to Ansett Australia and had been publicised indirectly in an article in their Flight Safety magazine "On Course". The article relating to CFIT was in the latest issue distributed prior to the accident.
- 1.17.24 Discussions of earlier CFIT accidents were, however, prominent in the CRM syllabus for the recurrent training programme.

CFIT Checklist

- 1.17.25 When the pilots of ZK-NEY were interviewed each said that in such an event their procedure for responding to a “hard” GPWS warning involved the use of “go-around” power. However, the most effective response to a “hard” warning from the GPWS requires the use of maximum power immediately rather than “go-around” power.
- 1.17.26 One item on the CFIT checklist was “You annually practice recoveries from terrain with GPWS in the simulator.” There was no simulator for the Dash 8 nearer than the United States (in Seattle), and there was no published procedure in the operator’s Dash 8 flight manual or other Ansett New Zealand Dash 8 document to advise pilots on the most appropriate action expected by them in the event of a GPWS warning. Ansett New Zealand advised that they covered the “appropriate pilot reaction to a GPWS warning” in the course of pilot training and expected it to be “well known by aircrew”. The First Officer stated he had received no training in this regard.
- 1.17.27 The CAA said they were aware of the CFIT initiative and were one of the sponsors of the video which accompanied the Flight Safety Foundation programme.
- 1.17.28 Following the accident Ansett New Zealand published a procedure for the required response to a GPWS warning in their Dash 8 Operating Manual as follows:

A General

(1) Except in VMC by day, an aural warning from the GPWS will be acted upon as a command.

B Procedure - GPWS Warnings

(2) Upon activation of aural ‘TERRAIN TERRAIN’, ‘TOO LOW TERRAIN’ and or ‘WHOOH WHOOP PULL UP’ warning (with or without the associated PULL UP switchlight), proceed as follows:

(a) POWER LEVERS.....Advance to go-around power

(b) AUTO PILOT.....Disengage

(c) ROTATE TO GO-AROUND ATTITUDE

Immediately rotate to go-around attitude while applying go-around power and establish a positive rate of climb.

(d) CONFIRM/SELECT CONDITION LEVERS TO MAXIMUM RE-CHECK POWER

Climb at the normal manoeuvring speed for the flap position. Trade excess airspeed for altitude by initially rotating to a higher nose-up pitch attitude until reaching the desired climb speed.

(e) FLAPS.....Call for the go-around flap position if the flaps are extended beyond that position. Otherwise, do not reposition flaps.

(f) LANDING GEAR.....Once positive rate of climb is established select....UP

(g) CLIMB.....at the manoeuvring speed for existing flap position until terrain clearance is assured.

1.17.29 The manufacturer's current Dash 8 Flight Manual procedure as amended in November 1993 stated:

Whenever the 'TOO LOW - TERRAIN' OR 'WHOOO WHOOP PULL UP' announcements are heard, immediately establish the power setting and attitude which will produce the maximum climb gradient consistent with the aircraft configuration.

1.17.30 The concept of a "sterile"⁶ flight deck was also listed in the CFIT checklist. The restricting of access to the flight deck during critical periods of the flight is encouraged to prevent distraction to the crew at these times.

Flight Attendants

1.17.31 In Ansett New Zealand there were various references to guide the flight attendants. Because flight attendants on Dash 8 aircraft were all Senior Flight Attendants their instructions in the BAe 146 "In-flight Procedures Manual" were taken as applying for the Dash 8 where appropriate. They had no special instructions applicable to the Dash 8. In respect of the requirement to be seated the instruction in the BAe 146 In-flight Procedures Manual read:

No Smoking Sign Flashes

Make final cabin security check
Land position - forward Flight Attendant seat no later than extension of landing gear.

In respect of entering the flight deck the instruction read:

Flight Deck Procedures

(2) Do not enter the flight deck after take-off until the aircraft is established on climb and do not enter after the Fasten Seat Belt sign has been switched on for landing, however, in the event of any extreme matter, entry to the flight deck is allowed.

1.17.32 Ansett New Zealand's standard operating procedures required one of the pilots to cycle the "No Smoking" sign, twice, at 5000 feet altitude.

1.17.33 The cabin crew were advised, by the cycling of the "No Smoking" sign twice, to make a final cabin check and be seated by the time at which the undercarriage was extended. Thereafter the cabin crew could converse, if necessary, with the flight deck occupants using the interphone.

1.17.34 In this case the "No Smoking" sign was cycled twice, five minutes before the impact. Just over three minutes later the flight attendant went to the flight deck and advised the crew of a passenger's concern about the right main undercarriage not lowering.

1.17.35 CASO 10, the Civil Aviation Safety Order relating to "Cabin Attendants", defined a Cabin Attendant as:

a crew member, other than a flight crew member, responsible to the pilot in command for the maintenance of order and discipline in passenger compartments and for providing assistance to passengers in the event of sickness, accident or emergency.

⁶ "Sterile" in this context means keeping the crew on the flight deck free from non-essential activities and interruptions during critical phases of flight.

1.17.36 Civil Aviation Regulation 73 required:

(1) Safety belts or safety harnesses shall be worn by all crew members and passengers in an aircraft at the following times:

(a)...

(b)...

(c) when an aircraft is flying at a height above the terrain of less than 1000 feet.

Provided also that the Director may exempt absolutely or subject to such conditions as he thinks fit from any or all of the requirements of paragraphs (a) to (d) of this subclause cabin attendants,...". No exemption was applied to Ansett New Zealand Cabin Attendants in respect of this Regulation.

Crew resource management

1.17.37 Both pilots had received CRM training. The Captain had attended five LOFT training sessions as a First Officer in the BAe 146 simulator and four sessions of CRM. Each of these sessions was flown in the right-hand seat and he was required only to complete the duties expected of a First Officer. The First Officer's exposure was one four-hour CRM session. In common with most Dash 8 First Officers he had no experience of LOFT.

1.17.38 The Ansett CRM programme was the responsibility of the BAe 146 Assistant Fleet Manager. The Flight Safety Co-ordinator was one of those who acted as a "facilitator" for the lectures and presentations on the subject to the Dash 8 crews (i.e. pilots and flight attendants).

1.17.39 The CRM programme had evolved from the KLM Human Factors, or "Khu-Fac" course, through a programme devised for Ansett Australia by NASA in conjunction with the University of Texas, toward a programme more directly related to the Australasian culture and problems experienced by Ansett Australia and Ansett New Zealand. The evolution of this programme was conducted in conjunction with Ansett Australia.

1.17.40 The programme included four hours in the Recurrent Training School syllabus and was critiqued by each pilot attending with the aim of using their comments to design a course more oriented toward Ansett crews, thus making it more effective.

1.17.41 As there was no Dash 8 simulator available to Ansett New Zealand closer than Seattle, the operator considered it impracticable to employ simulator training for its Dash 8 pilots and limited their Dash 8 crews' CRM training to the classroom exercises. These sessions did not place the crews in a simulated flight deck situation but did involve discussions of other airline crews' mistakes in particularly well-known accidents

CAA operator certification and surveillance

1.17.42 In accordance with the provisions of Section 9 of the Civil Aviation Act 1990, the DCA issued an Air Service Certificate in accordance with Civil Aviation Regulation 136, to authorise Ansett New Zealand Limited to operate aircraft within New Zealand for commercial purposes, subject to the operator's compliance with the Operations Specifications which form part of that Certificate.

- 1.17.43 Ansett New Zealand Limited's Air Service Certificate number AS 12862 was last re-issued on 18 July 1994 and was valid from 24 July 1994 to 23 July 1996. This Certificate approved the conduct of air transport services carrying passengers and goods for hire and reward.
- 1.17.44 Section 15 of the Civil Aviation Act 1990 enabled the DCA to carry out such inspections and audits of the holder of an ASC as he considered necessary in the interests of civil aviation safety and security.
- 1.17.45 The Director had established a Safety Certification Group headed by an Assistant Director whose responsibilities included:
- ensuring that prior to the issue of an aviation document or approval the appropriate safety rules and standards had been complied with.
 - ensuring that aviation document holders were monitored in accordance with CAA safety policy.
 - ensuring that key tasks were carried out by competent and trained persons either as employees or 'contract for service' staff.
- 1.17.46 Two of the Controllers responsible to the Assistant Director Safety Certification were the Controller Operator Certification and the Controller Audit and Inspection. The main purpose of the Controller Audit and Inspection included:
- Managing the resources that carried out the CAA monitoring programme.
 - Ensuring the planned monitoring programme was effective in contributing to the CAA safety targets.
 - Ensuring compliance with the CAA policy and procedures relating to the monitoring function.
 - Liaising and co-operating with the group controllers and
 - Ensuring the group standards and targets were met.
- 1.17.47 The primary output of the Audit and Inspection Section was to monitor compliance with aviation and security safety standards in accordance with the provisions of the Civil Aviation Act 1990.
- 1.17.48 The Controller's job description, which was updated in August 1994 and current at the time of the accident, included a requirement to assist his Assistant Director "to produce this output in the most cost-effective manner....."
- 1.17.49 The Controller's first key task was to ensure the audit and inspection programme was achieved.
- 1.17.50 His tasks also included ensuring budget targets were met in a cost-effective manner.
- 1.17.51 The Controller Audit and Inspection had been in the position for eight months. He had completed the CAA Internal Auditing Course and had several years' experience with the CAA as a safety auditor covering aeronautical service areas.
- 1.17.52 The Swedavia-McGregor Report on Civil Aviation in New Zealand envisaged operators in the aviation industry being responsible and accountable for the safety of the operations in which they were engaged. Swedavia-McGregor saw surveillance as the CAA's primary tool for ensuring that operators performed according to the standards set. The authors suggested the tool box for this surveillance would include audits, inspections, spot checks, periodical meetings with the management of the operator, collection and analysis of selected data, route inspections, check flights and "simply talking to people within the system".

- 1.17.53 The functions of the CAA are determined by Section 72 of the Civil Aviation Act 1990 and these include in Clause 72B (b) “To monitor adherence to safety and security standards within the civil aviation system”.
- 1.17.54 DCA advised “Our current audit approach makes two important assumptions that are relevant...First, we take the view that 100% compliance with the Rules and Regulations will result in a level of risk that is acceptable to the community. Thus our current audit approach emphasises compliance. Second the Rules and Regulations are minimum standards which will achieve a level of risk acceptable to the community. Thus policies, processes and actions by an operator that exceed the regulatory requirements are at the operator’s discretion. An example of this would be a CFIT programme conducted by an operator. Third the industry is currently in the transition from long established regulations to new Rules.” “The CAA audit process has incorporated over recent years some aspects of encouraging and supporting the movement of the industry from the old to the new. In particular this encouragement and support has emphasised the use of management systems as a means of improving operator compliance and self-checking. This has resulted in emphasis, in CAA audits, on conformance with operators’ own manuals and procedures.”
- 1.17.55 The CAA Safety Audit Training notes dated May 1994 defined a “safety audit” as “The objective examination of evidence to determine whether an organisation has a management system in place which will ensure compliance with relevant safety standards and is implementing that system.”
- 1.17.56 The CAA conducted the safety audit, or series of audits, depending on the size of the subject organisation. Each audit consisted of one or more audit modules which related to a certain area of the company, and which usually required from the auditor similar aviation-related skills.
- 1.17.57 The scope of a safety audit was determined by the number of modules covered and the area of operation which each addressed.
- 1.17.58 The six phases of any audit were initiation, preparation, investigation, analysis, reporting and follow-up. Follow-up sometimes included visits to the organisation to assess the efficiency of corrective action taken as a result of a previous audit.
- 1.17.59 The CAA had decided that the Audit and Inspection Unit had insufficient staff to conduct audits on the scale it considered necessary. When the accident occurred DCA was in the process of recruiting four additional staff to increase CAA’s capacity (two each for the flight operations and airworthiness areas of activity).
- 1.17.60 The CAA had also decided that some of the numerous audit modules were unnecessary and others needed remodelling. A review of the modules was in progress at the time of the accident but the audit programme for each operator was planned to involve one complete 12-month cycle in real time.

1.17.61 The report forwarded to operators by the CAA after it conducted an audit advised:

The prime system adopted by CAA to assess safety is to measure compliance with the relevant legislation. However, safety can be influenced by matters not covered in legislation. Safety auditors are required to highlight such matters by raising findings which are categorised as:

Non-compliance	Where an operator is not complying with the relevant legislation
Non-conformance	Where an operator is not conforming with its own documented procedures
Observation	Something that the auditor wishes to comment on that will be helpful to the client.

Considering the breadth of the legislation and safety issues, an auditor may not totally cover every matter during an audit. The object is to assess the client's operation by a systematic sampling of activities. Statistical analysis of sample findings indicate to CAA trends in safety.

1.17.62 CAA auditors were conservative with the time used to prepare for and to conduct an audit as the time had to be charged out to the company being audited.

1.17.63 Ansett New Zealand was established as an operator before the CAA was created in its present form. Audits were being carried out on Ansett New Zealand based on a selection from the appropriate audit modules, rather than in accordance with a programme customised for the operator.

1.17.64 The surveillance of Ansett New Zealand by the CAA was based on a series of phased audit modules, the implementation of which was advised well in advance and, as far as practicable, at the operator's convenience. The CAA auditors had the power to conduct spot checks at any time should they consider such action warranted.

1.17.65 While a review of the plan of the audit modules for Ansett New Zealand showed, in the 12 months preceding the accident, CAA had achieved two out of nine 24-monthly checks, 10 out of 42 annual checks, none out of 12 six-monthly checks and 8 out of 16 three-monthly checks, CAA's comment was as follows:

The full list is not a stated programme which the CAA considers needs to be carried out in a certain time frame. It is the total field from which appropriate audits are selected and programmed.

This was also explained as the result of the inherent time taken to review each of the modules and cull those which were non-applicable or redundant. DCA advised that for the years ending June 1993, June 1994 and June 1995 the hours spent on auditing Ansett New Zealand were 170.75, 97.75 and 142.75 respectively.

1.17.66 Of the Dash 8 route checks (scheduled as three-monthly) two were conducted by auditors one of whom was not qualified on the aircraft type. Neither auditor was in current flying practice on the Dash 8 aircraft. DCA explained that "although four per year is theoretically possible, the CAA was conducting one or two per type per year. A higher frequency than this could not be supported by the level of occurrence reports notified." Those responsible for the route checking of the operator's flight crew did not participate in the operator's simulator (BAe 146) or CRM training sessions, and carried out no spot checks, check flights or in-depth follow up on the route checks. In accordance with standard practice, route checks were conducted in the course of normal revenue flights.

- 1.17.67 The discrepancies detected by CAA audits were of a minor nature and gave no indication of the potential for an accident of the type which occurred.
- 1.17.68 CAA records indicated that in general any non-compliances and non-conformances detected were dealt with responsibly by Ansett New Zealand who also responded positively to any observations made.
- 1.17.69 A management audit of Ansett New Zealand by the CAA had been completed just prior to the accident. At the time an Operations Manual System was being developed by Ansett New Zealand Ltd in support of an application for Certification under Rule 121.
- 1.17.70 Changes had occurred in the Flight Safety structure of Ansett New Zealand since its initial recognition as an Approved Organisation by CAA. The CAA had been advised of these changes to the Flight Safety structure by a notice of a revision to the Flight Operations Policy Manual on 29 July 1993.
- 1.17.71 A check of the CAA library copy of the Ansett New Zealand Flight Operations Policy Manual showed that the amendment had been incorporated by the librarian in November 1993. Apart from the incorporation of the amendment in the CAA copy of the Manual no evidence that the change had been noticed by the CAA surveillance procedures was found. There was no record of an acceptance of this amendment by the Controller of Operator Certification although DCA advised that an audit on 25 May 1995 used the then current operations manual system as the standard.
- 1.17.72 The flight safety organisation of the operator had been noticed during the management audit completed on the operator immediately prior to the accident and accepted without comment.

1.18 Additional information

Crew training and rostering

- 1.18.1 Ansett New Zealand had added one Dash 8 to their fleet in the year prior to the accident and were operating nine BAe 146 and three Dash 8 aircraft at the time of the accident. The addition of the extra aircraft had entailed recruiting and training additional crews and reorganising existing pilots in compliance with the career structure agreed to in the Pilots' contracts.
- 1.18.2 The policy was that when a vacancy occurred, each First Officer on Dash 8 aircraft would move one step closer to becoming a First Officer on the BAe 146 aircraft, the BAe 146 First Officers would move toward command on the Dash 8 aircraft and the Dash 8 Captains would move toward command on the BAe 146.
- 1.18.3 Ansett New Zealand designed the associated training process to commence in time to have each of the necessary crews trained and in current practice when the new timetable involving the additional Dash 8 aircraft came into force.
- 1.18.4 Each of the crew members met the minimum regulatory requirements for flying the Dash 8 aircraft on scheduled air transport operations. They also met the operator's minima of 5000 hours total flight time, 2000 hours command time with a valid ATPL for the Captain and 2000 hours total flight time with a valid ATPL for the First Officer. Nevertheless, the Dash 8 experience level in the crews as a whole had been diluted by the expansion so the operator provided sufficient incentive for a senior captain to remain on the Dash 8 as Fleet Captain instead of commanding a BAe 146.
- 1.18.5 The United States' National Transportation Safety Board (NTSB) suggested that a minimum of 150 hours on type in the previous 120 days was desirable for one member of a crew which included a "greenhorn" pilot. The First Officer had 162 hours on type (all in the last 90 days)

with a total flying experience of 6460 hours. The Captain had a total of 7765 hours flying time and had a total of 273 hours on type (173 in the last 90 days).

- 1.18.6 The NTSB also considered that operators should be encouraged to pair First Officers of relatively little experience with Captains having a relatively high level of experience and vice versa. The operator had a policy of not flying pilots together as a crew unless one of them had been rostered on type for at least two months. Total flying experience was not a rostering consideration as the operator's policy of recruiting experienced pilots made this unnecessary.
- 1.18.7 Although normal progression saw most Captains on the Dash 8 having previous time as First Officers on the type, the Captain on this aircraft had no such previous experience.

Response to undercarriage system malfunctions

- 1.18.8 In the past three years the uplock for the main undercarriage legs, in the operator's Dash 8 aircraft, had exhibited a tendency to fail to release immediately the undercarriage was selected "DOWN". In seven cases, reported by the crews involved, the alternate lowering procedure had to be used to release one of the main undercarriage legs to obtain the normal configuration of the undercarriage for landing. On these occasions (each of which occurred in VMC) the Captain of the crew that experienced the system malfunction had filed a GFR but there were other crews who had not filed a GFR or otherwise reported when they had a similar malfunction.
- 1.18.9 The GFRs were passed through the Regional Flight Manager to the operator's engineering staff for evaluation. After due consideration in conjunction with the entries in the Maintenance Logs, the maintenance procedures were changed in an attempt to minimise the chances of further malfunctions. (See Section 1.6.)
- 1.18.10 The response to these malfunction notices had been limited to the action taken by the engineering staff. The GFRs had not been passed on to the operator's Flight Safety Co-ordinator, nor had the Dash 8 pilots as a group been made aware of the problem other than in the course of casual conversation. Ansett New Zealand stated that each pilot transitioning to the Dash 8 had to execute, or have demonstrated to him, the "Landing Gear Malfunction Alternate Gear Extension" procedure during conversion training. The training files for each pilot showed that the "Landing Gear Malfunction Alternate Gear Extension" was done and the instructor involved confirmed that the full QRH procedure was executed by each of the pilots by reading the QRH and completing the necessary actions. The Captain and First Officer each stated that at no time during their training did they execute the full QRH procedure.
- 1.18.11 No consideration had been given to additional preparation for crews to deal with this specific system malfunction by discussing or rehearsing the CRM action to be taken in such an event. Until the time of the accident the crews involved in "non-normal lowering of the undercarriage" incidents had overcome the problem successfully although, unlike the situation which faced the crew on this occasion, each aircraft had been in VMC when the system malfunction occurred. Of the other First Officers who were interviewed, one had experienced confusion with the two similar items on the checklist as in the case of the First Officer on the accident flight.

Human performance

- 1.18.12 An examination of the CVR and DFDR records showed that in the 30 minutes prior to the aircraft's collision with the terrain, the crew were involved in the following events which an aviation psychologist considered to be "attentional slips, memory lapses and mistakes".
- A query from the First Officer to the Captain as to whether the Air Traffic Controller had said "12 DME arc" or "14" when she had said "14" clearly and the First Officer had repeated it back to her correctly 30 seconds earlier,

- The Captain quoting the wrong minima when he briefed the First Officer on a circling approach to runway 25 at Palmerston North (i.e. MDA 480 feet instead of 660 feet, and 1600 m visibility instead of 2800 m) and the First Officer not drawing his attention to the mistakes,
- The Captain not setting the appropriate power to maintain a normal approach path as the aircraft neared the descent profile,
- The Captain not setting the appropriate power to regain a normal approach path after the aircraft had descended through it,
- The First Officer's incorrect calculation of the required altitude at 10 DME and the Captain's response of, "Check" (as a confirmation rather than an instruction to verify the calculation),
- The First Officer's incorrect tracking of his checks in the QRH "Alternate Gear Extension" checklist,
- The Captain not paying sufficient attention to the aircraft's flight path while assisting the First Officer with the application of the QRH "Alternate Gear Extension" checklist,
- The Captain not querying the absence of any altitude monitoring calls by the First Officer after the non-normal undercarriage lowering procedure was commenced. (The Captain expected such calls from his First Officer.), and
- The aircraft's deviation from the descent profile going unrecognised by the Captain.

Early start

- 1.18.13 The roster for the day required a reporting time for the crew of 0410 hours. A complaint had been raised by all but two of the pilots affected by the roster, about the 0410 hours reporting time and the overnight stay involved. As a result the schedule had been revised to reduce the duty hours and to avoid the need for a night away from base at the end of the day. Following this change no further complaints were received by the operator.
- 1.18.14 The majority of the nine Dash 8 pilots interviewed said they experienced a feeling of tiredness on the third leg of the Flight 702/703 schedule after the early start, and that they recognised a need to be more vigilant. Some said that they increased the frequency of their checks on the aircraft's systems and position to minimise the chances of any reduction in the standard of their conduct of the flight.
- 1.18.15 0410 hours was an unusual start time for the operator's schedules. The early start was shared among the Dash 8 crews equitably, normally being restricted to two and not more than three such duties in each 28 day period. On the day of this accident the crew of ZK-NEY had flown two legs without incident and were nearing the end of the third leg when the event took place.
- 1.18.16 The pilots of ZK-NEY each stated that they were not aware of any adverse reaction to the early start. They reported they slept well on the night prior to the flight and on each of the two nights before that. They had been off duty or on light duties during the three days before the early start. In addition they had breakfasted and were working in their more normal daytime environment at the time of the accident.
- 1.18.17 The pilots were aware that they had to awaken just after 0300 hours for their duty. Therefore they retired early on the evening of 8 June. They rested well and both attested that they felt fit and rested when they reported for duty at 0410 hours. They normally had a rest period which included nine to ten hours sleep and on the two nights prior to that preceding the accident they each had that amount. On the night prior to the accident they had achieved some five or more hours sleep each. Each stated that they were used to early rising and the early start was not a problem.

Fatigue

- 1.18.18 Expert medical opinion was that the duty period worked by the crew was not sufficiently long to have been the cause of critical pilot fatigue. Both pilots had been awake for approximately six hours at the time of the accident. While they had experienced up to three hours of sleep loss as a result of the early start, this would have been in part offset by longer sleeps on the two previous nights.
- 1.18.19 Subjective tiredness during the earlier part of the duty period was the result of circadian rhythm patterns of sleepiness as much as the result of sleep loss. The circadian rhythm effects on their performance and sleepiness would have diminished significantly by 0900 hours.
- 1.18.20 Medical opinion was that, while they had experienced some subjective tiredness due to the early morning start, it is unlikely that they would have been critically fatigued in the thirty minute period leading up to the accident.

The non-precision approach

- 1.18.21 Ansett New Zealand specified standard operating procedures in the Dash 8 Operating Manual to be followed by flight crews during an instrument approach. The system for monitoring and cross-checking the approach between the two pilots was a verbal one, essentially, with a number of calls specified for the pilot not flying (PNF).
- 1.18.22 On the VOR/DME Runway 25 approach the calls applicable to the First Officer (who was the PNF) included:
- Approaching the descent point.
 - Descent point and/or passage of VOR.
 - Passing the outer marker or its equivalent on DME, check altimeters for accuracy.
 - "VOR" when outside 1 dot left or right. After 1500 feet "VOR" when outside ½dot.
 - The current deviation from altitude each two nautical miles inbound.
 - The required altitude at the next two nm DME point ahead until 1500 feet, thence at each nautical mile.
 - Any intervening limit altitude.
 - Approaching the altitude limits, and if altitude reached before arriving at the position shown on the profile.

In addition, the landing checklist was to be completed as the aircraft was configured in accordance with the approach procedure.

- 1.18.23 The SOP for non-precision approaches was to fly a constant profile descent, rather than descending to the minimum descent altitude, or to the next step-down limit altitude specified on the approach chart, then flying level until the relevant DME distance before descending to the next step. The approach was required to be flown manually, without use of the aircraft's flight director.

- 1.18.24 The procedure for monitoring the 5% descent profile was by mental arithmetic, using a formula to derive the appropriate altitude for a particular DME distance on the final approach. This formula was expressed as “three times plus or minus the appropriate hundreds of feet”. The “hundreds of feet” constant was specific for each approach, based on the elevation of the aerodrome and the displacement of the DME from the runway threshold. In the case of the Palmerston North VOR/DME Runway 25 approach, the formula was "three (hundred) times plus 400 feet" so that, for example, at 9 DME the altitude required was $3(00) \times 9 + 400 = 27(00) + 400 = 3100$ feet. Essentially this gave the same altitudes as the advisory table on the Approach Chart, but the information was calculated by pilots directly from the actual DME distance displayed on their instrument panels, rather than from referencing the table on the chart.
- 1.18.25 The First Officer in common with some other pilots marked his own Approach Chart with this formula for the particular approach. He stated that he always calculated the height required mentally, and referred to the approach chart to monitor his calculations.
- 1.18.26 Most Ansett New Zealand pilots who were interviewed stated that this profile calculation had been novel to them when they joined the company, but having become familiar with it they favoured it and found it easier to use than the advisory table had been.
- 1.18.27 Ansett New Zealand’s standard configuration points on an instrument approach were at 2000 feet for "gear down", 1800 feet for "flap 15", and 1500 feet for "condition levers max". The engine power was set to 35 to 40% torque, following flap selection to achieve the rate of descent required for a 5% descent profile. This was usually about 600 feet per minute for a typical ground speed.
- 1.18.28 The Ansett New Zealand Route Guide specified an early configuration of the aircraft for the Palmerston North VOR/DME 25 approach, requiring "gear down" and "flap 15" by 10 DME, and "condition levers max" at 1500 feet. They explained that this was to “produce a stabilised constant approach profile that would prevent otherwise inevitable GPWS warnings when adhering to the published profile.”
- 1.18.29 The altitude alert/select controller was part of the Dash 8 air data system. It displayed to the pilots a selected altitude on a digital display in hundreds of feet, which was selected by a rotary knob. When the aircraft reached 1000 feet from the selected altitude, the warning light on each altimeter was illuminated. This light extinguished again when the aircraft was within 250 feet of the selected altitude, so that no warning was given when cruising at a steady altitude. The system also provided a visual warning in the event of a deviation from the set altitude.
- 1.18.30 In addition to the alert light and the digital display, the selected altitude data was available to the flight director, operating the pitch command bar on each pilot's ADI, and to the autopilot, to command that the aircraft be levelled at the pre-selected altitude.
- 1.18.31 The Ansett New Zealand SOP for using the altitude alert system on an instrument approach was to set the MDA when the aircraft was cleared for the approach. In the case of their Dash 8 aircraft, the altitude could only be set in hundreds of feet and as the MDA was 640 feet the altitude was set at 700 feet. When the alert light illuminated, with 1000 feet to go, the missed approach altitude was then to be set. The CVR record indicated that the system was set to 700 feet for the approach on which the accident occurred.
- 1.18.32 It was not SOP to set intermediate step-down limit altitudes during the approach. This was because of the warning window of between 1000 and 250 feet. If the next step to be set was less than 1000 feet, the light would illuminate straightaway; if it was more than 1000 or less than 250 feet from the current altitude it would not illuminate. The warning given in this context was likely to be inappropriate and contradictory. The effect of the SOP was that after the "1000 feet to MDA" warning, the system was set to ensure that in the event of a missed approach the correct

altitude would be captured. The operator did not have an aural warning device fitted to the altitude alerting system.

- 1.18.33 The altitude alert/select system was capable of providing unambiguous descent guidance to each step-down limit altitude if it was used with the flight director or the autopilot. It was Ansett New Zealand's standard operating procedure not to use the flight director on non-precision approaches because it would require each altitude step to be set and confirmed by the crew with a consequent potential for distraction from the task of profile monitoring. In addition they considered that with the autopilot engaged a vertical mode engagement would be required which could be mis-set and result in a profile deviation, "with a potential for going unrecognised".
- 1.18.34 The radio altimeter system produced a digital display, in a window on each pilot's ADI, of the height up to 2500 feet above local terrain. It had a decision height function, where if a decision height for an ILS was set in another window, an annunciator would illuminate at or below that height. This decision height setting was only used on ILS approaches.

Experience of the Runway 25 VOR/DME Approach

- 1.18.35 The Captain had experienced the Runway 25 VOR/DME Approach to Palmerston North Aerodrome only once and he was PNF at the time. The First Officer had flown the procedure several times before.
- 1.18.36 Ansett New Zealand approved the use of the Runway 25 Approach but avoided it whenever practicable, because of the extra track mileage it involved over the alternative of using the Runway 07 Approach followed by a circling approach to runway 25, and because in westerly conditions the terrain beneath the approach path often generated orographic turbulence to the discomfort of the passengers.

Captain's response to abnormal situations

- 1.18.37 In the event of a system malfunction the operator required "When conducting emergency or abnormal procedures, the Captain will assume manipulative control and positively monitor the aircraft's flight path, while the First Officer reads the appropriate checklist". (Dash 8 Operating Manual Section 4, Page 2, dated August 1991)
- 1.18.38 Further, in the operator's Flight Administration and Procedures Manual in Section 2 on page 44 dated July 1993, the following guidance was provided:

9. EMERGENCY/ABNORMAL PROCEDURES

A. Flight Path Monitoring when Carrying out Abnormal or Emergency Procedures.

- (1) Flight path surveillance may be vital to the safety of the aircraft during conduct of an abnormal or emergency procedure.
- (2) When handling emergencies or abnormal procedures, the Captain should assume, or specifically assign to the First Officer, responsibility for monitoring the flight path of the aircraft. Captains should ensure that emergency or abnormal procedures are implemented in such a manner as to minimise any distractions, that could divert the assigned pilot's attention from this task.
- (3) Emergency procedures must be implemented at all times; however, prior to implementing any abnormal procedures, Captains should make a judgement as to whether in-flight rectification is necessary, or desirable, having regard to system redundancy, traffic and weather conditions, flight time to destination and the extent to which the normal operation of the aircraft is affected.

- 1.18.39 There existed in the Dash 8 crews a variety of interpretations of the operator's directions in this matter, and the correct sharing of duties in the event of a system abnormality. These fell into three broad groups:
- The Captain flies the aircraft and acts as a single pilot while the First Officer concentrates on the accomplishment of QRH checklist, each acting without any monitoring from the other.
 - The Captain flies the aircraft but the First Officer is still responsible for checking the safety of the aircraft and giving check altitude calls while completing the QRH checklist without any monitoring from the Captain.
 - The Captain flies the aircraft but keeps a check on the First Officer's conduct of the QRH checklist while the First Officer in turn still cross-checks the Captain's conduct of the flight.
- 1.18.40 Ansett New Zealand saw these variations of interpretation as utilisation of the flexibility which enabled the Captain to best utilise the crew resources in the situation confronting him. Their "fundamental and overriding principle (and effect)" sought in the written procedure was to ensure the aircraft was not placed in jeopardy. They intended the procedure to require the Captain to "immediately respond to the abnormal situation by an immediate separation of responsibilities between aircrew with the consequent benefit of ensuring that one of the crew specifically **assumes** or is **assigned** responsibility for monitoring the flight path and flying the aircraft, leaving the other to attend to assessing the nature of the problem or to attending to the appropriate procedure for the abnormality."
- 1.18.41 Some senior pilots stated the "operator culture" which they taught was that if a system abnormality occurred during an approach to land, the approach was to be abandoned and the aircraft climbed to a safe height where the aircraft was to be held in accordance with Air Traffic Control instructions until the system abnormality had been dealt with, except in the event of a dire emergency requiring an immediate landing. There was no written instruction to this effect.
- 1.18.42 This "operator culture" was not known to some of the pilots interviewed, including the Captain. Some were of the view that if the malfunction was minor it was quite in order to attempt to rectify the problem while continuing the approach.
- 1.18.43 In accordance with the operator's instructions, when the undercarriage problem was encountered on the accident flight, the Captain instructed the First Officer to carry out the procedure in the QRH adding, "I'll keep an eye on the aeroplane while you're doing that."

Quick Reference Handbook checklist

- 1.18.44 The Ansett New Zealand Flight Operations Manual, Section 4 Emergency and Abnormal Procedures, paragraphs C (2) and (3), pages 3 and 4, dated October 1993 and October 1992 respectively, required in relation to actioning the QRH:

(2) Althoughall abnormal items are carried out by reference to the checklist or Operating Manual all crew members are required to have a sound working knowledge of these procedures.

(3) Many of the reference items in the abnormal are question and answers, or straight item and action. In either case the First Officer must read aloud all written guidance, including notes, and action or proceed through the appropriate reference items as directed by the Captain.

- 1.18.45 In the case of this accident the First Officer looked up the QRH index, located the appropriate checklist, then read part of the heading, omitted reading aloud the note which followed the heading, read the side heading "Approach and Landing checklist" aloud, then began reading each line of the checks.
- 1.18.46 The first check was "Pressurisation" but before the First Officer could action it the Captain interrupted and directed, "Oh just skip her down to the actual applicable stuff." The First Officer then continued, "Landing Data, Altimeters, Tanks, Belt Smoking, ..OK Airspeed below a hundred and forty knots". The Airspeed check was the first item to be read aloud in full. He continued "and landing gear inhibit switch - Inhibit" after which the Captain responded "OK it's 140." The First Officer continued "Landing Gear Selector - Is Down. The Captain acknowledged, "Yes." The First Officer then said, "Landing Gear Alternate Release Door Fully Open, which it is."
- 1.18.47 The Captain called Ohakea ATC at that time to confirm "Ansett 703 established on finals". The First Officer observed, "Yes thanks, and insert.." and paused while the Captain completed an exchange with ATC after which the First Officer continued, "insert this handle", at which point he was interrupted by a horn alerting the crew that the undercarriage was not down. The Captain responded "It's noted.", and the First Officer continued, "insert handle at, till, oh yeah and operate until main gear locks, actually, nose gear."
- 1.18.48 In the above exchange the First Officer had missed two lines in the Checklist, "Main Gear Release Handle...Pull Fully Down" and "L/G (Landing Gear) Alternate Extension Door.....Open Fully & Leave Open".
- 1.18.49 The Captain noted this and called, "You're supposed to pull the handle,...." The First Officer replied, "yes, it's got it actually after that, yes that's pulled, here we go." The GPWS then sounded and the aircraft collided with the terrain.
- 1.18.50 The omission of items from checklists was not a new problem and was addressed by the Flight Safety Foundation (FSF) as recently as May 1995 following earlier studies and recommendations by the FAA and NTSB in the United States.
- 1.18.51 A review of the operator's Dash 8 QRH checklists revealed that their design and quality met most of the FSF's recommended criteria for legibility and clarity of intent. One recommendation which was not incorporated, however, was that each check be numbered consecutively. This particular suggestion had relevance in this case as the check had two similar lines next door but one; i.e. "Landing Gear Alternate Release Door..... Open Fully and Leave Open" and "Landing Gear Alternate Extension Door Open Fully and Leave Open" were separated by the item, "Main Gear Release Handle.....Pull Fully Down".

1.18.52 There were two checklists, 14B and 18A (see Figure 7), which included the procedure for “alternate gear extension”. These checklists were not identical. The differences are shown below:

14B		18A
<u>#2 ENGINE HYD PUMP CAUTION LIGHT ON WITH HYD QTY BELOW NORMAL, GEAR EXTENSION</u>		<u>LANDING GEAR MALFUNCTION ALTERNATE GEAR EXTENSION</u>
Landing field length is increased by 20% over flap 15° or Flap 35°. Following this procedure gear cannot be retracted and nose steering is inoperative.		<u>Note:</u> The following procedure is applicable to all landing gear and landing gear indication malfunctions and/or the illumination of LDG GEAR INOP caution light on. <u>Caution:</u> Landing gear cannot be retracted, nose wheel steering is inoperative max cross wind 20 kts
GEAR SELECTOR	DOWN	LANDING GEAR SELECTOR LEVER DOWN
GEAR ALTERNATE RELEASE DOOR	OPEN FULLY	L/G ALTERNATE RELEASE DOOR OPEN FULLY & LEAVE OPEN
GEAR ALTERNATE EXTENSION DOOR	OPEN FULLY	L/G ALTERNATE EXTENSION DOOR OPEN FULLY & LEAVE OPEN
Operate hand pump until movement becomes stiff (LEFT AND RIGHT green and L DOOR AND R DOOR amber lights ON).		Insert pump handle and operate until main landing gear locks down (LEFT & RIGHT green lights ON & L DOOR & R DOOR amber lights ON & movement becomes stiff)
LANDING GEAR ALTERNATE RELEASE & EXTENSION DOWN LEAVE FULLY OPEN		(Nothing similar)

Ground proximity warning system

1.18.53 After the Captain assisted the First Officer with the QRH checklist the GPWS gave a warning that the aircraft was closing with the “Terrain” at an unacceptable rate.

1.18.54 The warning was between 4.5 and 4.8 seconds before the impact.

DHC-8 EMERGENCY - ABNORMAL CHECKLIST 14B

#2 ENGINE HYD PUMP CAUTION LIGHT ON WITH HYD QTY BELOW NORMAL, GEAR EXTENSION

Landing field length is increased by 20% over Flap 15° or Flap 35°. Following this procedure gear cannot be retracted and nose steering is inoperative.

DESCENT APPROACH AND LANDING CHECKLIST

- * PRESSURISATION SET
- * LANDING DATA CHECKED/SET
- * ALTIMETERS CHECKED
- * EXTERNAL LIGHTS SET
- * HYDRAULIC/STBY PUMPS NO 2 NORMAL
NO 1 ON
- * ECU SELECTOR TOP
- * BELT/SMOKING ON
- * SYNCHROPHASE OFF
- * BLEED AIR SET
- * ANNUNCIATORS CHECKED
- * AIRSPEED 140 KTS MAX
- * L/G INHIBIT SWITCH INHIBIT
- * GEAR SELECTOR DOWN
- * GEAR ALTERNATE RELEASE DOOR OPEN FULLY
- * MAIN GEAR RELEASE HANDLE PULL FULLY DOWN
- * GEAR ALTERNATE EXTENSION DOOR OPEN FULLY
Operate hand pump until movement becomes stiff (LEFT AND RIGHT green and L DOOR & R DOOR amber lights ON).
- * NOSE GEAR ALTERNATE RELEASE HANDLE PULL FULLY UP
(Check nose green and N Door amber lights ON)
If any of the green locked down lights fail to illuminate:
- * GEAR LOCKED DOWN INDICATOR LIGHT SWITCH ON
Check for illumination of appropriate alternate lights.
- * LANDING GEAR ALTERNATE RELEASE & EXTENSION DOWN LEAVE FULLY OPEN
- * ANTI-SKID SWITCH TEST
- * GEAR DOWN 3 GREENS
- * FLAPS 15° /35°
- * CONDITION LEVERS MAX
-----LANDING CLEARANCE-----

STBY HYDRAULIC PUMP OVER HEAT

(#1 OR #2 STBY HYD PUMP CAUTION LIGHT ON)

FLAPS EXTENDED-----YES-----CREW AWARENESS
↓
NO

- * STBY HYD PRESS SWITCH NORM

HYDRAULIC FLUID OVER TEMP

(#1 OR #2 FLUID HOT CAUTION LIGHT ON)

GROUND

- * OPERATE SERVICES OF AFFECTED SYSTEM

FLIGHT

*CREW AWARENESS - LAND AS SOON AS POSSIBLE

18A DHC-8 EMERGENCY - ABNORMAL CHECKLIST

LANDING GEAR MALFUNCTION ALTERNATE GEAR EXTENSION

Note: The following procedure is applicable to all landing gear and landing gear indication malfunctions and/or the illumination of LDG GEAR INOP caution light on.

- * Only items marked ▲ need be completed if the AFTER TAKE OFF scans have not been completed.

APPROACH AND LANDING CHECKLIST

- * ▲ PRESSURISATION SET
- * ▲ LANDING DATA CHECKED/SET
- * ALTIMETERS CHECKED
- * TANK AUX PUMPS ON
- * EXTERNAL LIGHTS SET
- * HYDRAULICS/STBY PUMPS CHECKED/ON
- * ECU SELECTOR TOP
- * BELT SMOKING ON
- * ▲ AIRSPEED 140 KTS MAX
- * ▲ L/G INHIBIT SWITCH INHIBIT
- * ▲ L/G SELECTOR LEVER DOWN
- * ▲ L/G ALTERNATE RELEASE DOOR OPEN FULLY
& LEAVE OPEN
- * ▲ MAIN GEAR RELEASE HANDLE PULL FULLY DOWN
- * ▲ L/G ALTERNATE EXTENSION DOOR OPEN FULLY
& LEAVE OPEN
Insert pump handle and operate until main landing gear locks down (LEFT & RIGHT green lights ON & L DOOR & R DOOR amber lights ON & movement becomes stiff).
- * ▲ NOSE GEAR ALTERNATE RELEASE HANDLE PULL FULLY UP
Check nose green light & N DOOR amber light ON.
If any gear locked down (green) light fails to illuminate:
- * ▲ GEAR LOCKED DOWN INDICATOR LIGHT SWITCH ON
Check for illumination of appropriate alternate lights.
- * ▲ ANTI-SKID TEST
- * ▲ BLEED AIR SET
- * ▲ ANNUNCIATORS CHECKED
- * ▲ GEAR DOWN 3 GREENS
- * ▲ FLAPS 15° /35°
- * ▲ CONDITION LEVERS MAX
-----LANDING CLEARANCE-----

CAUTION: Landing gear cannot be retracted, nose wheel steering is inoperative max cross wind 20 kts.

Figure 7
Dash 8 QRH checklists
(Reproduced at 80% of full size)

1.18.55 The leader of the CFIT task force advised:

The aircraft was closing with the ground at 35 feet per second but the altitude loss incurred by a 2.5 degrees per second pull up and immediate application of maximum thrust would have been less than 150 feet. In many past incidents the pilot response (to a GPWS warning) was in the order of a second, the average has been 5.5.

1.18.56 A study based on incident data from two major airlines resulted in the following information in relation to pilot reaction to a GPWS warning in IMC conditions:

Average pilot reaction time	5.4 seconds 1.2 minimum 13 maximum
Average rotation rate	1.4 degrees/second 0.4 minimum 3.3 maximum
Average climb pitch attitude *	8.2 degrees 4.1 minimum 17.6 maximum

* Recommended pitch attitudes vary between 15 and 20 degrees nose up.

1.18.57 Specification 14 stating the United Kingdom CAA technical requirements for the GPWS certification states under "System Capability":

For a GPWS installation to be approved, the conditions under which it gives a warning shall be specified and shall be acceptable to the CAA. NOTE. The design aim should be for the GPWS to provide maximum warning of terrain hazard consistent with attaining a low rate of unnecessary and unwanted warnings. Warnings of the terrain hazard should be at least 20 seconds before ground collision would occur if no corrective action were taken, but the CAA accepts that this cannot be achieved in all circumstances, if acceptable freedom from nuisance warnings is to be achieved. However, it is considered likely that warning times of less than ten seconds could prove to be inadequate in many circumstances except those in which rapid crew response can be expected (e.g. final approach). In these circumstances five seconds may be adequate.

1.18.58 A review of recommended responses to GPWS warnings within Ansett Australia and associated airlines showed that there was a general emphasis on two factors essential to produce the best angle of climb obtainable in response to a GPWS warning: prompt application of maximum power and rotation to 15 to 20 degrees nose up as soon as practicable.

1.18.59 The opinion of the manufacturer's Chief Test Pilot was that in the case of the Dash 8 aircraft the best procedure was to advance the power levers and condition levers to maximum thrust and RPM respectively and climb at the appropriate go-around speed. He did not advocate pitching the aircraft up to 15 to 20 degrees because of the risk of stalling the aircraft at this critical stage.

1.18.60 The accident was close to and below a telecommunications transmitting tower. The range of frequencies and power of the transmission from these aerials were examined by the manufacturers of the radio altimeter and found to be of insufficient power to be likely to cause a malfunction of the radio altimeter.

1.18.61 The aircraft manufacturer's avionics representative advised that there was no likelihood that the operation of a computer, other electronic device or a cell phone would have affected the aircraft's flight instruments.

2. Analysis

General

- 2.1 The aircraft was being flown on an IFR/IMC non-precision approach to the aerodrome in the course of a scheduled passenger service.
- 2.2 When the First Officer selected undercarriage “DOWN” the right main leg failed to extend. The Captain instructed the First Officer to carry out the appropriate QRH procedure, and undertook to fly the aircraft and monitor its safety (“keep an eye on the aeroplane”) himself. Shortly after that the aircraft descended below the published approach profile and the aircraft collided with the terrain with the result that four occupants lost their lives. Most of the remainder were seriously injured and the aircraft was destroyed.
- 2.3 In reverse chronological order the significant issues involved in the investigation of this accident were:
- the pilots’ response to the GPWS warning,
 - the performance of the GPWS equipment,
 - the response of the crew to the abnormal operation of the aircraft’s undercarriage system,
 - the pilots’ execution of the VOR/DME approach to runway 25 at Palmerston North,
 - the influence of the weather conditions on the conduct of the approach,
 - the fitness of the crew to perform the flight,
 - the provision of air traffic control during the approach to the aerodrome,
 - the design of the runway 25 VOR/DME approach to the aerodrome,
 - the serviceability of the aircraft for the flight,
 - the airline’s preparation of the crew for the flight,
 - the airline’s follow-through on their decision not to modify the aircraft undercarriage system,
 - the airline’s flight safety system,
 - the CAA’s monitoring of the actions taken by the airline in response to the issue of modifications on the DHC-8 undercarriage system,
 - the effectiveness of the airline’s written instructions for maintaining the safety of the aircraft, and
 - the efficacy of the CAA’s auditing in ensuring that the airline complied with the applicable rules and regulations and conformed with the documentation it provided to obtain CAA approval for its operations.
 - The potential for the terms of the pilots’ contract with Ansett New Zealand to require the deactivation of cockpit voice recorders in aircraft operated by the company.

In addition the issues which affected the survival of the aircraft’s occupants were addressed.

The pilots’ response to the GPWS warning

- 2.4 There was no indication on the CVR record that the crew were alerted to the impending collision with terrain by the GPWS visual or audio warnings. Although the DFDR record showed no evidence of a significant increase in engine torque following the audio alert which was audible on the CVR record, it did show an up elevator input to a maximum of 6 degrees in the last three seconds of the record. This was followed by the aircraft pitch angle increasing to a maximum of 8 degrees nose up and an average increase in vertical acceleration of approximately 0.3 g’s. These recorded parameters indicate that a pull-up was initiated which mitigated the effects of the initial collision with the terrain. The aircraft’s initial impact which occurred some three seconds

before the main impact was such that it could have occurred without interrupting the DFDR reading.

- 2.5 On occasion pilots have recovered, in response to a GPWS warning of an impending collision with the terrain, by reacting in as little as a second, but an average reaction time is 5.5 seconds. In the case of ZK-NEY the warning given was between 4.5 and 4.8 seconds. The rising terrain ahead, and the shortness of the GPWS warning, suggested that in this case an optimum response including the immediate application of maximum power would have been insufficient to fly the aircraft clear of the terrain.
- 2.6 The airline had not published a response procedure for a “hard” GPWS warning in their Flight Operations Manual for the Dash 8, although such was published shortly after the accident. The manufacturer’s Flight Manual, which was available in the aircraft, did, however, have a procedure for responding to such a warning.
- 2.7 The procedure which the pilots said they would have followed in response to a GPWS warning was similar to that which the company published subsequent to the accident; they each referred to setting “Go-around power” and a pitch attitude for the best rate of climb.
- 2.8 It is vital that the aircraft’s full potential, of speed and power available, be used immediately in response to a “hard” GPWS warning, i.e. maximum power must be set as soon as practical coupled with an immediate initiation of a rotation in pitch to a nose-up angle to achieve the best angle of climb in the first instance.
- 2.9 This information had been promulgated by international flight safety organisations and repeated at frequent intervals for several years before the accident.
- 2.10 The manufacturer encompassed this advice in general terms in the Dash 8 Flight Manual stating, “immediately establish the power setting and attitude which will produce the maximum climb gradient consistent with the aircraft configuration.” but this advice should have been more specific. After the accident the manufacturer’s test pilot advised the best procedure for the Dash 8 was to advance the power levers and condition levers to maximum thrust and RPM respectively and to climb at the appropriate “go-around” speed.

The performance of the GPWS equipment

- 2.11 This accident demonstrated that there are occasions when aircraft terrain clearance is not maintained at a safe level, and the back-up measures suggested by the CFIT checklist will prove their worth. The installation of a GPWS was one of these measures. Although New Zealand legislation did not require a GPWS to be fitted to turboprop aircraft, it was installed as a standard item in the Dash 8 by the aircraft manufacturer, and Ansett New Zealand maintained the GPWS as a serviceable item.
- 2.12 Factory simulations by the GPWS manufacturer indicated that under the worst scenario there should have been in excess of 12 seconds more warning to the crew than occurred in this case.
- 2.13 The GPWS installation in the Dash 8 met the FAA criteria for such equipment when it was installed in the aircraft, and the individual components that could be tested after the accident appeared serviceable. It is important therefore that the reason for the short warning be established by the certifying authority, in conjunction with the manufacturers of the aircraft and the GPWS, as soon as practicable to retain the industry’s confidence in these systems.
- 2.14 The only replicable scenario which produced a GPWS warning as short as that given in this case was related to a loss of radio altimeter tracking. It was impracticable to determine if this happened in this case as the radio altimeter readings were not recorded in the DFDR. There was, however, no record of radio altimeter malfunctions in the maintenance history of the aircraft.

- 2.15 The possibility of interference with the proper operation of the radio altimeter being caused by transmissions from the aerial tower adjacent to the accident site was explored with the assistance of the radio altimeter manufacturer and the operator of the transmitters using the aerial tower. Laboratory tests indicated that there was insufficient power radiated from the aerial tower to cause any interruption to the radio altimeter's performance.
- 2.16 The GPWS manufacturer had made available modifications to minimise the occurrence of unwanted and nuisance warnings, during an aircraft's approach over high ground, without jeopardising "hard" warnings in this area of greatest potential for a CFIT accident. The aircraft manufacturer had advised the airline that the modifications were suitable for the Dash 8 aircraft. The GPWS manufacturer had also addressed a Service Information Letter to "All Chief Pilots and All Flight Operations Managers" recommending the embodiment of these modifications.
- 2.17 The company was not convinced these modifications were relevant to the Dash 8 aircraft and decided not to embody them. This decision was based on the belief that early configuration of the aircraft was preferable as it not only eliminated the redundant and nuisance warnings but also relieved the crew of any systems selections that could have the potential to interfere with the pilots' primary task of flight path monitoring.
- 2.18 The operator had established the practice of selecting undercarriage and flap early to prevent false warnings during the approach to Palmerston North and for other approaches over rugged terrain. This practice reduced the efficacy of the GPWS should the aircraft be in danger of colliding with the terrain.
- 2.19 As a non-precision approach over high terrain was the segment of a flight which provided the highest potential for a CFIT accident, any procedure which reduced the effectiveness of GPWS warnings at this time was a retrograde step. Although the lower speed associated with undercarriage and flap selected made some compensation for this, it did not redress the reduction in the warnings appropriately.
- 2.20 On this flight one undercarriage leg failed to extend and no flap was selected. Therefore the normal warnings, appropriate to an aircraft without undercarriage or flap lowered, should have been available immediately prior to the occurrence of this accident. Contrary to the airline's contention, the operational requirement to lower the undercarriage early did create the opportunity for the crew to be distracted by the abnormal system operation and was thus a contributory factor.

The crew's response to the abnormal operation of the undercarriage system

- 2.21 Some senior pilots asserted that there was an operator culture of "always making time to deal with a problem by aborting the approach to resolve an abnormality whenever it was practical to do so". However, the operator's written procedures gave the Captain the discretion to decide whether to endeavour to resolve the problem while continuing the approach or to discontinue the approach and address the problem while circling in protected airspace.
- 2.22 The Captain's decision to continue the approach, flying the aircraft and monitoring its flight path, and to allocate to the First Officer the task of responding to the abnormal system operation was also in accordance with the operator's procedures.

- 2.23 Having made the decision to continue the approach, the Captain appeared to be aware of the limits of the time available in that he first told the First Officer to “..whip through (the QRH), see if we can get it out of the way before it’s too late.”, and 34 seconds later he instructed him to skip through the first part of the checklist and go “to the actual applicable stuff”. This he was entitled to do in accordance with Ansett New Zealand’s written procedures.
- 2.24 However, the Captain’s decision to continue the approach introduced time constraints on his CRM. Had he involved the First Officer and reviewed the situation adequately he could have established some pertinent facts which may have caused him to decide to postpone the approach. These considerations included:
- the aircraft was not stabilised on the approach profile;
 - hand flying the approach in IMC with no external references would demand most of his attention; and
 - the need for him to apportion his time between observing the First Officer actioning the QRH check list, manipulation of the aircraft’s controls and monitoring the aircraft’s flight path, had the potential to overload him.
- He might also have involved the Flight Attendant in the CRM associated with the situation had there been more time available.
- 2.25 The time taken by any Captain to make decisions while hand flying the aircraft is longer, significantly, than when he is the PNF. Therefore it may be preferable for the First Officer to have manipulative control of the aircraft as a matter of course, in the case of an abnormal situation arising during the flight, until the Captain has considered the action required in response to the problem.
- 2.26 The actions required by the QRH checklist were best conducted by the First Officer. Nevertheless, the Captain’s potential to detect the aircraft’s predicament could have been enhanced had he designated the First Officer as PF while he took stock of the situation. The operator’s standard operating procedure that when conducting emergency or abnormal procedures the Captain will “assume manipulative control” of the aircraft, was to ensure that the senior pilot was PF during the abnormal situation. This SOP did not preclude the Captain handing over control to the First Officer while he considered the most appropriate course of action.
- 2.27 The First Officer had made the call “On profile” as the aircraft descended through the appropriate approach profile. At that time the aircraft’s rate of descent was excessive but the Captain did not appear to perceive the need to increase power to reduce the rate of descent to an appropriate figure.
- 2.28 Some 15 seconds later the Captain noticed the undercarriage system had failed to operate properly and announced his intention to “look after the aeroplane”. At this time the aircraft was some 300 feet below the advisory profile but 300 feet above the limit altitude.
- 2.29 Although the aircraft was on an instrument approach in IMC, the company’s procedure did not require the First Officer to continue monitoring the aircraft’s flight path once the Captain allocated to him the task of implementing the appropriate QRH checklist.
- 2.30 The reason for an absence of a cross-checking process on the approach during the response to the abnormal situation may have been the company’s rationale that in a two-pilot crew one pilot would be fully committed with the task of flying the aircraft and monitoring its progress while the other needed to devote all of his attention to rectifying the problem.

- 2.31 The Captain stated that when he was a First Officer the company taught him that the First Officer was still required to monitor the aircraft's altitude in such circumstances. Some senior pilots in the company were also of the view that altitude monitoring remained the First Officer's responsibility after he had been instructed to action the QRH checklist. This was not a written company procedure and the First Officer had not been taught to continue this monitoring in such circumstances.
- 2.32 After the instruction to skip through some items on the checklist, the First Officer read the list correctly until he missed two essential items. This could have given the Captain another cue as to the desirability of aborting the approach to regain control of the situation. Instead he diverted some of his attention to assisting the First Officer at the expense of his self-assigned task of monitoring the aircraft's flight path.
- 2.33 The Captain's response in initiating the QRH action prescribed by the operator and advising that he would fly the aeroplane while the First Officer completed the checklist was appropriate but the intention, while appropriate, was not followed. Had the situation it created been handled as intended, the undercarriage system abnormality which occurred on ZK-NEY should not have led to a collision with the terrain.

Quick reference handbook checklist

- 2.34 The First Officer actioned some of the required items on the QRH checklist out of sequence on his first attempt. The PNF could expect to be interrupted at any time during the reading of a checklist, for a variety of reasons. Therefore each pilot's training and the design of the checklist should minimise the potential for items on a checklist to be read out of sequence.
- 2.35 The progressive movement of pilots between the BAe 146 and Dash 8 fleets meant that it was unlikely that any Dash 8 pilot would have the opportunity to practise each of the checks in the QRH which related to system abnormalities. However, the abnormal situation which resulted from one main undercarriage leg being "hung-up" was addressed by each pilot during his Type Rating training. The pilots of ZK-NEY each stated that when they practised this abnormal procedure during their training they did not execute the full QRH procedure.
- 2.36 As many abnormal situations were not demonstrated, the Ansett New Zealand QRH checklists were intended to enable pilots to correct the effects of a range of abnormal situations without previous rehearsals. The operator relied on the QRH checklists, and a written requirement for pilots to be familiar with the action required in each abnormal situation, to guarantee the correct action would be taken by any pilot in response to an abnormal system operation.
- 2.37 The layout of the wording of the QRH checklist for the undercarriage alternate lowering procedure was capable of inducing a loss of sequence by the reader, due to the similarity of the words in two lines and their proximity to each other. Had the First Officer completed the checks in the order called for, the Captain would not have had his attention diverted to the execution of the QRH checklist procedures so this item is worthy of further attention, particularly as it arises on each of the QRH checklists relating to undercarriage lowering.
- 2.38 The suggestion that each check on the list be numbered sequentially was not embodied; however, in other respects the design of the checklist met most of the other practices recommended by the Flight Safety Foundation for such lists. The numbering of each check on the list could provide an additional cue for a pilot to re-establish his place following any interruption which required him to divert his attention from the list, particularly when similar text appeared in lines close to each other.
- 2.39 Although only one QRH was carried in the aircraft, the lettering of an abbreviated checklist, on the "Landing Gear Alternate Extension Door", faced the Captain's seat, enabling the Captain to check the significant steps of the procedure.

Sterile flight decks

- 2.40 The CFIT check list advocated that operators observe a sterile flight deck policy. Apart from “extreme matters” Ansett New Zealand expected the pilots not to be disturbed by any entry to the flight deck when the aircraft was below an altitude of 5000 feet, and that the Flight Attendants would be seated once the pilots had signalled them so to do. The Flight Attendant’s instructions required her to aim to be seated immediately after the “No Smoking” chime signal and no later than when the undercarriage was lowered.
- 2.41 The Captain had not advised the Flight Attendant that the pilots were dealing with an undercarriage fault. Therefore when she noticed the right undercarriage had not extended normally, during a discussion with a passenger, she opened the flight deck door to mention the matter to the pilots. This action was taken after she should have been secured in her seat but as she was not aware that the pilots knew of the problem it was appropriate that in accordance with CRM principles she drew it to their attention.
- 2.42 Although only Senior Flight Attendants were rostered for duty on the Dash 8 aircraft it would have been more effective for the operator to publish separate instructions for Dash 8 Flight Attendants instead of relying on the Flight Attendants to translate the BAe 146 instructions for the requirements of their duties on the Dash 8.
- 2.43 The operator’s instructions for BAe 146 Flight Attendants did permit the Flight Attendant to enter the flight deck at any time in connection with an “extreme matter”. While the Flight Attendant could have remained seated and used the interphone to discuss the matter with the crew the alternative which she chose, of opening the flight deck door and speaking to the pilots, was understandable and may have been less intrusive than using the interphone.
- 2.44 After she had spoken with the pilots she resumed discussion with a passenger seated one row back and across the aisle from her assigned seat. This was not desirable in the circumstances. Although the operator’s image is enhanced by the caring interaction between the passengers and Flight Attendants a quick word of reassurance would have been sufficient at that stage of the approach.
- 2.45 Having done this it would have been appropriate for her to take her seat as her continued safety was important to the passengers should the situation deteriorate. An important purpose of the requirement for Flight Attendants to be carried in scheduled passenger service aircraft is to assist the passengers in the event of any emergency. No emergency had occurred at that stage but it was the Flight Attendant’s duty to take advantage of the rearward facing seat and upper torso restraint to enhance her chances of survival in the event of a mishap on the approach to land, one of the stages of the flight recognised for its high potential for accidents.
- 2.46 In normal circumstances the company practice for signalling the cabin crew to be seated gave Flight Attendants ample warning to comply with the Civil Aviation Regulation requirement to be seated and secured whenever the aircraft was less than 1000 feet above the terrain.

The pilots' execution of the descent and VOR/DME approach to the aerodrome

- 2.47 The CVR and DFDR records and the ATS radar plot indicated the pilots achieved an appropriate descent and joining procedure for the approach and also flew the inbound track within limits. There were, however, some aspects of the briefing and cross-checking during that period which indicated an unexpected lapse in concentration on the task in which they were involved.
- 2.48 The Captain made two errors in the initial briefing for the Runway 07 Approach and neither was corrected by the First Officer. These errors would have been significant if the aircraft had been cleared for a circling approach to runway 25 as requested.
- 2.49 Although the First Officer did make an error initially with one calculation of the company's formula for the height at one DME range, this had no effect on the conduct of the flight. What was not achieved, however, was an appropriate reduction in the aircraft's rate of descent as soon as it reached the intended approach profile.
- 2.50 The failure of the aircraft's pilots to maintain situational awareness is evidenced by the aircraft's deviation from the glide path after the First Officer advised, "On profile". The Captain did not increase the engine thrust sufficiently, at that time or subsequently, to maintain or thereafter to regain the appropriate flight path. That no comment was made by either pilot relating to altitude, and no appropriate adjustment made to the engine thrust by the pilot flying, attests to the pilots' failure to appreciate their predicament.

The influence of the weather conditions

- 2.51 The aftercast of the weather which prevailed on the approach to Palmerston North indicated that the wind conditions would have produced an orographic downdraught in the lee of the hills crossed by the approach to runway 25. A comparison of the radar and DFDR information with the manufacturer's rate of descent charts indicated the downdraught averaged some 410 feet per minute as the aircraft descended below its intended flight path. This would have aggravated the consequences of the Captain not setting sufficient engine thrust, by reducing the time available for him to correct the situation.
- 2.52 It is also probable that the weather conditions prevented the pilots from sighting the terrain at any time which would have enabled them to appreciate their predicament and take the appropriate evasive action.

Human performance

- 2.53 The unexpected comments and misunderstandings by one or other of the pilots and the failure of the monitoring process to detect these, pointed to a shortcoming in the standard of performance of the pilots.
- 2.54 The pilots had each demonstrated, to the company's satisfaction, that they were capable of fulfilling their respective roles on the aircraft type competently and neither pilot had an appreciable accumulated sleep deficit in the 72 hours prior to the flight.

Fatigue

- 2.55 The potential physiological effects of the early start were studied in an attempt to determine if the design of the crew roster had jeopardised crew fitness to conduct the flight to an extent which would explain their unexpected attentional slips, memory lapses, and mistakes.
- 2.56 Analysis of three physiological factors known to produce fatigue-related performance decrements (cumulative sleep debt, prolonged wakefulness and circadian factors) indicated that fatigue levels

were not at a sufficient level to explain adequately the pilots' lapses immediately prior to this accident.

2.57 While a number of attentional slips, memory lapses, and mistakes identified as being contributory to the accident were of a type that may be caused by fatigue, these are also observed frequently for reasons unrelated to the effects of fatigue on performance. While the early morning start caused some inevitable sleep loss, the ameliorating effects of circadian rhythms and the rest available on the prior two days would have offset any fatigue developing in the course of the duty period.

2.58 The level of fatigue was not of an intensity which could have been the sole cause of the series of crew errors observed, for which alternative factors are more probable explanations. However, a contributory effect of subcritical fatigue on these other factors can not be excluded.

Errors

2.59 Research into aviation accidents shows that when human error occurs it is often caused by failures in the cognitive information processing system. Usually these failures occur in the absence of any effect known to cause cognitive impairment such as stress and fatigue.

2.60 The sequential steps in the information processing system can be described as: information detection, perception and diagnosis, decision making and goal setting, strategy and procedural selections, and action. The efficiency of the information processing system is affected by physiological arousal, and attention.

2.61 Errors resulting from problems with information processing can be categorised into three basic types: skill-based attentional slips and memory lapses, rule-based mistakes and knowledge-based mistakes. In the first type of skill-based error there is an unintended deviation or deviations from a sound plan, whereas in the second and third types, the plan itself deviates from the necessary actions to achieve a goal.

2.62 The examination of the CVR record showed that the crew made a number of errors of the attentional slip and memory lapse type in the 30 minutes prior to the aircraft's collision with the terrain. These categorised by type were:

Attentional slip

- The Captain not setting the appropriate power to maintain a normal approach path as the aircraft neared the descent profile.
- The Captain not setting the appropriate power to regain a normal approach path after the aircraft had descended through it.
- The Captain not paying sufficient attention to the aircraft's flight path while assisting the First Officer with the implementation of the QRH "Alternate Gear Extension" checklist.
- The Captain not recognising the aircraft's deviation from the descent profile.
- The Captain not querying the absence of any altitude monitoring calls by the First Officer after the non-normal undercarriage lowering procedure was commenced. (The Captain expected such calls from his First Officer to continue monitoring the altitude.)

Memory lapse

- A query from the First Officer to the Captain as to whether the Air Traffic Controller had said “12 DME arc” or “14” when she had said “14” clearly and the First Officer had repeated it back to her correctly 30 seconds earlier.
- The Captain quoting the wrong minima when he briefed the First Officer on a circling approach to runway 25 at Palmerston North (i.e. MDA 480 feet instead of 660 feet, and 1600 m visibility instead of 2800 m) and the First Officer not drawing his attention to the mistakes.
- The First Officer’s incorrect tracking of his checks in the QRH “Alternate Gear Extension” checklist.
- The Captain correctly briefing the VOR/DME approach to runway 25 and reminding himself and the First Officer that the approach was “right on the limits” so they had to stick to the three times plus four hundred profile, and then omitting to fly the approach in that manner six minutes later.
- The First Officer’s incorrect calculation of the required altitude at 10 DME and the Captain’s response of “Check” (as a confirmation rather than an instruction to verify the calculation).

2.63 Singularly and collectively, these attentional slips and memory lapses reduced the pilots’ awareness of their situation. Given that most of the errors were attentional in that the pilots failed to detect and capture the relevant information available to them, the subsequent efficiency of their information processing, decision making, actions and reactions, was diminished.

2.64 The undercarriage problem exacerbated this effect by distracting and capturing the pilots’ attentional resources.

2.65 Information on pre-dispositional individual factors was not available; therefore an analysis of why the pilots’ cognitive processes failed and how they failed to operate optimally was not practicable. Analysis of these factors in conjunction with the situational factors would have been required to judge how they may have affected the individuals’ abilities to process information. The pre-dispositional factors include innate attitudes and abilities, thinking (cognitive) styles, personality, training and previous experience.

Air traffic control

2.66 The provision of Air Traffic Control service to the aircraft was in accord with the standard practice.

2.67 One aspect that did cause the pilots of ZK-NEY some confusion was the ATCO’s instruction, “... stop descent at six thousand feet, intercept the 14 DME Arc for the VOR/DME approach runway 25”. This instruction was valid and correctly phrased but during a subsequent RTF exchange in response to a query by the First Officer to clarify this, the ATCO stated, “Ansett 703 affirm minimum descent on the arc is 6000”.

2.68 The First Officer had recognised the original instruction was not a clearance for the approach and the ATCO was entitled to hold the aircraft on the arc, at an altitude above the minimum specified, but sought confirmation to resolve a discussion between himself and the Captain. However, the ATCO’s response was taken literally and out of context and a further flight deck discussion arose as to the published minima on the DME arc. Each discussion was a minor distraction. Although

the exchanges between the two pilots to clarify their understanding of the ATCO's instructions were appropriate, the pilots should have understood the intent of the ATCO's original instruction.

The design of the VOR/DME approach

- 2.69 In view of the known orographic effects and GPWS warnings experienced by aircraft using the Runway 25 VOR/DME approach to Palmerston North, the detail of the design of the approach was reviewed. It was found that it embodied the applicable ICAO standards.

The undercarriage uplock

- 2.70 When examined after the accident the right uplock exhibited a wear pattern consistent with contact between the detent area of the latch and the uplock roller. The measured wear was beyond the limits specified by the undercarriage manufacturer in the relevant component maintenance manual. Fire damage precluded metallurgical determination of the hardness of the latch surface and assessment of impact effects upon the observed wear pattern.
- 2.71 The undercarriage manufacturer considered that the wear condition, as found, was sufficient to have prevented release of the undercarriage leg using the normal undercarriage extension procedure. The manufacturer also considered the wear would have increased the pull which would have been required on the Main Gear Release Handle but would not have prevented manual/alternate release.
- 2.72 Maintenance experience following the introduction of the Dash 8 aircraft into service recognised potential for various improvements to the uplock latch and roller assemblies, including measures to overcome indenting of the latch. (See paragraph 1.6.36 onwards.)
- 2.73 Periodic inspections of the uplock, including the latch detent area, were carried out by Ansett New Zealand Engineering Ltd in accordance with the aircraft Manufacturers Maintenance Programme. Technical Instructions to engineering staff included inspection of the latch for indentation.
- 2.74 In October 1994 an AOM issued by the manufacturer emphasised to operators that pre-modification 8/1828 uplocks (as fitted to ZK-NEY and ZK-NEZ at that time) were sensitive to latch wear and that worn uplocks tended to show progressive operational problems which might result in the main undercarriage failing to release using the normal system.
- 2.75 A subsequent review by Ansett New Zealand Engineering Ltd in December 1994 resulted in the decision to install the improved uplock assemblies in the Dash 8 fleet.
- 2.76 A Temporary Revision to the Manufacturers Maintenance Programme, issued in November 1994, added a note to the existing inspection procedure for unmodified uplock actuators. In relation to wear on the uplock latch at the point of roller engagement the note introduced the information that wear limits could be found in the relevant Component Maintenance Manual.
- 2.77 This revision had been received by Ansett New Zealand Engineering six months prior to the accident but had not been considered by the maintenance planning team for five months due to staff changes. As the pre-modification uplocks were due for replacement when the modification kits were obtained it was decided no action would be taken. While the length of time taken before the revision was considered was excessive, there was no compliance date or other indication of urgency on the Temporary Revision.
- 2.78 Had the maintenance planning team decided to incorporate the revision to take effect on the next inspection, that inspection would not have occurred until 7 to 10 days after the accident.

- 2.79 Inclusion of the revision note was a positive action by the manufacturer to update the Dash 8 Maintenance Programme, and the wear limits themselves, published in the Component Maintenance Manual, could be referred to by engineering staff to resolve whether in-service wear on an uplock latch was acceptable for continued service or the unit should be replaced. However, maintenance experience of undercarriage “hang-ups” due to known problems involving the unmodified uplock actuators and roller assemblies, awareness of latch susceptibility to wear, and existing Technical Instruction requirements relating to inspection of the latch detent area, already prompted engineering staff to exercise caution in accepting a latch exhibiting abnormal or excessive wear.
- 2.80 It could not be established conclusively at what date, aircraft operating hours, or cycles, the wear on the right uplock latch installed on ZK-NEY had exceeded the specified wear limits, nor if the extent of wear, as determined following the accident, had been affected by impact loads. Similarly it could not be established with certainty that the extent of wear on the uplock latch was solely responsible for the undercarriage “hang-up”. The aircraft’s service history and maintenance experience indicated that uplock roller performance and rigging considerations had contributed to previous “hang-ups” in addition to the adverse effects of latch wear or indentation.
- 2.81 Nevertheless, the tests carried out by the undercarriage manufacturer indicated that, at the time of the accident to ZK-NEY, wear on the uplock latch surface was sufficient to have prevented the right undercarriage lowering when the ‘DOWN’ selection was made.
- 2.82 Irrespective of the cause of the undercarriage ‘hang-up’, however, its occurrence on the accident flight introduced an abnormal situation which had to be resolved prior to landing. This in turn resulted in the attention of the pilots being diverted from the routine procedures and conduct of the approach being flown.

The airline’s flight crew training

- 2.83 Ansett New Zealand was an approved check and training organisation. They had established check and training captains and a ground school for this purpose.
- 2.84 The operator had expanded its aircraft fleet in recent times before the accident. The expansion required the enlistment of additional pilots and a movement of the existing pilots between aircraft types to preserve their career structure.
- 2.85 In general, Captains on the Dash 8 fleet were drawn from First Officers flying on the company’s BAe 146 fleet and the First Officers on the Dash 8 were new recruits. Neither of the pilots on ZK-NEY was an exception to this pattern.
- 2.86 The source of the pilots should not have detracted from the safety of the flight as each had a substantial flying background, had passed the company’s courses for their position and had been supervised for a significant period while line flying after qualifying to fly the Dash 8 aircraft.
- 2.87 Each of the pilots involved in this accident successfully completed an Ansett New Zealand Type Rating course for the Dash 8.

Crew resource management and line oriented flight training

- 2.88 Ansett New Zealand devoted part of the Dash 8 Type Rating course and recurrent training time to CRM and LOFT to prepare its crews to deal with “out of the ordinary” situations without jeopardising the safety of the aircraft.
- 2.89 While each of the pilots involved in this accident had attended classroom instruction in CRM, the First Officer stated his exposure had been limited to one introductory session. The CRM instruction involved watching videos of, and discussion relating to, known accidents in which CRM had not been exercised. The discussion concentrated on the factors which resulted in the distraction of the pilots from their prime responsibility of ensuring the aircraft maintained a safe flight path. Despite this ZK-NEY flew into the terrain in very similar circumstances.
- 2.90 The reason that the crew did not avoid the accident despite the CRM training could be related to the fact that the training was, in their case, knowledge-based rather than skill-based. The need for practical experience of the stress created by abnormal operations has been recognised by the institution of LOFT programmes flown in aircraft flight simulators.
- 2.91 Although the Dash 8 pilots did not practise decision making in the realistic environment of the simulator, the Captains had for the most part experienced this training in a BAe 146 simulator as First Officers. This Captain was no exception but he had no experience of dealing with LOFT as pilot in command.
- 2.92 The circumstance of a small airline operating without the advantage of a flight simulator is common and is accepted by the CAA. A review of other airlines’ approaches to the problem of effective CRM training without the reinforcement of a LOFT programme did not reveal a more appropriate manner in which to drive home the ease with which a crew can lose situational awareness in an environment of increased stress.
- 2.93 While no formal command training course was conducted for First Officers before they assumed the authority of Captains, new Captains underwent extensive supervised flying before they were “cleared to line”, i.e. allowed to act as pilot in command of the aircraft on scheduled passenger operations, without direct supervision. During their supervised Captaincy the pilots’ susceptibility to distraction was assessed and no Captain was cleared to line unless a satisfactory resistance to distraction was demonstrated.
- 2.94 In spite of these measures the operator experienced a CFIT accident which in general terms followed the pattern of the majority of similar events where the Captain and First Officer did not combine their resources efficiently.
- 2.95 As a consequence of inadequate crew resource management, the pilots of this aircraft did not ensure their aircraft maintained safe clearance from the terrain, following the recognition of the abnormal operation of a system. Their training in the potential for distraction; written advice to minimise the chances of distraction; and the Captain’s spoken assurance to the First Officer that he would look after the aircraft, were not followed proficiently.

Undercarriage modification

- 2.96 The tendency of one of the Dash 8 main undercarriage legs to hang-up on occasion was a problem of long standing. In August 1992 the manufacturer advised that a redesigned uplock actuator assembly was available to overcome the problem of main undercarriage leg hang-ups. The manufacturer recommended compliance at the operator’s discretion and the company decided not to embody the modification at that time.

- 2.97 Although a Technical Instruction was raised by Ansett New Zealand Engineering to include an inspection of the existing uplock latches for indentation, at the time of the decision not to modify the undercarriages, the operating crews were not advised of the decision. As this decision meant that there was a greater likelihood of the pilots having to implement the alternate lowering procedure and of passengers noticing that one undercarriage leg had not lowered, the company should have notified the pilots and cabin attendants and reminded them of the appropriate steps to take in such an event.
- 2.98 Had this decision been promulgated to a flight safety officer, or had a trained safety officer been involved in the decision making process, a potential would have existed for him or her to review the decision and to lend support to minimising any adverse effects or consequences of this decision.
- 2.99 Had the Flight Safety Officer been advised of the decision he or she could have been expected to:
- review the company's procedures for such an event,
 - ensure all affected crews were aware of the increased chances of an undercarriage system malfunction,
 - prompt Dash 8 pilots to review their CRM reaction to such a situation,
 - ensure Dash 8 pilots were familiar with the QRH procedure for such an eventuality, and
 - discuss with cabin crews the increased probability of and their appropriate reaction to such an event.

The airline's flight safety system

- 2.100 The Flight Safety Co-ordinator was chairman of a Flight Safety Panel of two which was convened on an ad hoc basis. He had the authority to approach the Chief Executive independently if he detected a flight safety problem which he could not resolve in any other way, but he was not involved in management decisions which had the potential to affect flight safety. Although his title included the word "Co-ordinator", the management system did not facilitate his co-ordination of the company's safety action.
- 2.101 The nature of rosters and schedules meant that while pilots and flight attendants might exchange pleasantries when they passed each other they seldom discussed any operational incidents outside of the periods of recurrent training.
- 2.102 The company had in place a system of General Flight Reports. Within the Flight Safety system Regional Managers and Fleet Captains responded to incident reports generated by crews, by distributing them to the appropriate managers for comment and action and then returning them with a copy of the comment to the originators.
- 2.103 While the reaction to the GFR was prompt it was not comprehensive in that there was no associated process for keeping all operating crew members advised of the problems which were identified by individuals or for advising them of the action they should take if they experienced a similar incident.
- 2.104 Flight safety was implemented within the company by a system in which each employee was deemed to be responsible for flight safety. None of these personnel had formal training in flight safety or accident prevention, nor were any individuals given the opportunity to attend any of the regular international conferences on these subjects.

- 2.105 Thus although the flight safety system achieved comprehensive consideration of reports of incidents and satisfied the person filing an incident report that his report had been properly considered, the system was essentially reactive. Wider promulgation of the incidents and action taken was seldom made to other employees.
- 2.106 An improvement of the potential for detecting flight safety hazards could be introduced by initiating safety surveys, giving personnel a formal opportunity for representation at a pro-active “think tank” involving each section of the company at regular intervals, and a more active role for the Flight Safety Co-ordinator in monitoring the flight safety actions already taken.
- 2.107 The investigation of this accident indicated that there was a fertile ground for an active and adequately resourced Flight Safety Co-ordinator to initiate a pro-active flight safety approach. In relation to this accident such an approach might include:
- development of a standard procedure for responding to a “hard” GPWS warning,
 - promulgation of the most efficient response to a GPWS warning in the BAe 146 and Dash 8 flight manuals,
 - developing a standard procedure for cross-checking altitudes during the response to an abnormal situation, and in normal operations,
 - promoting the use of the flight director on non-precision approaches
 - promoting a case for an aural alert on the altitude warning system,
 - reviewing the potential trap created by the practice of setting the altitude alert to an altitude below that to which it is safe for the aircraft to descend during a non-precision approach,
 - expediting the production of separate instructions for flight attendants on the Dash 8 aircraft,
 - co-ordinating a review of the QRH, and
 - publishing an “in-house” safety newsletter.
- 2.108 This accident was an example of the CFIT type of aircraft occurrence which is the leading cause of fatalities in civil aviation to-day and the subject of a campaign by an international aviation safety task force which aims to reduce the number of CFIT accidents to half its present rate by 1998.
- 2.109 Had the Flight Safety Co-ordinator known the details of the Flight Safety Foundation’s comprehensive CFIT checklist to assist companies to “evaluate specific flight operations and to enhance pilot awareness of the CFIT risk” it would have provided him with a sound base from which to improve the “terrain proofing” of the company’s operation.
- 2.110 Although most of the recommended practices in the CFIT checklist which had been developed were already part of Ansett New Zealand’s standard operating procedure, there were some areas in which improvements could have been made had the checklist been used.
- 2.111 Some of the undercarriage hang-up incidents were reported to the CAA which maintained a monitoring role on the action taken by all parties on such events. In this case CAA relied on the absence of any mandatory instruction from the State of Manufacture as confirmation that the operator’s actions were acceptable. They saw no need to take any action in the matter and did not.

The airline's written instructions

GPWS information

- 2.112 The GPWS manufacturer's Information Letter recommending the incorporation of Modifications 17 and 18 was sent to all operators on the same distribution as other information received by Ansett New Zealand. Although it was addressed to the Operator for the attention of the Chief Pilots and Operations Managers, the employees of Ansett filling these posts did not receive the documents. Had they done so the advisability of incorporating the modifications may have been more apparent to the company.
- 2.113 The requirement for a published procedure for the best response to a "hard" GPWS warning should be a normal complement to the installation of the equipment. The manufacturer's flight manual described a response procedure but this had not been transposed to the company's own flight manual. In this case both of the pilots in the subject aircraft were aware of the general procedure later published by the operator.
- 2.114 When the operator did publish a procedure for the Dash 8 aircraft it did not reflect the optimum procedure for responding to a GPWS warning.

The automatic flight control system

- 2.115 The automatic flight control system is one of the aids which is available on the Dash 8 for relieving the load on pilots, so Ansett New Zealand's practice of not allowing the autopilot or the flight director to be used on non-precision approaches removed a potential source of assistance from the ambit of the pilot in command.
- 2.116 It would be appropriate for Ansett New Zealand to re-investigate the use of the flight director on non-precision approaches to take advantage of this facility.

Procedure of setting MDA

- 2.117 On any instrument approach the pilot's primary reference for MDA or DA is the altimeter. Other systems such as radio altimeter and altitude pre-set/alerting systems supplement the altimeter.
- 2.118 The value of setting the minimum altitude on the altitude alerting system for each step of a VOR/DME approach was debatable in the case of the Runway 25 VOR/DME Approach to Palmerston North, when not using the flight director or autopilot, because each successive step was less than 1000 feet apart.
- 2.119 The use of the altitude alerter with the flight director did have the potential to overcome the ambiguity of the warning lights.
- 2.120 On the other hand Ansett New Zealand's standard procedure of setting the altitude alerting system to the MDA as soon as the aircraft was cleared for the final approach had the potential to mislead the crew in an unguarded moment into believing they were clear to descend to that altitude. This potential to mislead, however, was minimised by the required and trained procedures to follow the descent profile, and to cross-check the step limit altitudes with the relevant DME distances on the approach chart.
- 2.121 As it was so set, the alerting system's warning 1000 feet in advance of the selected altitude may have provided the crew with a supplementary warning of the inadvertent excessive loss of altitude but there was no indication on the CVR that either pilot saw the light. The absence of the optional aural alert denied them the optimum potential of this alerting system.

- 2.122 It was not the operator's practice to select a minimum height on the radio altimeter for non-precision approaches, even though this would have provided an additional alert if a loss of separation from the terrain reached a critical stage. In this accident if, for example, a height of 400 feet had been selected, a warning would have been given at that height to alert the crew that they were well below the intended terrain clearance altitude. The operator commenced an evaluation of the practicality of using the radio altimeter in this manner after the accident occurred.

Pilot monitoring of altitude

- 2.123 The operator's instructions gave the Captain discretion to decide if it was appropriate for him to fly the aircraft and monitor the flight path himself or to fly the aircraft with the First Officer continuing the monitoring. As a result of this the First Officer was entitled to assume he was relieved of any responsibility for monitoring the aircraft's specific altitudes while he actioned the QRH checklist, after the Captain advised him, "I'll look after the aeroplane."
- 2.124 Pilots in command on single pilot IFR operations are expected to fly the aircraft while they deal with any abnormal situation in addition to monitoring the aircraft's progress. On this occasion it was not unreasonable to expect the Captain to monitor the aircraft's progress as well as fly it while the First Officer implemented the items on the QRH checklist.
- 2.125 It would, however, be reasonable to expect the Captain to keep a weather eye on the First Officer's handling of the QRH procedure and this is where effective CRM training and the supportive LOFT are invaluable.

Captain's discretion to direct checklist items

- 2.126 The instruction that every reference item on the checklist was to be actioned or proceeded through as the Captain directed was appropriate. The Captain on the spot can assess the relevance of the checks to the particular situation and should have the flexibility implicit in this instruction, particularly as the Ansett New Zealand checklist does include checks which may already have been actioned.

Captain's discretion to continue approach

- 2.127 There was no written instruction which required the Captain to fly to a safe altitude in a protected area and review an abnormal situation. The absence of an instruction gave the Captain the discretion, which he exercised in this case, to attempt to rectify an abnormal situation while continuing the approach. For some minor events this was an acceptable course of action and it could have been in this case had the approach been stabilised when the problem arose and the consequent checks been performed correctly.
- 2.128 Again this was a matter requiring a sound grounding in CRM and the exercise of sufficient self-discipline to avoid any temptation to act in haste. To achieve the planned approach despite the additional workload created by an abnormal system operation required proficient CRM.
- 2.129 In this case while the original decision to continue the approach could be justified, it should have been abandoned as soon as the First Officer omitted important items from the QRH procedure.
- 2.130 After the accident, amendments were made to the operator's Operations Manual which require any abnormal situation to be resolved, wherever practicable, before an approach is continued. This new policy will go some way towards ensuring the crew give sufficient consideration to an in-flight problem, but further consideration should be given to the subject to ensure the basic checks are not overlooked if circumstances dictate the approach must be continued.

Checklists

- 2.131 The discrepancies between two QRH checklists for alternate lowering of the undercarriage were not due to the different abnormal operations which the checklist addressed. Both checklists differed from the manufacturer's checklist in not mentioning the important point that the alternate release handle may be stiffer to operate in a real situation than in the course of a demonstration.
- 2.132 The reference to the stiffness in real operation was of relevance in this accident in that tests showed that to release the main undercarriage uplock a significantly greater pull than normal may have been required because of the excessive wear on the undercarriage fitting.
- 2.133 These lists should be standardised as soon as practicable.

GPWS response

- 2.134 The absence of a written procedure for responding to a "hard" GPWS warning was a serious oversight. The consequences of this have already been discussed.

Published GPWS response (post accident)

- 2.135 It is important that the response to a "hard" GPWS warning utilise all the potential energy available to obtain the best climb angle in the shortest time practicable.
- 2.136 The present procedure should be reviewed to ensure that this would be achieved as discussed above.

No specific instruction for Dash 8 Flight Attendants

- 2.137 Ansett New Zealand conducted comprehensive training for its Flight Attendants, and only Senior Flight Attendants were rostered for Dash 8 duty. It could be therefore that Flight Attendants' instructions specific to the Dash 8 were not necessary.
- 2.138 However, the existence of such instructions would have made it easier to ensure a uniform interpretation of the duties required. The absence of such instructions was unexpected in view of the airline's philosophy that every aircrew duty should be completed as written.

The CAA auditing

- 2.139 The ambit of the CAA audit provided limited opportunity to detect shortcomings in the Dash 8 crew's potential to handle abnormal situations or emergencies competently. Their route checks made as part of the safety audits were infrequent and made only on scheduled flights. As no check flights were conducted there was no opportunity to witness the degree to which crews retained their CRM training or the efficacy of that training in the first instance.
- 2.140 The operator's suite of manuals which related to their operational practices was in the process of revision and acceptance when the accident occurred. Nevertheless the existing manuals addressed the areas in which detailed procedures were required of the crew in the operation of their aircraft and these had been audited by CAA on 25 May 1995.
- 2.141 The accident focused attention on some specific areas and in these there were some shortcomings in the operator's documents as detailed above.

- 2.142 The manuals addressed the responsibilities for each pilot in relation to monitoring minimum safe altitudes and the action required for the rectification of any abnormal situation which occurred in the course of a non-precision approach. Nevertheless there was a variety of philosophies among the Dash 8 crews, with the consequence of a potential for the neglect of altitude monitoring which occurred in this case. Had CAA conducted check flights rather than route checks there would have been a greater potential for them to detect the efficacy of the company's training for dealing with abnormal and emergency procedures. This is particularly so in the absence of an opportunity to review crews in LOFT and other flight simulator details.
- 2.143 Ansett New Zealand's safety organisation had altered materially since the documentation on which the operator was approved was accepted by CAA.
- 2.144 This change was reflected in an amendment to the Flight Operations Policy Manual. There was no documentation recording specific acceptance of the amendment by CAA but the absence of any response from the Authority was taken by the operator to constitute approval for the change in their Flight Safety organisation.
- 2.145 A more comprehensive CAA safety audit programme may have been effective in detecting some of the following indications of a potential for a reduction in the company's safety standards:
- The alteration of the direction of the in-house safety policy since the operator's structure had been approved,
 - the management not drawing to the attention of the Flight Safety Co-ordinator or to the operating crews their decision not to embody an undercarriage modification,
 - the infrequency of the Flight Safety panel's meetings,
 - the absence of any formal flight safety training for employees,
 - the non-conformance of the company with its written undertaking to provide exposure to international forums or safety organisations to keep abreast of developments in accident prevention,
 - the variations which existed between pilots in the practice of monitoring altitudes during a non-precision instrument approach,
 - the company procedure of permitting a Captain to be the only monitor of the aircraft's altitude when acting as PF,
 - the absence of a detailed procedure for responding to a "hard" GPWS warning,
 - the setting of MDA on the altitude alerter before it was safe to descend to that altitude,
 - the absence of any specific instructions for Dash 8 cabin attendants,
 - the shortcomings of the GFR system, and
 - the reactive rather than pro-active approach in the company's new direction in flight safety policy.
- 2.146 The requirement for the CAA's audit programme to be largely self-funding and that any time which was spent on an audit be charged back to the operator being audited, required the auditors to justify to the operator the extent of the time spent on preparing for an audit.
- 2.147 Internal job descriptions required the audit process to be cost-effective. This tended to reduce the effectiveness of the time spent on the site with the subject company.
- 2.148 At the time of the accident the CAA audit team had insufficient auditors and in consequence an inability to implement and review the audit programme promptly, no auditors who were current on Dash 8 aircraft, no requirement for check flights with operators, and a reluctance to spend time reviewing information about the operator. As a consequence the CAA did not carry out an in-depth audit programme and had insufficient data from its audits on which to base the substantiated assessment of the safety of a company's operations.

- 2.149 At the time of the accident the efficacy of the CAA's system to make a finding as to the safety of an airline operator based on the statistical analysis of the results of audits was thwarted by the small number of audit modules completed prior to the accident. Even an analysis based on the total audits made over the previous two years would be open to question. So few checks made over such an extended time base cannot be expected to give any reassurance as to the safety of an airline's operating practices. The results of such an analysis were similarly not a sound basis for assessing the required frequency for route checks.
- 2.150 The CAA's safety analysis of the company was not based on the results of audits alone. It also encompassed a review of the incidents involving that company which were recorded in the ASMS data system.
- 2.151 Any search of the ASMS for incidents related to a specific company would show each of the incidents linked in any way to that operator whether or not they had any responsibility for the incident. Thus if an auditor wanted to review the incidents recorded for a company prior to an audit he had to scroll through a significant list to establish those which were of interest to him and this was a factor in the time spent on preparation.
- 2.152 Another limitation of relying on reported incidents as a gauge of a company's safety record was that the more telling incidents were unlikely to be reported, particularly as there was no specific requirement to do so or guarantee of non-incrimination by so doing.
- 2.153 Despite the dedicated efforts of the available auditors the magnitude of the task was too great. The shortcomings of the existing planning of audits and resources available had been recognised by the CAA and the Authority was taking steps to improve the situation when the accident occurred.
- 2.154 As a result of its lack of audit staff the CAA audit system was not given the opportunity to prove its effectiveness in detecting the potential for this accident. The audits which had been completed on the company's operations had no real basis for assessment of their operating standards in the absence of any check flights to complement the impressions gained by route checks on routine scheduled flights.
- 2.155 Had these measures been accomplished the chances of the detection of the potential for a CFIT accident would have been enhanced.

Post accident considerations

Search and rescue facilities

- 2.156 Where there are survivors the expeditious determination of the position of a downed aircraft is invaluable as the rendering of first aid within 60 minutes of an injury being inflicted is recognised as a significant step in improving the chances of survival.
- 2.157 The delay in locating the aircraft should have been minimised by the activation of the aircraft's ELT and the potential which existed for a playback of the radar recording of the aircraft's approach to Palmerston North.
- 2.158 Although the replay of recorded radar information takes some time it could, in some circumstances, provide valuable assistance in establishing the whereabouts of an aircraft.
- 2.159 The effectiveness of the ELT was reduced because it depended on an aerial fixed to the skin of the aircraft by hard wiring, which was disrupted in the impact. Enhancing the survivability of the ELT aerial system would be a desirable improvement to its usefulness in locating an aircraft involved in an accident at a remote site.

Survivability of the aircraft's occupants

- 2.160 After the initial impact the aircraft lofted and collided with the terrain twice more before coming to rest facing in the direction from which it had come. The two flight deck crew were seriously injured in the impact and the flight attendant lost her life. Thus there were no crew capable of organising and directing the surviving passengers.
- 2.161 Although most of the occupants of this aircraft survived the impact, almost all of the survivors had some serious injury. Nevertheless some were capable of assisting and rendering first aid to the remainder.
- 2.162 The first aid kit's location was not marked conspicuously and it would have taken a search among the chaos in the fuselage to locate the fire extinguishers, but these items could have been of material assistance in the situation which resulted from this accident. A useful first aid kit and small portable fire extinguishers are carried on every airline aircraft for just such an eventuality, but generally their locations are not publicised on the passenger briefing cards or by other significant labelling. Means should be explored to ensure the existence of this life-saving equipment is displayed more conspicuously.
- 2.163 One serious consequence of this accident was that a passenger escaped from the aircraft but subsequently lost his life as a result of becoming involved in a fire which erupted suddenly from a minor source. It is probable that this source fire could have been extinguished by the use of the portable extinguishers on board.

CVR installation

- 2.164 The action taken by NZALPA and Ansett New Zealand in negotiating a pilots' contract which sought to ban the installation of CVRs in the company's aircraft was not in keeping with the support normally given to the installation of this equipment by the two parties. In this investigation the CVR was of significant value in eliminating many unnecessary areas of inquiry and assisting in the resolution of others. The availability of the CVR record should be preserved in the interests of aviation safety.

3. Findings

- 3.1 The flight crew were properly licensed and fit to conduct the flight.
- 3.2 The Captain and First Officer had completed the company's normal Dash 8 type conversion training and checking successfully.
- 3.3 Although the Captain and First Officer were experienced pilots the Captain was not experienced as a Captain, nor was the First Officer experienced as a co-pilot, in a two-pilot crew.
- 3.4 The Captain had completed the company's command training successfully.
- 3.5 The aircraft had a valid C of A and Maintenance Release.
- 3.6 The estimated weight and balance of the aircraft were within the limits at the time of the accident.
- 3.7 The failure of the undercarriage to extend normally, which occurred during the aircraft's instrument approach to Palmerston North, was probably due to the wear on the right main undercarriage uplock latch.

- 3.8 The extent of wear on the uplock latch as determined after the accident exceeded the Messier-Dowty limits referred to in Temporary Revision SUP-383 to the Manufacturers Maintenance Programme issued in November 1994.
- 3.9 The five-month period which elapsed before Temporary Revision SUP-383 was reviewed was excessive.
- 3.10 The wear on the right main undercarriage uplock latch would not have prevented the manual release system from operating.
- 3.11 The operator's initial decision not to modify the aircraft's undercarriage should not have jeopardised the safety of the aircraft significantly.
- 3.12 The operator's original decision not to modify the aircraft's undercarriage should have been promulgated to Dash 8 crews and to Ansett New Zealand's Flight Safety Co-ordinator.
- 3.13 The operator did not take the optimum steps to ensure that Dash 8 crews could deal with any malfunction of the undercarriage system safely in the light of the Dash 8 aircraft's history of the main undercarriage not extending normally.
- 3.14 The necessity to lower the right main undercarriage using the alternate gear extension procedure should not have endangered the aircraft on its approach to Palmerston North.
- 3.15 The operator's QRH checklists need to be improved to ensure standardisation in reference to similar procedures and to avoid the potential for the reader to confuse similar nomenclature on lines in close proximity.
- 3.16 The Captain had briefed for the instrument approach correctly and flew the approach track properly.
- 3.17 The aircraft was allowed, inadvertently, to descend below the instrument approach profile and below step limits until the aircraft collided with high terrain.
- 3.18 The Captain did not apply sufficient engine power to intercept and maintain the approach profile during the latter stages of the instrument approach to Palmerston North Aerodrome.
- 3.19 The First Officer was not performing his normal task of monitoring the instrument approach because he had been instructed to carry out the alternate gear extension procedure and the Captain had advised him that he would "keep an eye on the aeroplane".
- 3.20 An alternative decision by the Captain to discontinue the approach and climb the aircraft to a safe altitude to carry out the alternate gear extension procedure would have facilitated the crew's safe execution of the task.
- 3.21 The absence of a company standard operating procedure for the crew to discontinue an approach while they dealt with an abnormal situation may have influenced the Captain's decision to implement the alternate gear extension procedure while continuing with the approach.
- 3.22 The breakdown in monitoring the aircraft's altitude during the approach was contributed to by each pilot having a different understanding of his responsibilities in this respect in the event of an abnormal situation arising.
- 3.23 Although the aircraft was influenced by a significant downdraught during the approach the resulting increase in its rate of descent could have been countered with the engine power available.

- 3.24 The breakdown in monitoring the aircraft's altitude during the approach to Palmerston North was unlikely to have been due primarily to any fatigue resulting from the pilots' early start for duty.
- 3.25 A "pull-up" manoeuvre was initiated before the collision which lessened the severity of the aircraft's initial ground impact.
- 3.26 Had the GPWS given the expected advance warning of the collision, it was likely that this accident would have been avoided.
- 3.27 The GPWS warning was insufficient for the aircraft to be extricated from its perilous position.
- 3.28 The cause of the GPWS failure to give adequate warning was not established.
- 3.29 The failure of the GPWS to give sufficient warning could not be related to radio interference from any passenger's portable electronic equipment.
- 3.30 The failure of the GPWS to give sufficient warning could not be related to radio interference from radio transmission aerials adjacent to the accident site.
- 3.31 The failure of the GPWS to give sufficient warning was not related to the operator's policy of early configuration of the aircraft for landing on the Runway 25 VOR/DME Approach to Palmerston North Aerodrome.
- 3.32 The design of the Palmerston North VOR/DME Runway 25 Approach met the relevant criteria.
- 3.33 Air Traffic Control radar gave sufficient information for the aircraft's flight path to be monitored during an instrument approach.
- 3.34 The Air Traffic Control organisation was not required, nor did it have the staff or equipment resources, to monitor aircraft flight paths for adequate terrain clearance during instrument approaches.
- 3.35 Air Traffic Control advice that the minimum altitude for Ansett Flight 703 on the 14 DME arc was 6000 (feet) was ambiguous.
- 3.36 The flight attendant's action in advising the pilots of the undercarriage failure to extend was in accord with good CRM practice.
- 3.37 The key members of the operator's flight safety organisation would have benefited from formal training in flight safety and accident prevention.
- 3.38 The operator's Flight Safety Co-ordinator and its flight safety programme would have benefited if, in addition to membership of the domestic Airline Flight Safety Committee, the company had been a member of key international flight safety organisations.
- 3.39 The CAA's approval of Ansett New Zealand was appropriate, based on the information available to the authority.
- 3.40 The CAA at the time of the accident was not staffed adequately to carry out competent auditing of all of the companies which it had approved.
- 3.41 The CAA's audit staff numbers were not adequate to ensure that Ansett New Zealand operated to the standards with which it had undertaken to comply.
- 3.42 The CAA's auditing might have detected weaknesses in the operator's procedures if it had carried out check flights during its auditing in the period leading up to the accident.

- 3.43 The locations of the aircraft's first aid kits and fire extinguishers were not marked adequately for any potential user to locate them readily.
- 3.44 The proper use of the portable fire extinguishers available on this aircraft had the potential to prevent the loss of a passenger's life.
- 3.45 The impediment to the occupants' egress from the aircraft, due to damage to the cabin interior and accumulated debris, did not affect the chances of survival in this accident.
- 3.46 The emergency services responded competently despite the adverse weather conditions and difficult access to the site.
- 3.47 The emergency locator transmitter's efficiency was reduced significantly by the loss of its aerial.
- 3.48 The location of the accident site might have been discovered some minutes earlier if the ELT's aerial had not been lost.
- 3.49 The aircraft's flight recorders provided an invaluable source of information for the investigation of this accident.
- 3.50 The agreement between the operator and the pilot member of the Air Line Pilots' Association, in relation to cockpit voice recorders, had the potential to deprive investigators of a valuable source of information for the investigation of any accident involving the operator's aircraft.

Causal factors

- 3.51 The investigation identified the following causal factors:

Crew

- 3.51.1 The Captain did not ensure the aircraft's engine power was adjusted correctly for the aircraft to intercept and maintain the approach profile.
- 3.51.2 The Captain's lack of attention to, and/or mis-perception of, the aircraft's altitude during the approach.
- 3.51.3 The pilots' diversion from the primary task of flying the aircraft and ensuring its safety, by their endeavours to correct an undercarriage malfunction.
- 3.51.4 The Captain's perseverance with his decision to attempt to get the undercarriage lowered without discontinuing the instrument approach in which he was engaged when the situation arose.

- 3.51.5 The absence of a requirement for cross-monitoring of the aircraft's altitude while executing the QRH "Alternate Gear Extension" procedure.
- 3.51.6 The First Officer not executing the QRH procedure in the correct sequence, which distracted the Captain.

Systems

- 3.51.7 The inadequate warning given by the GPWS.

3.52 Contributory factors

Operator

- 3.52.1 The operator not ensuring its pilots were aware of the recurring undercarriage malfunction.
- 3.52.2 The limitations of the knowledge-based CRM training for Dash 8 pilots.
- 3.52.3 The operator's QRH checklist for alternate gear extension which held potential to be difficult to follow sequentially.
- 3.52.4 The operator's requirement to configure the aircraft with undercarriage down earlier than normal on this approach.

Weather

- 3.52.5 The existence of a significant orographic downdraught on the lee side of the ranges beneath the aircraft's flight path.

Systems

- 3.52.6 The failure of the right undercarriage to extend normally when selected "down".

CAA

- 3.52.7 The CAA's lack of audit staff to detect the weaknesses in the operator's standard operating procedures during its audits.
- 3.52.8 The absence of check flights by qualified CAA auditors to supplement their scheduled route checks.

4. Safety Recommendations

4.1 It was recommended to the Chief Executive Officer of Ansett New Zealand that he:

- 4.1.1 Ensure, with immediate effect, that each Ansett pilot assigned to crew a Dash 8 aircraft practise and remain familiar with the alternate gear extension procedure under suitably qualified supervision (042/95); and
- 4.1.2 Issue an interim instruction that, unless overriding considerations prevail, in the event of any system abnormality occurring during an instrument approach in instrument meteorological conditions the Captain shall discontinue the approach and climb to or maintain a safe altitude until the appropriate procedures relating to the abnormality have been completed correctly (043/95); and

- 4.1.3 Re-emphasise, to each of the Company's pilots, the potential for the pilot flying to be distracted from the routine operation of the aircraft during the execution of an emergency procedure or even a relatively minor system abnormality procedure, particularly if an unexpected need to give assistance with the procedure develops (044/95); and
- 4.1.4 Review the status of the Flight Safety Co-ordinator to ensure that officer has a balanced input from the company's management, operations, and engineering staff on which to base an accident prevention programme (103/95); and
- 4.1.5 Enhance the opportunity for the Flight Safety Co-ordinator to attend international flight safety conferences and training seminars (104/95); and
- 4.1.6 Explore ways of making Ansett New Zealand's CRM training more realistic by use of a flight simulator or otherwise (105/95); and
- 4.1.7 Review Ansett's QRH checklists for "Landing Gear Malfunction Alternate Gear Extension" and "#2 Engine Hyd Pump Caution Light on with Hyd Qty Below Normal, Gear Extension" with a view to standardising the procedures where actions should be identical, and eliminating the possibility for confusion between "alternate release door" and "alternate extension door" during the reading of the checklist (106/95); and
- 4.1.8 Take immediate steps to embody the modifications designed to minimise nuisance warnings by the Dash 8 GPWS (107/95); and
- 4.1.9 Review Ansett New Zealand's use of configuration procedures designed to obviate unwanted GPWS warnings (108/95); and
- 4.1.10 Review Ansett's practice of setting MDA once established on the approach, with a view to implementing a procedure which will not set the MDA before it is safe to descend to that altitude (109/95); and
- 4.1.11 Explore the practicality of connecting the radio altimeter output into the DFDR (110/95); and
- 4.1.12 Investigate the practicability of using the radio altimeter to give back-up warning during non-precision instrument approaches (111/95); and
- 4.1.13 Investigate the practicability of using the FD and autopilot to alleviate the load on the pilot flying during non-precision instrument approaches in IMC (112/95); and
- 4.1.14 Initiate instructions to flight attendants that:
- are specific for each aircraft type which they operate,
 - enhance the concept of a sterile flight deck during critical phases of a flight,
 - clarify the need for them to be seated as soon as practicable after the signal to do so is given (113/95); and
- 4.1.15 Renegotiate the pilots' contract with NZALPA to remove the condition which is intended to prevent the company from installing CVRs in their aircraft (126/95).

Ansett New Zealand responded on 13 May 1996 as follows:

042/95 Each Ansett Pilot assigned to crew DHC-8 aircraft has completed an in-flight training detail and check observation involving an actual alternate gear extension.

In addition, it is proposed to include in all future recurrent training, an upper air exercise that will re-emphasise both this specific abnormal procedure and the management of other abnormal checklists.

It should be noted that this aircraft is not simulator supported and that in flight abnormal training can only, and will only, be carried out in a manner consistent with the safe and prudent management of actual in-flight aircraft operation.

The use of simulators for initial conversion is currently under investigation.

043/95 Ansett New Zealand has, in conjunction with Ansett Australia, issued an amendment to the General Operating Procedures that define an absolute requirement to resolve all abnormal checklists; either prior to entering the approach phase or where an approach has been commenced it is to be discontinued to allow checklist completion at a safe altitude unless a greater emergency exists.

Ansett New Zealand's policy and procedures dealing with the management of abnormal and flight path control are already comprehensively detailed in Operation Manuals, General Operating Procedures and Flight Training references, and are given great weight in all of our training, both initial and recurrent.

This recommendation has been adopted by all Ansett Group airlines and is now embodied in our Standard Operating Procedures.

044/95 A Notice to Pilots has been issued re-emphasising our Standard Operating Procedures in regard to Pilot distraction during Emergency and Abnormal Procedure management.

All of the required references already exist.

Pilot distraction is already a fundamental component of our Cockpit Resource Management programme and is specifically targeted in our 'hands on' LOFT training in simulator supported aircraft.

103/95 Ansett New Zealand's objective of ensuring that its management of Flight Safety is of a high standard and at a level consistent with the highest industry standards in an ever-changing environment, has led to the creation of a new management structure for flight safety, as part of a wider re-organisation. This re-organisation has rendered the earlier position of "Flight Safety Co-ordinator" obsolete. The Flight Safety programme previously managed by the Regional Flight Managers, and supported by the Flight Safety Co-ordinator, has now become the prime focus and responsibility of the newly created position of "Flight Safety Manager". The new management structure is designed to ensure that the Flight Safety programme has a balanced input from the Company's management, operations, and engineering staff, and that that input is overseen by the Flight Safety Manager, as a basis (inter alia) upon which to base the Company's Flight Safety programme which embodies accident prevention objectives and techniques.

Accordingly, although the Flight Safety Co-ordinator position no longer exists, the apparent intent of the recommendation (103/95) has been adopted by Ansett New Zealand.

- 104/95** The Flight Safety Manager is to undergo tertiary training in Aviation Safety Programme Management during 1996, and thereafter it is intended that the Flight Safety Manager will attend relevant international conferences on Flight Safety.

Accordingly, this recommendation has been adopted by Ansett New Zealand.

- 105/95** Ansett New Zealand is presently negotiating for the development and use of a Dash-8 simulator facility located in Sydney, and once contractual provisions are in place for the use of this facility, Ansett New Zealand will progressively introduce its use into Dash 8 training, including CRM aspects. The simulator is anticipated to be available throughout New Zealand during 1996, and will be used by the Company in its training programme as soon as available.

The inherent difficulties of achieving effective LOFT training, where a simulator cannot be employed, is not a problem unique to Ansett New Zealand. The Company agrees, that CRM training can obviously be made more effective by the use of a Simulator, however in circumstances where a simulator was not available, Ansett New Zealand made a significant effort to introduce all practicable realism for Dash 8 crew in this phase of their training.

Accordingly, Ansett New Zealand has explored and is in fact now negotiating for the use of a Dash 8 Flight Simulator in its training programme, and as such, adopts this recommendation. In conclusion it should be noted however that until very recently, no Dash 8 Simulator has been available, and accordingly out of necessity alternative methods of crew familiarisation and training were employed.

- 106/95** The QRH has been critically reviewed by Ansett New Zealand, and as a result has been re-formatted to reflect current Bombardier (manufacturer) policy. Differences in terminology have been discussed with Bombardier, and Ansett New Zealand understands that Bombardier will initiate editorial changes in due course. The terminology used to describe aircraft equipment is properly a matter for the manufacturer and not the responsibility of the aircraft operator. Accordingly, Ansett New Zealand has adopted and implemented this recommendation as far as it is able to do so, but those aspects which are within the province of the aircraft manufacturer remain the manufacturer's responsibility. Ansett New Zealand suggests that a Safety Recommendation directed to the manufacturer regarding terminology would be appropriate.

Accordingly this Safety Recommendation has been adopted and implemented by Ansett New Zealand.

- 107/95** Ansett New Zealand is not presently able to provide its response to this Safety Recommendation as it is awaiting engineering confirmation from the manufacturer/Allied Signal.

Ansett New Zealand is examining the Safety Recommendation and upon receipt of further information and evaluation thereof, the Company will advise the Commission of its position.

- 108/95** Since the accident, Ansett New Zealand has critically reviewed its policy as regards aircraft configuration. The Company considers it significant that while the Manufacturers Manual is silent on the issue of non-precision approaches, in general, the manufacturer's recommendation in relation to precision approaches is that the flaps are extended to approach setting **before** guide slope capture, i.e. descent. (See Flight Manual section 4/3/7).

The practise of early configuration is intended to enhance rather than compromise safety of the flight during the landing approach phase, and the procedure does not prevent the GPWS from providing effective warning. The early configuration procedure appears common to a number of airlines, indeed to all airlines both in New Zealand and overseas that Ansett New Zealand has contacted regarding this matter.

It would therefore appear, that Ansett New Zealand's policy and procedure of aircraft configuration reflects "mainstream" aviation practise and is not a procedure or practise unique to the Company. Accordingly, before the Company takes any further steps in relation to this practise and/or departs from the practise, Ansett New Zealand proposes to further study and review the practise with a view to assessing whether the advantages of positive flight safety resulting from the practise outweigh any safety disadvantage.

In short, Ansett New Zealand has adopted the recommendation by reviewing the Company's procedure, but to date no change to the Company's procedure has been initiated.

109/95 Ansett New Zealand has reviewed the practise of setting MDA (in the ALT SEL) and has concluded that the practise is indeed appropriate.

Given that the ALT SEL cannot be "disconnected" from the Auto Flight Guidance System, it is consequently always "live", and as a result will warn of deviation from, or approach to any set altitude. The system is designed to provide a protection in respect of cleared altitude.

Setting the ALT SEL to any other altitude than MDA (i.e. missed approach altitudes, commencement altitude, or any intermediate altitude within 1,000 feet of setting), would result in continuous warnings that would have to be ignored by the flight crew. Ansett New Zealand considers that any practise which has that effect is itself patently unsafe.

The setting of MDA provides a real warning when approaching MDA, and Ansett New Zealand notes that such a warning would have occurred on the accident flight.

It is noted that during a precision approach the system is automatically disabled to preclude inappropriate warnings.

Further the ALT SEL plays no part in the instrument scan, and neither should it. The system is set to provide a warning approaching the cleared altitude, in this case the MDA.

Instrument approach profiles are not flown by reference to ALT SEL, and neither is MDA referenced from the ALT SEL, in this or in any other airline of which Ansett New Zealand is aware. MDA is referenced by the altimeter and the safe achievement of any MDA, on any kind of approach requires adherence to the published profile for that approach.

Therefore, following its review of the practise (as recommended by this Safety Recommendation), Ansett New Zealand concluded that to the extent that the recommendation suggests the implementation of a procedure which would not involve the setting of MDA "before it is safe to descend to that altitude" that such suggested procedure would in practise be detrimental to flight safety, with the result that Ansett New Zealand having reviewed the matter, has concluded that it will not adopt any recommendation to implement such a procedure.

110/95 This recommendation has been examined and the recommendation has been adopted by Ansett New Zealand.

- 111/95** This Safety Recommendation in fact appears to have resulted from Ansett New Zealand's suggestion to the Transport Accident Investigation Commission Investigators, and Ansett New Zealand has in fact included this practise in its "Standard Operating Procedures".

Accordingly, the Safety Recommendation has been adopted by Ansett New Zealand.

- 112/95** Ansett New Zealand's policy not to use the Autopilot, or Flight Director has been critically reviewed in the light of this Safety Recommendation. The characteristics of the systems installed on both aircraft types operated by Ansett New Zealand, are such that the potential hazards of that practise may well outweigh any workload benefit.

In respect of the Dash-8 aircraft, the Auto Flight Control System (AFCS) which incorporates the Autopilot, is only approved for use on CAT 1 Precision Approaches.

Additionally, the Manufacturer's limitations provide for a minimum height for Autopilot use of 1,000 feet AGL, precluding use on approaches where this limitation is likely to be infringed.

Accordingly the use of Autopilots and to a lesser extent Flight Directors, is not considered by Ansett New Zealand to be presently practicable; however, before reaching a final decision on the matter, the Company proposes to continue its investigation and review and to seek advice from both the Manufacturer and other operators. Ansett New Zealand for the reasons expressed above, has not to date adopted the Recommendation.

- 113/95** This Recommendation appears to reflect Ansett New Zealand's present policy as expressed by the Company's current procedures. Type specific instructions are included in Standard Operating Procedures, as are the procedures considered necessary to implement the concept of a sterile flight deck during "critical phases of a flight".

Accordingly, whilst Ansett New Zealand agrees with the apparent intention of this Safety Recommendation, the Company considered that its present procedures meet the Safety Recommendation for the instruction of Flight Attendants.

- 126/95** Ansett New Zealand believes in the significant contribution of CVR to accident investigation and as it has in the past, it will make every endeavour to reach agreement with its pilot employees and NZALPA which will result in the CVR operating in its aircraft.

This recommendation will be accordingly adopted.

4.2 It was recommended to the Director of Civil Aviation that he:

- 4.2.1 Take urgent steps to complete his review of the adequacy of CAA audit staff numbers for carrying out safety audits on operators in accordance with their stated policy (114/95); and
- 4.2.2 Require better information to be displayed by aircraft operators to aid passengers and potential rescuers to locate onboard first aid kits and fire extinguishers (115/95); and
- 4.2.3 Initiate with the aircraft manufacturers an investigation into the practicality of enhancing the survivability of the aerals of any ELTs in passenger transport aircraft which are hard wired into aircraft (116/95); and

- 4.2.4 Expedite the implementation of his plans for obtaining the appropriate staff numbers to achieve their planned safety audits in the appropriate time scales (117/95); and
- 4.2.5 Explore the practicability of instituting check flights to supplement the audit process on approved operators. (118/95)
- 4.2.6 Explore the practicability of instituting check flights to supplement the audit process on companies. (118/95)

The Director Civil Aviation Responded as follows:

114/95 CAA safety audit policy as applied to the various classes of aviation operations is subject to ongoing review and refinement, and the CAA continually reviews all of its staffing requirements to ensure that adequate front-line and support staff are employed to meet its needs. In acknowledging the intent of its recommendation the CAA does not accept that its auditors or auditor numbers were in any way germane to the accident.

115/95 Requirements regarding emergency equipment and passenger briefings are contained in Rule CAR Part 91, which has undergone full consultation with interested parties and is nearing the Final Rule stage. However CAR 91.113 and 92.215 may not be as explicit as the Commission has recommended in terms of providing information on the location of first aid kits and fire extinguishers. The recommendation will therefore be treated as a petition (in terms of CAR Part 11) to amend CAR Part 91 and will be considered at the first opportunity.

116/95 In New Zealand Civil Airworthiness Requirements Leaflet C.4, the CAA mandates standards for the installation of ELTs. Four times in this standard which are particularly relevant to the Commission's recommendation require the ELT installation to be such that:

- 'the location of the transmitter and antenna will minimise the potential for damage in accidents by impact or fire;'
- 'the transmitter and external antenna (if used) are mounted as close to each other as possible;'
- 'the attachment of the transmitter and external antenna (if used) to the airframe can support a 100g load applied through their respective centres of gravity in the plus and minus directions of the three principal axes of the aircraft;'
- 'the coaxial cable between transmitter and antenna has vibration-proof RF connectors on each end and when installed is secured to aircraft structures leaving some slack at each end;'

The intention is to minimise the probability of damage to the transmitter and antenna and their becoming separated in a crash. Nevertheless, the CAA will refer the Commission's recommendation to the relevant manufacturers of airline aircraft with a view to further enhancing the survivability of ELT antennas.

117/95 Reviews of CAA staff numbers are sensitive to industry performance and activity levels. Audit staff numbers have increased steadily over the past year, with an additional six positions having been filled or currently in the process of being filled.

118/95 The CAA can accept this recommendation only to the extent it does not cut across the operator's clear responsibility to train and supervise its own

employees. Check flights of individual flight crew by the CAA would be an example of a very detailed sample of the effectiveness of an airline's training systems, and would be relatively infrequent, while surveillance of the airline's own checking of flight crew (including observation by the CAA of the airline's check flights) would be the more common level of audit.

The CAA accepts the value of check flights on this basis.

4.3 It was recommended to the Chief Executive of the Airways Corporation that he:

- 4.3.1 Investigate with the equipment manufacturer the practicality of developing and incorporating a minimum safe altitude warning system (MSAW) for the Airways Corporation's AIRCAT 2000 radar system as soon as practical (119/95); and
- 4.3.2 Put in place a system, to be available on request, to recover and make available as soon as practicable any relevant recorded radar information which might assist the Search and Rescue Co-ordination Centre to locate a missing aircraft (120/95); and
- 4.3.3 Review the terminology used by approach controllers, in RTF with pilots, when they wish to restrict an aircraft's descent on the DME arc to an altitude greater than the minimum depicted on the applicable VOR/DME chart (121/95).

The Chief Executive Airways responded as follows:

- 119/95** An investigation will be carried out to determine the following:
- 1. The current availability of off-the-shelf equipment which could be added on the AIRCAT 2000 to give minimum safe altitude warning alerts to ATC.
 - 2. The cost of such equipment.
 - 3. Specific details as to what warnings can be given and how they are triggered.
 - 4. Details on what if any systems of this type are currently being used by other ATC service providers and their effectiveness.
 - 5. Whether any currently available equipment, if it had been operational in the accident area, could have avoided the accident involving ZK-NEY.
 - 6. What if any enhancements would need to be made to currently available equipment in order that it could have been used to avoid the accident.
 - 7. The cost of any such enhancements.
 - 8. Airways' legal liability exposure resulting from the use of such a system.
 - 9. The New Zealand aviation industry's desire for Airways to be involved in the provision of a minimum safe altitude warning service.

This investigation has already begun with work having been completed on the first two items. We consider that it would be reasonable to expect that the investigation should be completed by 31 December 1996. It should be noted that this investigation will aim to determine the practicality of developing and incorporating a suitable facility into Airways' systems but any implementation would be entirely dependent on the findings of the investigation.

A system is in place, and was so at the time of the accident, whereby relevant recorded radar data can be made available as soon as practicable to the Search and Rescue Co-ordination Centre if requested by the SAR Co-ordinator. On 25 April 1996 we enhanced our procedures so that in the event that an aircraft went missing while specifically in receipt of radar service we will immediately carry out the relevant search of radar data and provide information on the result of the search to the SAR Co-ordinator as soon as it becomes available. This initiative would be taken whether or not the SAR Co-ordinator made a request for the information.

121/95 This recommendation will be adopted. The relevant changes to terminology have been drafted and it is planned that they will be included in the 18 July 1996 amendment to the Manual of Air Traffic Control.

4.4 It was recommended to the Minister of Transport in Canada that :

4.4.1 In conjunction with the aircraft manufacturers and the manufacturers of the GPWS and the radio altimeter he promote a study to determine why the GPWS did not provide a greater degree of warning in the environment of the DHC-8 accident near Palmerston North, New Zealand, on 9 June 1995, and

If it can be shown that the GPWS installation did not perform its intended function appropriately, take the necessary measures to validate the original certification of the Sundstrand Mk II GPWS installation in the DHC-8 aircraft. (122/95)

Transport Canada responded as follows:

The New Zealand Transport Accident Investigation Commission's Safety Recommendation has been reviewed by Transport Canada's airworthiness personnel and discussions with the Dash 8 manufacturer have been initiated.

The issue of whether the GPWS installed in the accident aircraft performed its intended function appropriately is a serious concern to Transport Canada. We are therefore prepared, in conjunction with the aircraft manufacturer, to initiate a review of the certification of GPWS installation in the DHC 8 aircraft. If any area of uncertainty in the certification is identified, you can be assured that Transport Canada will take appropriate action.

Wider accident investigation related issues of GPWS performance in prevention of CFIT accidents in the particular environment and terrain of the accident site would be logistically impractical and outside the scope of the Transport Canada certification review.

Currently, Transport Canada has limited knowledge of the accident and therefore, the Transport Accident Investigation Commission should anticipate future requests for technical information related to the accident.

4.5 It was recommended to the President of the New Zealand Air Line Pilots' Association that he:

4.5.1 Renegotiate, as soon as practicable, the pilots' contract with Ansett New Zealand to remove the condition which is intended to prevent Ansett New Zealand from installing Cockpit Voice Recorders in their aircraft. (123/95)

The New Zealand Air Line Pilots' Association responded on 14 May 1996 as follows:

1. NZALPA advocates the use of cockpit voice recorders (CVR's) and other recorders for the purposes of accident and incident investigation by independent and trained air accident investigators.
2. NZALPA does not accept that the contractual provision has the intention ascribed to it by the Commission, nor that this Report is an appropriate forum to make recommendations ascribing "intent" to contractual provisions.
3. The contractual provision is not inconsistent with the International Civil Aviation Organisation (ICAO) requirements of member states.

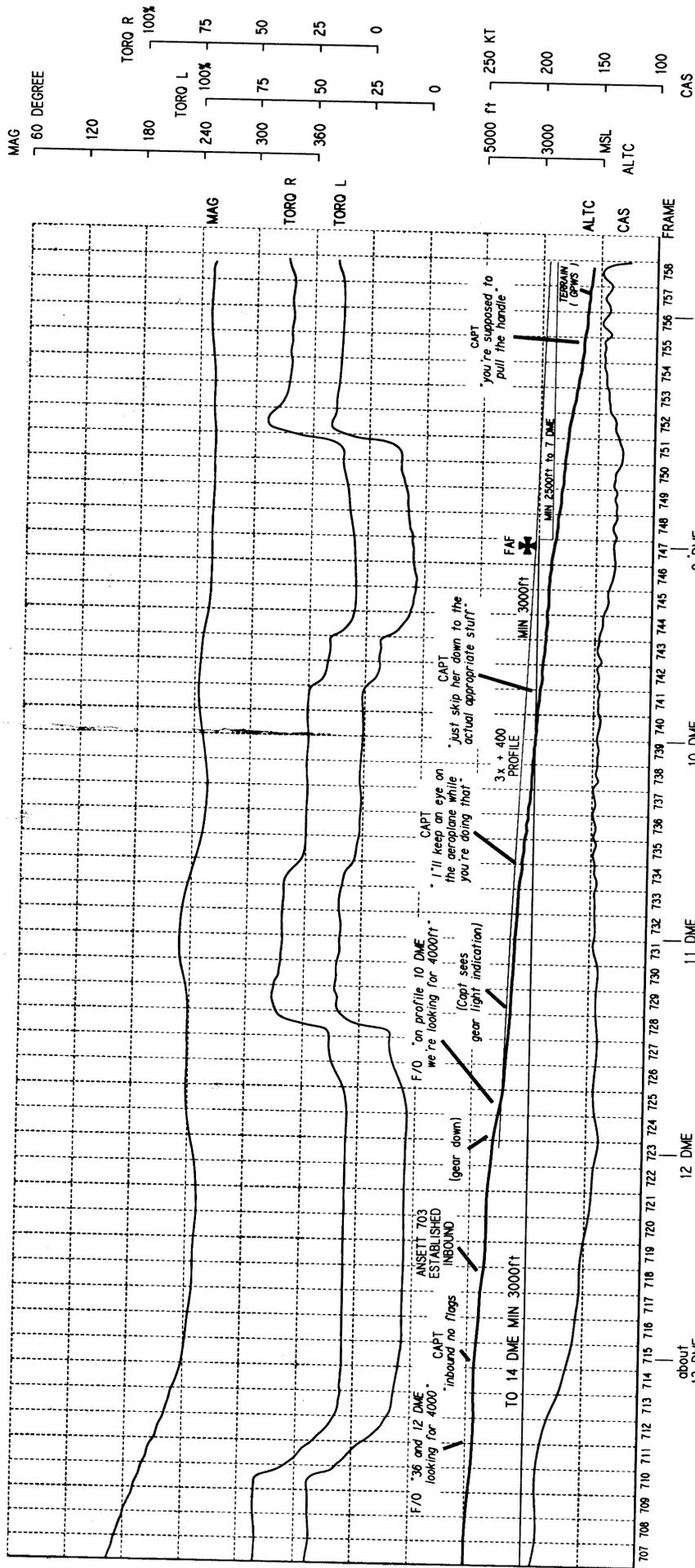
4. The contractual provision relates specifically to the implementation of paragraph 5.12 of Annex 13 to the Chicago Convention 1944 in particular and to the implementation of Annex 13 in general.
5. The contractual provision has not operated to prevent the presence of CVR's on Ansett New Zealand Aircraft.
6. Annex 13 has not been embodied in New Zealand legislation, and this failure is not consistent with the obligations of the New Zealand government under Article 37 of the Convention.
7. New Zealand's non-conformance with its international obligations in this regard is demonstrably out of step with the legislative developments in countries of similar status such as Australia, Canada, the USA and the United Kingdom.
8. In the absence of such legislation the contractual provision is appropriate.
9. NZALPA is only one of over 120 parties to the Ansett New Zealand Limited pilots' contract.
10. The attitude of the pilot parties to the contract towards its possible amendment will be influenced by the actions of the Transport Accident Investigation Commission in annexing a purported CVR transcript to an accident report, and of the New Zealand Police in seeking to access the CVR for purposes other than those anticipated by Annex 13.
11. The negotiation of an amendment by way of clarification may be more appropriate than the removal of the provision as stipulated by SR 123/95.
12. Adoption of the Safety Recommendation 123/95 at this time would not be in accord with NZALPA's obligations to its members, its national and international associate bodies, or to the wider aviation community in the absence of legislative embodiment of Annex 13.
13. NZALPA is making and will continue to make representations to the Government of New Zealand with regard to the development of legislation in New Zealand which would give prominence and effect to Annex 13 and will assess its ability to adopt the Safety Recommendation in the light of the legislation in place in New Zealand from time to time.
14. NZALPA would welcome the support of the Commission in our attempts to have appropriate legislation brought into existence in New Zealand.

NZALPA is neither practically, legally, nor morally in a position to adopt SR 123/95 at this time.

17 March 1997

M F Dunphy
Chief Commissioner

Appendix A

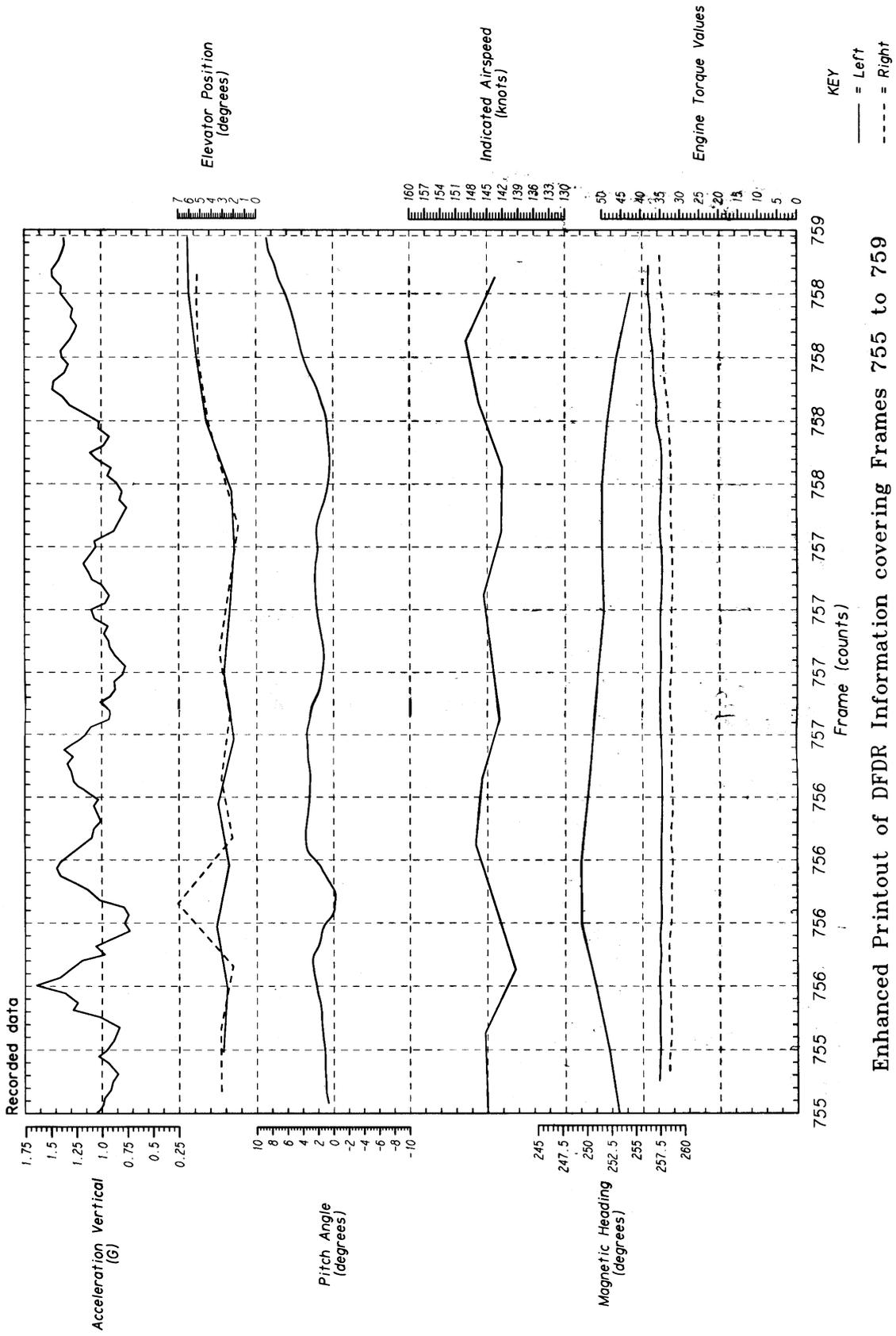


See Enhanced View Appendix B1

- KEY**
- MAG = Magnetic heading
 - TORO L = Torque value left
 - TORO R = Torque value right
 - ALTC = Coarse altitude
 - CAS = Compeed airspeed
 - FAF = Final approach fix

Printout of DFDR Information de Havilland DHC-8, ZK-NEY

Appendix A1



Enhanced Printout of DFDR Information covering Frames 755 to 759



Appendix B

**Flight Safety Foundation
CFIT Checklist
Evaluate the Risk and Take Action**

Printing and distribution sponsored by

Simufite

Flight Safety Foundation (FSF) designed this controlled-flight-into-terrain (CFIT) risk-assessment safety tool as part of its international program to reduce CFIT accidents, which present the greatest risks to aircraft, crews and passengers. The FSF CFIT Checklist is likely to undergo further developments, but the Foundation believes that the checklist is sufficiently developed to warrant distribution to the worldwide aviation community.

Use the checklist to evaluate specific flight operations and to enhance pilot awareness of the CFIT risk. The checklist is divided into three parts. In each part, numerical values are assigned to a variety of factors that the pilot/operator will use to score his/her own situation and to calculate a numerical total.

In *Part I: CFIT Risk Assessment*, the level of CFIT risk is calculated for each flight, sector or leg. In *Part II: CFIT Risk-reduction Factors*, Company Culture, Flight Standards, Hazard Awareness and Training, and Aircraft Equipment are factors, which are calculated in separate sections. In *Part III: Your CFIT Risk*, the totals of the four sections in *Part II* are combined into a single value (a positive number) and compared with the total (a negative number) in *Part I: CFIT Risk Assessment* to determine your CFIT Risk Score. To score the checklist, use a nonpermanent marker (do not use a ballpoint pen or pencil) and erase with a soft cloth.

Part I: CFIT Risk Assessment

Section 1 – Destination CFIT Risk Factors	Value	Score
Airport and Approach Control Capabilities:		
ATC approach radar with MSAWS	0	_____
ATC minimum radar vectoring charts	0	_____
ATC radar only	-10	_____
ATC radar coverage limited by terrain masking	-15	_____
No radar coverage available (out of service/not installed)	-30	_____
No ATC service	-30	_____
Expected Approach:		
Airport located in or near mountainous terrain	-20	_____
ILS	0	_____
VOR/DME	-15	_____
Nonprecision approach with the approach slope from the FAF to the airport TD shallower than 2 3/4 degrees	-20	_____
NDB	-30	_____
Visual night “black-hole” approach	-30	_____
Runway Lighting:		
Complete approach lighting system	0	_____
Limited lighting system	-30	_____
Controller/Pilot Language Skills:		
Controllers and pilots speak different primary languages	-20	_____
Controllers’ spoken English or ICAO phraseology poor	-20	_____
Pilots’ spoken English poor	-20	_____
Departure:		
No published departure procedure	-10	_____
Destination CFIT Risk Factors Total		(-) _____

Section 2 – Risk Multiplier

	Value	Score
Your Company's Type of Operation (select only one value):		
Scheduled	1.0	_____
Nonscheduled	1.2	_____
Corporate	1.3	_____
Charter	1.5	_____
Business owner/pilot	2.0	_____
Regional	2.0	_____
Freight	2.5	_____
Domestic	1.0	_____
International	3.0	_____
Departure/Arrival Airport (select single highest applicable value):		
Australia/New Zealand	1.0	_____
United States/Canada	1.0	_____
Western Europe	1.3	_____
Middle East	1.1	_____
Southeast Asia	3.0	_____
Euro-Asia (Eastern Europe and Commonwealth of Independent States)	3.0	_____
South America/Caribbean	5.0	_____
Africa	8.0	_____
Weather/Night Conditions (select only one value):		
Night — no moon	2.0	_____
IMC	3.0	_____
Night and IMC	5.0	_____
Crew (select only one value):		
Single-pilot flight crew	1.5	_____
Flight crew duty day at maximum and ending with a night nonprecision approach	1.2	_____
Flight crew crosses five or more time zones	1.2	_____
Third day of multiple time-zone crossings	1.2	_____
Add Multiplier Values to Calculate Risk Multiplier Total _____		
Destination CFIT Risk Factors Total × Risk Multiplier Total = CFIT Risk Factors Total (–) _____		

Part II: CFIT Risk-reduction Factors

Section 1 – Company Culture

	Value	Score
Corporate/company management:		
Places safety before schedule	20	_____
CEO signs off on flight operations manual	20	_____
Maintains a centralized safety function	20	_____
Fosters reporting of all CFIT incidents without threat of discipline	20	_____
Fosters communication of hazards to others	15	_____
Requires standards for IFR currency and CRM training	15	_____
Places no negative connotation on a diversion or missed approach	20	_____
Company Culture Total (+) _____ *		
115-130 points	Tops in company culture	
105-115 points	Good, but not the best	
80-105 points	Improvement needed	
Less than 80 points	High CFIT risk	

Section 2 – Flight Standards

	Value	Score
Specific procedures are written for:		
Reviewing approach or departure procedures charts	10	_____
Reviewing significant terrain along intended approach or departure course	20	_____
Maximizing the use of ATC radar monitoring	10	_____
Ensuring pilot(s) understand that ATC is using radar or radar coverage exists	20	_____
Altitude changes	10	_____
Ensuring checklist is complete before initiation of approach	10	_____
Abbreviated checklist for missed approach	10	_____
Briefing and observing MSA circles on approach charts as part of plate review	10	_____
Checking crossing altitudes at IAF positions	10	_____
Checking crossing altitudes at FAF and glideslope centering	10	_____
Independent verification by PNF of minimum altitude during stepdown DME (VOR/DME or LOC/DME) approach.....	20	_____
Requiring approach/departure procedure charts with terrain in color, shaded contour formats	20	_____
Radio-altitude setting and light-aural (below MDA) for backup on approach	10	_____
Independent charts for both pilots, with adequate lighting and holders	10	_____
Use of 500-foot altitude call and other enhanced procedures for NPA	10	_____
Ensuring a sterile (free from distraction) cockpit, especially during IMC/night approach or departure	10	_____
Crew rest, duty times and other considerations especially for multiple-time-zone operation	20	_____
Periodic third-party or independent audit of procedures	10	_____
Route and familiarization checks for new pilots		
Domestic	10	_____
International	20	_____
Airport familiarization aids, such as audiovisual aids	10	_____
First officer to fly night or IMC approaches and the captain to monitor the approach.....	20	_____
Jump-seat pilot (or engineer or mechanic) to help monitor terrain clearance and the approach in IMC or night conditions	20	_____
Insisting that you fly the way that you train	25	_____
<hr/>		
300-335 points	Tops in CFIT flight standards	
270-300 points	Good, but not the best	
200-270 points	Improvement needed	
Less than 200	High CFIT risk	
		Flight Standards Total (+) _____ *

Section 3 – Hazard Awareness and Training

	Value	Score
Your company reviews training with the training department or training contractor	10	_____
Your company's pilots are reviewed annually about the following:		
Flight standards operating procedures	20	_____
Reasons for and examples of how the procedures can detect a CFIT "trap"	30	_____
Recent and past CFIT incidents/accidents	50	_____
Audiovisual aids to illustrate CFIT traps	50	_____
Minimum altitude definitions for MORA, MOCA, MSA, MEA, etc.	15	_____
You have a trained flight safety officer who rides the jump seat occasionally	25	_____
You have flight safety periodicals that describe and analyze CFIT incidents	10	_____
You have an incident/exceedance review and reporting program	20	_____
Your organization investigates every instance in which minimum terrain clearance has been compromised	20	_____

You annually practice recoveries from terrain with GPWS in the simulator	40	_____
You train the way that you fly	25	_____
<hr/>		
285-315 points	Tops in CFIT training	
250-285 points	Good, but not the best	Hazard Awareness and Training Total (+) _____ *
190-250 points	Improvement needed	
Less than 190	High CFIT risk	

Section 4 – Aircraft Equipment

	Value	Score
Aircraft includes:		
Radio altimeter with cockpit display of full 2,500-foot range — captain only	20	_____
Radio altimeter with cockpit display of full 2,500-foot range — copilot	10	_____
First-generation GPWS	20	_____
Second-generation GPWS or better	30	_____
GPWS with all approved modifications, data tables and service bulletins to reduce false warnings	10	_____
Navigation display and FMS	10	_____
Limited number of automated altitude callouts	10	_____
Radio-altitude automated callouts for nonprecision approach (not heard on ILS approach) and procedure	10	_____
Preselected radio altitudes to provide automated callouts that would not be heard during normal nonprecision approach	10	_____
Barometric altitudes and radio altitudes to give automated “decision” or “minimums” callouts	10	_____
An automated excessive “bank angle” callout	10	_____
Auto flight/vertical speed mode	-10	_____
Auto flight/vertical speed mode with no GPWS	-20	_____
GPS or other long-range navigation equipment to supplement NDB-only approach	15	_____
Terrain-navigation display	20	_____
Ground-mapping radar	10	_____
<hr/>		
175-195 points	Excellent equipment to minimize CFIT risk	
155-175 points	Good, but not the best	Aircraft Equipment Total (+) _____ *
115-155 points	Improvement needed	
Less than 115	High CFIT risk	

Company Culture _____ + Flight Standards _____ + Hazard Awareness and Training _____
+ Aircraft Equipment _____ = CFIT Risk-reduction Factors Total (+) _____

*** If any section in Part II scores less than “Good,” a thorough review is warranted of that aspect of the company’s operation.**

Part III: Your CFIT Risk

Part I CFIT Risk Factors Total (–) _____ + Part II CFIT Risk-reduction Factors Total (+) _____
= CFIT Risk Score (±) _____

A negative CFIT Risk Score indicates a significant threat; review the sections in Part II and determine what changes and improvements can be made to reduce CFIT risk.

In the interest of aviation safety, this checklist may be reprinted in whole or in part, but credit must be given to Flight Safety Foundation. To request more information or to offer comments about the FSF CFIT Checklist, contact Robert H. Vandel, director of technical projects, Flight Safety Foundation, 2200 Wilson Boulevard, Suite 500, Arlington, VA 22201-3306 U.S., Phone: 703-522-8300 • Fax: 703-525-6047 • Telex: 901176 FSF INC AGTN.

FSF CFIT Checklist © 1994 Flight Safety Foundation

Appendix C

EDITED EXTRACTS FROM THE COCKPIT VOICE RECORDER TRANSCRIPT

Transcript of a Fairchild A-100 A cockpit voice recorder (CVR), s/n 51656, installed on a DHC-8 (Dash 8), ZK-NEY, which collided with terrain during an instrument approach to Palmerston North Aerodrome, on 9 June 1995.

LEGEND

AA	Auckland	OA	Radio transmission from another aircraft
ACC	Area Control	OH	Ohakea
AEV	Aircraft's "electronic voice"	PM	Palmerston North
APP	Approach Control		
A703	Ansett 703		
CAPT	Voice of Captain	#	Expletive
FA	Voice of Flight Attendant	-----	Unintelligible word / words
FO	Voice of First Officer		
IDENT	Morse code identification of radio navigation aid		
NP	New Plymouth		

NOTE: Times are expressed in New Zealand standard time (NZST), UTC plus 12 hours, at the commencement of each voice recording.

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
	<i>Start of Recording</i> <i>Start of Transcript</i>		
		IDENT PM 08:52:14	dot dash dash dot, dash dash (. - - . - -)
FO 08:52:19	Palmerston nav two on the one four eight no nav flags		
CAPT 08:52:27	OK		
		FO A703 08:56:53	Ohakea Control Ansett seven zero three maintaining flight level two two zero received Palmerston Echo one zero one two
		ACC OH 08:56:59	Ansett seven zero three Ohakea good morning, when ready descend to flight level one three zero, Palmerston weather Echo confirmed, I'll advise if the zero seven approach is available
CAPT 08:57:08	one three zero		
		FO A703 08:57:10	wilco, flight level one three zero Ansett seven zero three, morning
CAPT 08:57:14	set and armed, ten thirteen still on the standby		

*INTRA-COCKPIT COMMUNICATION**AIR-GROUND COMMUNICATION*

Time & Source	Content	Time & Source	Content
FO 08:57:16	check		
CAPT 08:57:18	I certainly hope it's available, I don't really want to do two five		
FO 08:57:24	yeah		
CAPT 08:57:24	I've done it once that was enough		
FO 08:57:27	It's quite a long way around there, isn't it?		
CAPT 08:57:28	yeah		
CAPT 08:57:36	top of descent fifty four, visual or VOR depending on what we get, flap fifteen landing ninety five plus ten one oh five		
FO 08:57:48	set		
CAPT 08:57:49	that's landing runway two five, seeing as it's gusty, I'll stick with flap fifteen		
FO 08:57:55	yep		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
CAPT 08:58:04	and if we have to do the VOR DME runway zero seven second of March ninety five very similar to what you briefed, anticipating radar vectors or tracking via Ohakea, thence a radar heading for the final approach and inbound zero six nine not below fifteen hundred at nine miles not below seven thirty at seven miles, the descent profile three times minus three hundred down to four hundred and eighty feet QNH and sixteen hundred metres of vis requirement, and missed approach point two point five miles and the missed approach climbing left hand turn outbound two two nine and then back right hand to overhead into the holding pattern at fifty six hundred or as instructed		
FO 08:58:47	check		
CAPT 08:58:49	elevation one forty nine feet		
FO 08:58:51	check		
CAPT 08:58:55	and I'll brief on the, other one if we actually have to do it		
FO 08:58:58	yep		
CAPT 09:02:29	and descent and approach checklist		

*INTRA-COCKPIT COMMUNICATION**AIR-GROUND COMMUNICATION*

Time & Source	Content	Time & Source	Content
FO 09:02:31	descent and approach checklist, cabin pressure		
CAPT 09:02:33	set		
FO 09:02:34	set, fuel panel		
CAPT 09:02:36	is set		
FO 09:02:37	set, check complete to altimeters		
CAPT 09:04:50	leaving flight level two two zero on descent one three zero ten thirteen still on the standby		
FO 09:04:54	check		
CAPT 09:06:57	and MSA through here, in case I didn't mention it, is eleven three hundred DME steps of forty five miles down to forty eight hundred fifteen miles to thirty six hundred		
FO 09:07:04	check		
		ACC OH 09:07:06	Ansett seven zero three descend to five thousand feet radar terrain Ohakea QNH one zero one two

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
CAPT 09:07:11	five thousand on one two	FO A703 09:07:13	five thousand one zero one two Ansett seven zero three
FO 09:07:17	five thousand's checked		
FO 09:08:55	(yawn) oh gee, excuse me, I'm tired	OA 09:09:08	Ohakea good morning Airlink three one one flight level one eight zero copied Palmerston's Foxtrot one zero one one
		ACC OH 09:09:15	Airlink three one one Ohakea good morning when ready descend to flight level one three zero Palmerston weather Foxtrot confirmed
		ACC OH 09:09:40	Airlink zero four eight Ohakea descend to four thousand feet Foxtrot confirmed
		ATC OH 09:10:37	Ansett seven zero three stop descent at six thousand feet intercept the one four DME arc for the VOR DME approach runway two five
CAPT 09:10:44	#	FO A703 09:10:46	stop descent at six thousand intercept the one four DME arc for an approach to two five Ansett seven zero three

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
CAPT 09:10:53	six thousand check		
		ACC OH 09:10:53	Ansett seven zero three that's correct, sorry the zero seven approach not available due departing traffic
CAPT 09:10:58	OK		
		FO A703 09:11:00	understood Ansett seven zero three
CAPT 09:11:02	OK six thousand		
FO 09:11:03	check		
CAPT 09:11:05	and the MSA on that part of the arc is fifty seven hundred, and		
FO 09:11:13	did she say twelve or four, one four DME?		
CAPT 09:11:15	well it's a fourteen mile arc no matter what she said		
FO 09:11:16	yeah it is isn't it, yeah		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content
CAPT 09:11:18	and coming in the one four eight left turn right hand arc fifty seven hundred until we're through the zero five zero when it's forty nine hundred
CAPT 09:11:35	and round we come lead in radial of zero six one and not interested in that holding pattern out there
FO 09:11:41	no
CAPT 09:11:42	inbound two fifty down the approach not below forty six hundred to start off with and not below three thousand at nine miles, not below seven, twenty five hundred at seven miles, and
FO 09:11:52	yep
CAPT 09:11:52	sixteen hundred at five
FO 09:11:54	make it a three times plus four hundred will we?
CAPT 09:11:56	eh?
FO 09:11:57	three times plus four hundred profile?
CAPT 09:11:58	that's it

Time & Source	Content
--------------------------	----------------

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
FO 09:11:59	yep		
CAPT 09:12:00	and it's right on the limits so we gotta stick to that		
FO 09:12:03	yeah OK		
CAPT 09:12:04	and non-standard procedure gear down flap fifteen at ten miles		
FO 09:12:10	yeah		
CAPT 09:12:12	I think that's about all down, oh, minimums of six hundred and sixty feet		
FO 09:12:15	yep		
CAPT 09:12:17	and we're through thirteen cleared to six, one zero one two twelve thousand three hundred sorry eleven thousand, two hundred and two oh fourteen knots		
FO 09:12:29	checked, and transition level, altimeters		
CAPT 09:12:32	check		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
FO 09:12:33	check, landing data		
CAPT 09:12:34	checked and set		
FO 09:12:35	checked and set, external lights (one chime)		
FO 09:12:40	set and, anti-ice		
CAPT 09:12:43	might as well have it on		
FO 09:12:45	take it on		
FO 09:12:49	anti-ice on and ignition normal ECU selected top check complete		
CAPT 09:12:52	OK, both the ADF's on Palmerston North		
FO 09:12:55	and approaching the arc		
CAPT 09:12:56	check, sixteen around we go left hand		

*INTRA-COCKPIT COMMUNICATION**AIR-GROUND COMMUNICATION*

Time & Source	Content	Time & Source	Content
		IDENT	dot dash dash dot, dash dash (. - - . - -)
		PM	
		09:12:58	
FO 09:13:04	and nav two course selector going to two five zero		
CAPT 09:13:08	check		
CAPT 09:13:24	and on the arc fifty seven hundred's the minima		
FO 09:13:34	yep		
CAPT 09:13:57	and auto pilot's disengaged		
FO 09:14:01	yep		
CAPT 09:14:04	you could set minimum descent altitude in the		
FO 09:14:13	she hasn't cleared us for the approach yet though has she, only cleared us to six thousand?		
CAPT 09:14:16	but once you are on the arc I think the procedure is to		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
FO 09:14:18	I'll just, I'll just confirm it with her, will I?		
CAPT 09:14:21	what?, I know we're cleared to six		
FO 09:14:24	yeah		
CAPT 09:14:31	once you're on the arc though you just set that thing to your minima, as far as I know		
FO 09:14:35	she didn't clear us for the approach though or anything, but		
CAPT 09:14:38	no		
FO 09:14:39	I'll just		
CAPT 09:14:40	I see what you mean		
FO 09:14:41	yeah		
		FO A703 09:14:42	Ansett seven zero three is established on the arc descending to six thousand

INTRA-COCKPIT COMMUNICATION

**Time &
Source** **Content**

CAPT oh well
09:14:49

CAPT we've got fifty seven hundred
09:14:56

FO yeah
09:14:58

CAPT whatever, don't argue
09:14:59

CAPT we won't argue
09:15:00

AIR-GROUND COMMUNICATION

**Time &
Source** **Content**

ACC OH Ansett seven zero three
09:14:47

FO A703 just confirm we are to maintain six thousand
09:14:50

ACC OH Ansett seven zero three affirm minimum descent on the arc is six
09:14:53 thousand

FO A703 understood Ansett seven zero three
09:14:59

ACC OH Ansett seven zero three just confirming your descent is to six thousand
09:15:04 feet

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
		FO A703 09:15:05	descending to six thousand Ansett seven zero three
FO 09:15:10	(thats not right is it), cause passing zero five zero we can go to forty nine, or fifty hundred it is actually on the arc here		
CAPT 09:15:18	yeah, we won't argue		
FO 09:15:22	No		
FO 09:15:32	oh well I suppose we can be out there at fourteen DME at five thousand anyway		
CAPT 09:15:38	mmm		
		ACC OH 09:15:51	Ansett seven zero three cleared VOR DME approach runway two five Palmerston QNH one zero one one
CAPT 09:15:56	zero one one		
		FO A703 09:15:57	cleared approach one zero one one Ansett seven zero three
FO 09:16:00	yeah now we're right		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
CAPT 09:16:01	OK		
FO 09:16:02	and I'll set the MDA for you		
CAPT 09:16:04	yep, that's it, what ever it is, seven hundred		
FO 09:16:06	six sixty, I'll set seven hundred		
CAPT 09:16:07	that'll do		
FO 09:16:10	and minimum descent altitude set		
CAPT 09:16:13	check		
FO 09:16:32	yep, and MSA here fifty seven hundred		
CAPT 09:16:35	check		
CAPT 09:16:52	oh of course we've got that strong south-westerly there		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
FO 09:16:56	say again?		
CAPT 09:16:57	I'm just wondering why it tended to keep blowing out on the arc but of course there's quite a strong south-westerly there		
FO 09:17:02	yeah, yeah		
CAPT 09:17:13	and I'm aware of the a limit of fifty seven hundred, (chime), even though there is no alert (chime)		
FO 09:17:19	no		
FO 09:17:35	oh you haven't asked for those landing checks yet have you?, no		
CAPT 09:17:37	no		
CAPT 09:18:05	just about there		
FO 09:18:07	fifty seven hundred until we cross the		
CAPT 09:18:10	zero five zero		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
FO 09:18:11	zero five zero		
CAPT 09:18:12	which is about almost		
FO 09:18:14	just coming up to it		
CAPT 09:18:15	that'll do us, forty nine hundred now		
FO 09:18:18	yep		
CAPT 09:18:19	and not below forty six hundred till established inbound		
FO 09:18:20	forty, forty nine yea now's the MSA, commencing, and you can probably commence the approach at that out here		
CAPT 09:18:27	yeah, yeah I guess so		
FO 09:18:30	that's about it		
CAPT 09:18:35	what have we got fifty three hundred ten eleven and landing checks		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
FO 09:18:39	landing checks, belts smoking		
CAPT 09:18:41	on		
FO 09:18:42	synchrophasers off hydraulics chamber pumps checked on check complete to bleed air		
CAPT 09:18:45	check		
CAPT 09:18:51	there's the lead in radial		
FO 09:18:53	yep		
CAPT 09:18:54	right hand on the inbound		
FO 09:18:55	and course bar's active		
CAPT 09:18:57	check		
CAPT 09:18:59	and going down to forty six hundred now		

INTRA-COCKPIT COMMUNICATION

Time & Source	Content
FO 09:19:20	thirty six, and twelve DME looking for four thousand
CAPT 09:19:26	check
CAPT 09:19:33	inbound no flags, no nav flags missed approach heading is, set, and that's two fifty of course
FO 09:19:41	check
CAPT 09:19:42	and minimum descent altitude's set
CAPT 09:20:06	gear down
FO 09:20:08	say again

AIR-GROUND COMMUNICATION

Time & Source	Content
FO A703 09:19:47	Ansett seven zero three established inbound
ACC OH 09:19:50	Ansett seven zero three roger ten miles contact Palmerston Tower one two zero decimal six
FO A703 09:19:54	one two zero six at ten DME Ansett seven zero three

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
CAPT 09:20:09	gear down		
FO 09:20:10	oh, OK, selected		
FO 09:20:14	and on profile, ten sorry hang on ten DME we're looking for four thousand aren't we, so a fraction low		
CAPT 09:20:21	check		
CAPT 09:20:25	and flap fifteen		
CAPT 09:20:30	oh #		
FO 09:20:32	actually no we're not, ten DME we're		
CAPT 09:20:33	(whistle)		
FO 09:20:34	# look at that		
CAPT 09:20:35	I don't want that		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
FO 09:20:36	no, # yeah that's not good is it, so she's not locked, so alternate landing gear		
CAPT 09:20:42	alternate extension, you want to grab the QRH		
FO 09:20:44	yep		
CAPT 09:20:45	whip through that one, see if we can get it out of the way before it's too late		
FO 09:20:48	yeah, right		
CAPT 09:20:52	and I'll keep an eye on the aeroplane while you're doing that		
FO 09:20:54	yeah OK		
FA 09:20:57	-----		
FO 09:21:01	yeah, we know		
FA 09:21:02	thank you		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
FO 09:21:04	landing gear inop, landing gear malfunction, alternate gear eighteen, oh right, alternate gear extension, approach and landing checklist, pressurisation		
CAPT 09:21:19	oh, just skip her down to the actual applicable stuff		
FO 09:21:20	yeah, landing data altimeters tanks belt smoking OK airspeed below a hundred and forty knots		
FO 09:21:26	and landing gear inhibit switch inhibit		
CAPT 09:21:28	OK, and it's one forty		
FO 09:21:31	landing gear selector is down		
CAPT 09:21:33	yep		
FO 09:21:34	landing gear alternate release door fully open, which it is		
		CAPT A703 09:21:38	and Ansett seven zero three established finals at Palmerston North

INTRA-COCKPIT COMMUNICATION

Time & Source	Content
FO 09:21:41	yeah thanks, and insert
FO 09:21:56	insert this handle, (horn)
CAPT 09:22:00	it's noted
FO 09:22:01	insert handle at, till, oh yeah and operate until main gear locks, actually, nose gear
CAPT 09:22:15	you're supposed to pull the handle, (laugh)
FO 09:22:16	yeah, it's got it actually after that, yeah that's pulled, here we go

AIR-GROUND COMMUNICATION

Time & Source	Content
ACC OH 09:21:46	Ansett seven zero three that's understood, and contact Palmerston Tower one two zero six
CAPT A703 09:21:49	one two zero six, thanks

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

Time & Source	Content	Time & Source	Content
AEV 09:22:25	terrain, whoop whoop pull-up, whoop whoop pull-up		
	(Sound of impact)		
09:22:30			
	END OF ABBREVIATED TRANSCRIPT		
	<i>END OF RECORDING.</i>		

Glossary of abbreviations used in this report

ACNZ	Airways Corporation of New Zealand Limited
ADI	Attitude director indicator
AGL	Above ground level
ALT-SEL	Altitude Select
amsl	Above mean sea level
AOM	All Operator Message
ASC	Air Service Certificate
ASMS	Aviation Safety Monitoring System
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATIS	Automatic terminal information system
ATP	Acceptance Test Procedure
ATPL (A)	Airline Transport Pilot Licence (Aeroplane)
ATS	Air Traffic Service
BAe	British Aerospace
BASI	Bureau of Air Safety Investigation (Australia)
°C	Celsius
CAA	Civil Aviation Authority of New Zealand
CAS	Calibrated air speed
CASO	Civil Aviation Safety Order
CEO	Chief Executive Officer
CFIT	Controlled flight into terrain
CG	Centre of gravity
CMM	Component Maintenance Manual
CRM	Crew resource management
CVR	Cockpit Voice recorder
DA	Decision altitude
DCA	Director of Civil Aviation
DFDR	Digital flight data recorder
DME	Distance measuring equipment
E	East
ELT	Emergency location transmitter
ETA	Estimated time of arrival
ETD	Estimated time of departure
FAA	Federal Aviation Administration (United States)
FAR	Federal Aviation Regulation (United States)
FD	Flight Director
FDAU	Flight data acquisition unit
FDR	Flight data recorder
FL	Flight level
fwd	Forward

G	Acceleration due to gravity
GFR	General Flight Report
GPS	Global Positioning System
GPWS	Ground proximity warning system
hPa	Hectopascals
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
ILS	Instrument landing system
IMC	Instrument meteorological conditions
kPa	Kilopascals
kg	Kilogram(s)
KLM	Royal Dutch Airlines
km	Kilometre(s)
LDG	Landing
LF	Low frequency
L/G	Landing gear (Undercarriage)
LLZ	Localiser
LOFT	Line Oriented Flight Training
Ltd	Limited
m	Metre(s)
°M	Magnetic
MAC	Mean aerodynamic chord
max	Maximum
MDA	Minimum descent altitude
METAR	Aviation routine weather report (in aeronautical meteorological code)
MHz	Megahertz
MK	Mark
MLG	Main landing gear
mm	Millimetre(s)
Mod	Modification
MSAW	Minimum safe altitude warning system
N	North
NASA	National Aeronautics and Space Administration
NDB	Non-directional radio beacon
nm	Nautical miles
No.	Number
NTSB	National Transportation Safety Board (United States)
NZALPA	New Zealand Airline Pilots' Association Industrial Union of Workers Incorporated
NZMS	New Zealand Mapping Service map series number
NZST	New Zealand Standard Time (UTC + 12 hours)
okta	Eighths of sky cloud cover (e.g. 4 oktas = 4/8 of cloud cover)

PANS-OPS	Procedure for air navigation services - operations
PF	Pilot flying
PIC	Pilot in command
PM	Palmerston North
PNF	Pilot not flying
PSEU	Proximity switch electronic unit
psi	Pounds per square inch
QNH	An altimeter subscale setting to obtain elevation above mean sea level
QRH	Quick Reference Handbook
RCC	Rescue Co-ordination Centre
Rev	Revision
RNZAF	Royal New Zealand Air Force
rpm	revolutions per minute
RTF	Radio telephone or radio telephony
S	South
SAR	Search and Rescue
SB	Service Bulletin
SIL	Service Information Letter
SOP	Standard operating procedure
SPAR	Special aerodrome report
SSR	Secondary surveillance radar
°T	True
TAS	True airspeed
TI	Technical Instruction
USA	United States of America
UTC	Co-ordinated Universal Time
VFR	Visual Flight Rules
VHF	Very high frequency
VMC	Visual meteorological conditions
VOR	VHF omnidirectional radio range
W	West

Annex C

The Author's Qualifications as an Air Accident Investigator

Flying Experience

The author served in the Royal Air Force for 18 years. He flew with Coastal Command, and spent 5 years at the Aeroplane and Armament Experimental Establishment, Boscombe Down, as Flight Trials Officer. His primary responsibility there was the development flight trials of the HS Nimrod maritime reconnaissance aircraft, from prototype to Squadron service. He was awarded the MBE on the successful completion of the Nimrod trials.

On returning to New Zealand, he flew as an instructor and commuter airline pilot, until he joined the Office of Air Accidents Investigation as an Inspector of Air Accidents. He holds an Air Transport Pilot Licence.

Accident Investigation

The author participated in the investigation of some 40 fatal accidents, mostly as Investigator in Charge, and numerous non-fatal accidents and incidents. He attended the following formal courses:

NTSB Basic Investigation Course, at Oklahoma City

Helicopter Accident Investigation, at University of Southern California

Crashworthiness and Survivability, at the International Centre for Safety Education, Arizona

Jet Engine Accident Investigation, at Chanute Air Force Base, Illinois

AAIB Air Accident Investigation Course, at Cranfield

After 7 years as an Inspector, the author joined the staff of Massey University, to teach accident investigation at undergraduate and postgraduate levels for 9 years.

There was very little published study material relating to Air Safety Investigation, so he had to write most of it himself. The Study Guides were, in effect, the textbooks.

Publications

A&AEE Technical Reports:

364/Nav - Assessment of proposed LORAN C Aerial Installation for the HS801

412/Nav - The Transient Response of the Decca Doppler 67M

417/Nav - Interim Report on the Assessment of the Navigation and Attack System Accuracy of the Nimrod MR Mk 1

A&AEE/953 (12th Part) - The Accuracy of the Navigation and Attack System of the Nimrod Mr Mk 1 in the primary mode of Navigation

Government Report: The Safety of Air Transport within Fiji (with Mr D G Graham)

Papers:

Reporting human factors accidents. A means of combining the Helmreich and Reason approaches to the investigation of aircraft accidents. In: Proceedings of the 27th International Seminar, International Society of Air Safety Investigators. Also presented by invitation at the IFATCA International Conference at Taipei.

Cognitive failure analysis of pilot error (thesis). An analysis of the pilot errors disclosed in a review of the entire New Zealand database, with a view to determining the types of errors, and possible corrective actions. In: Proceedings of the 4th International Symposium, Australian Aviation Psychology Association. Also presented at the ANZSASI Seminar, 1998, at Wellington.

Scientific methods for air accident investigation. An examination of the applicability of case study research methods to the accident investigation

process. In: Proceedings of the 31st International Seminar, International Society of Air Safety Investigators.

Investigating the Ansett Dash Eight accident with a Why-Because Graph. A case study in the application of Lewis's counterfactual analysis of causation to accident investigation. Presented at the ANZSASI Seminar, Cairns, 2001.

Analytical methods for accident investigation: an application of the Theory of Constraints. Presented at the 6th Australian Aviation Psychology Association Symposium, 2003.

Analysing systemic failure with the Theory of Constraints (with Dr L Hunt and A. Wright. In Human Factors and Aerospace Safety Journal 4(4) pp. 321-354.

Analysing the Dash 8 accident with the Theory of Constraints. Presented at the Asia-Pacific Regional Air Safety Seminar, Queenstown, 10-12 June 2005

Books:

Training accident investigators for the human factors investigation. In G.J.F. Hunt (Ed.), Designing Instruction for Human Factors Training in Aviation.

Investigating the general aviation accident. In D. O'Hare (Ed.), Human Factors for General Aviation Pilots.

Pilot error: Cognitive failure analysis. In B.J. Hayward and A.R. Lowe (Eds.), Aviation Resource Management.

Study Guides: Air Safety Investigation. (Textbooks used in Massey courses).