Modelling Pilot Decision-Making Errors in New Zealand General Aviation

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This thesis is dedicated with love and thanks

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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.

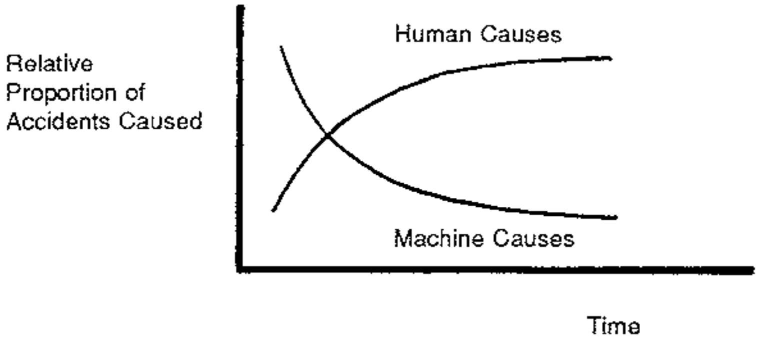

Figure 1: Trends in The Causality of Accidents: Extent to Which Accidents are Attributed to Mechanical or Human Causes. [Source: Nagel, D.C (1988), Human Error in Aviation Operations, p. 266, Fig 9.4]

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 ancestry and social environment, to the cognitive engineering approach demonstrated by Rasmussen's Taxonomy of Human Error (1982).

Section One: Specific Models of Air Accidents

Brandon (1980): Epidemiological Matrix.

Brandon (1980) has proposed an epidemiological study of causal agents in air accidents that is based on the Haddon Matrix of road transport accidents. This type of model studies accidents as similar to diseases, because both phenomena are unexpected events that strike without warning and result in undesirable consequences.

The matrix that forms this model shows the interaction of three agents that have been identified as determinants of accident involvement. It has been shown that illnesses result from exposure to an *environment* in which a number of infectious *agents* and susceptible *hosts* exist. Infection is solely dependent on which host inhales which agent - for all individuals there is a universal risk of becoming ill. Certain attributes will make a host more susceptible to an agent, and some specific environmental conditions will make an agent more potent. This is the case for accident involvement in this model, where it is argued that universal risk also applies. Given certain characteristics in the host, the agent and the environment, an individual will become involved in an accident (Gordon, 1949).

The basic matrix (shown in Figure 2 below) that forms the model was developed by Haddon (1967, cited in Langley & Mcloughlin 1987). An accident investigator is required to gather information that can be placed in each of the nine cells shown in Figure 2. The upper level identifies the three primary facets of accident occurrence (agent, host and environment) on the upper level. The second dimension divides the process of accident occurrence into three main stages. There are the events that determine whether or not the accident will take place *(Pre-events)*, the actual *Event* in which some form of excessive energy acts on people or property unfavourably, and the *Post-event* stage, which is concerned with salvaging people after their contact with the energy that is released in the accident.

	Host	Agent	Environment
Pre-Event			
Event			
Post-Event			

Figure 2: Example of The Haddon Matrix.

Brandon (1980) has developed a specific application of the Haddon Matrix to aviation accidents. The epidemiological factors identified in the model become more specific to air accidents, and are divided into four sections: human, environment, aircraft, and life support equipment. The human factors that are placed across the three stages of the accident include medical fitness of the pilot, use of emergency procedures, and the standard of post-accident care for the crew members.

The total model itself is a representation of the ways in which loss reduction interventions may be implemented to interrupt the transfer of energy from the agent to the host. There is no specific analysis of the agents that induced the accident, as the focus is on the mechanisms that were in place to act as barriers to the loss of control over, and the release of energy into the system.

This matrix has limited effectiveness as a device for the systematic collection of information about the causal factors in an accident. There is no option for representation of the sequence in which those various factors culminated in the accident, and no guidance for the placement of specific information about cognitive errors and functions in the event being studied onto the matrix.

Ricketson, Brown & Graham (1980): 3WTEIR.

The 3WTEIR model was developed by Ricketson, Brown & Graham (1980) in order to provide specific documentation of human error in error induced air crashes. The title of the model represents the questions that an investigator asks during the course of an investigation in order to establish the characteristics of the accident. This model recognises that there can be no analysis of causal information or development of preventative strategies if the required information about accidents is not made available from the findings of a crash investigation. The 3WTEIR model is designed to guide the accident analyst in the investigation of a crash. The investigator is firstly required to ask WHAT happened?, WHAT caused it?, and WHAT to do about it?

The information gathered is used to identify the task error (TE) that caused the accident. These are operator performances that deviate from the prescribed operations of the system, when it can be established that a correct performance by a person of normal or reasonable competence was possible. The inadequacy in the system that created the task error (I), and the remedial measure that is required to prevent the inadequacy reoccurring (R) are also identified in the model.

Task errors are created by an overload in the pilot-aircraft interface, which occurs when an element of the system does not operate in the manner in which it was intended or designed to. This imbalance can usually be traced to an inadequacy in the system at some point before the accident event. (More than one inadequacy can contribute to the accident sequence). The overload in the system forces the pilot to implement corrective measures while maintaining other normal system operations.

If the pilot is unable to correct the problem and maintain normal system function, errors are made. The consequences of these errors are determined by chance, and a near miss or an accident may result.

Remedial actions (R) can reduce the operational effect of the inadequacy by changing the nature of the energy transfer, and more than one remedy may be applied to one detected inadequacy. When the cause of the accident becomes known, the information can also be used to design a remedial action that will prevent the inadequacy acting as a trigger for other accident sequences.

Green (1985): Stress and Pilot Performance.

Green (1985) suggests that various forms of stress are likely to affect pilot performance. Environmental stressors are factors such as vibration, temperature or hypoxia which may lead to pilot incapacitation. Green adds that the primary environmental stressor that civil pilots will encounter is sleep deprivation, as the performance characteristics of the aircraft will limit the pilots exposure to factors such as altitude related oxygen deprivation.

Research by the Royal Air Force is cited by Green to suggest that environmental stresses are a low incidence factor in the 70 crashes investigated. This is substantiated by the findings of the Confidential Human Factors Incident Reporting Programme (CHIRP) in the United Kingdom, which suggest that environmental stresses, excepting sleep deprivation, are not a major causal factor of incidents in general and civil aviation.

A second type of stressor in aviation is acute reactive stress. This is the 'fight or flight response' to threats to the pilot's safety. Green cites the body of research that suggests that reactive stress will lead to increased arousal in air crew, but evidence gathered from CHIRP suggest that these stressors tend to disrupt responses rather than facilitate them.

Life stress concerns the stress on a pilot from life, or non-flying, events. These events are most often domestic, but the actual rate of impact on accidents cannot be determined as these factors are seldom considered in accident investigation. Green argues that lowered performance levels result from two factors.

Firstly, pilots may become so pre-occupied with their non-flight problems that their risk assessments in flight become under-estimated, as flight problems become 'trivial' in comparison to their other problems. Secondly, a preoccupation with a problem at home will impinge on limited information processing channels, so that frequently executed tasks become automated. Inappropriate responses may be emitted, or actions insufficiently monitored, and errors made. This work suggests that it is possible to identify at risk pilots, and develop some way to either remove pilots, or encourage them to remove themselves from the aviation system.

Vail & Eckman (1986): Biographic Influences on Accident-Involvement

Vail & Eckman (1986) compared rates of accident involvement on the basis of pilot sex from information gathered by the National Transportation Safety Board from 1972 to 1981. They found that there was a statistically significant difference in accident involvement between male and female pilots, even when data were controlled for different levels of flying experience and levels of exposure.

Male pilots between 30 and 44 years, had the highest rate (42%) of accident involvement. Private pilots were involved in the most accidents (again 42%), when the sample was examined for differences between various levels of flight. Individuals with low flying time on the type of aircraft in which the accident occurred were involved in 55% of all crashes. The data concerning the relationship between total flying experience and accidents suggested that as experience increased, crash involvement was higher.

In the three categories of flying experience (0-99, 100-999, and 1000-10000 hours) the rate for involvement rose from 16.7%, to 39.8% and 42.8% respectively. While this may simply reflect an exposure effect of accident occurrence, these findings do suggest that there is some quantitative differentiation in accident involvement for some pilots.

Schwartz (1988): Error Chains.

In a sequential model which identifies eleven types of pilot error, Schwartz (1988, 1990) suggests that accident prevention is a matter of breaking the sequence of accident inducing causal factors. However, accident avoidance is dependent on situational awareness. Flight crews need to be aware that the way the aircraft is being operated increases the risk of an accident.

Eleven clues within a cockpit system indicate when an error sequence is developing, if the flight crew are able to detect their presence. These eleven clues are:

1) Ambiguity: when two or more independent sources of information do not agree.
2) Fixation or preoccupation: when air crew attention is focused on one thing to the exclusion of all others.
3) Confusion.
4) Violating minimums: violation of defined minimum operating conditions or specification, as defined by regulations or flight directives.
5) Undocumented procedures: use of unapproved procedures to deal with normal, abnormal or emergency situations.
6) Failure to monitor progress and state of flight.
7) Failure to gather information from outside aircraft.

8) Failure to meet targets.
9) Unresolved discrepancies.
10) Departure from Standard Operating Procedures (SOP's).
11) Communication breakdown.

These links will tend to occur sequentially, and will not necessarily be related to each other or apparent to the flight crew. Schwartz recommends training in situational awareness as a means of ensuring that flight crews are actively collecting information that allows them to detect these errors.

Reason (1991): Latent Failures.

Reason (1991) suggests that accidents or emergencies develop when latent failures in the aviation system are activated in the presence of other, active causal factors. Latent failures are present in the system well before the accident event occurs. They are decisions or actions that have dormant consequences, which only become evident when combined with local, or active, triggering agents.

These active factors are individually insufficient to cause an accident, but are necessary for the accident conditions to develop. Accidents in complex systems that have built-in defence mechanisms do not result from single causes, but from unforeseen and unpredictable interactions between active and latent factors.

Active agents, or triggers, can be characterized as human failures at the point of direct operator-system interaction. They are errors or rule violations that have immediate consequences. Because of their nature and the highly visible link between their presence and the actions of operators, these errors are most likely to be detected and cited as primary causal factors in accident investigations.

Latent failures are more likely to be caused by individuals who are spatially and temporally removed from the human-machine interface (management decisions for example). Figure 3 shows the Latent Failure model.

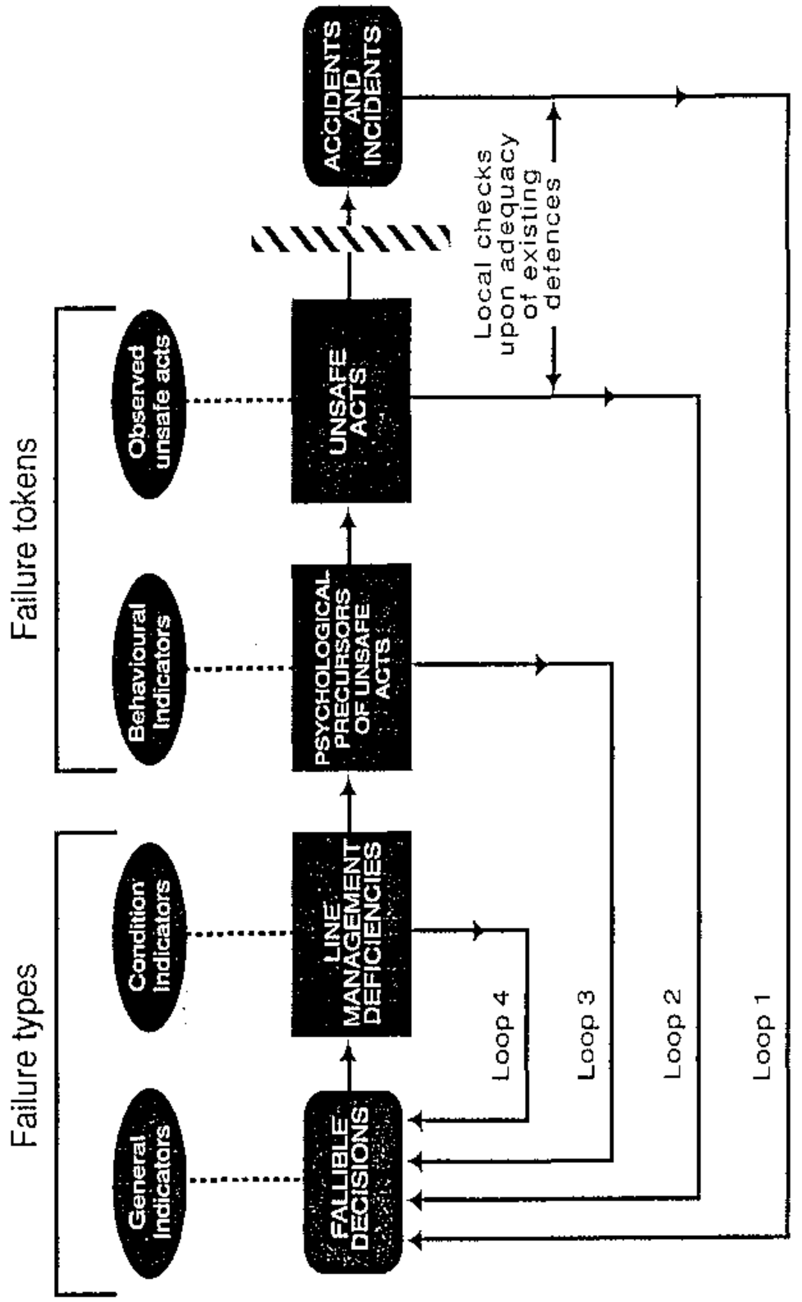

Figure 3: The Latent Failure Model. [Source: Reason, J. (1991). The Contribution of Latent Human Failures To the Breakdown of Complex Systems. Journal of the Australian Bureau of Air Safety Investigation, 9 (September), p. 11.]

The line management decisions that produce errors may include faulty training programs, maintenance deficiencies, or inadequate procedures. The psychological precursors of unsafe acts are latent states in the operators that will create the potential for unsafe acts. They are primarily the result of failures in training. Barriers are specific engineered safety devices intended to limit the damage resulting from the release of energy associated with the accident. Accidents can only occur if there is a "limited window of opportunity" (Reason 1991, p. 6) in this defence system.

Failure tokens in the figure represent the direct causes of the accident which can be found among the events that immediately precede the accident. Wagenaar & Reason (1990) argue that there are an infinite number of possible failure tokens contributing to all possible accident occurrences.

However, these tokens are produced by generalised failure types which are present in events that have few common characteristics in their surface appearances. These causes of accidents are hidden 'deeper' in the accident sequence, and are more removed from the events immediately preceding the accident. Reason argues that by eliminating failure types, failure tokens would also be removed from accident sequences.

The feedback loops in the figure represent ways in which information can be gathered about accidents. Loop one represents traditional accident reporting, while the second mechanism uses information about unsafe acts gathered through 'incident' reporting. These two loops represent traditional points of information collection and intervention design.

Reason suggests that loops three and four are not generally used in organizations, but have the potential to be effective points of safety design because they can reflect failure types rather than failure tokens. However, he also notes that the collection of efficient and accurate information at these levels is redundant if the information is not acted on in an effective manner.

Section Two: The Driver in Road Transport Accidents

The models reviewed in this section identify and describe the factors which influence driver or pilot decision making rather than the accident process per se. While several information processing models of vehicle control have been developed (Fell 1976, and Janssen (1979, cited in Michon 1985), the strongest focus on operator error has occurred in studies of more general psychological processes. Information use models of driver behaviour have generally not considered the motivational forces that influence driver decisions to drive in a car that is unsafe, or to execute unsafe manoeuvres during the journey. Human error is in terms of the concept of accident proneness, theories of risk taking and risk perception, and the effect of social contexts on driver performance in this section.

While most of the models reviewed in this section have been developed from the study of road transport accidents, information relating to pilot characteristics and crash involvement is also examined.

Quenault (1968): Dissociation and Driving Style Model.

Quenault (1968, cited in Bristow, Kirwan, & Taylor, 1982) used systematic observations of driving behaviour to develop a four level model of the relationship between 'driving style' and potential accident involvement.

Motorists from the British public drove a 12 mile track accompanied by two researchers, who observed the frequency of occurrence of certain drive indices taken as representations of the cognitive and affective style of the driver (Shaw & Sichel 1971). These indices included the use of the rear view mirror in the car, the frequency that the driver overtook other vehicles, compared with the frequency that the driver was overtaken, and unnecessary manoeuvres.

Quenault developed a model incorporating four types of driving style from the results. He was able to identify general groups within which these four driving styles appeared to be predominant. Safe drivers were those drivers not involved in any near-accidents or unusual manoeuvres during the test. These drivers were described as people who take the necessary precautions, drive with anticipation and who are aware of what is going on in their environment. Injudicious drivers failed to use their rear view mirrors in over 25% of actions, and were involved in near misses. They were also marked by a tendency to engage in unusual manoeuvres and unnecessary variation in speed. Quenault identified 'dissociated active' drivers as those who overtook more cars than they were passed by, and who failed to use their mirror in over 25% of actions. He characterised these individuals as impatient and unpredictable. Dissociated passive drivers were "patient and stolid [with] a set pattern of driving behaviour [which was] to some extent irrespective of the demands of the situations" (Shaw & Sichel, p. 364). They did not use their mirrors, but were not involved in many over-taking manoeuvres.

A major component of the driving styles was the degree of dissociation of the drivers. This quality was linked to driver awareness of information required for a safe level of driving. Dissociated drivers appeared to have poor judgement, and a lack of awareness or anticipation of the situations they encountered. They appeared to be far less emotionally affected by near misses, which were usually accidents that had been averted by the skills of other drivers.

The results of the Road Research Laboratory work in this area have shown that there are definite patterns of driving behaviour. These may be associated with the ages of the drivers but, as suggested by Shaw & Sichel, could also be linked to aspects of 'personality'. Thus this study provides early support for Schwartz's suggestion that situational awareness is linked to accident involvement.

Models of Accident Proneness

Researchers' efforts to associate accident involvement with "enduring and stable personality traits, or innate personality characteristics that cause ...[people]... to be more susceptible than others to having accidents." (Voge 1989, p. 89) is traditional in safety research. The search for permanent indicators of individuals' potential for accident involvement is grounded in a belief illustrated by Tillman's (1949) statement that "man lives as he drives" (cited in Shaw and Sichel 1971, p. 158), and the review of research into epidemiological predictors for aviation accidents presented by Booze (1977).

McKenna (1982) defines accident proneness as the tendency for accident events to be distributed unevenly through communities, so that certain segments of a population are repeatedly involved in accidents. McKenna (1985b) also notes that the specific definitions of the behaviours that identify accident proneness tend to vary across researchers. This trend in the research can be found by reviewing some of the work done in the road transport field.

Brody (1963), McGuire (1976): Accident Involvement and Social History.

Brody (1963) describes accident prone individuals as likely to be distractible, impulsive, asocial and non-conforming, emotionally unstable, with exaggerated views of their ability. However, these individuals eventually stabilize their behaviours, and are no longer part of the population subgroup of accident repeaters. In this profile of accident prone individuals, involvement is attributed to interaction between peoples' base propensities for accident repeating, and chance factors such as exposure to hazards, stress, and inadequate senses of responsibility.

McGuire (1976) also attributes road crash involvement to 'general' driver personality. He comments that:-

> ... the higher the accident frequency, the more likely one is to be aggressive, prestige seeking... [with] a family history and current family relationships that reflect a high degree of disruption and conflict. (1976, p. 435).

These types of drivers are socially and emotionally immature, and more inclined to express aggressive emotions. Accident involvement is strongly associated with social skills and history, and these stable and inherent characteristics of drivers make many interventions redundant. The stable nature of these personality traits is relatively resistant to change.

Goodenough (1976): Field Dependency and Accident Involvement.

Goodenough (1976) examined field dependency (when perception is dependent on cues from the environment) in two groups of drivers differentiated on the basis of accident involvement. His model suggests that the task of a driver is to identify cues embedded in complex backgrounds (road signs against a background of lampposts), and that deficiencies in this skill can influence driver safety.

In the results of his research it was found that field dependent drivers were unable to differentiate elements of a complex scene into its component parts and therefore would not detect relevant warning stimuli. Field independent drivers were able to detect warnings and avoid accidents in the same experimental scenarios.

In aviation related research, there is also a strong body of literature which identifies a personality component in air crash involvement. Platenious & Wilde (1989) have been able to find evidence of a relationship between stable character traits and accident involvement. In a study of Canadian pilots, they found that there were significant accident involvement markers which included general life events and other factors in pilots' non-flying activities that were likely to have a preoccupying effect on their concentration. Although these terms encompass many factors, there were found to be similar effects across different types of pilots. A general willingness in pilots to take risks was also implicated with higher rates of crash involvement, as was a poor sense of humour and pilot arrogance.

Wolfe (1979): The Right Stuff.

As described by Wolfe (1979) the 'right stuff' is a phenomenon originating in the world of military (and especially naval) aviation. It works outside, and instead of, the military rank system to distinguish individuals from each other in terms of merit.

The amount of right stuff pilots possess not only determines their 'worth' as an aviator, but also acts as the primary ranking system in the community. Its effect is particularly powerful in dictating the types of behaviours that are expected from pilots, inside and outside of the aircraft cockpit.

Wolfe's book provides no explicit definition of the 'right stuff', but several quotes show the way in which this phenomenon operates. Bravery is a principle component of this quality, as indicated in the passage below:

> As to just what this ineffable quality was ... well, it obviously involved bravery. But it was not bravery in the simple sense of being willing to risk your life. ... No, the idea here ... seemed to be that a man should have the ability to go up in piece of hurtling machinery and put his hide on the line and then have the moxie (sic), the reflexes, the experience, the coolness to pull back in the last yawning moment - and then go up again the next day, and the next day ... (1979, p. 24).

Possession of this quality guarantees advancement in the aviation world:

> At every level in one's progress up that staggeringly high pyramid, the world was once more divided into those men who had the right stuff to climb and those who had to be left behind... (1979, p. 25).

Having the right stuff also demands behaviour befitting the status of (test) pilots. Pilots are expected to be heavy drinkers, reckless drivers, and to challenge the rules whenever possible. As described by Wolfe:

> Every unofficial impulse on the base seemed to be saying "Hell, we wouldn't even give you a nickel for a pilot who hasn't done some crazy rat racing [mock dog-fighting, or races in both aircraft and cars] ... It's all part of the right stuff (1979, p. 31).

> ... the system itself had said Skol! and Quite Right! to the military cycle of Flying and Drinking and Drinking and Driving, as if there were no other way. Every young fighter jock knew the feeling of getting two or three hours sleep and then waking ... having a few cups of coffee and a few cigarettes, and then carting his poor quivering liver out to the field for another day of flying ... remarking later "I don't advise it, you understand, but it can be done". [Provided you have the right stuff...](1979, p. 37).

These types of behaviours and elitist attitudes make up the right stuff. They affect decisions about flight after sleep deprivation, alcohol consumption, and general risk taking. If internalised by pilots, the right stuff myth may develop to become a stable response pattern. Although not a personality trait per se, right stuff attitudes and responses become an inherent part of flying behaviours.

Voge (1989): Failing Aviator Syndrome.

Voge (1989) identifies the characteristics of a short term condition (Failing Aviator Syndrome) that may produce behaviours associated with 'accident proneness' in pilots. Pilots with this condition tend to be involved in accidents as the result of errors of judgement, rather than errors of omission or commission. High accident involvement is associated with high levels of alcohol consumption, difficulty in interpersonal relations, egocentric perfectionism, and a poor sense of personal limitations (Reinhardt 1967, Alkov 1975, cited in Voge 1989). An association with high self opinion, resentment of authority and risk induced accident occurrence has also been found. There is some suggestion that the pilot may have internalized the 'right stuff' style of pilot behaviour, and this is reflected in the types of accidents that occur. Generally, pilots are involved in crashes that result from risk taking and stunt flying.

This condition is precipitated by over-exposure to stress, and its effects are compounded if the pilot initially has poor stress coping mechanisms. This model thus provides identifiable signs that pilots are performing tasks at less than optimum levels.

Lester & Bombaci (1984), Buch & Deihl (1984): Hazardous Thought Patterns.

More defined constructs of specific thought patterns and response tendencies associated with accident involvement have been developed by the research team at Embry-Riddle Aeronautical University (ERAU). Five antecedents to irrational pilot decisions and associated thought patterns (anti-authority, resignation and external control, impulsiveness, invulnerability, and macho) have been identified by Lester & Bombaci (1984), and Buch & Deihl (1984). Antidotes to them have been incorporated into many pilot training programs as Pilot Judgement Training (PJT).

The first pattern is anti-authority, and is associated with resentment towards any outside authority with control over pilots' behaviours. The second is a resignation to an agency of external control where pilots are fatalistic and feel that they have no control over their lives. An accident or near miss is attributed to an external force. The entity to which this control is attributed varies with cultural and religious beliefs.

Impulsiveness is phenomenon where pilots are likely to act quickly and implement the first possible course of action in a situation, while invulnerability thought patterns reflect an 'it won't happen to me' attitude. Pilots become convinced that their actions will not result in an accident and engage in undesirable behaviours. Over-confident (male) pilots tend to adopt a macho approach, and attempt difficult tasks for the benefit of an externalized (and possibly imagined) audience in order to prove superiority and gain admiration.

In a validation study to test the construct validity of these patterns, it was found that three of the response patterns accounted for 77% of responses. Invulnerability was the most common pattern accounting for 43%, while impulsive thoughts accounted for 20%, and a further 14% of the sample had macho responses.

Interestingly, anti-authority and resignation thoughts only accounted for 23% of the sample when combined. There is still some debate as to whether these two thought patterns are distinct from, and less common than the other three patterns. An opposing view suggests that macho, invulnerability and impulsiveness patterns are somehow linked to anti-authority and resignation response types. While there is still debate over the precise nature of these forms of human error, the evidence does suggest that there are stable and systematic differences between pilots in terms of dominant (and hazardous) thought patterns.

Ingham (1991): Social Context Effects.

Ingham (1991a, 1991b, 1991c, 1991d) suggests that the presence of passengers in a car produces changes in driver behaviour. The relationship between driver and passenger dictates whether these changes will be towards or away from safety oriented behaviour. Many explanations have been developed for deteriorations in driver performance in the presence of passengers.

Channel capacity theories suggest that, as information processors, humans have a limited capacity to attend to information. When a passenger enters the driving environment, the driver is distracted and unable to gather and deal with information effectively. Drive state theories attribute changes to social facilitation effects. Here, the presence of the passenger results in increased arousal in the autonomic nervous system, and performance is dictated by the individuals' most well learned response pattern.

Results of studies conducted by Ingham (op cit), Rolls, Hall, Ingham, & Mcdonald (1991), and Rolls & Ingham (1992) suggest that aspects of the social dynamics between the people in the car, such as evaluation apprehension and impression management, determine the nature of behavioural changes. Behaviour in social situations is predominantly governed by individuals' desire and need to create appropriate (and therefore favourable) impressions on others.

In order to build a reputation, an individual's behaviour is determined by social roles and their associated rules of conduct. Because individuals operate in different social worlds, their behaviours will change with the different roles that they perceive are expected from them. Hence, a teenager will drive recklessly with age peers, conservatively with parents (to ensure continued use of the vehicle), and will combine the two styles if driving to impress, but not frighten, an intimate friend. The process of acquiring a reputation is not dependant on the actual presence of passengers. Impression generation can be effectively achieved through story telling and word of mouth.

Economic Models of Human Risk Taking.

It is apparent that motor responses are not the only factors in accident occurrence, and that internal psychological mechanisms mediate crash involvement. Although these factors are not the stable and inherent personality variables proposed in accident proneness frameworks, there are situationally determined variables that affect pilot performance. These variables seem primarily to influence pilot information processing, and their propensity to engage in risk taking behaviours.

Some research into these phenomenon has been conducted by O'Hare (1990) who noted a tendency for optimistic self-evaluations by pilots. This self-appraisal was accompanied by relatively low levels of awareness of the risks and hazards associated with general aviation activities. Accordingly, subjects with these characteristics were more wiling to take risks. The representation of risk taking behaviours by individuals in the control of transport systems is therefore important in an investigation of pilot error effects.

Michon (1985) notes that there is a strong research body in the study of human risk taking behaviour in road transport environments. He identifies three major types of model: Risk Compensation (Wilde 1982, 1985, 1988), Risk Threshold (Naatanen & Summala 1985), and Risk Avoidance (Fuller 1984). These models are economic, or decision theoretic approaches to human risk taking behaviour. As discussed by Oppe (1988) these centre on the extent to which risky behaviour is governed by expected, rather than actual loss.

In Wilde's (1982) model, drivers seek to maintain the perceived level of risk at some acceptable threshold level, and only initiate safety behaviours when that threshold has been crossed. Fuller (1984) argues that safety behaviours are the result of threat avoidance, and that the recognition of the threat to the driver is dependent on the information processing and learning experiences of that driver. Naatanen and Summala (1985) suggest that drivers have a normal state of zero perceived risk to themselves, and only engage in safety behaviours when they perceive the risk rise above that level.

Wilde (1982): Risk Homeostasis Theory.

The basic premise in Risk Homeostasis Theory (Wilde 1982, 1985, 1988) is that when making safety related decisions, road users compare the level of risk to which they are exposed with the level of danger they are willing to accept. Inhibition and activation of responses is calculated economically. If costs outweigh benefits, actions are perceived as risky, and inhibited. If benefits outweigh costs, there is no inhibition of the action.

As described by this model, economic estimations of risk are only calculated with perceived consequences, and are not necessarily an accurate reflection of all the possible outcomes for an action. Wilde suggests that:

> ... due to inter-individual differences in danger detection skills, some individuals will incur more actual accident risk than matches their target level... (1988, p 444).

Individuals may make a calculation with only the information available to them, and incorrectly assume that an action is not risky. Normally cautious drivers may estimate a low risk to themselves, but their awareness of their own safety record prevents them from gathering enough accurate information to perform the calculation accurately.

When describing active risk taking, Wilde suggests that in some instances drivers may accurately calculate that an action has more costs than benefits and is therefore risky. But under some conditions, the risk of incurring costs is outweighed by the utility to the driver of the successful completion of that action. In these cases, action utility outweighs the inhibitive effect of the awareness of risk.

Under these responses to danger and risk, the only appropriate intervention strategies are those which increase subjective risk experiences for drivers, and reduce the utility of risky behaviours. Because drivers' perceptions of their own capabilities determine the discrepancy between actual and perceived, education is needed to increase subjective risk estimations. Interventions to improve car control skills may not modify individuals' accident likelihoods.

Increasing driver skill may have a counter-productive effect, as it may lower drivers' subjective evaluations of risk to themselves. This is borne out by the findings of Platenius & Wilde (1989), and O'Hare (1990) which show that generally pilots are prone to underestimate the risks that they are exposed to when flying, and to overestimate their abilities to cope with any problems that might be encountered. A similar effect was reported by Star (1969, cited in Slovic 1987) where pilots estimated the risks associated with flying at a lower level than college students, and 'experts'.

Slovic (1987): Risk Perception and Voluntary Exposure to Danger.

Some explanation for this apparent overconfidence in general aviation pilots can be found in the work of Slovic (1987), who suggests that risk perception changes according to the amount of dread fear associated with the activity. He cites Starr (1969) who sampled risk perceptions of individuals with regard to various activities. The results showed that people accept levels of risk 1000 times greater for voluntary activities than for involuntary ones, even if the activities provide the same level of benefits. This suggests that voluntary exposure is a key mediator in risk acceptance.

Slovic used factor analysis to identify two factors that appear to determine risk acceptance. The specific characteristics of these factors are shown in Figure 4. The dread fear of an activity is determined by the perceived degree of control over the activity, the catastrophic potential of the event (number of people affected by a single mishap), the equity of any costs and benefits involved, and the extent of potentially fatal consequences. Activities scoring highly on measures of dread risk are perceived as risky, and requiring strict legislative control. Unknown risk reflects the extent to which hazards within the activity or technology are new, unknown and undetectable.

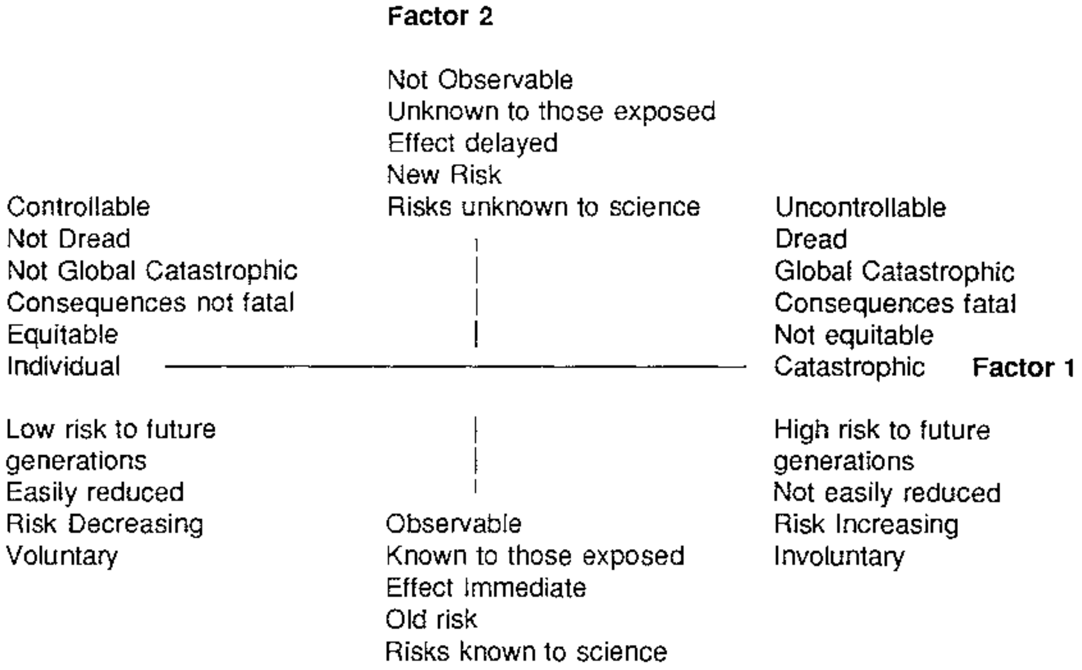

Figure 4: Characteristics of Factors Associated with Risk Acceptance. [Source: Slovic, P. (1987). Perceptions of Risk. Science, 236(4), p. 282.]

Thus, it can be seen that pilots may believe that they are fully aware of the risks associated with aviation, and are able to control them. Accordingly, they develop an overconfidence in their estimations of the danger to which they are exposed.

Fuller (1984): Risk Avoidance.

Fuller's (1984) model is a behavioural analysis of the responses of drivers confronted with warning stimuli. These stimuli are associated with aversive properties from a learned association between the stimulus and some form of hazard. Risk taking in this model is the result of incomplete or faulty learning of the implications of warning stimuli. Risk taking behaviour can be learned if the association between warning and negative consequences is weakened.

Following the presentation of a warning, drivers can make an anticipatory avoidance response which, when completed, will render any subsequent need for warning stimuli irrelevant. Anticipatory responses are a reflection of the information processing skills of the driver. These skills include a knowledge of the conceptual rules of driving, as well as active information searching and processing.

Should drivers fail to make an anticipatory response, two possibilities emerge. The first is that the behaviour is maintained, and the actual hazard is encountered. The driver than has to make a delayed response to the hazard. In comparing anticipatory and delayed responses, it can be seen that anticipatory responses have a higher utility for crash avoidance. Initially this is because more time is available, with no reliance on car control skills for crash avoidance.

If vehicle course is maintained and no hazard encountered, the driver begins to perceive inconsistencies in the accuracy of the warning stimuli. Risk taking behaviour becomes more likely, as the contingency that maintains the aversive nature of the warning has been weakened.

Accident involvement is the result of faulty learning experience, where a driver has not learned response consequences and is unable to recognise aversive (warning) stimuli. Risk taking occurs because no aversive consequences have resulted for the driver from actions in the past, so the behaviours have no negative value. Drivers are unaware that their safety is threatened, and therefore initiate no compensatory behaviours.

Naatanen & Summala (1985): Risk Threshold.

The Risk Threshold Model (Naatanen & Summala 1974) suggests that perceived risk is calculated by the driver as the product of the probability of a road crash occurring, and the cost of such a crash. Thus;

subjective risk = crash probability X crash cost.

The theory suggests that, under normal circumstances, drivers perceive risk to themselves as nil, even though there are inherent risks in the driving activity. It is only when this perception is altered and drivers believe that they are at risk, that compensatory or safety oriented behaviour emerges. In this model, drivers react to avoid risk, rather than act to incur it (Summala 1985).

When the perceived level of risk exceeds zero, drivers will avoid danger by inhibiting risk taking behaviour. Safety interventions using skills training are again largely redundant, because compensatory action is only undertaken when the driver feels that they have crossed the threshold of the acceptable risk. Education is needed to alter subjective risk evaluations.

The results of risk research remain controversial. The economic models of risk behaviour demonstrates the extent to which decisions to engage in risk is a function of expectations of loss. In light of information about hazardous thought patterns, it can be seen that interventions need to alter pilots' perceptions of the dangers that they encounter in aviation. Slovic 's work explains the apparent over-confidence of general aviation pilots in terms of pilot familiarity with the environment, and the extent to which pilots believe that they have control over the system. Research developed around accident proneness concepts has isolated less concrete internal psychological influences on risk taking behaviour. As yet, there is no synthesis of these ideas into a single explanation of human risk taking behaviour, and no representation of the influence on risk taking on accident sequences. A more general model is needed which will incorporate some of these findings into a framework that can capture the accident sequence.

Thus, while research evidence gives strong indications that there are certain behaviours which are primary influences on accident involvement, little specific information to aid the development of intervention strategies is given. It has been determined that social context effects, stresses, and risk taking mechanisms form situational and environmental factors that influence pilot judgement and decision making in a manner that had previously been modelled as 'accident proneness'. The impact of these variables must be considered in accident investigation and prevention.

Section Three: Human Error in Industrial Accidents

Information already discussed has shown that human error is one of the primary causal agents in aviation accidents. Information processing and decision making are the cognitive processes associated with these errors. Studies of road transport accidents show that 'soft' psychological factors (risk taking, social context and general pre-disposition to err) are also important considerations in the analysis of the accident process.

In the models reviewed in the last two sections, there has been little apparent amalgamation of these 'hard' and 'soft' psychological factors that are implicated in crash involvement. Models have generally represented pilot/driver system control to be a function of information processing activities, without considering other psychological influences on behaviour.

Accident models developed in industry may provide the inclusion of soft variables that appears necessary for the consideration of all factors in the aviation human error sequence. Selection of the models reviewed in this selection (and in the overall chapter) is based on the extent to which the models have defined and specified human error. Thus, relatively major works have been omitted from the review, while other less widely known models have been included. The prime criteria for the inclusion of models in this section has been the extent to which a detailed breakdown of human error is available. This facet of models was considered in isolation of the overall detail of the accident process.

Thus, the cognitive engineering approach of Rasmussen (1982), which details cognitive activities in problem solving, but does not present an accident sequence per se, is included over more general models of accident occurrence such as the Manning Framework (1974), or Perrow's description of the Normal accident (1984). Kjellen's Deviation Model (1984a, 1984b) is a general description of the accident process derived from an extensive review of accident literature. This model does not consider individual accident inducing agents, so human error is not defined to the degree required in this study. A similar deficiency prompted the omission of Johannsen's (1988) application of the Skills, Rules, Knowledge Model of cognitive behaviours developed by Rasmussen (1983, 1986, 1987a, 1987b) to the task of Fault Management in problem solving. While the model was concerned with the information processing and decision making activities of operators, there was no identification of the errors associated with those activities that may induce accidents.

The Management Oversight Risk Tree (Johnson 1975), a widely recognized fault tree analysis of accidents, is only reviewed in part. Three of the 13 sub-components are used to examine human error phenomena. The remainder of the model is not reviewed, on the grounds that an extensive investigation of management structures in accident occurrence is not as relevant to this aviation related research as is a thorough representation of accident inducing pilot behaviours.

Heinrich (1931): Domino Theory.

Possibly the earliest attempt at developing a model of accident sequences, Heinrich's Domino Theory (1931, cited in Heinrich & Granniss 1959) can also be presented as a description of human error mechanisms. Five mechanisms of accident occurrence are identified in the model, each activating the following component. The first three factors are those which create the conditions in which the accident occurs.

Although the components that form the model can be compared with aspects of the widely discredited theory of accident proneness, it can be seen that the first domino in Figure 5 (ancestry and social environment) considers the role of recklessness and other aspects of the operator's environment and behaviour that may influence accident involvement. Heinrich is especially concerned with "undesirable traits of character that may be passed along through inheritance" (1959, p. 15), or be passed on through environmental influences.

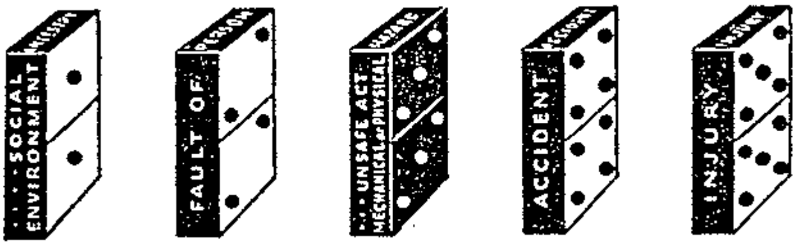

Figure 5: Domino Theory. [Source: Heinrich, H.W. & Grannis, E.R. (1959). Industrial Accident Prevention: A scientific approach. (4th Ed.). New York:McGraw-Hill, p. 14].

Faults of the person include recklessness, violent temper, and inconsiderateness. This may cause unsafe acts to be committed, or hazards to be present in the environment.

These two dominoes represent aspects of the cognitive and emotional qualities of the operator which produce the unsafe acts that initiate the transfer of energy in the sequence. Unsafe acts can occur directly before the accident event, or act as latent errors (Reason 1991) to impede the performance of safety barriers.

Factors considered in the examination of these acts include the communication accompanying actions (warnings and authorization), the speed of operation, the safety of equipment and the position used, the use and effectiveness of safety equipment, and the attitudes of the staff involved. They are also translated into the unsafe physical and mechanical conditions that result from these behaviours, and can include the absence of safety equipment, inadequate lighting, and poor housekeeping procedures.

Surry (1969): Decision Sequence.

Surry (1969) presents a sequential model of 12 points in problem related decision making. She suggests that the development of an accident occurs in two stages. Initially a safe situation becomes unsafe, and this unsafe situation then develops into an accident event. Within these cycles, Surry identifies three phases of information processing. The first is a perception phase, which examines the information input to the operator. The second phase examines with operator cognitive processes, while the third questions the operator's ability to carry out their intentions. In Figure 6, these are labelled perception, cognitive processes, and physiological response respectively.

The events that lead to an accident initially function as indicators that a dangerous situation is developing. They warn an operator that a secure situation is being changed in some way to become a dangerous one. The factors that facilitate this change are present in the wider environment of the individual, and can occur long before, and in locations far from the accident site. Surry shows this in the 'man and environment' component at the very start of the model.

Surry suggests that the changes preceding accident events can be halted under certain conditions of information use and response by the operator. These conditions are represented by the questions that form the twelve points of the sequence. They are asked by the accident investigator, and are answered as either 'yes' or 'no'. Any negative response to these questions will result in the situation progressing immediately to the extreme states in both cycles of the model. That is, danger build-up becomes a state of imminent danger in the first cycle, and the threat of danger release becomes damage in the second cycle. This change is shown by the arrows in Figure 6.

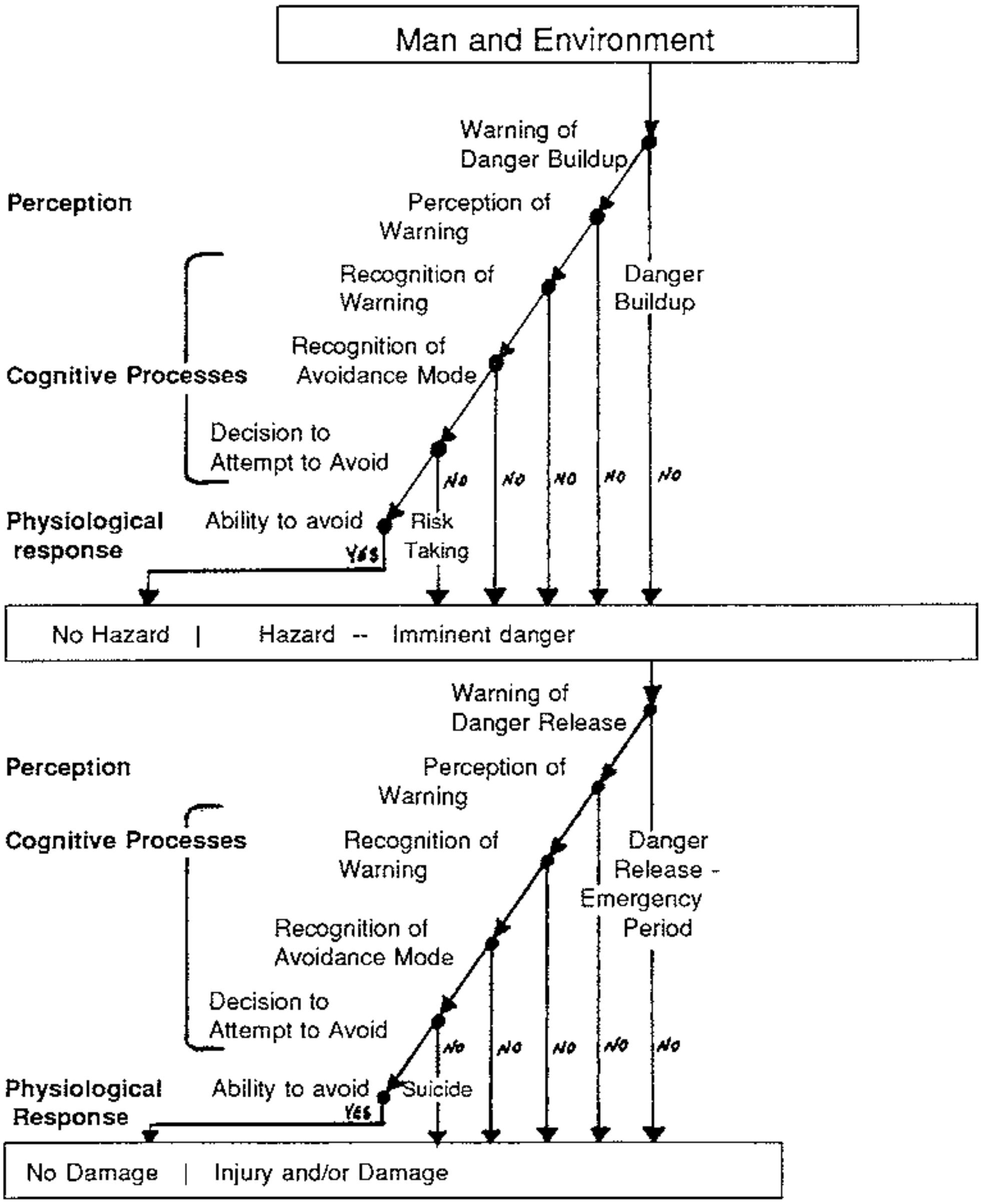

Figure 6: The Surry Decision Sequence. [Source: Surry, J. (1969) Industrial Accident Research: A human engineering appraisal. Toronto:University of Toronto, p. 36.]

A single positive response leads to the next question in the sequence, and a 'yes' response throughout the sequence breaks the flow of events and leads to the avoidance of the accident. The model focuses on the amount and relevance of the information received by the operator; was it sufficient for understanding the situation; was the information used correctly in formulating a response to the situation, and was the operator able to physically implement their action choice for accident avoidance. Human error can occur at any one of these points, and is represented by a 'no' response.

Representation of cognitive processes is strengthened by the inclusion of suicide and risk taking as possible explanations for operator failure to attempt to avoid danger. This allows consideration of the soft psychological variables that have already been shown to influence levels of accident involvement.

Benner (1975): Perturbation Theory.

Benner's Perturbation Theory (P-Theory) attributes accident occurrence to a failure by operators to adapt to unusual or unexpected changes. In this model, operators are 'actors' engaging in a set of successive, goal-driven events or activities. These activities occur in an environment of varying external influences which force actors to maintain a level of homeostasis in the task by engaging in adaptive behaviours. Homeostasis can only be maintained if actors are not overextended in their efforts to cope with the perturbations that occur when environmental factors differ from the expected or the usual.

If an actor fails to cope, an accident sequence is initiated. This loss of homeostasis serves to further over-stress the actor, leading to injury and harm. A near miss is a situation where a perturbation has resulted in an initial loss of homeostasis, but the actor has been able to adapt to the situation before damage results.

However, the P-Model also recognises that the external conditions which lead to system perturbations are the outcomes of their own influencing factors. These can also be analyzed as causal factors in the accident sequence. Thus, factors which are temporally remote from the actual accident event can be identified and modelled.

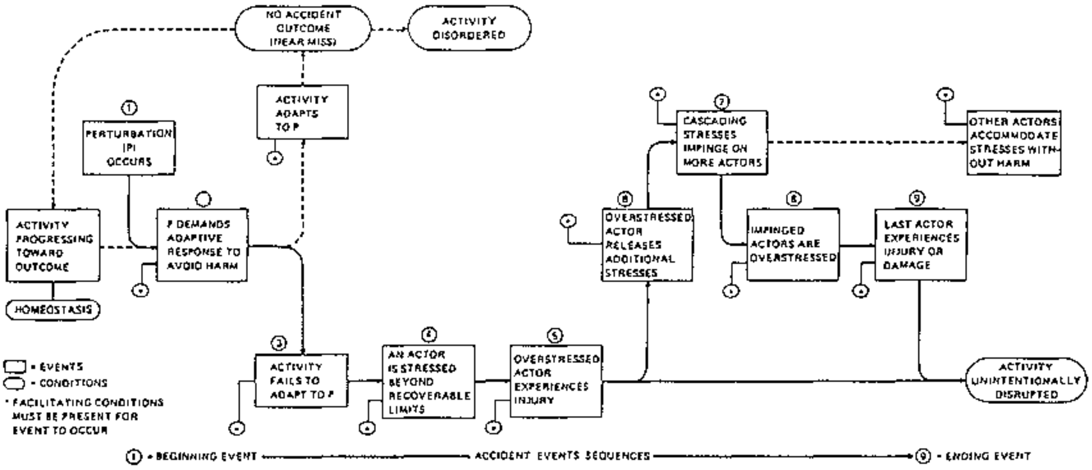

Figure 7: General Explanation of the Accident Phenomenon. [Source: Benner, L. (1975). Accident Investigations: Multilinear events sequencing methods. Journal of Safety Research, 7, p. 69.]

The primary factor in the accident is not the transfer of energy to the individual, but the loss of control that makes that transfer possible. Benner does not elaborate on the nature of the conditions that cause this loss of control.

The model does encourage accident investigators to examine factors in the accident sequence that might not be apparent at the crash site, but offers no further guidance about aspects of operator behaviour to consider.

Johnson (1975): Management Oversight Risk Tree (MORT).

Johnson's Management Oversight Risk Tree (1975, 1980) uses the premise that while no accident sequence is the same, common elements are repeated. These are the most useful targets for preventative strategies. The model seeks to describe the sequence of accident events and does so by searching for disturbances in the system's functioning. It focuses on three primary factors in accidents: specific oversights and omissions, assumed risks, and general management system weaknesses.

The complete analysis method is a complex fault tree. It commences with the undesired events that released energy into the system and created the accident. The tree then uses symbols to graph the relationships between the causes and consequences of those events.

This breakdown proceeds through four tiers, which become increasingly removed from the accident event, and two streams which consider management and system control factors. Johnson describes these streams as answering questions about what happened (inadequacies in system control) and why these events occurred (inadequacies in management factors).

Using an energy model of accident occurrence, Johnson defines an accident as the result of an unwanted energy flow into the system. This energy flow is not controlled by the safety barriers in the system, and goes on to injure or damage people or objects in its channel. The initial undesired energy flow was made possible by inadequacies in the generalised problem areas that form the lowest tier of the model.

In the process of analysing accident events to the specific components of these problem areas, MORT identifies 13 different sub-systems (A to L in

Figure 8) which influence the release of energy and the consequences of the presence of the energy in the system.

For example, the amelioration subsystem (A in Figure 8) requires descriptions of the extent to which a second accident was prevented, the adequacy of emergency actions, the medical services and rehabilitation services that were available, and the management protocol for post-accident requirements.

Many of the questions related to the performance of these subsystems during the accident are concerned with the ways in which the release of the unwanted energy could have been prevented or diverted away from the operators in the system.

Examination of the management related sub-sections shows that there is little application for their questions to a system such as aviation, where direct control of system operators is limited. While the analysis of factors such as the standards and regulations for flight may show poor control and unsafe practices, an examination of the components of human error would be more valuable for lowering accident rates.

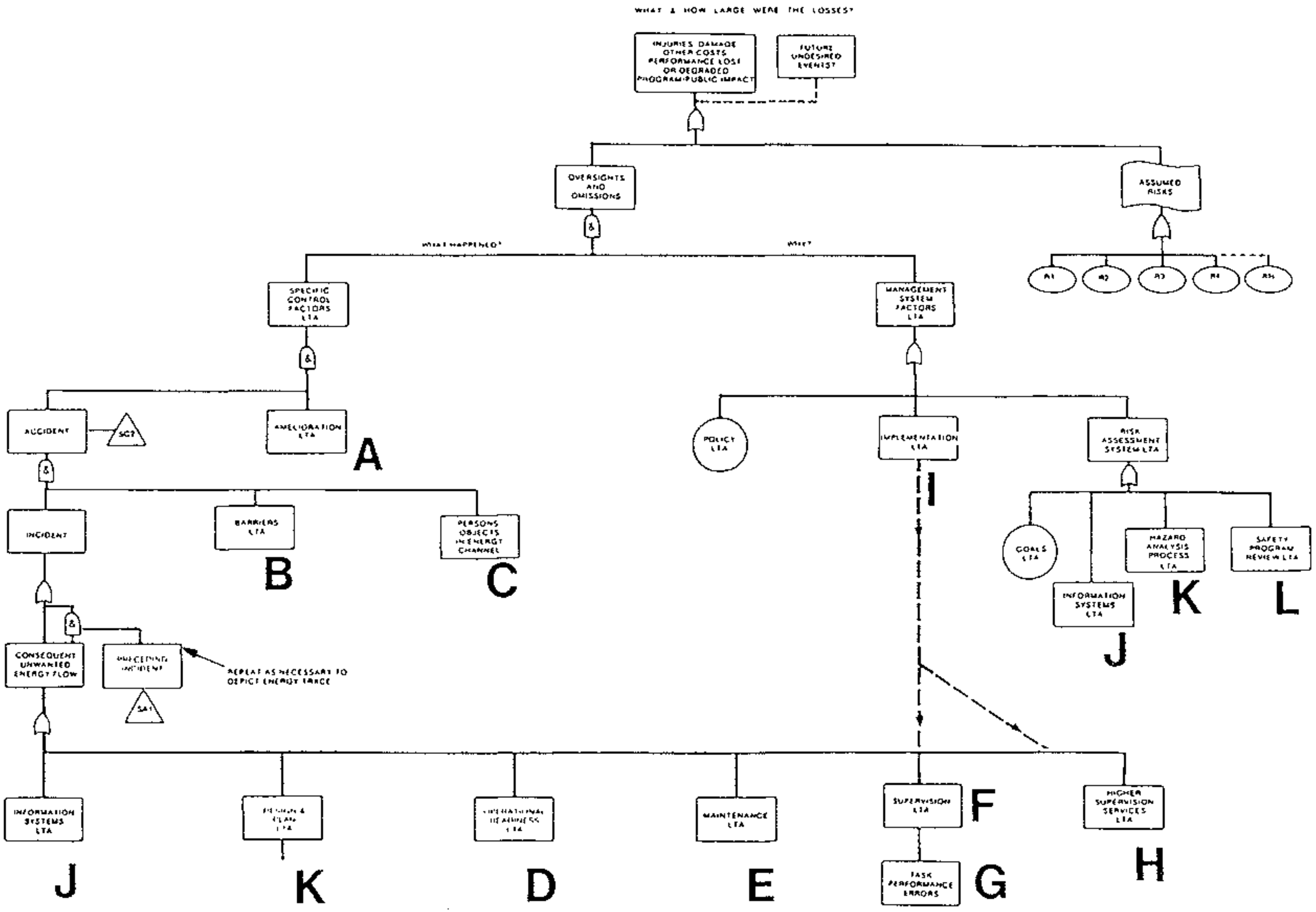

Figure 8: The Management Oversight Risk Tree. [Source: Johnson, W.G. (1980). MORT Safety Assurance Systems. New York:Marcel Decker, p. 160.]

Three of the 13 subsystems contain questions that can reflect human error aspects of accidents. Subsystem C contains questions about the presence of personnel in the energy channel during the accident sequence. This sub-system branches into two sections, which consider the presence of non-functional and functional personnel respectively. The second question for this section asks whether the evasive action of the individual was adequate or inadequate. Inadequacy might occur because of a failure to act, or as a result of situational conditions which made it impractical to act.

Sub-system E examines the maintenance of the system, where a distinction is made between preventative and inspection dependent maintenance. This part of MORT allows latent errors (as described by Reason 1991) to be examined more closely. MORT asks whether there was enough breadth in the plan of maintenance to include all aspects of the system that needed to be inspected and maintained. It also questions whether the execution of the maintenance plan was sufficient to prevent or reduce the effects of an accident. The questions in this section could identify the introduction of a latent error from inadequate or incompetent maintenance.

Sub-system G investigates the presence of Task Performance Errors in accident occurrence, and is the most specific analysis of human error in MORT. This model uses criteria based on Job Safety Analysis (JSA) to assist in the detection of task performance errors. The flowchart concentrates initially on the presence of JSA's for system operators, but also examines whether the accident was the result of Personnel Performance Discrepancies. The model can identify accidents that result from operator failure to perform tasks in accordance with procedures, or in the process described in the JSA.

There are also questions regarding the motivations of the individual in control of the system. The section examines two aspects of operator behaviour that are of interest to aviation research: the payoff matrix for safe and unsafe behaviour, and the occurrence of errors in responses to emergencies, which then create a new emergency or exacerbate the existing one. Here, there can be consideration of the degree to which pilot risk taking, and the culture which is associated with aviation (the Right Stuff, Wolfe 1979) contribute to aircrashes. There can also be investigation of the extent to which pilots can correctly remedy an undesirable condition during flight.

Although a complex description of the many factors that are implicated in accident occurrence, this model provides little representation of the accident sequence. There is not opportunity for relating the cognitive processes that may have contributed to the accident to the time line in which they occurred.

Further, MORT's size and detail make it unwieldy for the investigation of air accidents, where the amount of information about the accident sequence and causal factors is limited. In general aviation, it is doubtful that enough information could be gathered by investigators to make full use of the model. The scrutiny of management systems that is integral to the MORT Model becomes redundant in the aviation environment, where these mechanisms are not present.

Rasmussen (1982): Taxonomy of Human Error.

Rasmussen (1982, 1983, 1986, 1987a, 1987b) has developed a theory of human error which actively strives to move away from the concept of guilt that attributes causality for an accident to a human operator (Rasmussen 1987a). Instead, human errors are presented as the results of human-task or human-machine mismatches, which are generally the results of variability in either the system or the human controlling it. If identical mismatches occur repeatedly, errors are the result of design faults and can be corrected relatively easily.

Rasmussen identifies two forms of variability in the system: human error and component failure. Human error is described as the result of "unsuccessful experiments in an unkind environment" (1986 p. 150). He argues that the optimization of performance inherently involves experimentation in responses to situations. If these 'experiments' occur in an unkind environment, where there is no possibility for the operator to correct the effects of their (inappropriate) actions before they activate the undesired system response, then the experiment is categorized as an error. He argues that "human variability causes problems, and at the same time, is closely related to human learning and adaption" (1986, p. 151).

Therefore, variation in human performance is a problem solving behaviour. Rasmussen (1983, 1986, 1987b) has developed the Skills, Rules, Knowledge (SRK) Model of these responses and the three cognitive levels at which they occur. At each of the three cognitive levels, he identifies faults that can occur, which then become 'psychological mechanisms of human malfunction'. This model is presented in Figure 9. In this figure, the control of behaviour is represented as a three tiered hierarchy. Changes in the level at which problem solving behaviour occurs is related to operator familiarity with the environment. Decreased familiarity with the environment prompts cognition at a higher level in the sequence.

Skill-based behaviours occur with environmental familiarity, and are characterised by a high level of response automation. Performance is a sequence of skilled sub-routines that are selected from a large pool of alternatives. Information flow (depicted by the arrows in Figure 9) is controlled by feature formation.

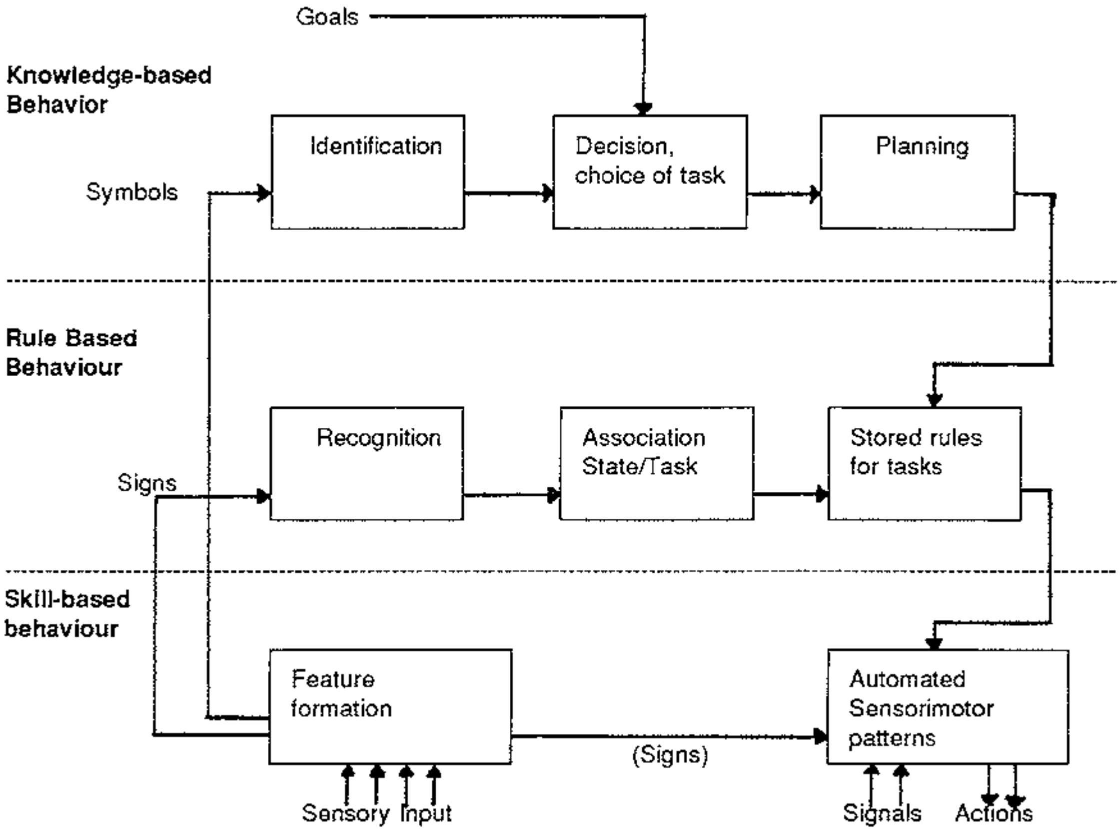

Figure 9: SRK Model of the Cognitive Levels of Behaviour Control. [Source: Rasmussen (1986). Information Processing and Human-machine Interaction: An approach to cognitive engineering. New York:North Holland, p. 155.]

This feature formation appears to be a psychological mechanism which serves to recognise or order information into meaningful patterns. During skill-based behaviour, information can act as a time-space *signal* and directly activates a pattern of sensory motor response, by-passing the feature formation process. Information can also be perceived as a *sign*, and activate a pre-determined sequence of skilled subroutines.

During rule-based behaviour, all data are perceived as signs. These are recognised and associated with rules for actions. From this recognition and association, stored rules are activated, which produce a sequence of sensorimotor response.

At the highest level of processing, information is perceived as a *symbol*.

This gives the operator access to concepts related to the functional properties of the systems, and therefore enables reasoning and planning. At this level of information processing, the situation has to be initially identified, and used in conjunction with mental models to form a decision. In order to achieve goals, this leads to planning procedures which initiate stored rules and sensorimotor responses. As shown in Figure 10, failures in this process of information flow occur in skill and rule based behaviours.

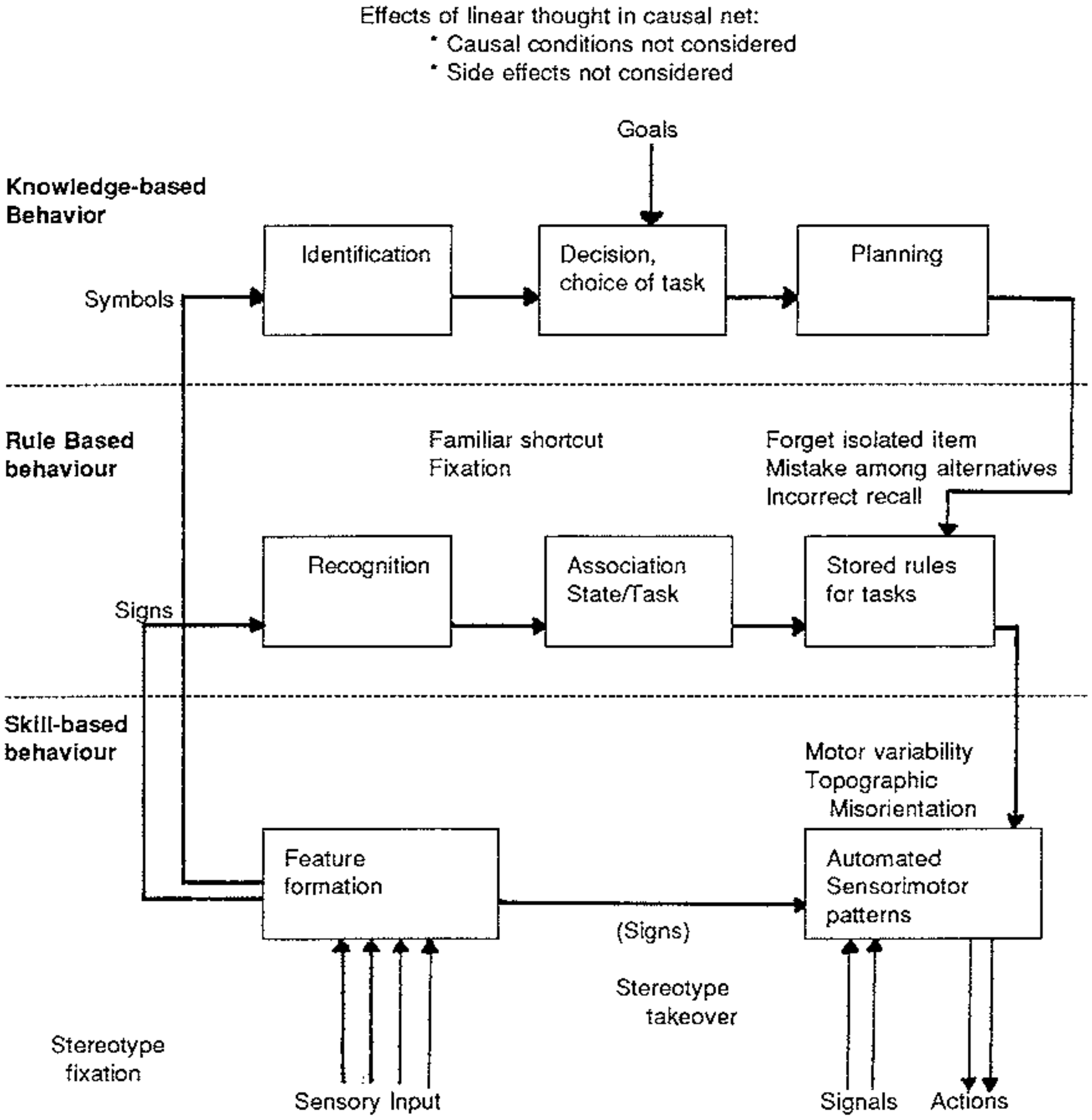

Figure 10: Errors in Cognitive Control of Behaviour: The Psychological Mechanisms of Human Malfunction. [Source: Rasmussen (1986). Information Processing and Human-machine Interaction: An approach to cognitive engineering. New York:North Holland, p. 155.]

In some cases, schema are activated that involve long sequences of acts. However, interference from *stereotype takeover may occur* when the attention of the operator wanders towards the consideration of other (future or past) actions. The activated schema is replaced by another schema which may reflect the change of attention, or familiar actions of the operator.

Stereotype fixation occurs when a sensorimotor schema is inappropriately activated, despite operator knowledge of the correct course of action. It is often found that everyday responses have been emitted in contexts in which they are highly inappropriate.

Rule based behaviours are subject to interference from *familiar short-cut fixation* (also described by Leplat & Rasmussen (1984) as *mental traps*). Evidence collected by Rasmussen suggests that highly skilled workers with choices from many alternatives will not switch to required analytical reasoning if they recognize a familiar pattern in information being processed.

The mental trap occurs because information received after a decision is made is rarely used to re-evaluate the situation. Instead, the operator responds to a known cue that is an incomplete part of the available information. Observations of sequential data are not recalled by operators, only the subjective evaluation of the information against their expectations. This is a familiar association short-cut (Rasmussen 1987b) is normally used to decrease mental effort during normal system operations.

Other errors occur at all three levels of cognitive control. At skill based levels, intrinsic human variability may result in errors in the performance of tasks that are highly familiar. These can be *motor variability*, where the time-space precision of operator control is inadequate for the task being carried out. Or, alternatively, topographic misorientation, which occurs if operators' internal world models lose synchronicity with the external world.

During rule-based behaviour, Rasmussen suggests that errors are most often the result of a faulty recall of rules. Here, operators may forget items that are isolated from larger memory structures, omit items isolated from the primary response sequence, or recall isolated items incorrectly. In familiar situations, operators may also introduce variability into the system through an incorrect selection of alternatives.

As familiarity changes, errors occur as a result of malfunctions in the process of adaption to variations in the task environment. The malfunctions that occur at the level of knowledge-based behaviour take two primary forms. Firstly, adaptation may not be possible because of constraints on knowledge about system functioning, the amount of data available, or because of excessive demands on the operator.

Conversely, adaptation may be unsuccessful because inappropriate decisions may produce actions that do not conform with system requirements. Errors may arise from the adoption of premature hypotheses, and *poor consideration of important conditions or unacceptable side effects.* These errors in internal information processes form part of the taxonomy of human error shown in Figure 11.

Because the relationship between task performance and internal human functions is not a perfect match, the taxonomy represents the cognitive process of decision making, the internal psychological mechanisms which produce error (Figure 8), and the external -influences on error occurrence (Rasmussen 1984).

The first part of this taxonomy considers the circumstances in which the error occurred: aspects of the *personnel task.* This box in Figure 11 contains components that are useful for task analysis. The *external modes of malfunctions* are the immediate and observable effects of the error, while the *internal modes of malfunction* describe aspects of the decision making process that were performed in a manner adequate for the task.

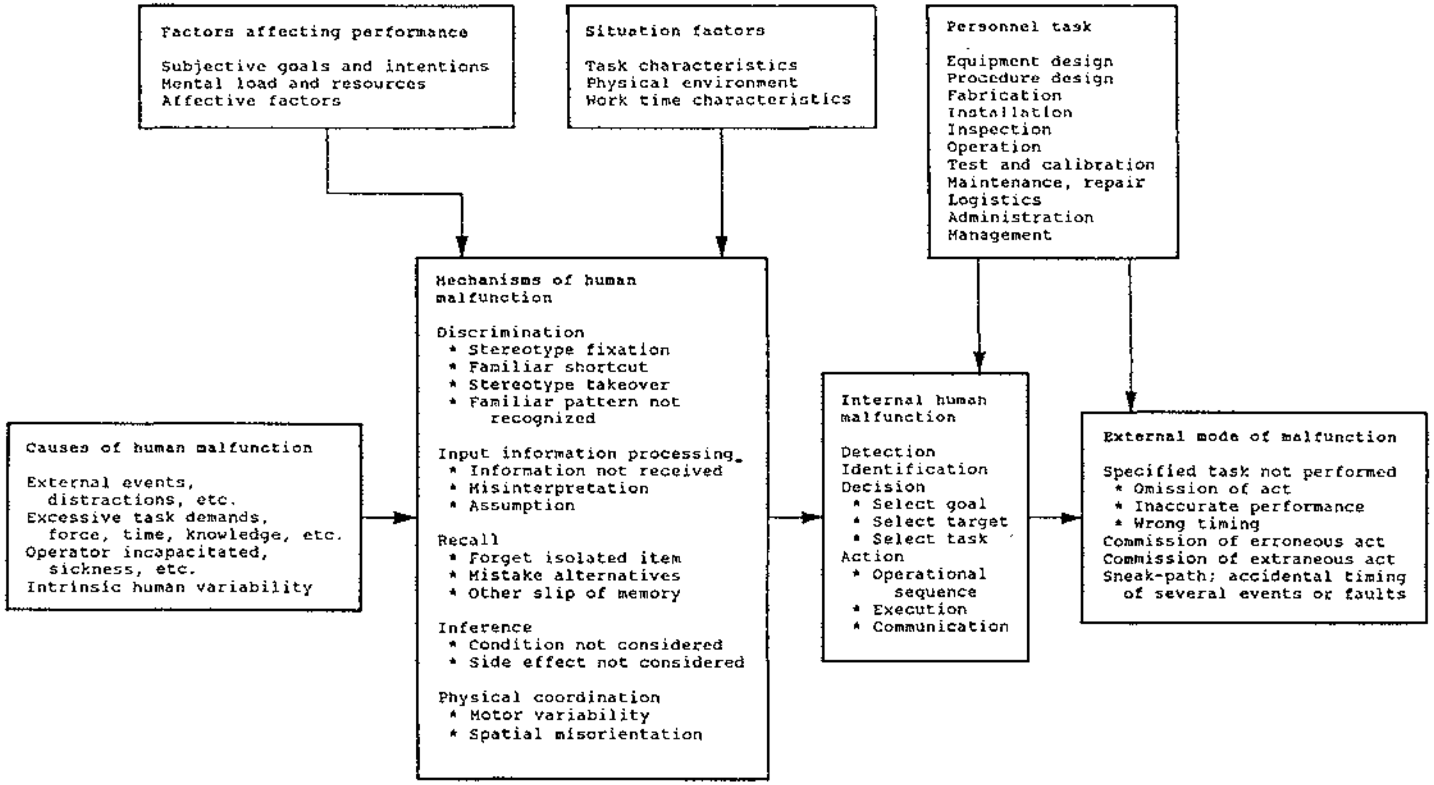

Figure 11: Taxonomy of Human Error. [Source: Rasmussen, J. (1982). Human Errors: A taxonomy for describing human errors in industrial installations. Journal of Occupational Accidents, 4, p. 323.]

The factors contained in the box identifying internal modes of malfunction are based on Rasmussen's decision ladder (1984, 1986, 1987a), shown in Figure 12. This ladder represents eight phases of information processing that occur during supervisory control tasks, and describes the change in operator information processing that occurs between the identification of a problem, the analysis of the situation and the development of a solution.

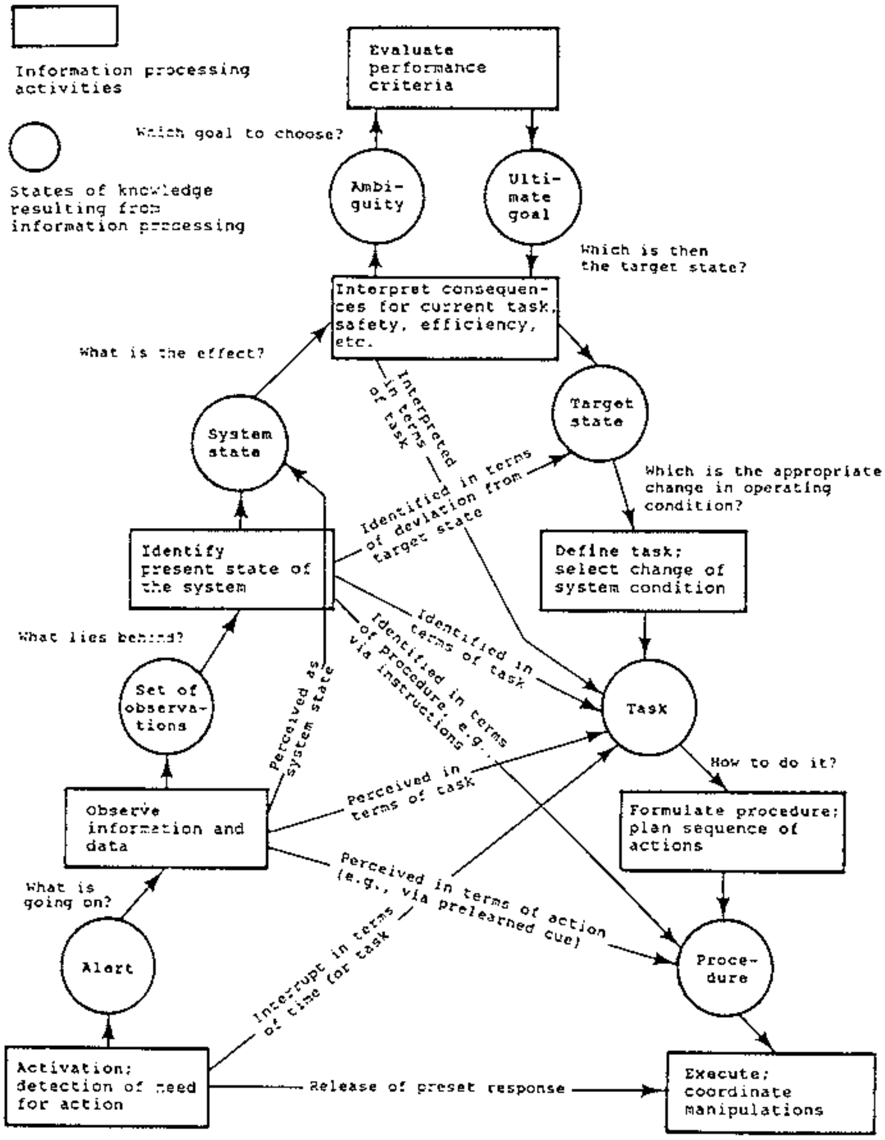

Figure 12: The Diagnostic Task in System Control. [Source: Rasmussen, J. (1986). Information Processing and Human-Machine Interaction: An approach to cognitive engineering. New York:North Holland. p. 7.]

In the first stage of problem solving, the operator detects the need for an intervention in the system and collects data which are analyzed in order to identify the present state of the system. This state is evaluated in terms of its consequences for the systems' established operational goals, and the operator chooses a target state to transfer the system to. From a review of the available resources, a task is selected to achieve this. Following this selection, the operator plans and executes a maximally efficient procedure. Errors can occur at all levels of this ladder.

Because information processing is not the only dimension on which human-system interaction can be represented, mismatches do not always result form spontaneous human variability. The taxonomy also considers the role that external influences play in creating human malfunctions. The *causes of human malfunction* are events, and *factors affecting performance* are the environmental conditions that influence the probability of error occurrence.

The description of these factors allows consideration of 'soft psychological' factors which influence performance. These might include operator motivation, workload and affective state in the analysis of a malfunction. A more detailed analysis of these factors is available from Figure 13.

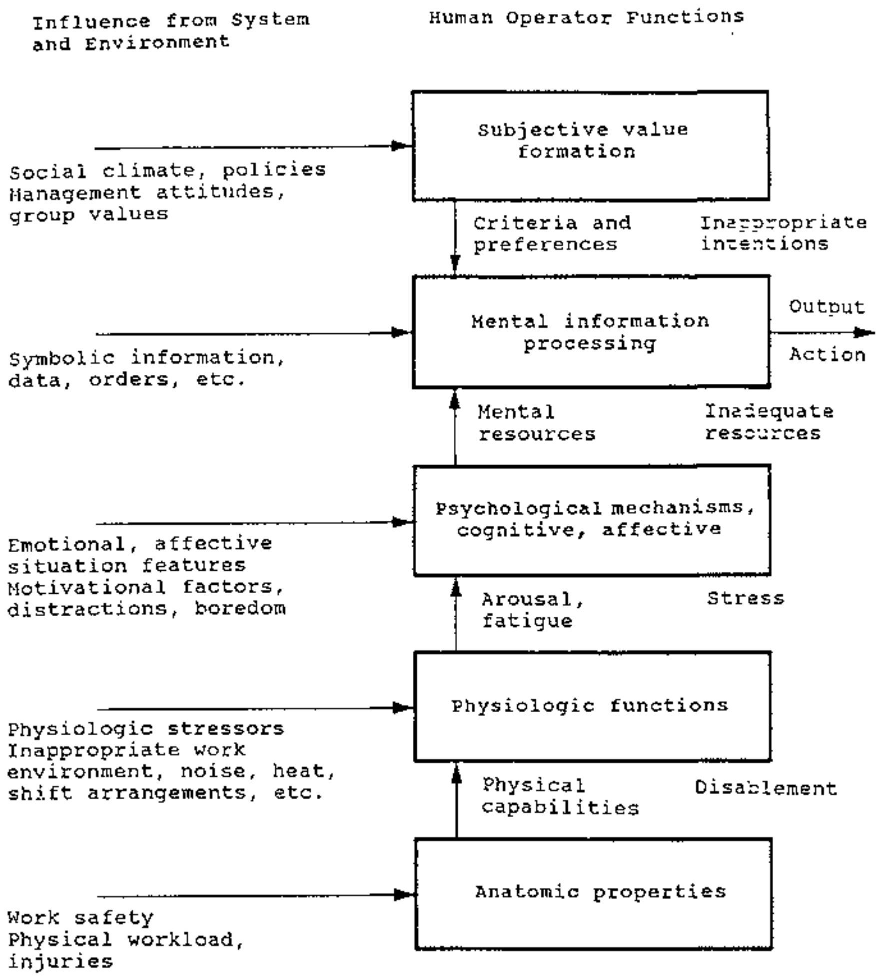

Figure 13: Model of Human-System Interaction. [Source: Rasmussen, J. (1986). Information Processing and Human-Machine Interaction: An approach to cognitive engineering. New York:North Holland. p. 64.]

Rasmussen (1986) suggests that these factors may not be observable in the accident sequence, but may have influenced events by modifying operator capability, subjective preferences in choices of strategy, and operator goals.

The Rasmussen taxonomy is a detailed and complex tool. It may contribute to the analysis of the cognitive and affective processes that contribute to a human malfunction, provided such information is available and meets acceptable standards of reliability and validity. Despite the detail with which the cognitive precursors of human error are described, the model becomes unwieldy in its detail.

Rasmussen does not provide strong behavioural indicators of the mechanisms that he describes in the taxonomy. It is also probable that the investigation of a human error accident would have to be conducted by an individual who is familiar with the psychological processes described in the model, and the various components of the model itself.

Bird & Germain (1986): Loss Causation Model.

In the Bird & Germain (1986) Loss Causation Model, accidents are attributed to unwanted energy transfers from operator-task mismatches. These mismatches occur at three levels, as shown in Figure 15. Accidents are depicted sequentially, and result from the loss of control over energy in systems.

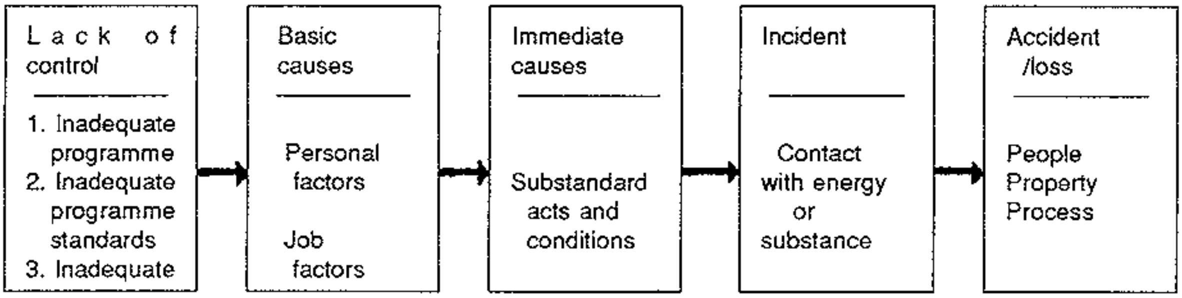

Figure 14: Accident Loss Causation Model. [Source: Calvert, D. (1989). Why Do Accidents Happen? - The causes and effects of loss. Safeguard, 8, p. 18.]

The immediate causes of an accident (those events that immediately precede the release of energy into the system) are substandard practices or conditions that release the energy, and allow loss to result from that release. These conditions or practices include communication errors, failures to follow procedure, inadequacies in use or design of protective equipment, and inadequate maintenance and house-keeping practices.Bird & Germain suggest that these immediate causes are symptoms for basic causes of accidents. In this stage of the model, personal factors correspond to many of the aspects of human error already discussed.

Components of these basic causes are placed in two categories. The first category details personal factors that contribute to accident occurrence. These include inadequate operator physiological or psychological capability, lack of knowledge or skill, and the role of stress and improper motivation on operator performance. The second category contains Job Factors in the work environment, including inadequacies in leadership, engineering, maintenance, equipment, work standards, and the use of equipment.

Reason (1987): Primary Error Groupings Matrix.

Reason's (1987) matrix of Primary Error Groupings (PEG's) is part of a model that describes human mistakes as the products of psychological forms of systematic human errors, and environmental factors. Reason argues human errors are the results of Basic Error Tendencies (BET's), rather than unique forms of erroneous performance for all operators in all situations. BET's are adaptations that produce generalised tendencies to err in human information processors under certain conditions. The errors that are manifestations of BET's vary as a function of the cognitive domain in which they occur. The products of this variation are Primary Error Groups, which are generalised descriptions of human errors.

When these primary error groupings are identified with the Situational Factors (for example age and psycho-pathological conditions) that affect the probability of their occurrence, Reason argues that it is possible to develop profiles of Primary Error Forms (PEF's). From these forms, it is possible to specify the conditions and form that errors will take.

The first of the five BET's identified by Reason are *ecological constraints*, or evolutionary limits on the capacity of the humans to process information in modern technological environments. In the context of the high technology systems that are now in use, certain instinctive responses appropriate for organisms that travel at 4-5 miles per hour have become maladaptive.

Because the human nervous system also acts as a 'change detector', psychological scaling mechanisms are not constant and vary in order to exaggerate responses to certain stimuli, and attenuate responses to others. Thus the nervous system is not a reliable measuring system, and these *change enhancing biases* should be considered as a factor in error events.

Resource limitations occur because only a limited number of cognitive structures are able to be maximally active at any one time. Operators are therefore limited in the number of tasks that can be performed at any one time, and overall performance effectiveness will decrease as a function of the number of tasks undertaken.

Human beings are able to recognise and use regularities in the environment to form *strategies and heuristics* to assist in the utilization of their limited processing resources for problem solving. However, Reason observes that there is an associated tendency for errors to made in the direction of the familiar and the expected. Default values, that reflect operator expectations or experience, are given to incomplete or ambiguous data. Systematic errors occur from over-reliance on schema and the use of incorrect schema. Other errors occur when schema are used to generate missing data from within the schema, rather than from external sources of sensory information.

The intersection of the BET's and the information processing domains forms the Primary Error Groups. These are divided into primary or secondary nodes. Primary nodes occur when a basic tendency has a strong influence on error occurrence. Secondary nodes indicate that the influence of the BET is reliant on some earlier stage in information processing, or else is unclear.

Reason identifies eight forms of primary error groups. *False sensations* occur when reality and the subjective experiences of the operator differ because the sensory system has misrepresented received stimuli.

Attentional failures occur in the cognitive processes of coping with distraction, processing concurrent stimuli, dividing attention between two simultaneous tasks, and the maintenance of general monitoring tasks.

Unintended words or actions are unintended deviations from intended behaviours which result from execution failures rather than planning failures. *Recognition failures* (or misperceptions) are incorrect interpretations of sensory data, particularly if data are impoverished and there is a strong schema-induced bias to detect the presence or absence of certain information. *Inaccurate or blocked recall* errors are problems associated with long-term memory processes, while *memory lapse* errors occur in volatile or short term memory and include forgetting list items, intentions or previous actions.

Errors of judgement encompass errors in judgment of risk, misdiagnoses, errors in social assessment and fallacies in probability assessment. *Errors in reasoning* consider processes of inductive, propositional and deductive reasoning, hypothesis testing, and concept formation.

In the context of aviation, false sensations and misperceptions are known accident inducing agents. However, the most likely cause of poor pilot decision making among the PEG's identified by Reason, are specific aspects of the errors of judgement grouping. In this taxonomy, poor decision making may be attributed to poor risk assessment, failures in the diagnosis of a problem, and psychophysical or temporal misjudgments. These in turn may be the result of errors in the use of strategies and heuristics, or faulty perceptions resulting from ecological constraints and resource limitations on information processing.

However, Reason's model is a proposed method for classifying error types rather than a definitive taxonomy of human error. Although factors contributing to errors of judgement are identified in the matrix, they not defined with specific descriptions of the behaviours that accompany them. The utility of the matrix for active accident investigation and the representation of the accident sequence is thus limited.

Green (1988): Phases in the Anatomy of an Accident.

In Green's (1988) model of the anatomy of an accident, the release of danger potential is not the result of single occasions of equipment failure or human error. He argues that "In a system of balanced design, major accidents will depend on a complex chain of events including equipment faults and latent risky conditions, together with human mistakes and errors" (1988, p. 193).

The occurrence of an accident or injury event is dependent on the efficiency of automatic safety systems, and therefore the reliability of the human maintenance of those systems. Accidents are the result of human failure at some stage in system operation or maintenance.

Figure 15 shows the course of an accident through three phases, in which a loss of control over energy in the system results in its release. In this figure, the change in system operation is preceded by either an abnormal event that alters the process, or by a normal event that releases a latent risky condition. These two conditions are precipitated by extraneous human acts, human errors, or technological failures that can be attributed to human failure in their operation or maintenance.

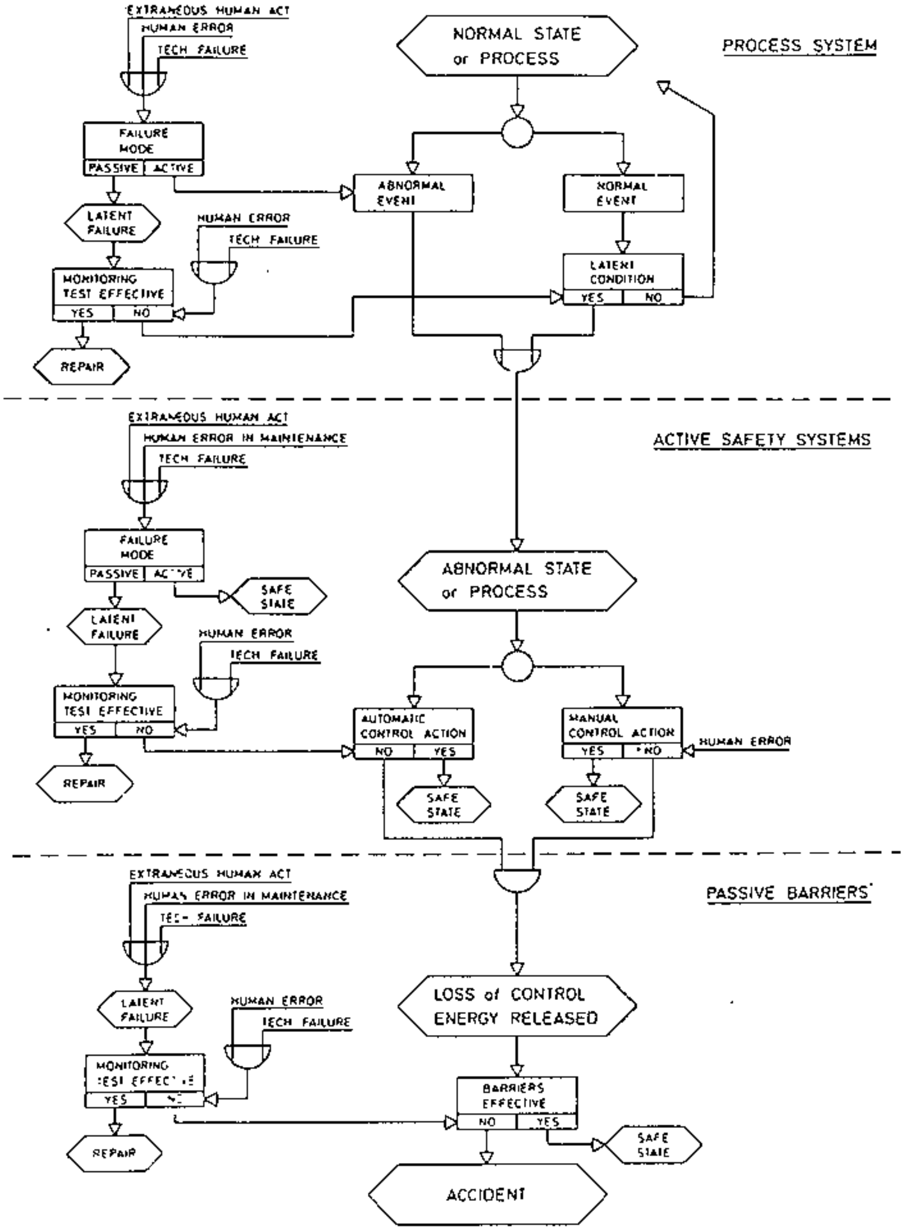

Figure 15: The Anatomy of an Accident. [Source: Green, A.E. (1988). Human Factors in Industrial Risk Assessment - some early work. In Tasks, Errors and Mental Models: A Festschrift to Celebrate the 60th Birthday of Professor Jens Rasmussen. Goodstein, L.P., Anderson, H.B., & Olsen, S.E. (Eds.). London:Taylor & Francis, p. 195.]

In the three phases that form the anatomy model, it can be seen that abnormal conditions can be introduced by human operators, or standard actions by control operators can release latent risky conditions that have been caused by previous inexact actions of other operators.

Safety in the presence of these abnormal conditions depends upon the presence and effectiveness of alternative means of system control. As shown in Figure 15, human error may introduce latent conditions into automatic safety control systems. Operators making error in their attempts to initiate protective actions may also induce an accident to occur. Green adds that operator responses may be accurate in familiar response situations, but in novel circumstances the ability of operators to identify and select appropriate remedial actions may be unpredictable and unreliable. Accordingly, their actions may serve to impede automated protective processes.

Figure 15 shows that if control is lost over the energy accumulations that result from the abnormal system states, safety in the system depends on barriers between the energy and personnel. Human errors in maintenance, activation and design can contribute to the occurrence of an accident event. Thus human error takes three forms in this model. It may produce an abnormal system state, it may exacerbate that state, and it can (directly or indirectly) impede the process of prevention and correction.

Research Questions

As has been discussed, the costs of air accidents in general aviation are high enough to warrant a commitment to safety, similar to that in passenger transport operations. Research has shown that air accidents are very often the results of inappropriate pilot actions. These behaviours often occur as failures in pilots' information processing and decision making activities, and the frequency of their occurrence may be reduced with an effective education programme.

Safety research indicates that effective interventions are based on the identification and removal of primary components of accident sequences. This identification of accident characteristics is facilitated by models of accident events; these models ensure a standardised and thorough collection of all pertinent information.

The review of air accident models in section one shows that although there have been detailed analyses of the accident sequence in air crashes, the cognitive factors contributing to those sequences have not been defined consistently or in sufficient detail. For example, the factor analytic technique used by Gerbert & Kemmler (1986), identifies broad categories of error and associated behaviours but offers no description of the cognitive processes that cause these errors.

Similar problems exist in models such as Brandon's Epidemiological Matrix (1980), and Ricketson, Brown & Graham's 3WTEIR Model (1980). Both of these models develop the accident sequence, and provide a useful protocol for air accident investigators. However, neither model is able to isolate specific characteristics of the pilot error components in crashes. The Error Chain developed by Schwartz (1988), identifies the types of errors that can be made in a cockpit where situational awareness is lost. Again, there is no discussion or definition of the mechanisms that contribute to this state.

Reason (1991) argues for consideration of the role that operator errors play in the development and activation of latent failures in aviation systems. This suggests the extent to which human failure is involved in accident occurrence.

More psychologically oriented research has identified pilot characteristics that appear related to accident involvement. Vail & Eckman (1986) have shown that the age of pilots influences crash occurrence. Research conducted by Green (1985) shows that pilot performance is a function not only of flight training, but also of factors outside the aircraft cockpit. While this information explains the occurrence of pilot error, there is little description of the cognitive processes that create these influences, or of the way in which these external influences are manifested in non-optimum pilot behaviours.

The road transport research reviewed in Section Two also demonstrates that inappropriate response during transport system control is also a function of psychological influences on performance. These have not been considered by many aviation models. The concept of accident proneness shows that there are characteristics in individuals that may make them more likely, at certain times, to be involved in accidents. Quenault's (968) work into field dependency, for example, shows perceptual influences on driver performance, while Brody (1963) and Mcguire (1976) show the apparent effect of social history.

Wolfe (1979), Lester & Bombaci (1984), Buch & Diehl (1984), Voge (1989), and Ingham (1991) show that psychological mechanisms related to social contexts and training also influence pilot decision making. These mechanisms act to bias the (especially) economic decision making process related to safety and risk oriented decisions.

Each of these studies offers part of an explanation of the mechanisms that may underlie the cognitive processes that determine pilot actions. However, there is little isolation of the specific behavioral indicators of these conditions, and no one model has been developed to demonstrate the way influences might interact in an accident sequence.

Within models of human error created for an industrial environment (reviewed in section three), only the Surry Model (1969) suggests itself as adequate to represent the accident sequence. It appears to combine information already available about the role of cognitive and affective processes in operator decision making, and to do so in a sequence that can be used as a protocol for the investigation of pilot error.

Some other models such as the Heinrich Domino Model (1931, cited in Heinrich & Granniss 1959), or Benner's Perturbation theory, may provide good sequential representations of accidents. However, they do not include the necessary information concerning psychological influences on accident occurrence.

The Surry Model is distinguished by its twelve step representation of the perceptual, cognitive and sensorimotor tasks which, if incorrectly performed may result in an accident. This model appears to meet the need for the systematic analysis and collection of information about the cognitive aspects of pilot error.

This thesis examines the extent to which the Surry Model can be used as an analytical tool. It investigates whether the Surry Model can be used to analyze air accident reports in order to isolate characteristics of pilot error. Ideally, the model can function as a template which can be used in the interpretation of the time lines that represent accident sequences in air accident reports.

This thesis also questions whether the Surry Model can function as a standardised protocol for the collection of information concerning pilot error. The format of the model has been used successfully as a checklist for collecting accident information by Andersson (1987, 1983). This suggests that the model should be able to be used by individuals who do not possess detailed information about cognitive processes or the model itself. When applied to a time line of aviation accidents, it should be able to be used to generate consistent interpretations of accident sequences.

Method

This thesis investigates the extent to which the Surry Model can generate specific information about pilot decision making errors in New Zealand recreational general aviation. The model was applied to cases selected from accidents between January 1980 and August 1991 which were reported to the agency responsible for air accident investigation in New Zealand.

The crashes selected for inclusion into the final data set involved fixed wing aircraft. They occurred in recreational flight by pilots holding any of the four categories of licence available in New Zealand (Student, Private, Commercial and Air Transport). A list of these cases is presented in Appendix 1.

The selection of recreational flight activities reflects the focus of this thesis on the development of a long term educative intervention programme for aviation. The structure of pilot licensing in New Zealand is such that all pilots are engaged in general or recreational aviation before progressing to advanced training and qualification for more commercial operations.

Relationships between the types of error made by pilots and passenger presence or pilot biographic characteristics was investigated. Information about pilot age, licence held at the time of the accident, total hours flying experience, hours flown in the type of aircraft in which the accident occurred, and the presence of any passengers on board the aircraft at the time of the crash was included in the data set.

This information was collected from multiple sources. At its briefest, the information was extracted from the annual summary of accidents published each year. These summaries provide a three to four line description of the accident event, and certain biographic details of the pilot. A summary of this type was available for every accident reported to the Transport Accident

Investigation Commission (TAIC), or to its predecessor, the Office of Air Accident Investigation (OAAI). Annual summaries were used in the initial screening of the data to select cases that occurred during recreational flight in fixed wing aircraft, and that were not the result of a mechanical failure.

More detailed information was collected from accident 'briefs'. These were produced for all accidents that were not the subject of a full investigation. In some cases, the information contained in these briefs had been obtained exclusively from pilot descriptions of the events in the accident sequence.

For major and all fatal accidents, a written report was released to the public. These reports presented the findings of full investigations into the events of the accidents. For these accidents, application was made to the TAIC to access the information that was used to generate the reports. This was granted with the proviso that any material not made public in the reports and briefs remain confidential.

Fitting the data to the Surry Model

In order to generate quantitative data, the twelve questions of the Surry Model were numbered in the order in which they appear in the model. The model was accepted as a self-contained checklist in the construction of a time line, or accident sequence of the accident (as used by Surry 1969, and Andersson 1978, 1979). This was developed from the information contained in formal reports about the accident and any other supplementary information available.

In the analysis of the time line, the evidence was used to generate a 'yes' or 'no' answer to the questions of the model. The point at which a 'no' answer occurred was recorded as the point at which the accident inducing decisional error occurred *(error type)*. These points became the data for analysis.

Statistical Treatment of the Data

The twelve points in the Surry Model were used as categories of error type in the construction of time lines. Frequency counts of the error types were taken and plotted on contingency tables. The biographic variables accompanying each case were also taken as categorical data, and tabulated. Pilot age was placed into young or old categories, passengers were coded by their presence or absence, and experience was judged to be above or below 500 hours.

Data about pilot licences were initially placed into the four categories available in New Zealand. However, the distribution of the data was such that 77.4% of the sample pilots held PPL's, and the remaining 22.6% of the cases accounted for pilots holding SPL, CPL and ATPL licences. Accordingly, the data were compressed to represent two types of flying available within the restrictions pertaining to each licence. Accidents involving pilots holding student or private licences were placed in a 'private' category, and accidents involving commercial or air transport pilots were placed in a 'commercial' category.

Non parametric chi-square techniques were used in data analysis. This statistic was selected as no assumptions about the normality or the homogeneity of variance in the sample (Siegal 1969, McCall 1990). However, using the twelve error types of the Surry Model, small cell sizes reduced the utility of the test. More that 20% of the cells formed by the tables had expected frequencies smaller than 5, and some tables had cells with expected frequencies less than 1. These cell sizes required the pooling of data for larger frequencies in cells (Howell, 1987).

The data were pooled to reflect the three psychological processes described by Surry (perceptual, cognitive and physiological responses) small cell sizes were still present. The data were finally condensed into the two cycles of the Surry Model, which produced satisfactory frequency counts for the cells. Statistical analysis was continued using 2 x 2 contingency tables. A more general examination for trends and patterns in the data investigated error types that accounted for 10% or more cases across the different variables.

Example of the Process of Time Line Construction

CASE STUDY : *Piper (PA28-140) ZK-DUT*

Pilot and Flight Characteristics:

Sex: Male

Age: 42

Lic: PPL

Hrs: 595

Type: 79.4

Synopsis of case

The aircraft departed on a special VFR departure clearance from Palmerston North at 1545 hours (NZST) for a VFR flight to Hastings. (This flight was a component of a flight Nelson - Palmerston North -Hastings, which had commenced at 1313 hours on the day of the accident). Prior to departure the pilot was advised by the duty Air Traffic Control Officer (ATCO) that the normal, adverse weather route through the Manawatu Gorge was closed. The pilot elected to "go and have a look".

Shortly after 1550 hours, several witnesses saw the aircraft flying south-east above the Palmerston North - Pahiatua Track. The wreckage of the aircraft was discovered 1500m north of the summit of the road at 0715 hours the next day.

Sequence/Time line of flight:

<u>1313</u> The aircraft took off from Nelson. The only weather update requested by the pilot was for the 'winds up to 10 000 ft' for Nelson forecast area. Actual weather forecasts for Paraparaumu and Palmerston North aerodromes were also requested. (No loadsheets for this flight were found in wreckage)

At 10 miles south of Longburn, the pilot advised the control tower that he was experiencing heavy precipitation and almost zero visibility. He asked if there was any other traffic in the area. He then received clearance for Control Zone in accordance with Special Visual Flight Rules.

<u>1435</u> The pilot taxied to the terminal and advised that a flight plan for Hastings would be filed in 30 minutes, weather permitting. The aircraft was on the ground for 1 hour, 10 minutes. During this time on the ground, the pilot discussed business with a local resident, and then telephoned details of VFR flight plan to the ATCO prior to boarding the aircraft. He did not contact Ohakea for a weather briefing (nor at Nelson for Palmerston North-Hastings sector).

<u>1545</u> The aircraft departed for Hastings. The ATCO (Palmerston North) concentrated on advising the pilot of the prevailing weather conditions. The pilot advised that he thought he could see a gap in the weather, and that he would go and 'have a look'.

<u>1548.25</u> After takeoff, the pilot acknowledged an instruction to contact Wellington Information, and advised that he was approaching Ashurst.

<u>1600</u> Witnesses at Aokautere reported sighting an aircraft approaching from Ashurst. The aircraft circled over Aokautere before heading South-east above the road known as the Palmerston North-Pahiatua track. Other

witnesses reported an aircraft following the road, which appeared to be in mist and cloud. The pilot had been instructed to contact Palmerston North Tower if the gorge was impassable. It is not known if this contact occurred. It appears that the pilot flew south-west seeking an alternative route across the Tararua ranges

The summit of road is at 1200 ft AMSL, and a witness in a car had been enveloped in fog on an upper part of the road. The cloud base at time of accident was estimated at 1000 ft AMSL. The aircraft impacted on hill above the road at 1350 ft AMSL.

1645 The aircraft was declared overdue at Hastings, 30 minutes after the flight planned ETA.

CYCLE ONE: SAFE SITUATION BECOMES UNSAFE:

The pilot elected to take-off from Palmerston North and investigate the possibility of flying under the bad weather at the Manawatu Gorge.

(1) Warning of Danger Build-up
Yes: Prior to leaving Palmerston North the pilot was advised by the duty ATCO that there was bad weather in the area of the gorge. However, there is no record that the pilot obtained a weather briefing from Ohakea or from Nelson for any of the areas of his flight.

(2) Perception of Warning
Yes: The pilot acknowledged the information from the ATCO and replied " The gorge is ... I was aware of that, but I'd just had a look from over here and it looks as though there's a gap underneath. I'd like to go and have a look if I may." Subsequently, the pilot replied to weather information about the cloud base over the gorge with "Thank you for your information. We'll still go and have a look over that way, and if it's not good enough, we'll

certainly come back."

(3) Recognition of Warning
Yes: The pilot's insistence that he was only going to have a look at the conditions, and stated intentions to turn back suggest that he was aware of the meaning of the warnings and the weather information that he had received.

(4) Recognition of Avoidance Mode
Yes: The pilot's comments about turning back would seem to indicate that he was aware of this alternative strategy should conditions prove to be unfavourable, and flight through the gorge be impossible under VFR.

(5) Decision to Attempt to Avoid
Yes: Although the pilot did not enter the area of poor weather over the gorge, he did not contact Palmerston North as instructed, and did not return to the aerodrome as expected. Instead, the pilot diverted onto a route that "could not be flown safely at low altitude, regardless of a pilot's ability, unless visual contact was maintained with key reference points" (p. 9, Air Accident Report).

It appears that at this point there were two options for avoidance of the bad conditions in the gorge. The pilot could have turned back to the Palmerston North aerodrome, or located an alternative route to the destination. Given the weather indications and the strong warnings of the ATCO, the most safe option would have been for the pilot to turn back. The least safe option would have been to carry on over the gorge.

However, the pilot did not press on over the gorge, and so elected to avoid the danger that was there. He did expose himself to the possibility that he was going to re-enter an area of danger.

(6) Ability to Avoid

Yes: The pilot was not under any restrictions concerning the choice of flight path. It was therefore possible to turn back and 'wait out' the weather. It was also possible to take a less safe option, effect the change of course that was required to enter the area of the Pahiatua Track.

CYCLE TWO: RELEASE OF DANGER

A previously unsafe situation became hazardous when the pilot did not elect the most safe option. Instead, he exposed himself to greater danger by selecting a route that required VFR conditions suitable for navigation while flying at low altitude. A route was selected that entailed a climb into a valley with limited visibility and space. This forced the pilot into instrument meterological conditions. The pilot's use of the road as the primary navigation aid suggests that visual reference to other points was lost early in the flight.

(7) Warning of Danger Release

Yes: The ATCO's warnings, and the visual evidence of deteriorating conditions would have warned the pilot that there was a low cloud base over the Pahiatua track route.

(8) Perception of Warning

Yes: It appears that the pilot used the road as the most discernable landmark for the last stages of the flight. Therefore, it appears unlikely that the pilot could not have known about his loss of reference visibility.

(9) Recognition of Warning

No: The last turn of the aircraft suggests that the pilot was trying to follow the tight curves in the road. This implies that the pilot was aware of the need to maintain some form of visual reference. However, it also appears that the pilot did not recognise this as an indication of the extent to which conditions had deteriorated. He did not try to initiate any attempt to improve the safety of the flight.

CONCLUSION: Instead of diverting back to the Palmerston North Terminal, the pilot elected to use a route that could not be flown safely under VFR in the meteorological conditions at the time. The pilot had no instrument rating, and had logged 18.15 hours actual instrument flight time under dual instruction.

The pilot appeared to be fully aware of the option to return to the terminal as an avoidance mode, but elected not to use it. Instead, he sought an alternative way over the ranges, and persevered with this route in violation of the regulations governing VFR flight. This decision to continue flight after weather over the gorge had proved to be unsuitable, and to then allow the flight to progress past a stage where VFR flight was sustainable, released the hazard into the system (cycle two).

Evidence at the crash site suggests that the pilot had been following the road, and that cloud had obscured forward visibility. A collision with the ground resulted from this violation of Visual Flight Rules. It can be argued that the last moment of avoidance was when the pilot elected to use the road as a primary navigational aid in conditions where there was no forward visibility. The fitting of the available information about the sequence of events in this accident onto the Surry Model stops at error type 9: Recognition of Warning of Danger Release.

Reliability Study

A reliability check of the data was used to address the second research question. It was investigated whether the model could be used consistently by individuals who had no previous familiarity with the model, and who were not specialists in cognitive psychology. Two flight instructors from different parts of the country were invited to examine a sub-sample of the data, and fit the Surry Model to these cases. The instructors were selected on the grounds of high rates of flying time, and extensive experience in training and educating pilots to all licence levels.

The instructors examined air accidents reports for ten fatal air accidents taken at random from the total sample. They were invited to use the model to interpret the time line of the accident, and to indicate which error type they believed was the cause of the accident. It had been observed that the degree of information collected during accident investigation varied as a function of the severity of the crash. In many of the more ‘minor’ events reported to the authority, only information supplied by the pilot was available for analysis. In one report for example, an accident was attributed to "strange wind conditions". Fatal accidents were used in order to ensure maximal consistency of the information about each case.

The frequency counts generated were tested for inter-rater reliability using Kendall’s Coefficient of Concordance (W). The coefficient was then tested for statistical significance using a Chi Square test.

Results

The sample of fixed wing light aircraft air accidents from 1980-1991 analyzed with the Surry Model contained 83 cases. Cases were differentiated on the basis of five pilot characteristics: pilot age, licence held, total flying experience (hours), number of hours flown on type aircraft, and the presence of passengers on board the aircraft at the time of accident. The error sequence of the Surry Model was coded into error types as shown in Figure 16.

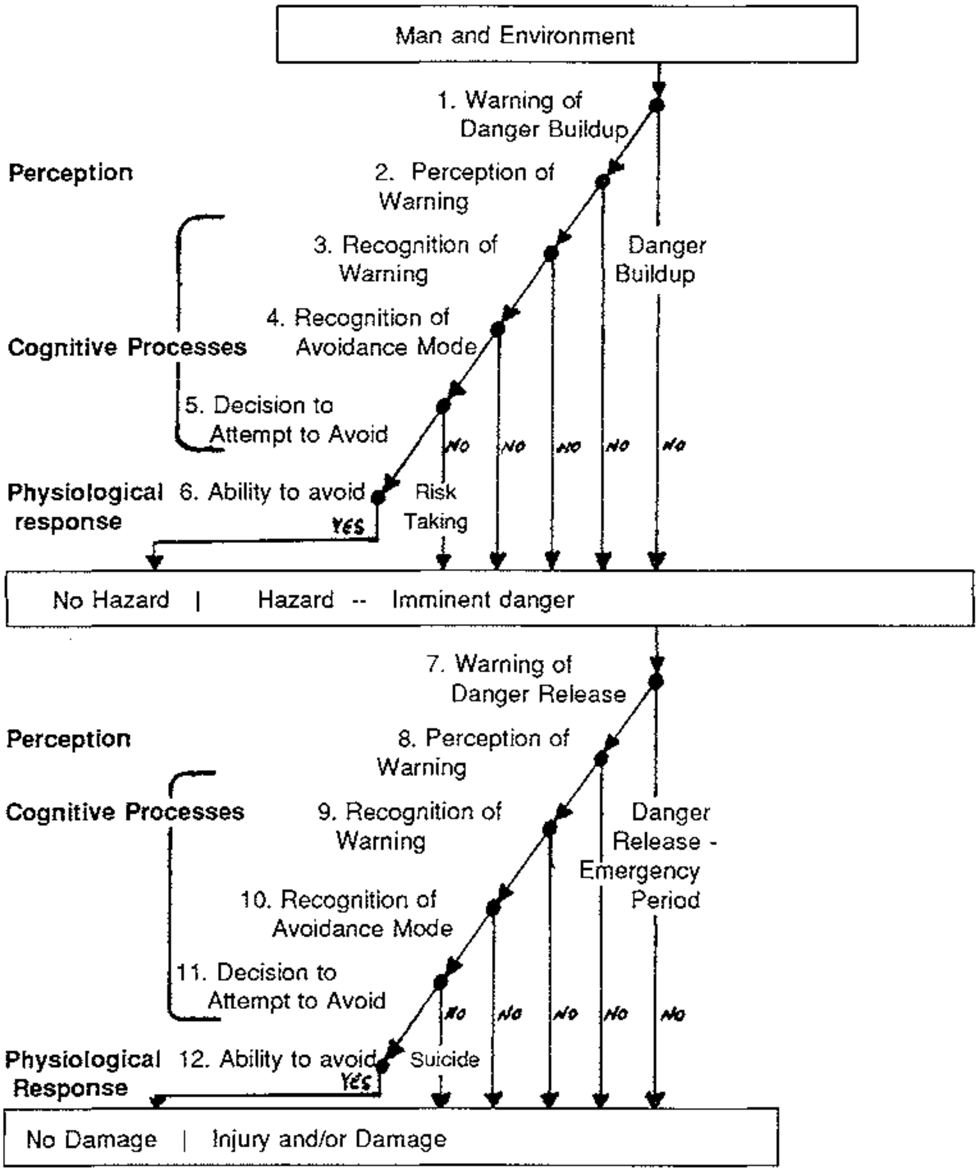

Figure 16: Questions in Surry Model and Error Type Codings. Taken from Surry, J. (1969). Industrial Accident Research: A human engineering appraisal. Toronto:University of Toronto, p. 36.

As can be seen in Table 1, the proportion of older to younger pilots is uneven, with 54 (65%) of the pilots in the sample in the younger age group. The error types assigned most often to the two categories of pilot age were error types 1 and 12. Error type 1 is associated with 35% of the accidents involving younger pilots, while the next most common error is error type 12 (failure to avoid release of danger). This pattern is repeated for the older pilots.

The majority of the accident inducing errors occurred during the danger build-up cycle of the accident sequence. Older pilots tended to make errors in the recognition of modes to avoid the release of danger (error type 10), while accidents were attributed to this error type for the younger pilots. Error type 4 was associated with 11.3% of the accidents involving younger pilots, while error types 3 and 6 were common for older pilots. Errors in the second cycle of the model were less common for both groups of pilots.

Table 1: Pilot Age (Years), the Number of Cases and Percentage of Sample Attributed to Each Error Type

Cycle	Error	15-44	%	45-70	%
Build Up of Danger	1	19	35	10	34.5
	2	1	1.8	2	6.9
	3	2	3.7	3	10.3
	4	6	11.1	1	3.4
	5	5	9.3	2	6.9
	6	4	7.4	3	10.3
Release of Danger	7	4	7.4	0	0
	8	1	1.8	0	0
	9	0	0	0	0
	10	0	0	2	6.9
	11	2	3.7	0	0
	12	10	18.5	6	20.7
	Total	54		29	

A Chi square test for the significance of the relationship between the two categories of pilot age and the two cycles of the model used Equation 6.4 for 2x2 contingency tables (Siegel 1969, p107). The Chi square test had a non-significant result:

$$\chi^2(1, \underline{N} = 83) = 0.014, \underline{P}>.05.$$

Table 2 shows the extent to which pilots involved in accidents could be differentiated on the basis of the highest licence they held.

Table 2: Number of Accidents in Sample Involving Air Transport (ATPL), Commercial (CPL), Private (PPL), or Student (SPL) Pilots.

Licence	N	%
ATPL	3	3.6
CPL	12	13.2
PPL	65	78.3
SPL	4	4.8

In the sample, 78.3% of the pilots held Private Pilot Licences (PPL), and 13.2% held Commercial Pilot Licences (CPL). Few pilots held student (SPL) or Air Transport Licences (ATPL).

Table 3 compares types of error made by pilots permitted to engage in commercial ventures (CPL and ATPL pilots), with those made by pilots prohibited from receiving monetary rewards for their services (SPL and PPL pilots).

Table 3: Number of Cases and Error Type for Private (PVTE) and Commercially (COM) Licensed Pilots

		PVTE		COM	
Cycle	Error	N	%	N	%
Build Up of Danger	1	25	36.7	4	26.7
	2	3	1.5	0	0
	3	5	7.3	0	0
	4	5	7.3	2	13.3
	5	6	8.8	1	6.7
	6	6	8.8	1	6.7
Release of Danger	7	3	1.5	1	6.7
	8	0	0	1	6.7
	9	0	0	0	0
	10	2	2.9	0	0
	11	2	2.9	0	0
	12	11	16.2	5	33.3

As shown in Table 3, clusters of cases at error types 1 and 12 became apparent with the comparison of commercially and privately licensed pilots. Of the accidents involving private pilots, 36.7% were associated with error type 1 (no warning of danger build-up), and 16.2% were the result of error type 12 (inability to avoid danger release). For commercial pilots, most crashes were associated with error type 12 (33.3%), followed by error type 1 (26.6%).

Private pilots showed a tendency to make errors in the first cycle of the accident sequence (70.4% of the cases were placed in this cycle), while errors made by commercially licensed pilots were more evenly distributed. Cases attributed to errors in the danger build-up cycle were 53.3% of the sub-sample, while errors in the danger release cycle made up 46.7%.

A Chi square test for the relationship between the cycle in which the error occurred, and the category of licence held by the pilot returned a non-significant result:

$$\chi^2(1, \underline{N} = 83) = 1.518, \underline{P} > .05$$

Table 4: Licence Held (Student, Private, Commercial and Air Transport) and Total Flying Experience (Hours).

Total Hrs	S	P	C	A	Total
0-500	4	41	3	0	48
501-1000	0	12	2	0	14
1001-1500	0	5	3	0	8
1501-2000	0	2	2	0	4
2001-2500	0	2	0	1	3
2501-3000	0	1	0	0	1
3001-3500	0	1	0	0	1
3501+	0	1	1	2	4

Table 4 displays data for pilot total flying experience. It can be seen that the sample was made predominately of private pilots who had less than 500 hours flying experience. Of the total sample, 57.8% (48) had less than 500 hours total flying experience.

Further analysis of the relationship between the flying experience of pilots and the types of errors made was restricted to accidents involving pilots holding Private Pilot Licences. This was the result of the uneven distribution of the licences held by accident involved pilots (see Table 2.) These data are shown in Table 5.

Table 5: Private Pilot Flying Experience (Above and Below 500 Hours) and Error Type.

Cycle	Error	>500	%	<500	%
Build Up of Danger	1	15	36.6	11	47.8
	2	1	2.4	2	8.7
	3	1	2.4	2	8.7
	4	3	7.3	0	0
	5	4	9.8	2	8.7
	6	4	9.8	2	8.7
Release of Danger	7	3	7.3	0	0
	8	0	0	0	0
	9	0	0	0	0
	10	1	2.4	1	1
	11	2	4.8	0	0
	12	7	17.1	3	13
	Total	41		23	

It can be seen that 'no warning' errors (type 1) and 'failures to avoid danger' (type 12 errors) were predominant. Other frequent error types for low experience pilots were type 5 (decision to not attempt to avoid danger) and type 6 (inability to avoid danger build-up), which were associated with 19.6% of accidents.

Accidents involving more experienced pilots were associated most often with error type 2 (non-perception of warning of danger build-up), error type 3 (non-recognition of warning), and errors 5 and 6. An equal number of cases (8.7%) were attributed to each of these error types.

The largest difference in cases attributed to an error type occurred at error type 4 (recognition of an avoidance mode during danger build-up), with a 7.3% difference between higher and lower experience pilots. A chi square test for the relationship between the cycle of the accident sequence in which errors occurred and pilot experience was non-significant:

$$\chi^2(1,\underline{N} = 64) = 0.901, \underline{P}>.05$$

Data were also collected to investigate the accident involved pilots' levels of experience on aircraft type. (In three cases, the air accident report did not contain this information.)

Table 6: Flying Time on 'Type' Aircraft (<50%, >50%) and Error Type

		<50%		>50%	
Cycle	Error	N	%	N	%
Build Up of Danger	1	23	42	5	19
	2	2	4	1	4
	3	2	4	3	11
	4	4	7	2	8
	5	4	7	2	8
	6	3	5	4	15
Release of Danger	7	3	5	1	4
	8	1	2	0	0
	9	0	0	0	0
	10	2	4	1	4
	11	2	4	0	0
	12	8	15	7	27
	Total	54		28	

Error types 1 and 12 were the most common errors for both groups, although a more general spread of errors was apparent for low type experience pilots (<50%). Pilots with more experience on type aircraft appeared to make more errors in the recognition of warnings of danger build-up (error type 3), and the ability to avoid that build-up (error type 6).

A test of the relationship between the cycle of the accident sequence in which errors occurred, and familiarity with the aircraft was non-significant:

$$\chi^2(1, \underline{N} = 80) = 0.037, \underline{P}>.05$$

The data in Table 7 show the type of errors made by pilots as a function of the presence or absence of passengers on the aircraft.

Table 7: Presence or Absence of Passengers and Error Type

Cycle	Error	Absent	%	Present	%
Build Up of Danger	1	8	26.6	22	40.7
	2	1	3.3	2	3.8
	3	2	6	3	5.8
	4	3	10	4	7.6
	5	3	10	4	7.6
	6	2	6	4	7.6
Release of Danger	7	1	3.3	3	5.8
	8	0	0	1	1.9
	9	0	0	0	0
	10	2	6	0	0
	11	2	6	0	0
	12	6	20	10	19.2
	Total	30		53	

Overall, more cases were associated with the presence of passengers than their absence. As in previous tables, the tendency for most cases to fall onto error types 1 and 12 is repeated (accounting for 35% and 19% of the total sample respectively). Error types 4 and 5 were each associated with 10% of the accidents that occurred when passengers were on board the aircraft. However, the frequencies associated with the other error types were within 3% of each other across the two categories.

A Chi square test of these data showed a non-significant effect of passenger presence on the cycle of the accident sequence in which the accident inducing error occurred:

$$\chi^2(1, \underline{N} = 83) = 0.531, \underline{P}>.05$$

Table 8 presents the overall distribution of the 83 cases in the sample across the 12 error types of the Surry Model.

Table 8: Frequencies of Sample Assigned to Each Error Type

Cycle	Error	N	%
Build Up of Danger	1	29	34.5
	2	3	3.6
	3	5	5.9
	4	7	7.9
	5	7	7.9
	6	7	7.9
Release of Danger	7	4	4.8
	8	1	1.2
	9	0	0
	10	2	2.4
	11	2	2.4
	12	16	19.1

Overall, the location of cases along the Surry Model was uneven, with 58 (69.95) of the accidents attributed to errors in the first cycle of the accident sequence. Table 8 also shows that 34.5% of the accidents in the sample were attributed to error type 1 (no warning of danger release), and 19.1% were associated with error type 12 (inability to avoid danger release). Error types 4, 5 and 6 were each implicated in 7.9% of cases respectively. No cases were associated with error type 9 (recognition of warning of danger release).

Results of Reliability Check

Table 9 shows the error types assigned to the ten cases used in the reliability check of the data generated by the Surry Model.

	Rater		
Case	A	B	C
1	5	2	5
2	5	3	1
3	4	3	5
4	4	3	3
5	5	2	3
6	5	3	1
7	3	4	3
8	5	2	3
9	5	1	4
10	1	3	12

Two flight instructors examined the ten cases, and their findings were compared with those used in the data already presented. As can be seen in the table, there was some agreement between the three judges, although no accidents were attributed to the same error type.

A statistical test of inter-rater agreement was conducted using Kendall's co-efficient of concordance (*W*). The co-efficient of 0.051 associated with these data was found to be non-significant:

$$\chi^2(9, \underline{N} = 10) = 1.377, \underline{P}>.05.$$

Discussion

This thesis investigated the characteristics of 'pilot error' in New Zealand recreation aviation. After an examination of literature pertaining to safety research, it became apparent that accident modelling could be useful in the investigation of the relationship between pilot responses and accident involvement. Following the review of models of failures in human performance taken from aviation, road transport and industrial environments, the Surry Model (1969) was selected as a potentially useful representation of human cognitive performance in accident sequences. Two research questions were developed. The first examined the extent to which the Surry Model (1969) of human error in industrial accidents was useful as tool for the analysis of pilot decision making errors. The second was concerned with the extent to which the Surry Model could be used as a standardised protocol for the generation of consistent information about pilot error in New Zealand.

Testing for statistically significant effects in the data showed non-significant effects. These appeared to be the result primarily of a small sample size, and it became apparent that a larger data base may be more useful in future studies. However, informal investigation of the errors made by pilots across different sub-samples showed that pilot biographical characteristics (such as pilot age, level of experience, and familiarity with the aircraft) had minor effects on the types of errors made. Case studies were found useful in illustrating an apparent relationship between passenger presence and accident involvement, although no statistically significant effects were found.

The results indicated that the Surry Model could not represent the need for anticipatory information collection during flight. Instead the sequence appeared based in classical systems theory, and assumed the presence of warnings about danger in the system. This assumption was contained in the first error type in the model, and the requirement for a 'no' answer at this point may have prematurely ended the representation of a majority of the cases in the sample.

Risk taking behaviour also seemed to be inadequately represented. There was an over reliance on economic models of risk related decision making, with little opportunity to represent occasions of active self-endangerment which introduced danger into the system. The model could only represent risk taking in decisions not to avoid danger once it had begun to accumulate.

The typical sequence of events in aircrashes appeared to differ from the temporal sequence depicted by the Surry Model. Hence, a majority of cases were attributed to the first cycle of the model, rather than an even distribution of cases over all 12 error types. Modifications to the Surry Model are presented in a revised form of the sequence.

The problems associated with fitting cases onto the Surry Sequence were used to isolate some of the characteristics of pilot error in New Zealand general aviation. Here, 'ambiguities' encountered in the model were used to generate 'antidotes' to safety problems apparent in the qualitative examination of air accident reports.

These antidotes are behaviours that may improve in-flight safety from the first moments of flight training. They include strategies of *active external information search* and *pilot self-monitoring*. These may assist pilots in the detection of danger from external and internal sources. Risk communication techniques could be used to facilitate the development of *worst case thinking* by pilots when confronted by potential hazards. This could combat hazardous thought patterns and some of the social context effects that appear to modify safety orientation.

Low levels of inter-rater reliability, and comments from the flight instructors taking part in the consistency check, showed that the structure of the model could not be used as consistently as had been anticipated. The lack of agreement between raters was attributed to a lack of information about pilot cognitive actions in accident sequences. This effect was confounded by ambiguities in the structure of the model, which promptеddiffering interpretations of the questions in the model.

Biographic Information and Error Occurrence

The impact of pilot age, experience, and level of flying (licence), on the types of errors made was investigated. The effect of passenger presence on pilot error was also examined.

Pilot Age

In the sample, twice as many of the young (between the ages of 15 and 44) pilots were involved in general aviation accidents. However, similar errors were associated with accident involvement for both groups; the same respective frequencies were associated with error types 1 and 12. The pattern of cases assigned to other error types varies between the two categories. Younger pilots seemed more likely to fail to recognise modes to avoid danger introduction, and older pilots either fail to recognise warnings of danger release, or are unable to avoid that danger. However, trends towards differences in the errors made by pilots of different ages in this data set are slight. The age effects in the data seem more likely to reflect the proportion of younger pilots involved in general aviation rather than age related tendencies to commit some forms of error over others.

Type of Licence Held

Of the accident involved pilots examined, the most commonly held licence was the Private Pilot licence. The regulations and structure of licensing in New Zealand however, increase the probability that pilots who engage in general aviation will hold private licences. This distribution in the sample may be an effect of the research question rather than private pilot performance. That is, private pilots are more likely to be engaged in general aviation activities, and were therefore more likely to be included in the data set.

The low representation of SPL holders shown in Table 2 may reflect the degree to which these pilots are supervised (as a function of the regulations pertaining to the holding of these licences). These pilots are likely to be young, inexperienced, and should not be participating in unsupervised cross country flights. Consequently, the low representation of student pilots is also attributed to rates of exposure to hazards.

Differential exposure rates may also have resulted in the lower rates of representation of pilots holding CPL and ATPL licences. These pilots may have a greater hourly exposure rate to accident opportunities, as they may engage in commercial flight activities. It is also possible that many of the accidents these pilots were involved in did not occur during general aviation activities per se, but occurred during more commercial operations. The exclusion of accidents occurring during these flights may thus not reflect the characteristics of the accident involvement of CPL pilots as a group.

The lowered rates of risk taking shown in Table 2 may also be a result of increased caution in more highly trained pilots, who may have higher costs associated with an accident.

Error Type and Total Pilot Experience On Aircraft Type

The data generated by the examination of experience effects in accident are unsurprising. Overall, it can be seen that pilots with low levels of experience with the type of aircraft in which the accident occurred were more likely to be involved in crashes. Their crashes were most often associated with the absence of warnings of danger, failures to avoid the release of danger, and risk taking. Pilots who were familiar with their aircraft appeared to have endeavoured unsuccessfully to avoid the crash in a majority of cases. In other accidents, it appears that they may not have had any warning of the build-up of danger, or been unable to avoid its build-up. Risk taking does not appear to have been a major contributor to accident involvement for this group of pilots.

The data suggest that pilots who were not overly familiar with the aircraft that they controlled at the time of the accident were less likely to detect that danger had been introduced into the system. If they did have this awareness, it appears that they were not able to prevent the situation deteriorating. Further, it appears that risk taking was a contributor to the accident involvement. In some cases, this error type may have been the result of a lack of familiarity with the performance envelope of the aircraft.

Error Types and Total Flying Experience of Private Pilots

Less experienced pilots had a higher rate of accident involvement than more experienced individuals. Table 5 shows that highest rates of crashes were associated with pilots with less than 500 hours flight experience.

The probability of accident involvement appeared to decrease as experience increased. This trend seems to differ from the accepted relationship between exposure to hazards and accident occurrence.

There were differences in the two primary error types for the high and low experience categories of pilots. It is possible that inexperienced pilots were less likely to recognise the development of dangerous situations, and not have the skills to cope with the situations that arise. More experienced pilots seemed more likely to be involved in irreversible accident sequences, and not be able to avoid the release of danger.

Accident involvement may reflect levels of pilot confidence rather than exposure. Information about the confidence levels of pilots in the sample is scarce, but the relative frequency of type 5 and type 6 errors (risk-taking, and inability to avoid the build-up of danger) may indicate that inexperienced pilots were more likely to attempt manoeuvres that were beyond their skills. It is also possible that these pilots may not correctly perceive the demands or dangers of certain activities; they may have the capacity to initiate the accident sequence, but not to modify their actions to avoid the consequences of their decisions.

Passenger Presence and Social context Effects

A chi square test showed no statistically significant relationship between the cycle of the accident sequence in which errors occurred and the social context effects associated with the presence of passengers or onlookers. However, Table 7 shows that during general aviation flight, more accidents (63%) occurred in the presence of passengers than in their absence. This difference may be attributable to the social dynamics that occur between pilot and passenger, or pilot and perceived audience. Individual case studies taken from the data provide interesting examples of the social context phenomena described by Ingham (1991).

Ingham (1991) suggests that the presence of passengers may enhance or inhibit pilots' propensities to engage in risky activities, according to the social interaction between the parties. The presence of passengers in the aircraft for whom pilots have caring feelings may increase senses of responsibility. Conversely, the presence of peers may induce unsafe behaviour as pilots compete for status. Impression formation is not reliant on the presence of others in the vehicle (or aircraft); reputations can be built via the presence of an audience or through story telling.

One accident occurred when a student pilot followed his instructor on a scenic flight in the area around their aeroclub. The instructor's aircraft performed a low pass over a house belonging to his parents and despite repeated warnings, the student attempted to repeat and embellish the manoeuvre. He died in the resulting collision with the ground.

In this case, friendly rivalry between the two pilots may have been aggravated by the presence of an audience and an arena. The desire to out-perform his instructor, and provide a display for the observers below him became a more powerful social control for the student than safety considerations.

In another case, a young pilot and his girlfriend engaged in low flying manoeuvres in the designated part of their local circuit. While performing a climbing turn, the aircraft stalled and crashed. Both occupants died. As noted by an instructor participating in the reliability check of the Surry Model, the accident seemed to be the result of "a young over-confident male who wanted to show off." In this case, it appears that the desire to impress his passenger prompted the pilot to perform manoeuvres beyond his capabilities.

While no specific identifiers about passenger/pilot relationships could be gathered from the air accident information, these two case studies present evidence to suggest that social context and impression management effects do operate in the cockpit.

Finding a counter to the effects of social context is hampered by the extent to which they may operate without direct passenger presence. As discussed by Ingham, social impression management is also achieved via word of mouth. The behaviours associated with this management can be linked to the five hazardous thought patterns identified by Buch & Deihl (1984) and Lester & Bombaci (1984). It is possible that is easier to counteract these thought patterns (as suggested in pilot judgement training) when they are a result of pilots' socialisation or expectations about in-flight behaviour. In the case of pilots reacting in to a social context however, targeting those thought patterns may be self-defeating. In certain contexts, dangerous behaviours become desirable in certain social contexts because of the danger associated with them.

That is, awareness of danger may not motivate pilots to modify their actions. Pilots who recognise that they have engaged in Macho thought processes will have no incentive to change those thoughts if the social context in which they are flying dictates 'machismo' as the acceptable and required mode of flight.

In a social context model, it seems unlikely that giving pilots the skills to recognise the effects of the five hazardous thought patterns, and the strategies to avoid them, will modify unsafe behaviours under all circumstances. Instead, it is proposed that changes in pilot levels of safety awareness could prevent the initiation of these behaviours, if they are seen as unacceptable in any situation.

In order to counter social context effects, it may be necessary to make pilots aware of the effects of social pressure to conform to a mode of behaviour that has inherent dangers, and motivate them to resist those pressures. More research is needed in order to determine how this might be achieved.

Inter Rater Reliability

Inter-rater agreement across ten fatal air accidents was tested using Kendall's Coefficient of Concordance *(W)*. The correlation coefficient for coding between the three judges was low, and statistically non-significant. However, examination of Table 10 shows that there were some consistencies in the way that judges used the Surry Model.

Data generated by the Surry decision sequence can be examined in three ways. As discussed previously, only the broadest description was available for the statistical investigation of biographic influences on accident involvement. In Table 9 , it can be seen that in 96.6% of the judgements made, accident occurrence was attributed to an error in the first cycle of the sequence. This tendency for errors to be identified in the first cycle of the model appears related to the similarity of the two sets of questions, and difficulty in separating the introduction of danger from its release into the system.

As noted by Instructor A, "answers here seem to depend very much on where you say the danger build-up becomes danger release." Instructor B also encountered difficulties in this area. In one case, the questions in the second cycle by were answered by referring to the questions in the first cycle. Thus, the characteristics of error types 1-6 were used to describe error types 7-12.

Rater agreement about errors across the three psychological mechanisms in the Surry Model was lower. Raters A and C agreed that cognitive processes (error types 3,4 and 5) were implicated in the majority of cases in the sub-sample, while rater B used error type 3 (failure to recognise warnings of danger build-up) to describe a majority of the cases. This implies that raters used the sequence to model accidents consistently, but each rater approached the analysis in a different manner.

For example, the judgements given by rater A were that risk taking was the most common cause of cognitive failures leading to accidents. Rater B had a tendency to attribute accidents to errors in the recognition of warnings (error type 3). This difference in the overall use of the model may be the result of individual differences in the interpretation of information contained in air accident reports.

Given that specific information about pilot cognitive action is often not available from air accident reports, it is possible that ambiguous and misleading information was interpreted differently by raters. Each may have used a different frame of reference in their analysis of the model. Rater C for example, was especially aware of the role of risk taking in accidents. Reports may have been interpreted so as to reflect that perception.

It therefore appears that the present form of the Surry Model can not be used as a consistent tool for the investigation of cognitive factors in crashes. While the model's checklist format may have proved beneficial in the investigation of air accidents, it can not at present facilitate the standardised interpretation of accident sequences by different individuals. This inconsistency of interpretation may also be a function of the amount of detail available about the accident sequence that is recorded in the current approach to, and format of, air accident reports.

Ambiguities in the Surry Model

Difficulties in the adaptation of the Surry Model to the aviation environment were related to ambiguities in the sequence's questions. The first ambiguity was a problem with the division of Surry's representation of the accident sequence into two cycles. During the process of fitting cases onto the sequence, it was often not possible to make a clear differentiation between the moment in which the danger was introduced into the system, and the moment in which it was released. It is suggested that the model can be reduced to fewer steps and still represent aviation accident sequences well.

The tendency for data to cluster around the first error type of the model (no warning of danger build-up) was attributed to an assumption that warnings of danger presence will be presented to the pilot. It is suggested that warnings of danger may be present in the aviation system, but must be actively sought out by the pilot. This difference in the representation of warnings lead to an inaccurate distribution of cases over the sequence.

The error type concerned with risk taking was also found to be unrepresentative of the forms which risk taking took in the accidents sampled. The Surry Model appeared to consider risk taking to be an accident inducing factor only when it involved a decision not to attempt to avoid a danger already present in the system. There was no opportunity to represent the active introduction of danger into the system by the pilot.

The presence and presentation of warnings: Error Type 1.

The strict interpretation for the tendency for cases to group around error type 1 in the sequence is that *in New Zealand general aviation, accidents most often result from a lack of warning that a danger has been introduced into the system.*

Two explanations for this trend seem apparent. Pilots may act to incapacitate or disregard warning systems present in the aircraft, and thus fail to receive warnings that might otherwise have been available. However, no cases in the sample were the result of these types of actions, as the weight and size of the warning systems (for example weather radars and ground proximity warning systems) generally prohibit their use in small general aviation aircraft. Alternatively, the absence of warning in the accidents examined may be a reflection of the concept of 'warning' used in the Surry Model.

The Surry Model is based on a traditional model of systems, which show one or more human operators interacting with physical components in order to produce a desired output. Typically the interaction between the operator and these components is controlled by operator responses to displays and signals from the components, as shown in Figure 16.

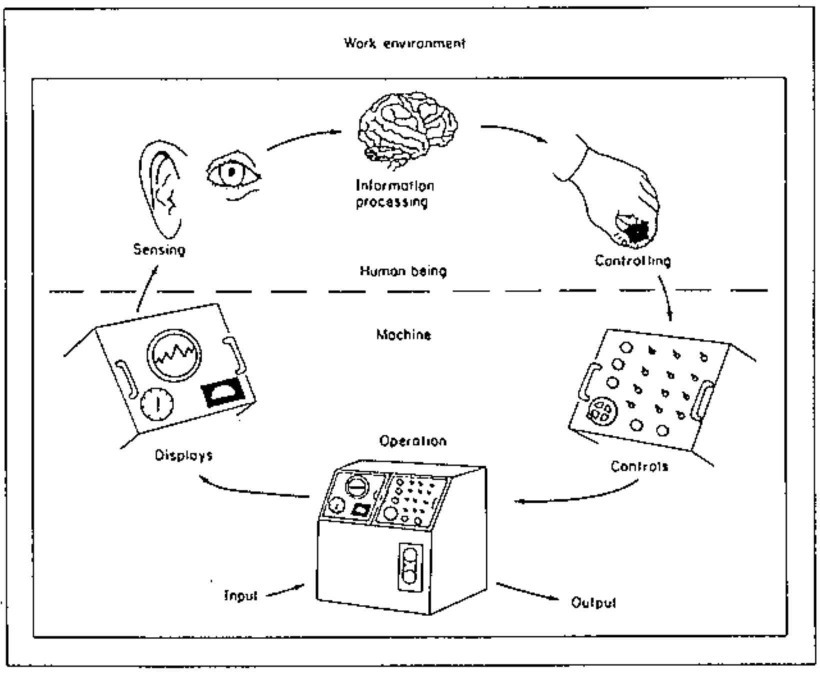

Figure 16: The Human-Machine Interface. [Source: Sanders, M.S. & McCormick, E.J. (1987). Human Factors in Engineering and Design. New York:McGraw-Hill, p. 14]

In these 'classical' systems, feedback is given to operators when danger is detected. The presence of these signals indicates the need for operators to actively control the system.

Thus, there is an implicit assumption in the Surry Model that deviations in a system will be detected by warning devices within the system. These devices will transmit some signal to the operator. However, in a dynamic system such as aviation, changes can occur independently of human input (Hess 1987). Operators must not only respond to changes, they must process information in an anticipatory way. As general aviation systems are restricted in the number of warning devices available, maintenance of desired system states requires active information searching and anticipatory control actions. In some cases, awareness of danger may only be available if it actively sought from external sources.

For example, although weather factors present a major danger to general aviation, very little instrumentation within a light aircraft can provide a pilot with up-to-date weather information. The onus is on pilots to collect as much information as possible from external sources before and during a flight (from Flight Information Services for example).

Thus a major distinction can be made between the Surry Model and air crashes. Whereas the warnings included in the first error type of the Surry sequence are expected to be *presented* to the operator, warnings available to pilots may, at times, only be *present* in the environment. Pilots may have to actively collect this information.

This difference is presented in Figure 17. In the industrial systems on which the Surry Model is based, warnings are presented to the operator who must then perceive and recognise them in order to implement avoidance strategies. The data generated by this research suggest that although warnings are often present in the general aviation environment, the operator must search them out. Only then can the process of danger recognition and avoidance be implemented.

	Surry Model	Revised Form
1.	Warning Presented	Warning Present
2.	Warning Perceived	Search for Warning
3.	Warning Recognized	Warning Detected
4.	Avoidance Implemented	Warning Understood
5.		Avoidance Implemented

Figure 17: The Presence and Presentation of Warnings

This revision to the model suggests that the attainment of full safety during flight may only be possible if pilots obtain information from sources outside the aircraft control interface.

A possible antidote to the problem of insufficient warning that is indicated by the frequency of cases associated with error type 1, may be the development of information search skills that can be termed active external information search, as shown in Figure 18.

An illustration of the benefits of this kind of safety behaviour can be seen in an accident that resulted from a failure to engage in external information search. This accident occurred when a pilot collected what information was available about weather conditions on his intended route, but then disregarded this and other pre-flight advice that the route was less than optimum.

While travelling this route, he encountered deteriorating conditions, but was not able to collect updated weather information via radio communication. He pressed on past a point where a precautionary landing at the nearby army air base was available to him. This decision, coupled with a choice to use a winding road as a primary landmark when flying at low level under a lowering cloud base, resulted in a fatal accident.

It is not possible to determine the exact sequence of events that followed this pilot's decision to commence the flight on the dubious flight route (rather than selecting an alternative flight path). It appears that there was a point at which the pilot made a second erroneous decision with regard to the weather conditions and the continuation of the flight.

The pilot either did not attempt to use information available from the environment, or elected not to act on it. Had he reacted to the information available to him during the flight, his decision to disregard earlier messages that his intentions could be dangerous may have been negated by a more safety conscious decision later in the flight. Had the pilot collected or acted upon environmental information not available from formal communication channels, he might have recognised the danger posed to him by the weather conditions, and landed safely, albeit away from his intended destination.

The clustering of so many cases onto error type 1 suggests that useful safety compensation for the dynamic nature of the aviation system can be developed. Trainee pilots could be taught to collect information from external sources during the course of a flight. However, the assumption is also made that pilots will react to any extra information about hazards in a manner which has maximum safety orientation. Accidents resulting from a failure to use information in this manner are discussed later.

Cycles in the accident sequence: error type 12.

Error type 12 (inability to avoid the release of danger) accounts for 19.1% of the data in Table 8. The strict interpretation of this grouping of cases is that a large proportion of the accidents examined resulted from the physical inability of pilots to avoid danger once it had been released into the system. These accidents occurred despite pilots recognising and responding to all available warnings and opportunities to avoid the crash.

Under the strict interpretation of the Surry Model, the most likely explanations for this cluster were either that there was not enough time for pilots to avoid the danger once they became aware of it, or that pilots had made some mistake in their execution of avoidance manoeuvres. However, there is evidence to suggest that these are not the only effects causing the cluster of cases on this error type. The two cycles of the Surry Model may not be appropriate for the dynamic nature of aviation systems.

As established earlier, there is a difference between the types of warning systems that exist in industrial and in aviation systems. It is also possible that the concept of danger build-up, described by the first cycle of the Surry Model, is not as useful in the investigation of aircraft accidents as might have been anticipated.

As shown by the loading of cases onto the first cycle of the model during data analysis, it is possible that the pattern of the introduction and release of danger into aviation systems does not fit onto the two cycles of the Surry Model. It appears that the six questions of the first cycle can represent the actions of pilots to the same extent as the full model.

This may be the result of more information about pilot actions being available to accident investigators when danger is only present in the system. Pilots may have more time to contact other agencies for help, and their overall response rate may be low enough for accurate recall of their actions during post-crash investigation. It is possible that once pilots attempt to avoid the consequences of danger release, they are less able to recall their actions, and there is a lower likelihood of recorded communications concerning the events in the accident sequence.

Alternatively, this cluster of cases onto error type 12 may be the result of a failure in the Surry Model to capture the apparently simultaneous nature of the introduction and release of danger in VFR flight. The ability to avoid a danger is determined by the extent to which advance warning of its presence is available to pilots. This cluster suggests that in general aviation, many pilots are not receiving sufficient advance warning.

Examination of cases suggests that the presence of danger in the aviation system often coincides with its release. Danger may be present in the aviation environment (a local weather system for example), but may remain a latent threat until the aircraft enters the danger's area of influence. Under the conditions governing VFR flight, awareness of danger may be dependent on contact with it.

Unlike the industrial systems represented by the Surry Model, an aircraft-pilot interface does not occur within a static environment of defined limits. While a danger may reside within an industrial system. In aviation, some forms of danger may only be avoided by the selection of an alternative location. That is, some sources of danger are inactive until the aircraft is moved to the location where they are manifested. Prior to this, the dangers are not necessarily discernable to the pilot.

In many cases, it was found that awareness of danger occurred simultaneously with its release into the system. The two cycles of the Surry Model did not accurately reflect this in the accident sequence. In one example, a pilot became disoriented in a local weather condition, and died as the result of his plane's collision with a tree. Information concerning the weather condition was not available from weather reports and other normal communications.

The sequence of this accident is independent of its 'real' time scale. Although the introduction of the danger can be measured from the development of the fog bank, the accident sequence begins from the moment that the pilot entered the area in which that condition could be visually detected, under visual flight rules.

In accidents such as this, there is no measurable interval between the awareness of danger in a system and its release. However, there may be a considerable time lapse between the build-up of the danger and pilots' awareness of it.

This suggests that modifications to the accident sequence in the Surry Model are required. Two options are available: either another cycle is introduced to provide a differentiation between the existence of a hazard and contact with it, or the model is reduced to reflect the concurrence of these two phases of the accident cycle. Evidence in the data suggest that the latter option may be more appropriate as, in many of the data manipulations, more cases were assigned to the first cycle than to the second. These empty cells indicate that the second series of questions in the model (from error types 7-12) has little utility in the analysis of aviation crash data.

Further support for this argument can be found in the reliability study. One of the instructors checking the consistency of the Surry Model interpreted the second cycle of the model entirely in terms of the first cycle. This instructor came to identical conclusions for both sets of questions. Thus, a revised model could contain only one cycle, containing questions concerned with identifying the moment in which the pilot-aircraft interface came into contact with the hazard, causing the release of danger. This revision is shown in Figure 18.

Evidence of Impending Contact with Danger

Search for Evidence

Evidence Detected

Warning Understood

.
.
.

Sufficient Time For Full Avoidance

Avoidance Response Executed Correctly

Figure 18: The Accident Sequence as a Single Cycle

This revision of the Surry Model appears most applicable for weather related accidents. In these cases, VFR pilots have little opportunities for advance (non-visual) notification of local weather patterns or rapid changes in conditions. However, it is also useful for the investigation of accidents resulting from catastrophic failures. Here, little or no warning is available of the danger in the system. If, as in one case, the structure of a wing fails, then danger is immediately released. Although it can be argued that the factors that induced the failure had been building up for some time, it is also true that the pilot would have been unlikely to detect these latent dangers in the general pre-flight examination of the aircraft.

The revision is also useful for other accident types - for example, landing on unsuitable airstrips. If the condition of an airstrip cannot be observed from the air, then the danger to the aircraft can still be ascertained. It is possible for pilots to obtain weather information for an area in order to predict whether, for example, they can expect a wet or dry landing strip. In some cases, they may be able to contact an individual to ascertain the condition of the airstrip. A failure to engage in these behaviours limits, and in the accidents examined in this study, limited awareness of danger on airstrips to the point of touch-down. In these accidents, contact with danger coincided with its release.

In other cases in the sample, accidents occurred when owners of private airstrips took-off from them, despite unsuitable conditions such as long grass or ruts. Here, it can safely be assumed that inspection of the strip should have identified any dangers before the strip was used.

The failure of the strip owner to detect the deterioration of the surface should be represented by the model. The second question in the revised model (active search for hazards) can include these factors in an accurate representation of the accident sequence. The revised model allows the investigation of detectable danger presence at any time before the accident event. It does not separate the moment of contact with the danger from the release of danger, thus it more accurately reflects the sequence of aviation accidents.

Correct responses and risk taking: Binary answers in the Surry Model.

In the process of fitting data onto the Surry Model, another problem became apparent. This involved the extent to which the binary form of the answers to the questions in the model's accident sequence (yes/no) could represent the flexibility and autonomy of pilots.

The model assumes that when a pilot recognizes an avoidance mode (error type 4), that it is the 'correct' one. That is, the model is based on an assumption that there is one single correct avoidance manoeuvre to avoid danger in the system.

Unlike the process systems on which the Surry Model is based, aviation systems do not operate within well defined boundaries that limit response options.

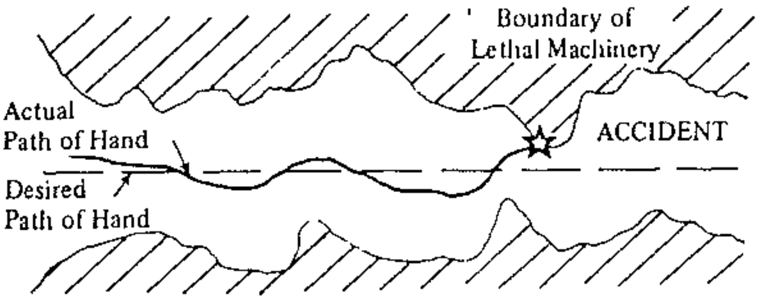

Figure 19: System boundaries and Operator Response Options. [Source: Surry, J. (1969). Industrial Accident Research: A human engineering appraisal. Toronto:University of Toronto, p. 32.]

As Figure 19 shows, the extent to which factors in industrial systems may vary is limited. These limitations serve as rules for operator behaviour. The dotted line represents the dictated path for operator actions. This ensures maximal distance from the hazard present in the process (the spinning lathe). However, the wavy line shows that human performance characteristics are a process of action and compensation. If operators' actions vary too greatly, they will exceed the system's safety boundaries. If detected early, contact with danger can be avoided by a movement that returns the operator to safe boundaries. Thus, Figure 19 shows that the direction and type of avoidance available to the operator is dictated by the operational boundaries of the system.

Using this model of danger avoidance in systems, the Surry Model was developed to code operator actions into a binary form: correct avoidance strategies are either recognized and implemented, or they are not. Using the flow chart process of the Surry Model, accident involvement after the recognition of an avoidance mode is represented in one of two ways. It is either attributed to a decision not to attempt to avoid the hazard (risk taking - error type 5), or to a physical inability to avoid the danger (error type 6).

In aviation, the boundaries for pilot response are not so well defined. The flexibility and dynamic nature of the aircraft system means that pilots may face multiple options for avoidance actions. Fewer guides for pilots require the recognition of *any* avoidance strategies before the evaluation of their merits. That is, pilots must first recognise which options are open to them, before they can evaluate the merits of those possibilities. Pilots in unusual or emergency situations face the choice between many options, when there is little external guidance for the particular situation presented. They can only be guided by common sense, standard operating procedures (SOP's) and regulations.

It is proposed that the concept of the single correct response, assumed in error type 4, is inaccurate when applied to an aviation system. Here, multiple avoidance modes are available, and no fixed response boundaries exist.

Instead, it is suggested that the question should examine whether pilots attempted to isolate possible procedures, and decrease the danger to which they were exposed. However, the detection of these behaviours is often limited by constraints on post-crash information about pilot cognitive processes.

The most accurate indicator of an attempt by the pilot to avoid danger would be a behavioural change that is safety oriented. Figure 20 shows this revision to the Surry Model.

Warning Recognised

Warning Understood

Avoidance Process Implemented
(Behavioural Change)

Response to Awareness of Danger

Figure 20: Behavioural Changes as Indications of Avoidance Response

If a behaviour change is detected, but is not oriented towards safety, it can be judged that the pilot engaged in a form of risk taking behaviour. However, this type of risk taking can not be modelled in the Surry accident sequence. The representation of risk taking that results from the Surry Model's assumption of defined system boundaries is inaccurate. Risk taking is described solely as a decision not to perform a safe manoeuvre. This is an active failure to avoid danger, and is a form of passive exposure to risk. The Surry Model does not consider that risk taking also occurs in decisions to actively perform unsafe actions.

Failures to perform actions that increase safety are a passive form of risk taking. While these decisions do not actively introduce or reinforce hazards into the system, they do allow lee-way for hazards to be present. In contrast, decisions to perform acts that may activate a latent danger, or which actively increase the amount of danger in the system, and are active risk taking behaviours.

In order to facilitate the representation of these different forms of risk taking in future investigations of pilot errors, it is recommended that pilot behaviour changes should be measured on a continuum from maximally safe to unsafe. This may allow investigators to consider the range of options which may have been available to pilots. It may also represent the degree to which pilots' behaviours were the result of risk taking, be it an active or passive form. This modification of the model is shown in Figure 20.

Evidence of Behavioural Response to
Awareness of Danger

Evidence that Behaviour is
Safety oriented

Result of Behaviour:
- Actively Introduces Danger
- Passively Introduces Danger
- Avoids Danger

Figure 21: Representation of Safety Orientation in Behaviour

The changes to the model (described in Figure 21) allow investigators to model accidents that have occurred as the result of the conscious magnification of danger in the system (active risk taking). During the process of collecting the data, it became apparent that in some cases pilot behaviour was the factor that caused danger to be present in the system.

This was demonstrated in the accident that occurred when a young, low time private pilot hired an aircraft with the intention of 'buzzing' a campsite where many of his friends were staying. During the course of several low passes (at times estimated as low as 50' AGL) the aircraft entered a part of the valley in which a reciprocal turn was not possible. The aircraft was not able to out-climb the terrain and crashed.

The Surry Model considers the non-use of avoidance strategies to be the primary manifestation of risk taking. Thus, there is no representation of the extent to which the selection or recognition of an avoidance mode can be 'interfered with' by a decision to engage in risky behaviour. Further, the model as it stands cannot represent cases where the presence of danger has been *actively* introduced by the controller of the system; this introduction may be an error of omission or commission (Norman 1981).

Failures to change behaviour, following awareness of danger may be linked to a decision by the pilot to engage in risk taking. *Mind set* effects that result from a commitment to risk taking behaviours may influence pilot strategies and information processing before and during contact with danger.

Because the Surry Model is concerned with operator actions during direct physical control of the system, data not directly related to operators' <u>control actions</u> are difficult to fit. Yet evidence suggests that pilots develop a mind set related to risky behaviour <u>before</u> they enter the first cycle of the Surry Model -before they assume control of the system, and before they encounter danger. This may be a function of their internal psychological state overall, as in the case of Failing Aviator Syndrome (Voge 1986), or it may be a function of a pre-flight decision to engage in a risky behaviour.

In the previous example of the flight undertaken for the express purpose of engaging in risky activities, it is possible that the pilot's level of information search for hazards diminished as a result of his pre-flight decision. This pilot may not have been using information in a safety oriented manner, but was only collecting information that would allow him to attain his risk taking goals.

It is possible that information about the nature of the terrain in which he was attempting his manoeuvre would have been selectively attended to. This effect of a decision to engage in risky behaviours could be termed risk distorted information use. The example given is an extreme case where risky activities required active preparation. However, similar effects may be present in accidents that result from pilot grand-standing in the presence of peers. Although there may have been no express intention to undertake risky manoeuvres, pilots may also perceive that it is acceptable to relax safety considerations in the company of certain individuals.

The use of binary answers in the Surry Model does not appear to capture the nature of the aviation environment. They can not represent the multiple options that may be available to pilots in emergency situations. It appears that a continuum of responses is needed. This may be able to capture the dynamic nature of flight, and to investigate the degree to which pilot responses are safety oriented.

Developing interventions for these behaviours becomes difficult. Pilot Judgement Training research has developed 'antidotes' to many hazardous behaviours, but relies on the ability of individuals to recognise hazardous thought patterns in themselves. These interventions also rely on individuals' motivations to reduce the effects of those thought patterns on their behaviour that this mechanism might induce.

In this research it is stressed that these antidotes are dependent on *self-monitoring* by pilots. In order to use these mechanisms, pilots need to be able to objectify their emotional, physical and mental state in order to evaluate their motives and fitness for flight. It is envisaged that this form of self-control may encourage pilots to self-diagnose conditions which may affect their safety-orientation during flight.

Support for the introduction of this type of self-evaluation can be found in accidents that occurred when pilots did not recognise 'warning signs' that physical and mental health problems were influencing their actions.
In one case, a pilot who had been complaining of ill health for several days before a flight, behaved un-characteristically in the course of the flight that led to his death. He was apparently unable to recognise behavioural warning signs that he was not normally responding to situations.

This normally polite and cautious pilot was rude to ATC operators, and used an unusual takeoff vector to embark on a regular route. However, more tellingly, he maintained radio silence in contrast to an established habit of regular radio check-ins during the course of a flight.

In another case, a pilot made basic navigational and judgemental errors and yet did not appear to recognise them as mistakes, much less as signs that he was not functioning optimally. Before commencing the fatal flight, this pilot had become disoriented, entered restricted airspace, and walked in front of an aircraft with a turning propeller. During the course of the flight, he again became lost, which was in part due to errors in his calculation of air and ground speeds. Witnesses reported that before takeoff, the pilot had responded to Air Traffic Control instructions and queries as if he were a new pilot - with hesitancy and uncertainty.

It is suggested that in these cases pilots either failed to recognise the changes and errors in their actions, or were unconcerned about their consequences. It is possible that some crashes that resulted from these behaviours can be avoided with the use of some form of self-monitoring techniques.

However, active self-monitoring, as discussed earlier, may not be effective in situations where awareness of inappropriateness of behaviours serves to make them desirable. Some accidents in the sample appeared to be the result of a social context in the cockpit which encouraged pilots to engage in manoeuvres that were beyond the capacities of both pilot and aircraft. The only apparent remedy for this type of active risk taking is to change the payoff for the pilots.

In light of the research literature that is available about the utility of safety interventions (see for example Adams 1988), it would appear that no one strategy will be permanently effective. Self-monitoring can only be an effective safety tactic for pilots who regard safe behaviours as desirable. Until social contexts are changed for other pilots, self awareness of danger is not a sufficient inhibiter of those behaviours.

Summary and Conclusions

In the course of this research, two main areas of discussion arose. The first was concerned with the structural characteristics of the Surry Model that were believed to have influenced the fall of data onto the model. The second was concerned with the information about, and corrections for pilot behaviours that appeared to be related to involvement in aircrashes. These characteristics were identified either through the process of inferentially interpreting the data, or as a result of the examination of the ambiguities in the model.

The biographic details, collected about the accident involved pilots, only served to complement data already gathered (in New Zealand) by the Air Transport Division of the Ministry of Transport (1989). There data were also compatible with findings presented in studies using overseas data (for example, Vail & Eckman 1986). As such, there was little or no information useful to the design of a safety intervention in these data.

In contrast, passenger presence effects showed potential safety utility, and the findings concerning these cases are incorporated into the summary of antidotes developed from this research.

The revised Surry Model

As discussed previously, problems arose in the process of generalising the content of the Surry Model to an aviation environment. The problem centred around assumptions of the existence of warnings in the system, and the representation of risk taking in the model. It was established that a distinction between the presence of a warning of danger in the system, and its presentation needed to be made in the first question of the Surry sequence. This ambiguity was attributed to the industrial foundation of the model, and its base in classical systems theory.

The second ambiguity in the model was concerned that in the Surry Model as it stands, there is no opportunity for differentiating between active and passive risk taking. Accordingly, it was argued that evaluations of pilots' responses need to be made on a continuum of safety orientation.

The structure of the model was modified as a result of the discussion of all three clusters in the data. These modifications are synthesised in Figure 22.

Evidence of Danger ('Warning' Present)

Search for Evidence of Danger

Evidence Detected

Warning Understood

Avoidance Process Implemented
(Change in Behaviour)

Behaviour Change Towards Safety

Change Sufficient to Avert Accident

Accident Averted   Accident Occurs

Figure 22: Completed Revision of the Surry Model

The technique for using the model remains the same: each point represents an opportunity for the pilot to avoid an accident. If each point is answered in the affirmative, the sequence is completed, and the accident avoided. If at any time a negative response to the point is detected, an accident occurs.

Because the differentiation between the introduction and the release of danger was not functional in the strict form of the Surry Model, the sequence has been condensed into one cycle. No option is provided for modelling active risk taking when the operator has introduced the danger into the system. It is argued that issues concerning the extent of warning about the danger, and the pilots' avoidance actions become redundant. Deliberate active risk taking implies the *conscious desire* to expose the self to danger.

The concept of warning in the Surry Model is limited to the consideration of the time in which the operator is in active physical control of the system. This is replaced with the representation of the extent to which there was evidence that the danger was present in the system. This allows the full temporal duration of the accident sequence to be examined, and moves away from the historical emphasis on the 'immediate' causal chain (events immediately preceding the accident).

Countering Behaviours Associated with Accident Involvement.

As a result of this research, extensive modifications to the Surry Model were suggested. In addition, some information was also generated regarding the nature of accident inducing pilot behaviour in New Zealand general aviation.

Table 10 shows these behaviours, and suggests some (general) remedies that may be useful in the reduction of the occurrence of these responses. These remedies could be considered as 'antidotes' to these behaviours in a manner similar to that used in Pilot Judgement Training.

It can be seen that many general aviation accidents resulted from a lack of warning for pilots. These may be reduced by encouraging pilots to collect information from sources outside the aircraft (active external information search). Accidents resulting from inadequate time to avoid danger might also be corrected in the same manner. Pilots will be able to collect information about hazards sufficiently in advance to avoid those hazards.

The frequency with which accidents are attributed to risk taking may be altered if pilots can be educated about the psychological factors which may influence their safety orientation (hazardous thought patterns and social effects for example). Accident reduction may be achievable if pilots can be trained to recognise these mechanisms, and their influences on behaviours, and voluntarily elect to remove themselves from the aviation environment.

Table 10: Conditions Attributed to Accident Causation, Their Causes and Suggested Remedies.

Condition	Cause	Remedy	Antidote
'Warning'	No information to avoid	More information to pilot	Active External Information Search
'Avoidance'	No time to avoid	Information in advance	Information Search
	Mistake in avoidance	Provide skills to avoid correctly	Training, Information Search
'Risk Taking'			
Passive			
No change in behaviour	Risk distorted information use	Enhance safety orientation: increase payoff for safety	Self- Monitoring
Active			
Behaviour change not safety oriented OR Danger introduced by pilot	No desire to avoid danger (social context, psych. mechanisms)	Remove pay-offs for exposure to danger	Self-Monitoring

It is believed that these antidotes can be readily incorporated into a formal training programme for novice pilots. This may help to ensure that pilots enter the aviation environment with a strong orientation towards safety, and be developing these habits and attitudes from the first moments of unrestricted flight. It is important to note that has been no validation of these concepts, and that further testing is required before their utility as a safety intervention can be accurately reported. The validation of these suggestions is the next research question that should be addressed.

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Appendix 1: Data List

Yr	C/S	Age	Lic	Hrs	Type	%	Pax	Surry
79	CHS	20	CPL	236	16	6.8	5	3
90	KVM	17	PPL	70	-	-	1	5
90	DPK	23	PPL	113	107	94.7	0	6
76	DUT	42	PPL	595	79	13.3	1	3
90	EIV	26	PPL	169	35	20.7	3	1
90	BPA	35	CPL	1648	82	5	0	5
88	TRC	43	PPL	1320	1070	81.1	0	6
88	KVZ	40	CPL	2000	500	25	0	12
89	CUU	26	PPL	357	31	8.7	3	5
88	CMQ	39	PPL	184	184	100	1	1
90	CWL	39	PPL	981	250	25	2	5
90	COJ	45	PPL	150	150	100	3	6
90	BKG	66	PPL	3633	1500	41	0	1
90	DOH	48	PPL	202	202	100	0	10
90	DHZ	60	PPL	284	123	43	3	12
91	CKK	54	PPL	261	94	36	1	12
90	KRG	35	PPL	365	230	63	0	4
90	ANQ	29	CPL	732	90	13	1	4
85	DON	60	PPL	880	3	0.3	3	6
84	DQM	49	PPL	314	14	5	0	1
84	TWO	34	CPL	423	0	0	0	4
86	DGK	55	PPL	1190	1175	99	1	12
85	DVC	41	PPL	636	301	47	0	2
84	CZM	30	CPL	287	27	9	0	1
81	AWI	40	PPL	502	163	32	4	1
90	CUI	25	PPL	113	8	9	1	6
81	CXE	20	PPL	209	141	68	1	12
81	CEG	30	PPL	154	83	54	1	7
80	BLL	42	PPL	553	173	31	2	1
83	BSF	38	PPL	860	200	23	0	1

Yr	C/S	Age	Lic	Hrs	Type	%	Pax	Surry
81	EHC	61	PPL	2100	700	33	1	1
82	EDJ	61	PPL	1635	3	0.2	0	10
80	DLO	19	PPL	150	12	8	0	12
80	DID	48	PPL	550	400	73	2	2
83	CSS	55	PPL	1389	734	53	3	3
87	DLK	70	PPL	595	7	1	3	1
80	AKU	57	CPL	1489	686	46	6	6
80	ATS	33	PPL	452	272	60	1	6
80	BZB	40	PPL	176	18	10	1	1
80	ZAP	26	CPL	430	20	5	0	1
81	EKB	30	PPL	150	40	27	1	1
81	BZC	55	PPL	596	208	35	0	1
81	BLT	35	PPL	1130	650	58	0	12
81	DRL	39	PPL	75	14	19	2	1
81	DHM	42	PPL	272	93	34	0	11
83	ELT	22	CPL	1390	50	3.5	2	7
83	DPM	19	PPL	172	-	-	3	1
83	ARL	35	PPL	130	89	68	1	12
83	DVF	51	CPL	1302	11	0.8	2	12
89	CXI	28	PPL	148	3	2	1	4
80	DRA	61	PPL	776	776	100	0	1
80	BWN	61	PPL	2600	36	1	2	1
84	DEV	21	PPL	99	15	15	0	7
84	BKH	42	PPL	260	9	3	1	7
85	ECU	48	PPL	528	120	23	1	1
85	DGA	29	PPL	350	130	37	0	11
85	JOE	46	PPL	396	38	10	0	5
80	BUE	26	CPL	1440	17	1	0	12
82	CNK	39	PPL	429	180	42	2	1
82	BJY	33	PPL	840	276	33	3	1
82	CIU	46	PPL	189	61	32	1	2
82	CFV	55	PPL	204	78	38	1	1

Yr	C/S	Age	Lic	Hrs	Type	%	Pax	Surry
84	CNV	36	PPL	116	114	98	3	1
90	DFV	34	PPL	2200	1600	73	1	12
84	BLU	25	PPL	316	80	25	0	12
84	PAS	25	PPL	300	60	20	1	1
86	WED	44	ATPL	10781	70	0.6	6	12
81	EHR	34	CPL	4098	3100	76	1	1
81	ELR	38	PPL	4162	-	-	1	5
90	WAF	20	PPL	80	57	71	0	5
91	DXG	38	CPL	820	110	0.4	5	8
89	ASG	57	ATPL	11906	67	0.5	1	12
90	DRG	20	SPL	36	36	100	0	3
90	DQY	45	PPL	282	14	5	5	3
86	EXC	19	SPL	59	59	100	0	4
90	JAM	35	PPL	343	130	38	0	1
89	CHL	40	PPL	1100	270	24	3	1
90	JBK	28	PPL	88	88	100	1	12
90	DOL	48	PPL	202	202	100	2	5
89	EZG	46	ATPL	2700	568	21	1	1
82	BWZ	38	PPL	191	180	94	1	1
89	EQQ	46	PPL	305	10	3	0	1
90	EHM	52	PPL	1946	1405	72	0	3