Modelling Pilot Decision-Making Errors

in New Zealand General Aviation

A THESIS PRESENTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF ARTS

IN SOCIAL SCIENCES AT MASSEY UNIVERSITY

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1992

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Acknowledgements

I would like to express my thanks to my supervisor, Dr Ross St. George, who has constantly provided me with help and support during the writing of this thesis.

To my parents David and Diana go my love and thanks for their support of the 'eternal stoodent', and the packets of toffee pops that died soon after making the hazardous trip south.

The Transport Accident Investigation Commission has been most helpful in granting me access to their investigation files. Without their co-operation, this research would not have been possible, and I would like to thank the staff there for the opportunity to use their time and resources.

Many other individuals and organizations have freely helped me with the research involved with this thesis, and I would like to take this opportunity to acknowledge their generous assistance. I would especially like to thank Peter Ham and Penny Mackay for their help and expertise.

This thesis is dedicated with love and thanks

to my life-partner Anna.

Abstract

Accident statistics indicate that the rate of mortality and financial loss associated with general aviation accidents is comparable with that of passenger transport operations. However, general aviation appears under-represented in literature pertaining to the development of safety interventions.

In this thesis, this apparent disparity is addressed in an investigation of pilot error in New Zealand general aviation. Using the precedent of accident modelling developed in industrial safety research, accident models taken from aviation, road transport and industrial settings are reviewed for their representation of human error. The Surry Model (1969), a twelve point sequence representing operator decision making processes, was selected for generalization to aviation.

The selection of this model was congruous with research literature identifying poor decision making as a primary causal factor in air accidents. Each of the points in the model represents an opportunity for accident avoidance if certain information processing requirements are met.

The model presents accident avoidance as the result of three processes: the correct recognition of stimuli, the correct cognitive processing of avoidance options, and the correct implementation of physiological responses. The accident sequence within which these processes occur is divided into two cycles: the build-up of danger in the system, and its subsequent release.

The model was applied to a data base of 84 cases involving fixed wing aircraft engaged in general aviation, selected from 1980 to 1991. The point at which an error in pilot decision making occurred was identified and coded using the twelve points of the Surry Model. These data were combined with information concerning biographic characteristics of the pilots, and the

number of passengers on board the flight. All pilots in the sample were male.

Two research questions were investigated. The first questions whether the Surry Model is a useful tool in the analysis of information about accident sequences. The model was used as a template, and laid over the time line of accidents, as they had been determined by air accident investigators.

The second research questions sought to determine whether the format of the model could be used as a protocol for developing time lines and questioning pilots during accident investigations.

A small final sample size resulted in a general dichotomizing of the variables for non-parametric Chi Square statistical analysis. The power and utility of the analysis was limited and could only show that, beyond chance effects, there were no biographic characteristics of pilots that influenced the cycle of the model in which the accident inducing error occurred.

No quantitative examination of the twelve error types identified by the model was possible. A low level of inter-rater reliability showed that the model was not as self-contained as anticipated. Raters appeared to use the model in a consistent manner, but modes of use varied between individuals. It is suggested that this may be a function of non-standardised presentation of human factors information in air accident reports, coupled with non-standardised interpretations of ambiguities in the model.

On the basis of the inferential interpretation of the data, two main areas of discussion arise. The first is concerned with 'ambiguities': the structural characteristics of the Surry Model that influenced the fall of data onto the twelve error types. It became apparent that the typical sequence of events in aircrashes differed from the temporal sequence depicted by the model, and that assumptions made in the model about the configuration of the pilot-aircraft interface were inaccurate. Accordingly, modifications to the model are proposed.

The second area of discussion is centred on 'antidotes': corrections for pilot errors identified as causal in aircrashes. The results indicate that some aspects of in-flight behaviour could be targeted for intervention. It is suggested that it may be useful to encourage pilots to engage in active information search from external sources in order to ensure that they supplement information available from the aviation system. Self-monitoring before flight may induce voluntary self removal from aviation activities. It is possible that some pilots may abstain from flight if they become aware that their performance has become impaired as a result of their physical or emotional condition.

It is also suggested that risk communication techniques could facilitate the development of worst case thinking by pilots who are confronted by potential hazards. Rather than a more traditional emphasis on the implementation of strategies after contact with danger, these antidotes may encourage the active avoidance of danger.

Introduction

Chapter One: The Argument for Studying Air Accidents

"There is no cause for New Zealand to be complacent about safety levels in civil aviation. This applies to all sectors of the aviation industry" (Swedavia-McGregor Report 1988, p. ii).

Aviation safety is an international concern. The development of the International Civil Aviation Organization (ICAO) in 1944 demonstrates a long standing, world-wide commitment to the reduction of air accidents. Despite improvements in safety on a passenger/mile travelled basis, more lives are threatened and lost in air accidents every year, as the capacity and complexity of airliners increases. A similar effect is occurring in general aviation, as flight has become more available as a purely recreational pastime. This chapter presents evidence that the number of lives lost and the overall number of accidents associated with general aviation is high enough to warrant a focus on safety equivalent to that in commercial aviation.

This chapter also discusses the disparity in the amount of public and media attention that is devoted to general and passenger transport accidents, and suggests that these differences result from different perceptions and expectations about safety in each situation. Evidence is presented that suggests that changes in safety orientation occur when individuals take sole control of transport systems, and that this effect also occurs strongly in general aviation.

A focus on pilots as targets for intervention is supported by a review of the extensive literature about air accidents, in which the high rates of 'pilot error', and growing dissatisfaction with that concept is described. Research that identifies pilot decision making errors as a primary factor in air crashes is reviewed.

This chapter also discusses the role of sequentiality in accident occurrence, and introduces the industrial safety principle of modelling accident sequences in order to interrupt the interaction of causal factors.

The Problem of General Aviation Accidents

Data are available that show that general aviation activities are associated with high rates of loss. In New Zealand, the Air Transport Report (1989) shows that there were 158 fatal or serious injuries sustained by individuals engaged in general aviation activities between 1980 and 1989.

International data also show the number of accidents that occur in general aviation. In the United States for example, Salvatore, Stearns, Huntly & Mengert (1986) report 45627 general aviation accidents between 1973 and 1983. Of these accidents 7165 were fatal. The Insurance and Reinsurance Group (1990) reports that in 1988 in the United States, there were 438 fatal accidents, resulting in 782 deaths. O'Hare & Roscoe (1990) also show that the rate of fatal aviation accidents reported to the NTSB during 1983 was almost 50% higher than that of commercial passenger transport operations.

The 1989 Annual report of the Canadian Aviation Safety Boards reports 501 civil aircraft involved in reported accidents, with 64 fatalities resulting from 3 accidents. Research on British air accidents between 1969 and 1981 shows a similar dominance of pilot factors as causal factors in accidents involving light aircraft (Underwood Ground 1984).

These accident rates have a high cost, both in terms of the lives lost and the property damage that results. In New Zealand, the Swedavia McGrego

Report used the National Roads Board estimate of the value of the human life to calculate that in the ten year period from 1980 to 1989, fatal general aviation accidents alone had an incurred cost of $35 million (NZ).

These costs, however, do not appear to be the result of mechanical failures during flight. Research into commercial plane crashes has revealed that the relative proportion of machine failures in accidents has decreased systematically with improvements in aircraft technology. This change is shown in Figure 1.

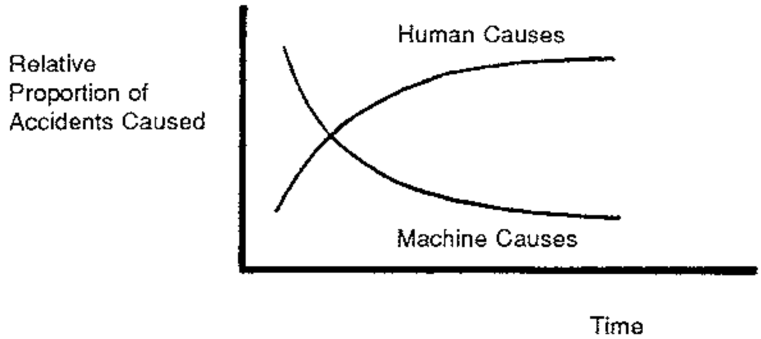

Figure 1: Trends in The Causality of Accidents: Extent to Which Accidents are Attributed to Mechanical or Human Causes. [Source: Nagel, D.C (1988), Human Error in Aviation Operations, p. 266, Fig 9.4]

However, a tradition exists of blaming pilots for accidents, regardless of contributing causal factors. An example of this precedent is presented by Wolfe (1979), who describes the reactions of naval test pilots when several of their number are killed in flying accidents.

After a string of accidents, the pilots gather to discuss the events. In one case:

> "They shook their heads and said it was a damned shame, but he should have known better than to wait so long before lowering the flaps."(1979, p. 13).

In another:

> "...they mentioned that the departed had been a good man but was inexperienced, and when the malfunction in the controls put him in that bad corner, he didn't know how to get out of it."(1979, p. 13).

After more accidents:

> "...[they] were incredulous. How could anybody fail to check his hose connections? And how could anyone be in such poor condition as to pass out that quickly from hypoxia?"(1979, p. 14).

> "...[they] remarked that the departed was a swell guy and a brilliant student of flying; a little too much of a student, in fact; he hadn't bothered to look out the window at the real world soon enough." (1979, p. 15).

Although attributions of pilot error have been traditional points for the termination of accident investigations, research has shown that though *blaming* pilots for crash occurrence is inappropriate, pilot factors are major agents in accident sequences and need to be investigated more thoroughly than has previously been the case.

Characteristics of Accidents - Pilot Error

Research conducted by Boeing as early as 1953 (cited in Nagel 1988) showed that cockpit crew errors were causal in 66.9% of reported accidents in air carrier operations. Hartman (1979) suggests that the level of human error involvement in air accidents is 70%, while Jensen (1982) reports that 85% of accidents occurring in the United States between 1970 and 1974 resulted from pilot error. In general aviation activities, Nagel (1988) suggests that pilot behaviours cause 9 out of every 10 accidents.

The Bureau of Air Safety Investigation of Australia (1988) cites human error in 85% of accidents. Errors that resulted from the actions of pilots accounted for 76% of all error.

In 1989, the New Zealand Office of Air Accident Investigation came to the conclusion that the most common feature of aircrashes was "human error on the part of the pilot (which may in turn be the result of inadequate training in a proportion of the cases)" (Air Transport 1989, p. 4). Chappelow (1989) presents data from the Royal Air Force that shows a pilot error rate in accidents of 40%.

Copas (1989) suggests that pilot error is more often a case of poor judgement rather than poor aircraft handling. He adds that "The general aviation accident rate is unlikely to decline significantly until those types of problems can be reduced" (p. 6). O'Hare (1990) reports National Transportation Safety Board records which identify human error in 50% of all fatal general aviation accidents over a five year period.

As can be seen from these reports, the involvement of human error in aircrashes is high, despite the lack of agreement about its specific role. It should also be noted that the 'popularity' of human error as an explanation for aircrashes is matched by an opinion among air accident researchers that this attribution of causality is in itself relatively meaningless.

Feggetter (1982) argues that despite a wide recognition of the importance of pilot error in accident occurrence, the concept has not been developed as far as it might have:

> "A satisfactory technique for the investigation of human error type accidents and incidents has not yet been standardized."(p. 1065).

Nance (1986) observes that:

> "Discovering that a human error - pilot error or otherwise - has occurred is merely a starting point. To have any hope of preventing such an error from causing an accident again and again, ... the underlying cause of that human failure must be revealed and addressed in future operations."(p. 229).

Hawkins (1986) also observes that:

> "The pilot error concept ... focuses on what has happened, rather than why it happened and so for this reason ... has been unhelpful in accident prevention activity."(p. 27).

Gerbert & Kemmler (1986) describe findings attributing accidents to human error as:

> "... rather crude and even inadmissible over-simplifications of very complex processes."(p. 1449).

Zeller (1972) comments that:

> "... pilot error has little, if any, meaning unless it is in some way related to the circumstances under which the error occurred, and specifies in some detail the error committed. Remedial action is dependent on this kind of detailed information."(p. 496).

Cath (1974) also notes that any investigation of an air accident should include a philosophy that a human error accident can have causes that vary from:-

> "... intentional suicide through various levels of unintended self destruction, through overwhelming summation of circumstances (over-load), to pure accidents of indifferent fate - i.e. the unavoidable mid-air."(p. 1300).

Similarly, Hill & Pile (1982) suggest that a finding of pilot error is one of 'exclusion'. They suggest that this judgement is reached when no other factor might have been found to account of the occurrence of the accident. This observation is supported by O'Hare (1986), who adds:

> "When accidents have occurred, and no obvious mechanical defect could be found, there has been a tendency to regard the cause of the accident as 'pilot error'. Whilst no-one would ever have regarded 'engine-error' or 'wing-error' as acceptable causes for an accident, ... the label has found general acceptability". (p. 18).

These comments indicate that there is growing dissatisfaction with the concept of human/pilot error, especially with the power of these terms to explain why accidents occur. The studies that criticize the use of the term generally suggest that a diagnosis of 'human error' is only a blanket term for a variety of mistakes made by pilots.

Researchers have thus sought to identify more specific components of the pilot error construct. For example, Ricketson, Johnson, Branham, & Dean (1973, cited in Sanders & Hoffman 1975) present a more detailed analysis of aviation human error when they suggest that faulty decision making and unnecessary risk taking are frequently occurring elements in pilot error accidents.

In a different study of American military data, Ricketson, Johnson, Branham & Dean (1973, cited in Ricketson, Brown & Graham 1980) found that nine factors developed from a factor analysis of military helicopter accidents accounted for 96% of the cases in a data base of 1520.

When this study was extended in 1975 (Dean & Neese, cited in Ricketson et al 1980), the same factors were implicated in 97% of helicopter crashes from 1969 to 1975 - some 5171 accidents. The nine factors identified in the initial study, and later supported in a larger data base, were disorientation, over-confidence, errors in procedural decisions, failures in crew co-ordination, errors in precise multiple control, limited experience, task oversaturation, attention errors, and weather conditions. The greatest loadings were placed on the failures in crew co-ordination (10%), attention errors (13%), procedural decisions (18%), and precise multiple control (20%) factors.

In an examination of British air accident statistics, Shuckburgh (1975) also found that an element of air crew error commonly associated with air crashes was decision making. More specifically, the error was the incorrect operation of the aircraft from Visual Flight Rules (VFR) into Instrument Meteorological Conditions (IMC). In analysis, this factor accounted for 30% of accidents attributed to flight crew error, while 'judgement' accounted for 17% of accidents.

Similarly, Jensen (1977) reports that 51.6% of fatal accidents, and 35.1% of non-fatal general aviation accidents in the U.S were attributed to bad decision making behaviour. O'Hare (1990) describes a common cause of fatal accidents in the U.S. as "faulty decision-making activities" (p. 599).

Roscoe (1980) and Jensen (1982) identified three characteristics of pilot error. In this model, pilot error occurs in procedural, perceptual-motor, or decisional activities. Procedural activities are linked to the management of the plane's power plant, fuel, vehicle configuration, navigation, and communication. Errors found in the perceptual-motor activities involved vehicle control, judgement of distance, speed, altitude, and geographical orientation.

Decision activities were also a primary source of error, and involved pilots' assessments of their skill and of the aircraft's capabilities. Navigation, planning and flight priority adjustment were also included in this factor.

Jensen & Benel (1977, cited in Jensen 1982) used this three tiered behavioural classification in an investigation of United States air accidents from 1970 to 1974. They found that 51.6% of fatal accidents resulted from faults in the decision making activities of pilots.

In 1986, Gerbert & Kemmler used factor analysis to isolate four dimensions of pilot error. These were errors in vigilance, information processing, perception, and sensorimotor activities. Vigilance errors included the failure to check and maintain altitude, delays in taking necessary actions, poor scanning of instrumentation, and the failure to check and maintain airspeed. Information processing errors were described as erroneous judgements, miscalculations, wrong decisions and faulty action plans. The behavioural manifestation of these errors tended to be penetration of IMC under VFR, the misjudgment of weather conditions, continuing a VFR flight under IMC, and navigational error.

Perception error types included the misjudgment of altitude and clearance, misjudgment of safe distance, the misjudgment of safe airspeed, spatial disorientation, the misjudgment of safe altitude and the failure to see obstacles. Sensorimotor and handling errors were associated with the failure to apply or the faulty application of procedures, the failure to implement necessary non-procedural actions, exceeding design stress limits of aircraft, and poor coordination of controls.

There can only be a cautious acceptance of these data as a representation of pilot error. Although the factor loadings are high, the correlational nature of factor analysis techniques makes causal attributions impossible. However, there do appear to be links between the two models of pilot errors. Jensen (1982) defines two forms of behaviour in *pilot judgement.* The first is the perceptual-motor tasks that occur during the course of a flight, while the second relates to the decisions that pilots face when they select between alternatives presented to them in the changing environment.

Jensen suggests that these two facets of pilot judgement can be placed on a continuum of cognitive complexity and decision time. Perceptual-motor tasks are highly learned response that can be performed rapidly, and have relatively little cognitive complexity. Decision making in contrast, involves a greater degree of complexity and time, if only because set procedures may have been forgotten by the operator.

He defines pilot judgement as the ability to search for, and establish the relevance of all available information regarding a situation, to specify alternative courses of action, and to determine expected outcomes from each alternative.

It also entails the motivation to choose and authoritatively execute a suitable course of action within the time frame permitted by the situation, where (a) 'suitable' is an alternative consistent with societal norms; (b) 'action' includes no action, some action, or action to seek more information (1982, p. 64).

It can be seen in the many studies of the characteristics of pilot error that there is little or no agreement on definitions of even common terms. The concept of pilot judgement has been used and accepted with no strict operational definition. This makes the use of the data generated by the studies reviewed difficult. Many researchers discuss the relationship between pilot error and pilot judgment, but it is difficult to compare and contrast their ideas.

Despite differences between these studies, an overall theme is present throughout the research into aviation accidents. Issues of pilot error and judgement revolve around human performance in decision making and information processing. Historically, accident investigation techniques have reflected the lack of differentiation between the many forms of pilot error that have been identified - accident reports have been characterised by a paucity of human factors information.

It would appear that not only is there a need for an intervention to lower the incidence rate of these kinds of errors, but that there is a need for the development of a means of systematic collection and analysis of information about errors during accident investigation. That is, a tool is needed which can be taken to the crash site by investigators, and used to generate information about the pilot's cognitive processes.

Interventions: Enforcement, Engineering, and Education

Despite growing dissent about the use and meaning of the term 'human error', there appear to be three forms of intervention widely accepted in safety research. These are the use of enforcement of regulations that aim to prevent the occurrence of accidents, engineered methods to reduce the damage that results from an accident, and educational programs to reduce the willingness of individuals to engage in activities that expose them to the risk of accidents. Although 'enforcement', 'engineering', and 'education' are traditional ways of reducing the frequency and consequences of accidents, it is suggested that they are not necessarily equally applicable to all circumstances in the aviation environment. This is especially so when it is considered that poor pilot judgement has been identified as a primary source of error in air crashes.

Enforcement interventions can take two forms. One is the placement of new restrictions on activities that are believed to contribute to accidents, while the other is more strict responses to transgressions of existing regulations. Because these options are relatively easy and inexpensive to implement, they are popular in the process of attempted accident reduction. This has been demonstrated by the changes in public opinion towards the legal treatment of individuals charged with drinking and driving offenses.

It might appear that this intervention is appropriate for general aviation because the New Zealand Civil Aviation Regulations (1953), and the new Civil Aviation Rules are the primary controls on pilots. However, there is no formal mechanism by which transgressions can be detected and punished at the time they occur (there are no 'air police' for example). Legislated safety devices are thus removed from their targets, and can only have limited impact on the aviation community.

This observation is tempered by the recent court actions taken against individuals in New Zealand who have been involved in accidents that have resulted from regulation infringements. While these actions may prompt some individuals to increase the degree to which they monitor their behaviour, it is also possible that some individuals hold attitudes that make them resistant to this kind of legal intervention. It is therefore difficult to determine the extent to which 'judicial' changes will influence safety orientation in the total aviation population.

It is suggested that legislation has limited *preventative* utility. Further, it is also questionable whether legislation would stop the occurrence of errors of judgement, as it would appear that poor judgement inherently implies a disregard of rules, be they safety regulations or legal requirements.

Engineering interventions are designed to reduce damage resulting from a accidents and therefore have limited preventative usefulness. In most cases, they are effective only after the accident sequence has been initiated and can only limit the extent to which damage can occur. Some risk theorists (for example Adams 1985) have argued that engineered safety devices might actively encourage system operators to engage in dangerous activities. This occurs because those individuals recognise the increased safety afforded by the devices, and increase the amount of danger to which they expose themselves by a similar amount.

This is not to imply that there are no technological advances which might be instrumental in the prevention of accidents. Evidence shows that mechanical failure is not often involved in accident occurrence. Engineered changes may only isolate a relatively minor aspect of accident causation.

Education appears to be a desirable technique as it can be directed at a specific target group. As discussed by Kirkwood (1988) for the road transport environment, it could be useful to target novice pilots for an intervention as any strategies learned may affect safety behaviours from the beginning of their careers.

This may provide an immediate decrease in levels of accident involvement, and possible improvements in the skills and standard of the 'next generation' of pilots. As trained pilots become senior members of the aviation community, their examples may assist in the development of safe flight in other young pilots who may learn from their actions and expressed attitudes. This type of vicarious learning is especially important when it is considered that every pilot holding a New Zealand licence will hold, or have held a Private Pilot licence.

An intervention that instils safe habits in trainee private pilots may therefore increase the safety skills of the highest level of pilot in civilian flight operations - the Air Transport pilot. Initial pilot training seems the most useful point at which to develop a safety education program because of the potential long term influence on the aviation community.

Support for the use of education to achieve this can be found in the Swedavia-McGregor report:

> Private pilot accidents seem to be largely related to skill, experience and attitudes. Attitudes are difficult to change, and because the private pilot may not fly many hours per year, skill and experience may develop slowly. Improvement in private aviation safety is therefore rather slow at present. (1988, p. 13).

Specific and direct safety education of the novice pilot may provide a counterbalance for inadequacies in knowledge and experience. It is also possible that training directed at this level of flight operation will influence overall pilot attitudes in situations removed from the initial period of education. In order to develop a program that can achieve this, it is necessary to collect maximal information about the causes of accidents, particularly with regard to the poorly defined areas of pilot error and judgement.

Designing Interventions: Data Collection and Accident Modelling

The analysis of accidents has traditionally been important in industrial safety research (Menckel & Carter, 1985). The information collected has been used to break accidents down into component causes, in order to interrupt the 'accident sequence'. Since Heinrich (1931, cited in Heinrich, & Grannis 1959) proposed the Domino Model of Accident Causation, it has been accepted that altering or disrupting the sequence of events leading to an accident can reduce the frequency or effect of its consequences.

This is a technique that is widely accepted and used. Leplat & Rasmussen (1984, 1987) suggest that analyses based on "causal models of the accident chain of events" (1987, p. 157) can identify design deficiencies and weaknesses in systems.

Tuominen & Saari (1982) describe systematic investigations of accidents as techniques for developing effective accident prevention techniques. Purswell & Rumar (1984) agree that models of accident processes can facilitate interventions with international and standardized accident data collection systems.

Suokas (1988) suggests that the utility of accident research lies in the identification of factors affecting the occurrence of accidents, and the subsequent focus of data collection onto relevant factors. These models provide guidelines about where to develop safety intervention programmes. It thus appears that the best way to approach designing safety interventions is to accurately model accident sequences, identify causal agents, and design them out of the system.

Research has already identified errors in pilot decision making and judgement as primary causal factors in air crashes. A model of accident occurrence which would be useful in the development of an aviation intervention would focus on these aspects of pilot behaviour.

Two principles have been developed in the tradition of modelling accident sequences. These principles have been adopted to such an extent by researchers that it can be argued that any complete model of accident causation must include them.

The first principle is that of sequentiality, proposed by Heinrich in 1931 (cited in Heinrich & Granniss 1959) in his axioms of industrial safety.

This principle is that

> ... the occurrence of an injury invariably results from a completed sequence of factors - the last of these being the accident itself (p. 86).

This principle has been widely adopted. Votey (1986), for example, describes accidents as random occurrences which have been caused by "potentially identifiable factors that may be traceable to the acts of victims or others" (p. 86), or to the environment in which the individual was working.

Laflamme describes "the presumed existence of typical sequences of events leading to accidents - previously initiated by a deviation in a man-machine system" (1990, p. 155) when discussing sequences in accidents. Johnson (1980) adds that these sequences provide many opportunities for intervention, and thus:-

> It seems essential ... that accident investigation methods and summaries give appropriate visibility to the complex realities [of events], rather than the simplistic categorization of conditions and acts so often found. (p. 75).

The second established characteristic of accidents can best be called multifactorality. It is generally agreed that the factors precipitating accidents are many and varied (Singleton 1973, Andersson 1990) and may be removed from the accident event (Thygerson 1977).

Hart & Honore (1959) for example, suggest that:-

> ... it seems easy ... to be mislead by the natural metaphor of a single causal 'chain', which may lead us to think that the causal process consists of a chain of single events, each of which is dependent upon (would not have occurred without) its predecessor in the 'chain', and so is dependent on the initiating action or event. (p. 67).

There may be conditions in the system which contribute to accident occurrence without being recognisable as part of the accident sequence. These have been referred to as 'latent risks' (Reason 1991 and Green 1988), which are activated by human errors outside accident sequence.

The extent to which the principles of sequentiality and multifactorality have been adopted in safety research indicates they are necessary for the development of comprehensive models of accident sequences. In this thesis, these axioms have been used as criteria for the selection of an appropriate model for the specific analysis of pilot error in aviation accidents.

Other characteristics of good models have also been described. Kjellen & Larsson (1981) suggest that models useful in the design of interventions should be suitable for practical investigation work, have concepts and definitions that are easy to understand, and be related to concepts and terms in general use. They should also be suitable for use with different types of systems and accidents, and identify all causal factors in the accident sequence.

Benner (1984) evaluated fourteen different types of models and also identified several aspects of superior models. He suggests that a good model should be a realistic accident representation, with a direct definition of the problem. It should include a comprehensive scoping of accidents, a framework for disciplining investigators' tasks, be accessible to laypeople, and be consistent with safety concepts. It would also be non-causal to avoid problems of 'blaming'.

The concern of Kjellen & Larsson (1981) and Benner (1984) with the accessibility of information contained in models is especially important for the investigation of pilot cognitive errors. Air crash investigators may not have specialized training in the identification and representation of cognitive behaviours, and any useful model must be able to present information in a form that is directly useable.

The evidence reviewed in this chapter indicates that there is a strong need for a safety intervention in aviation that focuses on the prevention of pilot decision making and judgement errors. Modelling accident sequences in crashes that result from these behaviours appears to be the most effective ways of identifying the components of these errors, so that the accident sequence can be interrupted. On the basis of accepted principles of accident modelling, various criteria have been established.

> *A model seeking to represent the characteristics of pilot error in New Zealand general aviation must provide a sequential representation of pilot decision making and judgement behaviours, in a manner that allows non-specialists to use and understand the information generated by it.*

Chapter Two: Reviewing the Models

This chapter reviews models of accident occurrence developed for transportation and industrial systems. It is divided into three sections. The first examines specific studies of air crashes, and is concerned with the investigation of the characteristics and causes of pilots error.
The second section examines models of accident occurrence developed in the rod transport environment, because there are distinct parallels between the control tasks of the operator in a driver-automobile interface and in a pilot-aircraft system. This section focuses on the extensive road transport literature about driver characteristics and accident involvement. The concept of accident proneness which has been well researched in the road transport arena, is related to the 'Right Stuff' myth of pilot bravado (Wolfe 1979), and Votey's research into Failing Aviator Syndrome (1986). Research into human risk taking behaviours is also reviewed.

The third section of the chapter reviews models of human error in industrial accidents. These models range from the early work of Heinrich (1931, cited in Heinrich & Granniss 1959), who attributed accident involvement to