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Aeronautical decision making: Experience, training and behaviour

Richard Batt

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Abstract

Decision making is fundamental to all aspects of flying operations. The results that flow from poor aeronautical decision making can be both swift and devastating.

The work of this thesis uses data from a variety of sources to investigate the following aspects of aeronautical decision making:

- accident and incident case histories and pilot decision making
- case-based versus rule-based pilot decision training
- pilot behaviours in the face of adverse weather

The first part of the thesis uses survey data to gain a better understanding of the role of accident and incident case histories in aviation safety and training. Anecdotal evidence suggests that exposure to case-based information can leave a lasting impression on a pilot and significantly influence their flying behaviour. To investigate this aspect more formally, information was obtained from a survey of 138 pilots. A questionnaire was then distributed to pilots worldwide and responses were received from 409 pilots, from all areas of aviation. The combined experience of pilots who responded was over 700,000 hours flying time.

The second part of the thesis uses experimental data to compare the effectiveness of aviation safety training using case-based material or rule-based material. Two experiments were carried out, based on the two areas that account for the majority of fatal general aviation accidents: flight into adverse weather and low flying. A total of 114 participants took part in the experimental studies.

The third part of the thesis is based on a set of 491 aviation accident and incident reports drawn from the Australian Transport Safety Bureau occurrence database. The study compares three groups of pilots who differed in their response to adverse weather conditions, as demonstrated by the following behaviours:

- VFR flight into IMC
- a weather-related precautionary landing
- some other significant weather avoidance action

A number of common themes emerged from the three parts of the thesis. There is strong support for the importance of case-based material in aviation safety and training. However, the results also suggest that aeronautical decision making can be best understood in terms of a model that combines both case-based and rule-based reasoning. Rule-based material provides a basic framework of standard procedures and recommended practices, particularly for novices, while case-based
material adds detail and salience to the framework, particularly in the form of affective markers linked to particular case histories.

One important aspect of the results can be summed up by the adage that 'a safe pilot is a proactive pilot'. That is, it is imperative for a pilot to take control of the situation before the situation takes control of them. The results also emphasise the dynamic nature of aeronautical decision making. A pilot may make a series of good decisions, but that is no automatic protection against a subsequent poor decision putting the safety of the flight at risk. Hence, it is critical that a pilot does not fly to the limit of their abilities, or let past success breed complacency.
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I would also like to acknowledge my mother, Phoebe, for the inspiration that learning is a life-long pursuit.

Most importantly, I would like to sincerely thank my wife, Janice, for her continual help, encouragement, and support throughout the project.
# Contents

Abstract

Acknowledgements

1. Introduction
   1.1. The central nature of decision making
   1.2. Thesis outline
      1.2.1. Accident and incident case histories and pilot decision making
      1.2.2. Case-based versus rule-based pilot decision training
      1.2.3. Pilot behaviours in the face of adverse weather
      1.2.4. Outline of literature review
   1.3. Decision making
      1.3.1. The ‘analytical’ view of decision making
      1.3.2. Are humans flawed decision makers?
      1.3.3. New perspectives in decision making research
      1.3.4. Decision making as ‘intuition’
      1.3.5. Affect and decision making
      1.3.6. Decision making in complex, dynamic, and time-limited situations
      1.3.7. Practical aspects of decision making
   1.4. Expertise
   1.5. Case-based reasoning
      1.5.1. The case-based reasoning approach to decision making
      1.5.2. Applications of case-based systems
      1.5.3. Hybrid case-based and rule-based systems
   1.6. Aeronautical decision making
      1.6.1. Definition of aeronautical decision making
      1.6.2. Growth in aeronautical decision making research
      1.6.3. Why aeronautical decision making is important
      1.6.4. Major themes in aeronautical decision making research
      1.6.5. Affect and aeronautical decision making
      1.6.6. The ‘ARTFUL’ aeronautical decision maker
   1.7. Weather-related decision making
      1.7.1. Weather accident statistics
      1.7.2. Weather-related decision making research
      1.7.3. A conceptual framework for weather-related decision making

Part 1 Occurrence case histories and pilot decision making

2. Identifying the effect of case histories on ADM
2.1. Survey outline 99
2.2. Survey results 101
   2.2.1. Are accident and incident case-histories recalled at critical flight times? 101
   2.2.2. Other issues raised in survey responses 122

3. Quantifying the effect of case histories on ADM 129
   3.1. Questionnaire outline 129
   3.2. Questionnaire results 130
      3.2.1. Demographic profile of pilots 130
      3.2.2. Flying history and experience 131
      3.2.3. Exposure to safety related aviation material 138
      3.2.4. Are accident and incident case-histories recalled at critical flight times? 139
      3.2.5. Pilots’ beliefs about learning from experience 142
      3.2.6. Factors affecting pilots’ beliefs about learning from experience 144

Part 2 Case-based versus rule-based pilot decision training 149
4. When To Turn Back 155
   4.1. Method 156
      4.1.1. Bad weather flying training material 156
      4.1.2. Bad weather flying test material 160
      4.1.3. The Icarus flight simulation program 160
   4.2. Data analyses 172
      4.2.1. Experimental variables 172
      4.2.2. Dependent variable - Final cloud 172
      4.2.3. Training variables 173
      4.2.4. Decision variables 174
      4.2.5. Demographic variables 175
      4.2.6. Psychological variable 175
      4.2.7. Flight performance variables 175
      4.2.8. Flight performance group 179
   4.3. Results 182
      4.3.1. Distribution of final cloud scores 182
      4.3.2. The effect of training group on weather-related decision making 183
      4.3.3. The effect of training on skilled and attentive participants 184
      4.3.4. The effect of training time and training score on weather-related decision making 186
      4.3.5. The effect of decision variables on weather-related decision making 186
      4.3.6. The effect of demographic variables on weather-related decision making 187
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3.7. The effect of Need for Cognition score on weather-related decision making</td>
<td>187</td>
</tr>
<tr>
<td>4.3.8. Interactions between variables affecting final cloud scores</td>
<td>187</td>
</tr>
<tr>
<td>5. How Low To Go</td>
<td>189</td>
</tr>
<tr>
<td>5.1. Method</td>
<td>189</td>
</tr>
<tr>
<td>5.1.1. Low-flying training material</td>
<td>189</td>
</tr>
<tr>
<td>5.1.2. Low-flying test material</td>
<td>192</td>
</tr>
<tr>
<td>5.1.3. The <em>How Low To Go</em> low-flying decision making scenario</td>
<td>193</td>
</tr>
<tr>
<td>5.2. Data analyses</td>
<td>195</td>
</tr>
<tr>
<td>5.2.1. Experimental variables</td>
<td>195</td>
</tr>
<tr>
<td>5.2.2. Dependent variable - Final altitude</td>
<td>195</td>
</tr>
<tr>
<td>5.2.3. Training variables</td>
<td>196</td>
</tr>
<tr>
<td>5.2.4. Decision variables</td>
<td>196</td>
</tr>
<tr>
<td>5.2.5. Decision group</td>
<td>199</td>
</tr>
<tr>
<td>5.2.6. Demographic variables</td>
<td>201</td>
</tr>
<tr>
<td>5.2.7. Psychological variable</td>
<td>201</td>
</tr>
<tr>
<td>5.3. Results</td>
<td>201</td>
</tr>
<tr>
<td>5.3.1. Distribution of final altitude scores</td>
<td>202</td>
</tr>
<tr>
<td>5.3.2. The effect of training group on low flying decision making</td>
<td>202</td>
</tr>
<tr>
<td>5.3.3. The effect of training for the quick decision group</td>
<td>203</td>
</tr>
<tr>
<td>5.3.4. The effect of training time and training score on low flying decision making</td>
<td>205</td>
</tr>
<tr>
<td>5.3.5. The effect of demographic variables on low flying decision making</td>
<td>205</td>
</tr>
<tr>
<td>5.3.6. The effect of Need for Cognition score on low flying decision making</td>
<td>206</td>
</tr>
<tr>
<td>5.3.7. Interactions between variables affecting final altitude scores</td>
<td>206</td>
</tr>
</tbody>
</table>

**Part 3** Pilot behaviours in the face of adverse weather 207

6. Identifying pilot weather-related behaviours 211

6.1. Weather-related decision making group dataset 211

6.1.1. The Australian Transport Safety Bureau database 211

6.1.2. Selection of weather-related decision making occurrences 212

6.1.3. VRF into IMC occurrences 216

6.1.4. Precautionary landing occurrences 219

6.1.5. Weather avoidance occurrences 220

6.2. Weather-related decision making group data analyses 222

6.2.1. Occurrence outcome 222
1. Introduction

This thesis describes a number of related studies into aspects of aeronautical decision making.

1.1. The central nature of decision making

Decision making is fundamental to all aspects of flying operations. From a low-time student pilot planning for a cross-country navigational exercise, to an experienced professional pilot carrying out a single-pilot IFR\(^1\) approach in bad weather, the basic principles are the same. In both cases the pilots are doing just what humans do most of the time; taking in information, trying to make sense of it, and then carrying out some action as a result. This model of human information processing can be summarised as follows (Nagel, 1988);

\[
\text{Information} \rightarrow \text{Decision} \rightarrow \text{Action}
\]

Decision making, then, is central to adaptive behaviour, and no more so than in an environment such as aviation.

Traditionally, aeronautical decision making was considered to be an intangible aspect of airmanship. Experienced and successful pilots embodied 'The Right Stuff' compared to lesser mortals. In contrast, the contemporary view sees aeronautical decision making as a cognitive function that is open to analysis on the basis of standard psychological theory and practice (Brecke, 1982; Stokes & Kite, 1994).

Research into the human factors related to aircraft accidents and incidents has highlighted decision making as a crucial element (Jensen, 1982; O'Hare, Wiggins, Batt, & Morrison, 1994). In addition, as technological advances have led to better designed and manufactured aircraft and fewer mechanical failures, the relative importance of human factors in accidents and incidents can only increase\(^2\).

As in all fields of human endeavour, performance in aeronautical decision making can range from the inspiring to the tragic, as the following two cases illustrate.

Case 1

On April 28 1988, a Boeing 737-200 operated by Aloha Airlines as Flight 243 experienced structural failure, fuselage separation and explosive decompression while enroute from Hilo to Honolulu, Hawaii, at 24,000 feet. Approximately 18

---

\(^1\) Instrument Flight Rules

\(^2\) One particular area in which there is a growing awareness of the importance of human factors is that of maintenance (Reason & Hobbs, 2003).
feet of the cabin skin and structure aft of the cabin entrance door and above the passenger floor line separated from the aircraft during flight. The cockpit entry door was detached and the flight crew could see blue sky through the area of the missing roof section. There were 89 passengers and 6 crewmembers on board. One flight attendant died when she was pulled out of the main cabin during the decompression.

The captain extended the speed brakes and began an emergency descent. Because of the slipstream noise the crew initially had to use hand signals to communicate. At 10,000 feet the captain retracted the speed brakes and began a gradual turn towards Maui airport. Initially, the flaps 1 position was selected, and then the flaps 5 position. However, extending further flap led to controllability problems and the captain decided to return to flaps 5 for landing. When the landing gear was extended during the approach, the main gear indicated down and locked but the nose gear green indicator did not illuminate. The manual gear extension procedure was carried out, but the green light still did not illuminate. While manoeuvring for the final approach the captain sensed a yawing motion and determined that the left-hand engine had failed.

A normal descent profile was established four miles out on the final approach and the aircraft landed at Maui Airport making a normal touchdown and landing rollout. An emergency evacuation was then carried out.

The handing of the Aloha Flight 243 emergency highlights many of the aspects of good airmanship and decision making. The crew were faced with an emergency situation well beyond anything they would have prepared for during simulator-based training. The aircraft had suffered significant structural damage and they had to deal with a range of problems including communication difficulties and a high airspeed and...
rapid rate of descent, as well as multiple failures of aircraft systems and components. They accomplished all of this with no further loss of life or damage after the initial structural failure (NTSB, 1989a).

Case 2
On [date] an Embraer EMB 110 Bandeirante aircraft, registration [XXX], crashed while enroute from [point of departure] to [destination], [country of occurrence]. The flight was a single-pilot VFR regular public transport operation. On board the aircraft were the pilot, a flight attendant and 15 passengers.

During descent to [destination], weather and cloud base information was passed to the pilot by the [destination] air traffic control tower. The pilot's acknowledgement of this information was the last transmission received from the aircraft. When the aircraft did not arrive at [destination], a distress phase was declared and a search was begun for the missing aircraft. Approximately two-and-a-half hours later, wreckage was located on a mountain ridge at an elevation of 8,700 feet. The aircraft had been destroyed and there were no survivors.

Weather conditions in the vicinity of [destination] at the time of the accident were reported to include 6-7 OKTAS of cloud between 8,000 feet and 9,000 feet, with rain showers and low cloud on the hills. Witness marks on the trees indicated that at the time of impact the aircraft was in a wings level, slightly nose-down attitude, indicative of a cruise descent profile.

The investigation determined that the aircraft struck the ridge while under control and operating in cloud below the lowest safe altitude. It was reported that the pilot frequently relied on the GPS for navigation and it was considered possible
that the pilot was not using a visual navigation chart for reference and therefore was not able to cross-check his GPS position against topographical features.

The investigation revealed that the pilot had a history of flying too close to terrain and of unnecessarily flying in cloud. He had been observed on previous occasions by other company pilots to fly into cloud without reference to navigation charts, and on two occasions passengers had intervened when the pilot had flown through cloud. Three months before the accident, an experienced pilot travelling as a passenger in the co-pilot's seat had taken control when the aircraft was about to enter cloud in the vicinity of high terrain. A month before the accident, a company employee travelling as a passenger became concerned when descent was commenced through cloud. The passenger left their seat and remonstrated with the pilot, who then climbed the aircraft into clear air and subsequently descended through a gap in the cloud.

The pilot's company check and training record noted concerns in regard to his attitude to weather and mountain flying, and the pilot had been counselled in relation to those aspects of his flying⁴.

The crash of Bandeirante registration [XXX] highlights the very harsh consequences that can quickly follow from poor aeronautical decision making. In addition, deficiencies in weather-related decision making can have particularly serious consequences.

The overall conclusion of these two cases, then, is that decision making matters. While it may at times appear to be a rather abstract and nebulous concept, nevertheless the outcomes that can follow from poor aeronautical decision making can be very real and immediate.

1.2. Thesis outline

The studies that form part of this thesis can be grouped into three areas under the following topics;

- accident and incident case histories and pilot decision making
- case-based versus rule-based pilot decision training
- pilot behaviours in the face of adverse weather

This thesis draws on a range of data sources and methods in order to approach the topic of aeronautical decision making from a number of different perspectives. For example, the work includes both qualitative and quantitative studies While some parts of the work are based on information received from pilots with varying levels of experience, other parts of the work are based on experimental studies with participants that do not have an aviation background.

The three main sections to this study are based on three different types of data sources, namely;

⁴ This synopsis is based on a draft report prepared by the aviation accident investigation body of the country in which the accident occurred. The accident synopsis has been de-identified as the final investigation report has not been released and is subject to legal proceedings in the country in question. The accident did not occur in Australia or New Zealand.
The three different data sources correspond to the three topic areas of the thesis. Firstly, the survey data section studies the role of accident and incident case histories in pilot decision making. Secondly, the experimental data section compares case-based and rule-based training in two areas of particular safety concern in general aviation, weather-related decision making and unauthorised low flying. Finally, the occurrence data section compares three groups of pilots who demonstrated different risk responses when faced with adverse weather during a flight.

At the time of thesis submission, the following works had been published based on the three parts of the thesis.

**Accident and incident case histories and pilot decision making**

**Case-based versus rule-based pilot decision training**

**Pilot behaviours in the face of adverse weather**


A brief outline of the rationale and work carried out in each of the three parts of the thesis is given below.

1.2.1. **Accident and incident case histories and pilot decision making**

Accident and incident case histories play a major role in aviation safety and training, both formally and informally. On a formal level many accidents and incidents are thoroughly investigated by national air safety authorities and the findings published with detailed background information, analyses, and conclusions. These reports are distributed throughout the aviation community with the aim of improving flying systems and practice at both the organisational and individual level. Information from these reports is used widely in flight safety periodicals, as well as in many aviation books and magazines. On an informal level...
anecdotes about the mistakes of the past often figure prominently whenever pilots meet. From cautionary stories that an instructor tells her students to 'hanger talk' late into the night, a wealth of experience is passed from pilot to pilot.

Anecdotal evidence suggests that case histories can often have a major effect on how pilots think about their flying operations. Many pilots report that reading a case history left a lasting impression that will alter their flying behaviour in the future. For example, on July 20, 1996, an experienced Canadian bush pilot died while trying to rescue his passengers after his Cessna 206 seaplane flipped as he was attempting a heavy-water take-off (Schonberg, 1997). The pilot managed to rescue two passengers but he and four others drowned. Another pilot, in describing the effect that this fatal crash had on his thoughts of a similar situation wrote,

*I know that I will never forget the story... It will become part of the training that I give to all my future seaplane students...
I know that I too have made poor take-off decisions. The next time that I am facing high winds, rough water, short take, a heavy load, etc., I will be thinking of this accident, and my decisions will be more conservative because of it.*

(Schonberg, 1997, p. 12)

To gain a better understanding of how previous accident and incident case histories might influence pilot decision making, a survey was developed and distributed to pilots via the Internet. Responses were received from 138 pilots around the world. The respondents were from all areas of flying, private and commercial, civilian and military, and ranged in experience from student pilots with only a few hours flying time to senior professional pilots with thousands of hours of experience. The responses were unstructured and provided a wealth of stories, information and insights. The qualitative survey results are presented in Chapter 2.

On the basis of the survey responses a questionnaire was developed to further quantify the preliminary findings. Again this was distributed worldwide via the Internet and responses were received from 409 pilots, across all areas of aviation. The combined experience of pilots who responded to the questionnaire was over 700,000 hours flying time. The questionnaire also requested demographic and flying history data, allowing a detailed comparison of pilots' responses across factors such as flying background, several measures of experience, age, and sex. The quantitative questionnaire results are presented in Chapter 3.
1.2.2. Case-based versus rule-based pilot decision training

The second section of the study follows from the first and introduces the concept of case-based reasoning to the study of aviation safety training. The dominant paradigm has depicted expertise as rule-based knowledge compilation (Anderson, 1982, 1993). An alternative model based on recent work in case-based reasoning is presented. From this point of view expertise is seen as a library of experiences (Riesbeck & Schank, 1989). Work in the second section consists of two experiments designed to investigate aspects of air-safety training using case-based material and rule-based material. The experiments were based on two areas that account for the majority of fatal general aviation accidents: flight into adverse weather and low flying.

The participants in the experimental studies were deliberately chosen not to have an aviation background. That was done to avoid the possibly confounding influence of any existing case-based or rule-based knowledge that pilot subjects would have brought to the study. All training material was presented by computer to enable the automatic recording of experimental information. After viewing the training material, participants completed a simulator-based flight scenario. A PC-based flight simulator program was developed and programmed by the author for this purpose.

In the first experiment, *When To Turn Back*, 57 participants completed a simulated light aircraft flight into deteriorating weather. For this experiment, the case-based training material was adapted from investigation reports of aircraft involved in weather-related accidents or incidents. In contrast, the rule-based material was a theoretical exposition stating the dangers flying in bad weather and outlining the principles of good flight management that must be followed in such situations. The method and results of the first experiment are presented in Chapter 4.

The second experiment, *How Low To Go*, presented a low-flying judgement task to 57 participants. Again the case-based training material was adapted from accident and incident case reports involving low-flying while the rule-based training material addressed the same topic but was theoretical in nature. The method and results of experiment 2 are presented in Chapter 5.

1.2.3. Pilot behaviours in the face of adverse weather

A VFR pilot may exhibit a range of behaviours when faced with adverse weather. For example, at the first hint that conditions are deteriorating, a pilot may decide that discretion is the better part of valour and immediately return to their point of departure and recount their brush with danger to an instructor or to fellow pilots in the clubrooms. At the
other extreme, a pilot may 'press on' into deteriorating weather, either unable or unwilling to see the increasing danger of the their actions, until the aircraft suddenly enters IMC and they have only minutes to rue their reckless behaviour before the flight ends in disaster.

A more typical scenario might involve a pilot who, in response to deteriorating conditions, initially continues the flight as planned, but subsequently decides to return, divert, or perhaps even carry out a precautionary landing. Then, in hindsight, they may analyse the situation in which they found themselves, and the actions that they took in response. In that way their experience may influence their behaviour in the future if, and when, they are confronted by a similar situation. In addition, the case-history that encapsulates their experience may also provide a salutatory lesson for others.

The work in the third section of the thesis is based on a set of 491 aviation accident and incident reports drawn from the Australian Transport Safety Bureau occurrence database. The study compares three groups of pilots who differed in their response to adverse weather conditions encountered during their flight. The three weather-related decision making behaviours compared in the study are:

- VFR into IMC
- a weather-related precautionary landing
- some other significant weather avoidance action

The cases in these three groups can be considered as lying on a behavioural continuum that reflects different levels of risk to the safe completion of the flight, with VFR into IMC representing the greatest threat to flight safety.

Quantitative results from the occurrence data section are presented in Chapter 6 and the qualitative results in Chapter 7.

1.2.4. Outline of literature review

**Decision making**

The literature review begins with a brief overview of traditional 'analytical' theories of decision making. Understandably, studies into aeronautical decision making have been almost entirely informed by theory and research drawn from the field of decision making in general. However, the main conclusion of the overview of traditional work in decision making is that it is probably of only marginal relevance to decision making as it is practised in complex, dynamic, and time-limited situations such as aviation. More recently, alternative approaches such as Naturalistic Decision Making (NDM) have provided an alternative framework that appears to have merit in understanding the type of decision making typically done by pilots during flying operations. Work
in two other areas to gain prominence in decision making research, intuition and affect, is also briefly reviewed. The section of the literature review on decision making concludes with a coverage of some areas of specific relevance to aeronautical decision making, namely, dynamic decision making, the problem-detection process, and plan continuation errors and confirmation bias.

Expertise
The literature review then briefly outlines concepts and research in the area of expertise. This follows from the section on decision making where one of the important distinctions to emerge is that between novice and expert decision makers. Different theories of expertise are briefly considered, including more recent work that describes expertise in terms of pattern recognition, a conceptualisation that fits well with approaches such as naturalistic decision making. The review then outlines work that characterises expertise as rule-based knowledge compilation, and discusses the limitations of that approach. This leads into an alternative view that sees expertise as a case-based library of experiences.

Case-based reasoning
Case-based reasoning is a model of how people learn from experience. As such, it is a useful model for studying how people develop expertise in domains such as aviation. The review of case-based reasoning briefly outlines the basic principles of the approach such as the Retrieve – Reuse – Revise – Retain cycle (Kolodner, 1993).

The review compares and contrasts case-based and rule-based cognitive models of knowledge acquisition and expertise. Examples are given of successful case-based reasoning systems in the field of aviation. For example, CASSIOPEE is a case-based reasoning system designed to support troubleshooting of CFM 56 aircraft engines (Heider, 1996). Also described is a case-based reasoning system developed by the FAA to choose air traffic control ‘plays’ from the National Playbook (Allendoerfer & Weber, 2004). This section of the review ends with information about hybrid case-based and rule-based systems, including CELIA, a system that models the developmental change from novice to expert that occurs with experience (Kolodner, 1993; Redmond, 1997).

Aeronautical decision making
This section of the literature review begins with a discussion about the definition of the term ‘aeronautical decision making’. The section then includes some original research indicating the relative growth in the academic field of aeronautical decision making research compared to the field of decision making in general. The main part of this section of the review then considers the three models that have underpinned much of the work done in the field of aeronautical decision making;
1.3. Decision making

What a piece of work is man!

Since time immemorial, people have held different views about the quality of human decision making. Shakespeare held man in high regard — noble in reason and infinite in faculties. In contrast, conventional researchers of decision making typically propounded a far more jaundiced view of the capabilities and limitations of the human decision maker. The conventional wisdom, based largely on the results of laboratory studies, was that humans were flawed decision makers who failed to live up to the normative standards set for them by researchers. More recently, however, a new group of decision researchers have taken a different perspective. In practice, they have studied the processes of effective decision making in real-world situations. Concurrently, a range of new theoretical approaches to human decision making have developed.

The following threads in decision making research are described in detail in the following sections:

---

5 What a piece of work is man! How noble in reason! How infinite in faculties! In form and moving, how express and admirable! In action how like an angel! In apprehension, how like a god! The beauty of the world! The paragon of animals!

Hamlet (II, ii, 115-117).
Introduction

• the traditional ‘analytical’ view of decision making
• perceived inadequacies in human decision making
• shortcomings of normative assumptions
• alternatives to ‘analytical’ theories
• decision making as ‘intuition’
• the role of affect

1.3.1. The ‘analytical’ view of decision making

Early research in human decision making drew heavily on work in economic theory. Von Neumann and Morgenstern (1947) first developed expected utility theory as an attempt to prescribe formal methods by which individuals could achieve optimal outcomes. From an analytical point of view, rational decision making was seen as a process of calculating and comparing subjective expected utility (SED) values (Dawes, 1988). The SED value of an alternative consisted of the sum of the utilities of its outcomes, each weighted by its probability. Normative strategies such as multi-attribute utility analysis (MADA) are based on SED theory and assume perfect information; all decision options and their relative costs and benefits are known, and that an optimal solution can be reached by combining this information via a mathematical formula (Chankong & Haimes, 1983). MADA is a compensatory decision making strategy in that when a course of action is rated low on one evaluative dimension this can be compensated for by a high value on another dimension. This type of formal analysis can be very computationally intensive and time consuming.

The type of research on which this early work on decision making was based consisted primarily of laboratory-based experiments. Subjects were typically presented with information relating to a choice decision task, and then asked to choose from a small set of predetermined alternatives. Research in the 1970s and 1980s showed that in such situations people often adopt noncompensatory decision making strategies, rather than exhaustively considering all options on all dimensions. Short-cuts or heuristics are used to provide a satisficing rather than an optimizing solution. However as heuristics simplify the true situation they can lead to systematic biases and errors compared to normative standards (Kahneman, Slovic, & Tversky, 1982). As a result, the conclusion of researchers was that people were often flawed in their approach decision making.

Common reasoning shortcuts identified by Kahneman, Slovic, and Tversky (1982) included the representativeness heuristic, the availability heuristic and the anchoring and adjustment heuristic. The representativeness heuristic refers to the likelihood that a decision maker will be particularly influenced by data that are representative of, or 'look
like', those of the hypothesis. This approach can ignore crucial base-rate information, leading to errors in decision making. Availability refers to the ease with which occurrences related to a particular hypothesis can be recalled. Hence, factors that promote the salience of particular data, such as recency, can introduce bias. Anchoring and adjustment describes a process in which an initially generated or given response serves as an anchor point, and other information is used to adjust that response. Typically, insufficient adjustment will be made in the light of new material that updates or supersedes the original information, again resulting in decisions that fall short of normative standards.

As decision complexity increases so does the likelihood that simplifying heuristics rather than normative methods will be used in decision making. For example, in situations with multiple decision alternatives, that is most real-life decision making, people prefer noncompensatory choice strategies rather than multi-attribute utility analysis (Payne, Bettman, & Johnson, 1992).

Given a wealth of evidence that normative procedures are often not followed the conclusion was that people were irrational and flawed decision makers. Traditional decision theorists have often been harshly critical of these perceived failings. For example, Lindley (1985) states,

There is essentially only one way to reach a decision sensibly. First, the uncertainties present in the situation must be quantified in terms of values called probabilities. Second, the various consequences of the courses of action must be similarly described in terms of utilities. Third that decision must be taken which is expected - on the basis of the calculated probabilities - to give the greatest utility. The force of 'must', used in three places there, is simply that any deviation from the precepts is liable to lead the decision maker into procedures which are demonstrably absurd.

(Lindley, 1985, p. vii)

In some cases the criticism of individual failings in decision making has led to a pessimistic view of the capabilities of humankind to solve the problems that it faces. For example, Simon (1957) states,

The capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behavior in the real world - or even for a reasonable approximation to such objective rationality.

(Simon, 1957, p. 198)

But what Simon and others seem to have ignored is that humankind has successfully evolved and adapted to its environment over aeons of time,
suggesting that, in practice, humans decision making skills are perhaps not as limited as some have suggested.

Even within the confines of the laboratory tasks employed in most traditional decision making research, there can be significantly different views as to the ‘best’ decision in a particular situation. However, in such situations it is the experimenter and not the subject who finally decrees what is the ‘correct’ normative model to apply. As a result, some critics have suggested that researchers who claim that the subjects in their experiments show flawed reasoning are themselves guilty of exactly that error (Stanovich & West, 2002).

It can be noted that decision making is not the only area of psychological research that has been held back because it was uncomfortable venturing outside the laboratory. For example, in decrying a similar situation in relation to memory research, Neisser (2000) states;

*The orthodox psychology of memory has very little to show for a hundred years of effort, in part because it systematically avoids the most interesting issues. Just as the naturalistic, ethological study of animal behavior turned out to be much more interesting than traditional studies of “animal learning”, so a naturalistic study of memory might prove more productive than its laboratory counterpart.*

(Neisser, 2000, p. 3)

Hence, decision-making, in common with a number of other areas of academic psychology, has suffered by being hidebound by a rather narrow and rigid orthodoxy that has not fostered innovative research. However, more recent development in decision-making research have moved beyond the strictures of earlier work.

1.3.2. Are humans flawed decision makers?

On reflection, the analytical model of human decision making can seem very disconnected from the reality of much everyday decision making. As Slovic, Finucane, Peters and MacGregor (2004) point out, it is unlikely that two people deciding whether or not to greet each other employ ‘street calculus’ to analytically make their decision (see Figure 3). A wealth of everyday experience tells us people just don’t make decisions like that.
Holyoak and Thagard (1995) recount the possibly apocryphal story of an eminent philosopher of science who encountered a noted decision theorist in a hallway at their university.

*The decision theorist was pacing up and down, muttering*

"What shall I do? What shall I do?"

"What's the matter, Howard?" asked the philosopher.

Replied the decision theorist: "It's horrible, Ernest – I've got an offer from Harvard and I don't know whether to accept it."
"Why Howard," reacted the philosopher, "you're one of the world's great experts on decision making. Why don't you just work out the decision tree, calculate the probabilities and expected outcomes, and determine which choice maximizes your expected utility?"

With annoyance, Howard replied: "Come on – this is serious."

(Holyoak & Thagard, 1995, p. 139)

The conclusion is that people aren't all that often analytical decision makers. As with many simple but important insights, this seems rather obvious in retrospect. As Klein (2003) points out,

We would never get through the day if we had to analyze every decision before we made it.

Klein (2003, p. xvi)

Two related aspects that decision theorists may give insufficient allowance for when casting judgment of peoples' decision making abilities relate to the time scale involved and to the operation of 'hindsight bias' (Fischhoff, 1975; Guilbault, Bryant, Brockway, and Posavac, 2004). It is unreasonable to argue that solutions that decision theorists may arrive at after exhaustive analysis over a considerable period of time should have been immediately obvious to those involved.

The role of timescale and hindsight bias are vividly demonstrated in an example given by Fischhoff (1987) that illustrates how different from analytical calculation real life decision making can be, and yet how often formal methods are used as a benchmark against which people are unfairly judged. In May 1979 an American Airlines McDonnell Douglas DC-10 crashed immediately after take-off from Chicago's O'Hare International Airport (NTSB, 1979b). Just after lift-off the No. 1 engine broke away with the engine pylon attached. Subsequent damage to the hydraulic system resulted in an asymmetrical slat configuration and the aircraft rolled to the left despite aileron and rudder deflections in the opposite direction. The No. 1 engine provided power to a number of systems and instruments, all of which failed when the engine was lost.
16 Aeronautical decision making

Figure 4. American Airlines Flight 191 just prior to impact at Chicago O'Hare International Airport.

The aircraft crashed approximately a mile from the end of the runway 31 seconds after take-off. All 271 people on board were killed. Fischhoff (1987) gives the following report in testimony before the U.S. House of Representatives Committee on Armed Services,

I had the opportunity to eavesdrop on a discussion involving the man assigned to the case by another major carrier. A panel of experts had sat since the accident and finally had come up with a theoretically feasible way of saving the plane. It had taken them two weeks, and the solution required the opposite of the normal response to loss of power at low altitude. Still they were going to claim 'operator error' for liability reasons. I followed the case and about six months later read a newspaper account of the investigators' conclusions. They had stopped short of pinning it all on the operator, but still claimed the plane was 'flyable'.

(Fischhoff, 1987, p. 4)

Such stories highlight that although there is a wealth of research material covering many different aspects of decision making much of it appears to bear little resemblance to real world problems. However, there has been a growing acceptance that the assumptions on which the jaundiced view of human decision making is based are significantly flawed (Meller, Schwartz, Ho, & Ritov, 1997). As Johnson-Laird and Shafir (1993) state,
The major psychological discovery about both reasoning and decision making is that normative theory and psychological facts pass each other by. People are not intuitive logicians, intuitive statisticians, or intuitive rational decision theorists.

(Johnson-Laird & Shafir, 1993, p. 6)

The magnitude of the gulf that exists between the approach of traditional laboratory-based decision making research and real world situations is evident when one considers the heroic assumptions that are implicit in analytical models of decision making. Klein (2002) discusses what he terms the ‘fiction of optimisation’ and lists an extensive list of assumptions that optimal choice models depend on;

- the goals must be well defined, in quantitative terms
- the decision maker's values must be stable
- the situation must be stable
- the task is restricted to the selection between options
- the number of alternatives generated must be exhaustive
- the optimal choice can be selected without disproportionate time and effort
- the options must be thoroughly compared to each other
- the decision maker must use a compensatory strategy
- the probability estimates must be coherent and accurate
- the scenarios used to predict failures must be exhaustive and realistic
- the evaluation of each scenario must be exhaustive

Situations that do not incorporate these factors have been described as involving ‘ill-defined’ problems (Jonassen, 2004; Pretz, Naples, and Sternberg, 2003), as opposed to the ‘well-defined’ problems of traditional decision research. As outlined by Maule and Svenson (1993), well defined problems are characterised by;

- clear goals of the choice situation
- well defined alternatives to choose from
- good information about the values and uncertainties of each outcome

While formal reasoning is the method by which well-defined problems are solved, informal reasoning is used to solve ill-defined problems (Evans & Thompson, 2004). In practice, and contrary to the assumptions of traditional decision research, informal reasoning plays a far greater part in everyday life than does formal reasoning.

The great majority of the everyday reasoning, including that of expert groups engaged in their professions, is informal. By contrast, most of the studies of human inference reported by psychologists in the literature are of formal reasoning.

(Evans & Thompson, 2004, p. 69)
Fifty years ago, at the outset of the cognitive study of decision making, the fundamental assumption was made that deductive reasoning and statistical inference were the cornerstone of rational thought. That assumption dominated research in the field to such an extent that it took decades for doubt to gradually grow and alternative approaches to develop (Thompson, 2004). Quite why the analytical approach to decision making took such hold when it appears to often bear little relevance to how people are likely to make decisions in the real world is not entirely clear. As Brehmer (1999) states,

*For reasons yet to be discovered by historians, the normative models ... acquired the status of standards of rationality, and deviations from what was prescribed by these models was seen as evidence that man was an irrational decision maker.*

(Brehmer, 1999, p9)

One of the upshots is that, as Brehmer (1999) points out, despite over 50 years of decision research, we still have very little idea about how people actually make decisions.

### 1.3.3. New perspectives in decision making research

The last two decades have seen the emergence of a number of new perspectives in the field of decision making research – so much so that the Introduction section of a recent monograph on the subject (Shanteau & Schneider, 2003) asks “Where to decision making?” The answer, recent publications in the field suggest, is in a number of innovative and interesting directions.

The overall thrust of these new decision making perspectives is that the process is much more complex than previously thought. A range of aspects related to the individual decision maker, and to the decision context, are now considered legitimate areas of enquiry where they were previously dismissed as irrelevant or irrational. A number of different ‘non-analytical’ approaches to decision making have been proposed, using terms such as ‘associative’, ‘experiential’, and ‘intuitive’. In particular, greater emphasis has been given to the importance of affect in many decision making situations (Loewenstein & Lerner, 2003; Peters, 2005) and to the crucial role of experience and expertise in decision making in specific domains (Salas & Klien, 2001). The role of heuristics in decision making has also been reappraised, with the emphasis shifting from heuristics as a source of error to one that sees them as an adaptive means of decision making in real-world environments (Gigerenzer & Selten, 2002).

Specific decision theories have developed to study decision making in complex, dynamic, and time-critical environments such as aviation flight operations, air traffic control, and nuclear power plant operation. Two
areas of research development in this area are Naturalistic Decision Making (NDM) and Complex Problem Solving (CPS). Research has also been carried out in the specific area of Dynamic Decision making (DDM). These issues are explored in more detail below.

**Turning the problem on its head**

The starting point for much recent decision making research outside the traditional research paradigm has been to redefine the problem. Rather than creating an artificial environment, and then criticising people for not playing by the rules, decision researchers have started asking questions such as "How do successful people actually make decisions in the real world?" Hence, an alternative viewpoint to analytical decision making theory is to accept as a starting premise that human decision making behaviour has evolved adaptively to meet certain real world needs. The task of decision research then becomes one of understanding both the nature of the decision making problems that people actually face in day to day life, and the methods that they use to successfully resolve them (Orasanu & Connolly, 1993).

<table>
<thead>
<tr>
<th>Researcher(s)</th>
<th>System 1</th>
<th>System 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epstein (1994)</td>
<td>analytic-rational</td>
<td>intuitive-experiential</td>
</tr>
<tr>
<td>Damasio (1994)</td>
<td>reason or analytical</td>
<td>emotion or experiential</td>
</tr>
<tr>
<td>Hammond, Hamm, Grassia, and Pearson (1987, 1997)</td>
<td>analysis</td>
<td>intuition</td>
</tr>
<tr>
<td>Gilovich, Griffin, and Kahneman (2002)</td>
<td>reason</td>
<td>intuition</td>
</tr>
<tr>
<td>Reyna, Lloyd, and Brainerd (2003)</td>
<td>continuum of rationality</td>
<td></td>
</tr>
<tr>
<td>Hsee and Rottenstreich (2004)</td>
<td>calculation</td>
<td>feeling</td>
</tr>
<tr>
<td>Slovic, Finucane, Peters, and MacGregor (2004)</td>
<td>analytic</td>
<td>experiential</td>
</tr>
</tbody>
</table>

Table 1. Nomenclature of reasoning systems.

One major theoretical underpinning of new decision making perspectives has been the concept of 'dual-process' theories of information processing (Epstein, 1994; Chaiken & Trope, 1999; Gilovich, Griffin, & Kahneman, 2002). Dual-process models posit that human information processing can take one of two distinct forms. The first is based on quick, effortless

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6 The terms 'System 1' and 'System 2' are used in this study for convenience. They are not descriptive terms used in the published literature.
processing that depends on well-learned prior associations, while the second involves more effortful processing using rule-based inferences and is employed only when people have both cognitive capacity and motivation (Smith & DeCoster, 2000). Different researchers have used different names for the two systems of reasoning (see Table 1). Reyna, Lloyd, and Brainerd (2003) suggest that rather than viewing the two systems as being dichotomous, it is more helpful to view them as lying on a continuum of rationality.

Epstein (1994) argues that the ‘rational’ system relies on the rules of logic and evidence, while the ‘experiential’ system works with images, metaphors, and narratives. Epstein also makes the distinction between what he describes as ‘intellectual knowledge’ and ‘insight’. Intellectual knowledge is derived from formal information sources and instruction, while insightful knowledge is gained by experience. Epstein (1994) claims that insightful knowledge gained through personally meaningful experience is more compelling and more likely to influence behaviour than impersonal abstract knowledge.

### Table 2. Inducement of intuition or analysis by task conditions.

<table>
<thead>
<tr>
<th>Task characteristic</th>
<th>Intuition-inducing state of task characteristic</th>
<th>Analysis-inducing state of task characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cues</td>
<td>large (&gt;5)</td>
<td>small</td>
</tr>
<tr>
<td>Measurement of cues</td>
<td>perceptual</td>
<td>objective</td>
</tr>
<tr>
<td>Distribution of cues</td>
<td>continuous highly variable distribution</td>
<td>unknown distribution; cues are dichotomous; values are discrete</td>
</tr>
<tr>
<td>Redundancy among cues</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Decomposition of task</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Degree of certainty in task</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Relation between cues and criterion</td>
<td>linear</td>
<td>non-linear</td>
</tr>
<tr>
<td>Weighting of cues in environmental model</td>
<td>equal</td>
<td>unequal</td>
</tr>
<tr>
<td>Display of cues</td>
<td>unavailable</td>
<td>available</td>
</tr>
<tr>
<td>Availability of organizing principle</td>
<td>unavailable</td>
<td>available</td>
</tr>
<tr>
<td>Time period</td>
<td>brief</td>
<td>long</td>
</tr>
</tbody>
</table>

Adapted from Hammond, Hamm, Grassia, & Pearson (1997).
Hammond, Hamm, Grassia, Pearson (1987, 1997) argue that people either use ‘analysis’ or ‘intuition’ when making a decision depending on the characteristics of the decision making environment. Environments with a large number of redundant perceptual cues, high uncertainty, no formal task model, and time constraints, will result in decision makers pursuing an intuitive strategy (see Table 2). Hence, intuition is likely to be the preferred approach to decision making in most naturalistic settings. Typically, intuitive decisions will be taken quickly, with little awareness of cognitive processing or of the method used, and with a high confidence on the part of the decision maker of the correctness of their decision (see Table 2). In practice, errors are likely to be normally distributed, with few catastrophic failures.

In comparison to intuition, which is well suited to naturalistic environments, Hammond, Hamm, Grassia, and Pearson (1987, 1997) suggest that analysis is the decision making method of choice for environments which resemble those found in most laboratory investigations of decision making. When solving a well defined problem based on a limited amount of structured information the preferred approach is to use a standard normative method of analysis.

Table 3. Properties of intuition and analysis.

<table>
<thead>
<tr>
<th>Property</th>
<th>Decision making strategy</th>
<th>Intuition</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive control</td>
<td></td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Rate of data processing</td>
<td></td>
<td>rapid</td>
<td>slow</td>
</tr>
<tr>
<td>Conscious awareness</td>
<td></td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Errors</td>
<td></td>
<td>normally distributed</td>
<td>few, but large</td>
</tr>
<tr>
<td>Confidence in answer</td>
<td></td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Confidence in method</td>
<td></td>
<td>low</td>
<td>high</td>
</tr>
</tbody>
</table>

Adapted from Hammond, Hamm, Grassia, & Pearson (1997).

Sloman (1996, 2002) also puts the case for two systems of reasoning, which he describes as a rule-based system and the other as an associative system. The rule-based system stores information in abstract form as procedural rules or rules of logic and operates by deliberate and sequential manipulation of internal representations. In comparison, the associative system encodes information in the form of statistical regularities and correlations, and computes on the basis of similarity and temporal structure.
Table 4. Characteristics of associative and rule-base systems.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Associative system</th>
<th>Rule-based system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principles of operation</td>
<td>Similarity and contiguity</td>
<td>Symbol manipulation</td>
</tr>
<tr>
<td>Source of knowledge</td>
<td>Personal experience</td>
<td>Language, culture, and formal systems</td>
</tr>
<tr>
<td>Nature of representation of basic units</td>
<td>Concrete and generic concepts, images, stereotypes, and feature sets</td>
<td>Concrete concepts, generic and abstract concepts, abstracted features, compositional symbols</td>
</tr>
<tr>
<td>Nature of representation of relations</td>
<td>Associations, Soft constraints</td>
<td>Causal, logical, and hierarchical</td>
</tr>
<tr>
<td>Nature of processing</td>
<td>Reproductive but capable of similarity-based generalization</td>
<td>Productive and systematic</td>
</tr>
<tr>
<td></td>
<td>Overall feature computation and constraint satisfaction</td>
<td>Abstraction of relevant features</td>
</tr>
<tr>
<td></td>
<td>Automatic</td>
<td>Strategic</td>
</tr>
<tr>
<td>Illustrative cognitive functions</td>
<td>Intuition, Fantasy, Creativity, Imagination, Visual recognition, Associative memory</td>
<td>Deliberation, Explanation, Formal analysis, Verification, Ascription of purpose, Strategic memory</td>
</tr>
</tbody>
</table>

Adapted from Sloman (2002).

Sloman points out that the inner workings of the associative reasoning system are not open to conscious reflection - the decision maker is only aware of the result of the computation and not the process used to produce the result. In contrast, for the rule-based reasoning system, the decision maker is aware of both the result and the underlying process by which the result was achieved.

Sloman argues that the associative system and the rule-base system can operate independently on the same problem, and therefore can sometimes come to simultaneous, contradictory beliefs. For example, the statement "Technically, a whale is a mammal" (Sloman, 2002; p 384) embodies the tension between two different perceptions, one intuitively compelling and the other factually correct.

As Sloman points out, the distinction between associative reasoning and rule-based reasoning may simply reflect the same distinction as that
between automatic and controlled processing in the case of perceptual-motor tasks (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Sloman (1996) argues that the two systems have overlapping domains that differ depending on the knowledge, skill, and experience that an individual brings to the decision making task. This proposal links with Rasmussen's (1983) conception of the progression, with experience, from knowledge-based, to rule-based, and finally to skill-based performance. With experience performance becomes automatic, based only on perceptual cuing and not on conscious analytical processing.

Performance is automatic when it is based on single-step direct-access retrieval of past solutions from memory.

(Logan, 1988, p. 493)

Initially, novices rely on rule-based processing. However, with experience they learn specific solutions to specific problems, which they retrieve when faced with the same problem again. Eventually, almost all responses will be case-based rather than rule-based, resulting in automatic performance (Logan, 1988). Gladwell (2005) has described this rapid cognitive process as one of ‘thinking without thinking’ where the decision maker uses ‘thin slices’ of experience to make snap judgements.

The increased realisation of the adaptive nature of non-analytic approaches to decision making has allowed a reappraisal of the utility of heuristics in decision making. For example, Gigerenzer and co-workers have stressed the usefulness and power of simple heuristics that fit the environment in which they are used (Gigerenzer & Todd, 1999; Gigerenzer, 2000; Gigerenzer & Selten, 2002). Gigerenzer has introduced the concept of an ‘adaptive tool box’ of ‘fast and frugal’ heuristics that can be applied effectively to real-world decision-making (Gigerenzer & Selten, 2002). In particular, heuristic principles can be applied to guide the search for information on alternative courses of action (search rules), to suggest when the search for further information should be discontinued (stopping rules), and to assess the relative merits of the alternative courses of action (decision rules).

Gigerenzer stresses that the purpose of the adaptive toolbox is not to guarantee an optimal solution, or even to ensure consistency. It is simply to provide strategies that help to achieve various goals by making decisions quickly, accurately, and with a minimum of effort (Gigerenzer, 2002).

Non-analytic approaches to decision making have been termed 'intuitive' approaches by some investigators (Bricknell, 1997). For example, Wagner (1991) has described managers involved in decision making as either rational technicians or intuitive craftspeople. Again, the weight of
evidence suggests that experienced managers do not rely heavily on analytical approaches for problem solving. The best predictor of effectiveness was the degree to which managers reasoned analogically from their personal experience. Bhaskar, Herstein and Hayes (1983) suggest that the more complex a domain the less efficacy formal analytical methods will have.

Schon (1983) studied five professions (engineering, architecture, management, psychotherapy, and town planning) to understand how professionals really go about solving problems. A central finding of Schon's work was that the practitioners he studied relied less on prescriptive formulas learned during their formal training than on the kind of improvisation learned in practice. Schon emphasises the importance of 'creativity' or 'intuition' in allowing practitioners to solve problems by recognising similarities to problems that have already been encountered.

1.3.4. Decision making as 'intuition'

Over the last ten years the term 'intuition' has arguably become the preferred term for describing non-analytical human information processing. This is perhaps surprising given the generally negative connotations of mysticism and the paranormal that the term has evoked in mainstream science. Nevertheless, the term intuition has increasingly been accepted in psychological research in general, and in the domain of decision making in particular.

Traditionally, intuition was not considered in a favourable light. For example, Tversky and Kahneman (1971, p 31) concluded that intuition should be regarded "with proper suspicion" and that researchers should "replace impression formation by computation whenever possible". However, that view has now changed significantly. In the last ten years a spate of lay-scientific books with intuition in the title have been published. For example, books such as Surgical intuition: What it is and how to get it (Abernathy & Hamm, 1995), Intuition: The Inside Story (Davis-Floyd & Arvidson, 1997), Educating intuition (Hogarth, 2001), Intuition: Its powers and perils (Myers, 2002), and Intuition at work: Why developing your gut instincts will make you better at what you do (Klein, 2003) are all written from a scholarly perspective.

Perhaps the negative view of intuition in some quarters in the past simply reflects the fact that we tend to mistrust that which we do not understand. Writing over forty years ago, Bunge (1962) suggests that;
intuition is] all the intellectual mechanisms which we do not know how to analyze or even name with precision, or which we are not interested in naming or analysing.

(Bunge, 1962, p. 68)

However, as Frantz (2003) recounts, even Herbert Simon, a noted researcher and one initially as skeptical of intuition as any, came to view intuition simply as subconscious pattern recognition. In doing so he showed that intuition need not be associated with magic and mysticism, but could be viewed as complementary to conscious analytical thinking.

A common theme to many conceptualisations of intuition is that people form nonconscious associations that influence behaviour without their awareness (Myers, 2002). As Myers (2002) states;

What you know, but don't know you know, affects you more than you know.

(Myers, 2002, p. 51)

However, as Bargh and Chartrand (1999) point out, much psychological theory assumes that people mostly process information consciously and systematically in order to engage in courses of action. In contrast though, the study of the 'cognitive unconscious' has increasingly gained acceptance (Uleman & Bargh, 1989; Hassin, Uleman, & Bargh, 2003). Bargh and Chartrand (1999) use the term 'thought lite' to describe mental process that are nonconscious, automatic, implicit and heuristic. Related concepts of have been termed 'non-conscious learning' (Lewicki, Hill, & Czyzewska, 1992), 'tacit learning' (Polanyi, 1996), and 'practical intelligence' (Sternberg, Forsythe, Hedlund, Horvath, Snook, Williams, Wagner, & Grigorenko, 2000).

Perhaps the clearest and most appropriate definition of intuition in the context of this study is that given by Klein (2003);

Intuition is the way we translate our experience into action.

(Klein (2003, p hh)

The characterisation of intuition as the crystallisation of experts domain knowledge has also been stressed by Goldberg (2005).

... intuition is the condensation of vast prior analytic experience; it is analysis compressed and crystallized.... It is the product of analytic processes being condensed to such a degree that its internal structure may elude even the person benefiting from it.... The intuitive decision-making of an expert bypasses orderly, logical steps precisely because it is a condensation of extensive use of such orderly logical steps in the past.

(Goldberg 2005, p 150)
1.3.5. Affect and decision making

One of the most significant developments in decision research brought about by the growing acceptance of 'nonanalytical' models of decision making relates to the role of affect. The last ten years have shown an increasing interest in the interplay of affect and cognition (Forgas, 2001; Davidson, Scherer, and Goldsmith, 2003; Isen and Labroo, 2003) and this has been reflected in an increasing awareness that rational behaviour depends on a complex interaction between affect (the experiential mind) and reason (the analytical mind) (Slovic, Finucane, Peters, and MacGregor, 2004). One fundamental finding of this new synthesis is that without affect, information lacks meaning (Peters, 2005). The role of affect in providing conscious information from unconscious appraisals of situations has been described by Clore, Gasper and Garvin (2001), and the role of affect in decision making has recently been reviewed by Loewenstein and Lerner (2003).

The recognition of the role of affect in decision making is supported by neurophysiological evidence. For example, research by Damasio has shown that affective deficits can degrade decision making capabilities (Damasio, 1994; Adolphs and Damasio, 2001; Bechara, Tranel, and Damasio, 2002). Damasio conducted experiments using subjects who had received damage to the frontal cortex. While their abilities in the areas of intelligence, memory, and capacity for logical thought remained intact, their ability to associate affective feelings with the anticipated consequences of their actions was impaired. In a card gambling experiment in which they could gain or lose a sum of money, subjects with prefrontal brain lesions did not learn to avoid decks with attractive large payoffs but occasional catastrophic loses. Although the subjects with frontal lesions responded normally (for example, in terms of galvanic skin response) to gains and losses as they occurred they did not learn to anticipate future outcomes.

Damasio argues that life experience leads to decision options and attributes being 'marked' with positive and negative affect linked directly or indirectly to somatic (i.e., bodily) states – hence the term 'somatic marker' hypothesis (Bechara, Tranel, & Damasio, 2002). A negative somatic marker can act as an alarm, warning the decision maker against that choice, while a positive somatic marker will have the opposite effect. Because decision making based on such a process can be relatively quick and effortless – in effect a mental shortcut – the term 'affect heuristic' has been used to describe the process (Finucane, Alhakami, Slovic, &

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7 The term 'affect' refers to positive or negative feelings about an object, option, attribute, or event, as experienced by an individual.

*Using an overall, readily available affective impression can be easier and more efficient than weighting the pros and cons of various reasons or retrieving from memory many relevant examples, especially when the required judgment or decision is complex or mental resources are limited.*

(Finucane, Peters, & Slovic (2003, p. 343)

In a similar vein, Gigerenzer (2002) states;

*In general, emotions can narrow down choice sets more effectively and for a longer time than cognitive search tools.*

(Gigerenzer, 2002, p 44)

Affect can influence decision making in a number of ways in addition to providing added information in the form of somatic markers. Affect can act as a 'spotlight' to focus the decision maker on particular information. Affect can act as a motivator, amplifying the likelihood of a decision maker taking action. Affect can also act as a 'common currency' by providing a shared scale against which disparate acts or outcomes can be judged, enabling a decision maker to easily 'compare apples with oranges' (Peters, 2005).

Affect can influence decision making by altering peoples' risk perceptions. There is evidence that peoples' judgement of the risk of an activity depends not only on what they think about the activity, but also on what they feel about it. In particular, if they feel positively about an activity then they are more likely to judge the risks as low and the benefits as high. Conversely, if they dislike an activity then they are more likely to judge the risks as high and the benefits as low. This result has been demonstrated in a number of fields of expertise including toxicology (Slovic, MacGregor, Malmfors, & Purchase, 1999) and finance (Ganzach, 2000).

If information is imbued with affect it will typically be more salient to a decision maker. Peters and Slovic (2000) provided information, with or without an affective scale, to subjects who were required to choose between health maintenance organisations (HMOs). The results showed that, compared to other sources of information, the data depicted in the bar graph were given more weight when a template of affective categories was superimposed on the graph (see Figure 5).
Overall satisfaction with Health Maintenance Organisation

Decision-related information either with affective information (top panel) or without affective information (bottom panel).

Adapted from Peters and Slovic (2000).

Figure 5. Different display templates for decision-related information.

Hendrickx, Vlek, and Oppewal (1989) found that warnings for a range of potentially risky activities were more effective when they were presented in vivid, affect-laden scenarios and anecdotes, rather than in the form of relative frequencies. Information was presented to subjects in the form of either ‘cognitive scenario information’ or ‘relative frequency information’, or both. It was found that variations in both information types affected subjects’ accident probability judgements, and that subjects combined information from both sources if available. However, the results showed that the presence of cognitive scenario information strongly suppressed the effect of relative frequency information. That is, subjects had a strong preference for scenario information and relied on it to the exclusion of frequency information. However, they would use frequency information if it was all that they had available to them.

Affect can influence perceptions of likelihood. For example, people are more sensitive to possibility rather than to probability with strong positive and negative events (Loewenstein, Weber, Hsee, & Welch, 2001; Rottenstreich & Hsee, 2001). That is, when people rely on feeling they are sensitive to the presence or absence of a stimulus, but are largely insensitive to the magnitude of the stimulus. In contrast, when people rely on calculation they react in a more graduated way to the magnitude of the
stimulus (Hsee & Rottenstreich, 2004). More formally, the value function for affect-based decisions is nearly a step function, while the value function for calculation-based decisions is closer to a linearly increasing function.

There is evidence that affect can mediate the influence of other factors on decision making, such as the form in which information is presented to a decision maker (Gigerenzer & Hoffrage, 1995). For example, Slovic, Monahan, and MacGregor (2000) found that mental health clinicians were more likely to make a conservative risk management decision when information was provided to them in frequency format as compared to probability format. The explanation was that presenting the information in frequency format was more likely to evoke mental images that were affect loaded.

Slovic, Monahan, and MacGregor (2000) asked clinicians to judge whether a potentially violent patient should be released or not. The descriptions of the risk of violence given to the clinicians were:

- **Frequency format**
  
  "Of every 100 patients similar to Mr Jones, 20 are estimated to commit an act of violence to others during the first several months after discharge".

- **Probability format**

  "Patients similar to Mr Jones are estimated to have a 20% probability of committing an act of violence to others during the first several months after discharge".

When information was presented in a frequency format, 41% of clinicians would refuse to discharge the patient, but when the same information was presented in probability format only 21% of clinicians would refuse discharge. Slovic, Monahan, and MacGregor (2000) suggest that the differences in decision outcomes may be due to the different mental images that the descriptions engender. The probability format will tend to create an image of a single individual, who may or may not be violent. The assessed risk, therefore, will be relatively low. In contrast, the frequency format will bring to mind an image that necessarily includes a number of violent patients. Hence, the mental picture is more frightening and affect loaded. As a result, the assessed risk is likely to be higher.

Loewenstein, Weber, Hsee, and Welch (2001) describe this type of response as reflecting a 'risk as feelings' appraisal in which behavioural responses to risk are mediated by image-based affective evaluations. As they point out, it is possible that a parallel analytical-based risk assessment may come to a different conclusion. However, as Loewenstein et al (2001) suggest, there is a possible evolutionary basis
for the disconnect that can occur between risk assessments on an emotional level as opposed to a cognitive level. For example, humans evolved in an environment in which fear of tigers was adaptive, but in which they were not exposed to the hazards of smoking tobacco. Hence, the former can evoke fear even in safe situations, while the manifest risks due to the latter do not evoke a strong avoidance reaction.

Bhattacharjee and Moreno (2002) found that the presence of affective information on decision making varied depending on the level of expertise of the decision maker. The client risk assessments made by less experienced auditors were significantly higher when the auditors were provided with negative affective information on the client than when they were not. In contrast, no such differences were found for the more experienced auditors.

In summary, there is good evidence that subtle situational differences may interact with affective considerations to significantly alter peoples’ decision making behaviour. Without affect, information appears to have less meaning and to be given less consideration in judgments and choice processes (Peters, 2005).

1.3.6. Decision making in complex, dynamic, and time-limited situations

One of the most significant criticisms of the analytical model of decision making is that it fails to incorporate the context of much real world decision making. In practice, decision making will often be a complex and dynamic ongoing process in a rich task environment, not a static one-off decision made in a basic laboratory environment. In many decision making situations even the problem to be addressed may be unclear or ambiguous. Often, the time available to make a decision will be limited. The decision maker may face a range of additional stressors such as environmental conditions or other factors that can affect human performance. In some situations, feedback as to the accuracy of a chosen course of action may be delayed or non-existent. While not all decision contexts will include all of these complicating factors, in many cases enough will be involved to make it impractical to employ an analytical decision strategy.

Two related fields of decision research have developed, relatively independently, over the last 20 years to address some of the shortcomings of previous research; Naturalistic Decision Making (NDM) and Complex Problem Solving (CPS).
The NDM approach is based on the assertion that decision making in real world situations is a joint function of two factors; the features of the task and the decision maker's knowledge and experience. This is in contrast to laboratory studies of decision making where experience is typically considered a confounding factor that must be controlled for, NDM researchers typically study participants with varying experience in a specific domain of expertise. NDM research has predominantly been associated with US researchers such as Klein (Zsambok & Klein, 1997).

The CPS approach considers the interplay of cognitive, motivational, and social aspects of problem solving, and has typically used computer-based ‘micro-world’ simulations to present subjects with a range of realistic problem solving environments. CPS research has mainly been associated with European researchers such as Dorner (Dörner & Wearing, 1995).

The link between NDM and CPS approaches comes from the fact that both relate to the study of behaviour in complex, dynamic, and ‘opaque’ task environments. Hence, in both cases the participant is faced not with simply choosing from a known set of decision alternatives, but with actively developing alternative courses of action.

NDM and CPS are complimentary in that the former has typically used field observations to study the performance of experts in a particular domain, while the latter has generally involved complex experimental simulations involving novice subjects. The bond of commonality of both NDM and CPS is that both concentrate on ‘real world’ tasks and scenarios. The NMD and CPS approaches are described in more detail below.

### Naturalistic decision making

Naturalistic Decision Making has been defined as the study of how people use their experience to make decisions in field settings (Zsambok & Klein, 1997; Klein, 1999; Salas & Klein, 2001). Historically, the emergence of NDM as a recognised field in decision making research can be traced to a 1989 conference in Dayton, Ohio, sponsored by the U.S. Army Research Institute. Three themes emerged from the initial conference (Lipshitz, Klein, Orasanu, & Salas, 2001);

- the importance of complexities such as time pressure, uncertainty, ill-defined goals, and high personal stakes in decision making in real-world settings
- an emphasis on studying people who had some degree of domain expertise

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9 The term ‘scaled worlds’ is also sometimes used to describe computer generated simulated task environments.

10 The environments are opaque in the sense that the functional relationships, interconnections and contingencies are not transparent to the operator.
• a recognition that the way people sized up situations was more critical than the way they selected between courses of action

The progress of NDM over time can be charted by the publication of successive conference proceedings. Conferences were held in 1989 with the proceedings published as Decision Making in Action: Models and Methods (Klein & Woods, 1993), in 1994 and published as Naturalistic Decision Making (Zsambok & Klein, 1997), in 1996 and published as Decision Making Under Stress: Emerging Themes and Applications (Flin, Salas, Strub, & Martin, 1997), in 1998 and published as Linking Expertise and Decision Making (Salas & Klein, 2001), and in 2000 and published as How Professionals Make Decisions (Montgomery, Lipshitz, & Brehmer (2004).

Orasanu and Connolly (1993) list eight important factors that characterise naturalistic decision settings;

• ill-structured problems
• uncertain dynamic environments
• shifting, ill-defined, or competing goals
• action/feedback loops
• time stress
• high stakes
• multiple players
• organisational goals and norms

Ill-structured problems – With ill-structured problems initial situation assessment becomes a crucial and difficult step. Typically, the decision maker will have to expend considerable effort generating hypotheses about what is happening and developing a set of possible responses. It may not even be obvious that the situation is one in which choice is required or allowed. By their nature ill-structured problems do not have a single optimal solution, instead there are likely to be several equally good ways of solving the problem.

Uncertain dynamic environments – The realm of naturalistic decision making is a world of incomplete and imperfect information. The decision maker may have to work with information that is ambiguous or of poor quality. In addition, the task environment is likely to be dynamic, changing substantially within the time frame of the decision making process.

Shifting, ill-defined, or competing goals – In real life settings the decision maker is likely to be faced with multiple goals, some of them unclear, and some of them opposed to one another. Balancing these competing forces is made all the more difficult by the changing nature of the task environment. As the situation evolves the significance of some goals may decrease while other objectives become more important. Often the
situation will present a series of decisions within decisions, with broader goals providing the framework within which narrower goals are set.

*Action/feedback loops* – Naturalistic decision making is an ongoing process rather than a discrete event. The decision maker is likely to execute a series of actions aimed at exploring the situation facing them as well dealing with the problem at hand. Additional information about the decision question can be obtained by monitoring the outcome of initial actions. By probing the environment in this way the decision maker can, if necessary, modify or refine their problem solving approach. Early mistakes can be countered by later corrective action. Decision making becomes a process of directing behaviour towards a broad goal rather than a discrete event involving a choice dilemma.

*Time stress* – In many naturalistic settings decisions must be made in minutes or even seconds. Decision strategies that require extensive evaluation of multiple options are simply not feasible. Instead, less complicated strategies that involve analysing fewer options in a non-exhaustive way are likely to be appropriate. Quick evaluative methods rather than deliberate reflective thought are needed to ensure that the decision maker is not overtaken by events. The time limitations in naturalistic settings can result in high levels of personal stress, possibly leading to degraded vigilance and performance.

*High stakes* – In contrast to the types of decision making tasks studied in laboratory settings many real world scenarios involve considerable potential for gain or loss by the participants. Decision making outcomes may have major financial implications for an individual or organisation, or a poor judgment may result in injury or even death. Again, this can lead to high levels of stress that, in turn, can affect the decision maker's behaviour.

*Multiple players* – Rather than involving just a single individual, decision making in naturalistic settings often has several, or even many, participants. The relationship between the different parties may range from tightly structured to just a loose grouping. Different team members may not share the same understanding of goals or situational status. Often individuals within the group may have competing interests as well as interests in common.

*Organisational goals and norms* – Naturalistic decision making often takes place within an organisational setting. Rather than working as an individual in isolation the decision maker may be subject to outside direction and constraint. Organisational values and goals may effectively limit the range of options available to the individual. In some settings standard operating procedures or similar guidelines may direct the decision maker to follow certain proscribed courses of action. These
types of factors are again difficult to reproduce in artificial laboratory settings.

Clearly, traditional decision-making theory is not adequate for modelling decision making in naturalistic settings. Klein (1993) has outlined a recognition primed decision making theory that is aimed at better understanding decision making in complex dynamic settings.

Recognition primed decision making

The recognition primed decision (RPD) model proposes that decision making by experienced decision makers in naturalistic settings involves two main processes: situation assessment and mental simulation (Klein, 1993). Firstly situation assessment is used to generate a plausible course of action, and then mental simulation is used to evaluate the proposed option. The RPD model of decision making was developed from studies of experienced practitioners in the field, people such as fireground commanders, critical care nurses, military battleground planners, and other real-world decision makers. As Klein (1993) outlines, the decision making methods of these experienced practitioners appeared to bear little resemblance to the analytical strategies typified by laboratory based decision research;

They argued that they were not ‘making choices’, ‘considering alternative’, or ‘assessing probabilities’. They saw themselves as acting and reacting on the basis of prior experience; they were generating, monitoring, and modifying plans to meet the needs of the situations.

(Klein, 1993, p. 139)

In none of the cases studied did there appear to be evidence for the extensive generation of alternative courses of action. Rarely were even two options contrasted. Often it appeared that a full search for an optimal solution would have delayed action to the point that control of the situation was lost. Instead, the decision makers relied on their abilities to recognize and appropriately classify a situation. Once this was done, in many cases the required action was obvious. Hence, decision making was seen as being a recognitional process. If time permitted, the decision makers would use mental simulation to evaluate the proposed course of action before implementing it. They would imagine how the option was likely to unfold, including what problems might arise. If this evaluation revealed significant flaws in the plan then further consideration was needed. If the problems were minor the plan could be modified, but if major flaws were uncovered then the plan would be rejected in favour of an alternative course of action. It is due to this assessment by mental simulation that Klein (1993) asserts that the decision is primed, rather than absolutely determined, by the way the situation is recognized.
Klein (2003) describes the RPD model as consisting of the following elements:

- cues enable the recognition of patterns
- patterns activate action scripts
- action scripts are assessed through mental simulation
- mental simulation is driven by mental models

In the RPD model, decision making is a dynamic process in which situation assessment, based on patterns of cues, activates mental models and action scripts that the decision maker has available from prior experience (see Figure 6). In that way, experienced decision makers can evaluate a possible course of action by imaging how events would unfold if they carried it out. The process of 'mental simulation' allows them to spot potential problems and to alter the proposed action script as appropriate.

![Figure 6. Recognition Primed Decision model.](image)

From Klein (2003).

Klein (1993) argues that there are four important aspects to successful situation assessment. Firstly, the decision maker must have a good understanding of the types of goals that can realistically be accomplished in the situation. Secondly, they must have the ability to highlight the important cues within the context of the problem environment. Thirdly, they must form expectations that can be used to check the accuracy of
their situation assessment. And fourthly, they must be able to identify typical actions to take. In outlining a case of RPD decision making in action, Klein (1993) describes the initial assessment of a fireground commander responding to a fire in the vertical laundry shaft of a four-story apartment building.

The situation assessment included plausible goals (he believed there was time to put it out before it got out of control), critical cues (he needed to find out how far the fire had spread up the shaft), expectancies (he believed that the firefighters could get above the fire in time to put it out), and an obvious course of action (send teams with hoses up to the first and second floors).

(Klein, 1993, p. 140)

Klein (1993) summarizes a range of aspects in which the RPD model of decision making differs from classical decision models. The RPD model focuses on situation assessment rather than judging one option to be better than others. The RPD decision maker makes good use of their domain experience. Hence, they can identify a reasonably good option almost immediately, rather than generating many options in a semi-random fashion. The RPD model focuses on serial evaluation, rather than a parallel comparison of options, and relies on satisficing rather than optimizing. Once a course of action has been chosen, mental simulation is used to evaluate the option, which is then modified or discarded as appropriate. Finally, a recognitional strategy allows the decision maker to take action at any time, based on the option currently being evaluated. In comparison, with a formal decision making strategy, no action can be taken until the end of the process reveals the optimum solution.

Interestingly, work nearly forty years ago (Williams & Hopkins, 1958) noted the type of recognition primed decision making later described by Klein (1993). During a study of pilot decision making involving radar display information Williams and Hopkins concluded that decisions were made,

... not in terms of the pilot's selection of a course of action from among the alternatives available, but rather in terms of his diagnosis of the state of the system. In other words, the pilot does not choose a course of action but he does decide what is the nature of the situation. Once he has decided what the state of the system is, the course of action is specified.

(Williams & Hopkins, 1958, p. 10)

Complex Problem Solving
As outlined above, the field of Complex Problem Solving research has many similarities to the Naturalistic Decision Making approach to the
study of decision making in real world situations. The models used in CPS microworlds utilise very complex computerized scenarios that are based on a large number of highly interconnected variables. Some of the microworld scenarios have included fire fighting (NEWFIRE; Brehmer, 1999), advising an African tribe (MORO; Jansson, 1999), and controlling a medical system (Gardner & Berry, 1995).

While both CPS and NDM emphasises the importance of real-world problem solving, they are complimentary approaches in that NDM has the advantage of high external validity, while CPS has the advantage that the system variables can be experimentally manipulated to study their effects on decision making behaviour.

Funke (2001) describes the five typical qualities of a CPS scenario as:

- complexity of the situation
- connectivity between variables
- dynamic nature of the problem
- lack of transparency
- multiple concurrent goals

Wenke and Frensch (2003) have reviewed research into possible relationships between performance on CPS tasks and measures of human intellectual abilities. Overall, the evidence does not suggest a strong link between general intelligence and performance on CPS tasks, particularly when goal specificity and transparency are low and the semantic content is rich. In relation to specific intelligence components, when goals are specified there are moderate to substantial correlations between CPS performance and processing capacity, reasoning ability, and learning potential. Inconsistent results have been obtained for the relationship between system knowledge and CPS performance.

Wenke and Frensch (2003) report that there is good evidence that differences in CPS performance are related to differences in task knowledge and strategy. For example, having a good mental model of the task and pursuing an active intervention strategy are associated with increased CPS performance. On the other hand, feedback-delay negatively affects performance.

**Dynamic decision making**

Decision making can also be viewed in terms of the static, sequential or dynamic nature of the decision making situation (Maule & Svenson, 1993). That is, a decision may be a ‘one off’, or one of a sequence of decisions, or an input to a system that is continually changing even without action by the decision maker. Much real-world decision making is dynamic in nature.
Dynamic decision making is characterised by choosing among various options at different points in time in order to control or optimise the performance of a dynamic system. Typical real-world examples include fire fighting, navigational control, battlefield decisions, and medical emergencies (Busemeyer, 2001). Dynamic decision making is an ongoing process in which later decisions depend, in part, on earlier actions taken by the decision maker. In addition, the environment can change spontaneously, as well as from earlier actions. Hence, in studying decision making in dynamic situations it is not valid to just examine a single decision in isolation. It is only by examining the final outcome of the complete process that one can judge the overall adequacy of the decision maker's response. Some aspects that differentiate typical dynamic decision making environments include uncertainties and complexities such as ill-structured problems and shifting, ill-defined goals. In many situations time stress may also be a factor (Orasanu & Connolly, 1993).

The dynamic nature of much decision making can be both a blessing and a curse. While it allows continual opportunity for a decision maker to correct past mistakes, it also means that at any point they are only as safe as their last decision. They can never rest on their laurels.

Brehmer (1999) stresses the dynamic nature of much real-world decision making. For example, in many complex situations the decision maker will continually adapt their response in light of changing circumstances. Often mistakes can be identified and corrected in time. The process is one of continual monitoring and feedback. Dominguez, Flach, McDermott, McKellar, and Dunn (2004) interviewed surgeons about their process of risk assessment in laparoscopic surgery. Surgeons typically described their decision making as an ongoing activity, starting with an initial "I would just take a look and see". Decision making was a dynamic process that involved a complex mix of facts and risk assessment. Surgeons described their safety judgement in terms of their 'comfort level' and were continually assessing whether they were still within their comfort zone. Dominguez et al (2004) describe this awareness on the part of surgeons of their comfort level as demonstrating 'meta-cognitive based self-regulatory behaviour'.

Research has identified a number of reasons as to why people have difficulty in dynamic decision making environments. For example, decision making performance may be limited by an inability to plan sufficiently far ahead (Rapoport, 1966), or the operator may have a faulty mental model of the system (Sterman, 1994). In particular, humans have considerable difficulty in making judgments in situations that involve non-linear systems or systems with delayed feedback. Instead, operators typically act as though the system is linear with zero lag (Brehmer, 1992).
How people adapt to a dynamic decision making environment can be influenced by both task and individual characteristics. Time constraints and the number of times a task is executed have been shown to influence individuals' ability to successfully control a dynamic decision system (Kerstholt & Raaijmakers, 1997). In fact, the influence of these two factors is inter-related. For example, Gonzalez (2004) reported that simply repeating a decision making task under time constraints did not, in itself, translate into better performance on the task. In fact, subjects who completed more trials under severe time constraints exhibited inferior performance to those that completed fewer trials but who had more time for reflective decision making during each trial.

Atkins, Wood, and Rutgers (2002) studied the effects of feedback format (tabular or graphical) on performance and learning in a dynamic decision making task. In line with the distinction between analytical and intuitive decision making, they suggest that providing information in tabular format would be expected to induce a slower, more analytical, approach to problem solving while providing feedback in graphical format would be expected to induce a faster, more associative, form of processing. Their results showed that the graphical group performed better on the task at all levels of complexity, but that the tabular group showed stronger evidence of learning. Atkins, Wood, and Rutgers (2002) suggest that this apparent contradiction may be due to the fact that the better performance of the graphical group may have reduced the processing and interpretation required of them, and hence reduced the potential for them to learn the complexities of the task.

Models of how people learn in dynamic decision making environments have typically focussed on ‘instance’ based explanations of the process, an approach analogous the case-based reasoning. For example, Dienes and Fahey (1995) propose a model that assumes that ‘action’ and ‘outcome’ pairs are stored together in memory as a result of dealing with the system. Stored instances can later be retrieved on the basis of similarity to the current situation. Dienes and Fahey (1995) reported that this model dealt better with delayed feedback than did a rule-based approach. Gonzalez, Lerch, and Lebiere (2003) propose an instance-based learning theory in which people learn in dynamic decision making situations by accumulation, recognition, and refinement of instances. In the Gonzalez et al model an instance consists of information about the decision-making situation, the action taken, and the resulting outcome.

1.3.7. Practical aspects of decision making

Two aspects of decision making research deserve specific consideration because of their relevance to the domain of ADM;
• the problem-detection process
• plan continuation errors and confirmation bias

These aspects are briefly considered in the sections below.

**The problem-detection process**

Problem-detection is at the nub of much real-world decision making. Once a decision-maker realises that they are facing a problem, and actively considers the alternatives open to them, then often the battle is half won.

Klein (2003) proposes a model of the problem-detection process based on research involving domain experts (neonatal intensive care nurses, weather forecasters, and navy air defence operators). The model incorporates three factors into the process; the type of problem, the level of expertise of the individual concerned, and the 'stance' of the individual. The term stance refers to the level of alertness of the operator to potential problems.

From Klein (2003).

**Figure 7. The problem-detection process.**

Each of the problem-detection factors can be negatively affected by 'barriers' that degrade the potential for a problem to be identified. In
addition, at a broader level, organisational barriers can also adversely affect the problem-detection process. Figure 7 outlines the main aspects of Klein problem-detection model.

Klein (2003) highlights a number of specific barriers to successful problem-detection. For example, problems with a gradual onset are likely to be harder to detect than those that appear rapidly. If more than one thing goes wrong at the same time, then it is likely that the operator will focus on the first or the most salient sub-problem, hence neglecting other problem factors or the potential interplay of problem factors. If a lot or activity is taking place then it can be harder to detect a ‘signal’ amongst the ‘noise’. For example, an air traffic controller on a busy shift may be more likely to overlook a subtle constellation of cues indicative of a potential problem than they might be during a quieter work period.

An operator taking an ‘active’ stance will be actively monitoring all sources of information and continually on the lookout for potential problems. By fostering an attitude of always questioning and cross referencing, even when everything seems to be alright, an operator can prime themselves to recognise the first signs of potential danger. They will be sensitive to the emotional reaction of surprise and to their instinctive reactions – if it just doesn’t feel right, then it probably isn’t.

**Plan continuation errors and confirmation bias**

The world is a dynamic yet stable place. Adaptive behaviour in such an environment requires a balance between change and no-change. A decision maker must, therefore, typically steer a middle course between changing their assessments of the ongoing situation too readily, or not changing their assessments readily enough. Too far in one direction can result in a lack of stability: too far in the other direction can lead to a rigid approach that fails to adequately adapt to changing circumstances.

Situations in which pilots continue with their original plan of action despite information that suggests that the plan should be changed have been termed ‘plan continuation errors’ (Orasanu, Martin, & Davison, 2001)\(^\text{11}\). Because the pilot does not detect the changed circumstances, or correctly assess their increasing significance, an initially manageable hazard may increasingly pose a threat to flight safety. Hence, there is a link between plan continuation errors and poor situation awareness (Goh & Wiegmann, 2001). In effect, the pilot’s understanding of the circumstances they face gradually diverges from the reality of the situation.

\(^{11}\) Plan continuation errors have also been called plan revision errors (Muthard & Wickens, 2002).
Plan continuation errors are more likely to occur in situations where the pilot initially receives compelling and unambiguous cues that the plan is safe, and then only weak or ambiguous cues that the situation is changing or not as they first thought. There is evidence that the prevalence of plan continuation errors may be relatively high. For example, in a simulated flight experiment in which pilots were asked to select one of two flight paths through hazardous airspace, pilots committed plan continuation errors on nearly one-third of trials (Muthard & Wickens, 2002).

The propensity to determinedly stick to a chosen course of action is also shown in the related concept of 'confirmation bias'. Confirmation bias refers to the fact that people tend to interpret incoming information on the basis of their current understanding of the situation. Typically, they will uncritically accept information that confirms their view of what is happening, and downplay or discount evidence to the contrary. Hence, confirmation bias affects how information is perceived and interpreted. If an operator’s mental model of the situation is wrong, then they will tend to erroneously accept information that aligns with that wrong mental model.

Wickens and Hollands (2000) suggest that confirmation bias may exist in part because of the considerable cognitive effort needed to abandon an old hypothesis and reformulate a new one. In addition, greater cognitive effort is needed to deal with negative (e.g., disconfirming) information, as opposed to positive (e.g., confirming) information.

The Kegworth accident in which the crew of a British Midland 737 shut down the wrong engine is a good example of where confirmation bias may have been one aspect of poor decision making (AAIB, 1990). When the Kegworth pilots shut down the wrong engine the symptoms went away, 'confirming' the accuracy of their action. Later, the crew did not go back and analyse exactly what information they had used in determining which engine was malfunctioning.

1.4. Expertise

Research into the nature of expertise is to a large degree still in its infancy. Different research schools have produced at times contradictory results, mainly due to their different perspectives and to the different assumptions on which their work is based. On the one hand, some research has suggested that a simple linear model of relevant factors will typically make more accurate predictions than a purported expert (Dawes, 1988). On the other hand, there is the conception of expertise as a rare skill that develops only after extensive instruction, practice, or experience.
Much traditional research into the nature of expertise has focussed on domains such as chess, athletics, and musical performance (Charness, 1989). In domains such as these, the focus has typically been on aspects such as the role of deliberate practice, processing speed, or the ability to remember large amounts of information. However, many domains of expertise drawn from everyday life and work do not fit this pattern. Instead, they typically require decisions to be made in the face of ambiguous and/or incomplete information (Smith, Shanteau, & Johnson, 2004).

Shanteau (1992a) argues that the apparent contradiction between these different views of expertise can be resolved by recognizing the mediating role played by the characteristics of the task domain. In particular, experts are more likely to outperform novices in environments that are static, have a high degree of predictability, and where feedback is readily available. The performance of experts is relatively good when decisions have to be made about objects, but when decisions have to be made about people, performance is relatively poor. This is because human behaviour is inherently less predictable than physical stimuli. Examples of domains in which expert decision making has been shown to be relatively good or poor are shown in Table 5 (Shanteau, 1992a).

Table 5. Domains of good and poor decision performance.

<table>
<thead>
<tr>
<th>Good performance</th>
<th>Poor performance</th>
</tr>
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<tbody>
<tr>
<td>Weather forecasters</td>
<td>Clinical psychologists</td>
</tr>
<tr>
<td>Livestock judges</td>
<td>Psychiatrists</td>
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<tr>
<td>Soil judges</td>
<td>Court judges</td>
</tr>
<tr>
<td>Auditors</td>
<td>Student admissions</td>
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<tr>
<td>Chess masters</td>
<td>Behavioural researchers</td>
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<tr>
<td>Physicists</td>
<td>Counsellors</td>
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<td>Mathematicians</td>
<td>Personnel selectors</td>
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<tr>
<td>Accountants</td>
<td>Parole offices</td>
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<td>Insurance Analysts</td>
<td>Stockbrokers</td>
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<tr>
<td>Physicians</td>
<td>Physicians</td>
</tr>
</tbody>
</table>

From Shanteau (1992a).

There is a general consensus that expertise is domain specific (Cellier, Eyrolle, & Marine, 1997). Hence, expertise differs from other conceptualizations of above average performance that concentrate on
individual differences due to inherited general or specific abilities, or to general learning and experience (Ericsson & Smith, 1991).

One early theory of expertise was the information-use hypothesis. The information-use hypothesis was based on the assumption that experts used more information than non-experts. However, the available evidence suggests that this is not the case. Shanteau (1992b) reviewed a number of studies that investigated expertise in different domains (auditors, physicians, nurses, and livestock judges) and concluded that experts tended to use the same amount of information, or even less, than novices. Both experts and novices were able to recognize and make use of multiple sources of information. However what distinguished experts from novices was the type of information they used. Experts used the same number, or fewer, significant cues as novices, but the information they used was more relevant (Shanteau, 1992a). The difficulty for novices is that the definition of relevant is context sensitive. Information that is highly relevant in one case might not be significant at all in another, and a considerable degree of expertise is necessary to make that judgement. Camerer and Johnson (1997) have suggested that experts’ domain knowledge allows them to search less for information, but in a more directed way. From this perspective, expertise can be characterised as the ability to evaluate task context. For example, experts are adept at recognising inconsistencies in the problem information and hence are more skilled in screening different hypotheses (Ericsson & Smith, 1991). The evidence, then, does not support the information-use hypothesis. Early adherence to the information-use hypothesis led to the erroneous conclusion that by relying on only a few cues, experts were inferior decision makers.

More recent work has lead to a better understanding of exactly what the defining aspects of expertise are. There is a considerable body of evidence that pattern recognition is fundamental to expertise (Johnson, 1988). Not only do experts tend to have a larger repertoire of patterns in their domain of expertise, they can also discern patterns with a greater number of elements and with a greater number of links between elements (Cellier, Eyrolle, & Marine, 1997). Hence, experts are able to perceive patterns of information that non-experts either overlook or can not see. A range of research suggests that while novices are able to identify critical cues in a particular domain, experts are better at discerning interactions among the cues (Klein & Hoffman, 1993). Superior pattern recognition skills mean that experts are better able to form an immediate representation of the problem that systematically cues their knowledge in a way that novices are not able to do (Ericsson & Charness, 1994). This in turn helps them to construct an accurate mental model of the decision
space that they can apply as a reasoning tool (Shanteau, 1988; Shanteau, 1992c).

Experts are better at seeing and understanding the dynamics of a situation (Klein & Hoffman, 1993). In aviation parlance, they are better at 'keeping ahead of the aircraft'. For example, an experienced pilot can rapidly diagnose the state of the aircraft from a scan of the six primary flight instruments. Familiarity with the patterns of readings indicative of particular aircraft malfunctions enable the pilot to quickly diagnose flight problems (Wickens, Stokes, Barnett, & Davis, 1987). Similarly, Federico (1995) found that military experts dealt with dynamic situations better than novices, and evaluated situations in a more context-dependent way.

Experts understand a problem at a deeper and more conceptual level than novices who tend to have a more superficial representation of the problem. Hence, experts are better able to 'see' the underlying structures of problems than novices (Orasanu, 1993). Experts' representations are more likely to be semantically or principle based. This results in experts being more efficient information processors. For example, for experts working in information-rich naturalistic settings, the intercorrelations between stimuli tend to reduce the number of cues that are used. In contrast, because non-experts have difficulty forming a mental model of the situation they lack awareness of the interrelations among variables, leading to difficulty in combining and integrating relevant information (Salthouse, 1991) and making it more likely that they will be influenced by irrelevant information (Shanteau, 1992a).

Schvaneveldt, Durso, Goldsmith, Breen, and Cooke (1985) describe work on defining and measuring the conceptual structures of expert and novice fighter pilots in relation to two air-combat situations, a complex split-plane manoeuvre in air-to-air combat and a simpler low-angle strafe manoeuvre in air-to-ground combat. The results showed that different levels of experience among the pilots were reflected in the pilots' different conceptual structures. Compared to novice pilots, the concepts of expert pilots were more coherently clustered into meaningful groups.

The evidence suggests then that while novices tend to rely on analytical decision making strategies experts are more likely to employ methods based on pattern recognition, leading to decision making that accords with Klein's (1993) description of recognition primed decision-making. The ability to judge 'typicality' allows an expert to quickly see which cues are relevant and which goals are feasible, to recognise a typical course of action, and to know what to expect next. For example, Ericsson and Smith (1991) argue that experts tend to retrieve a solution as part of

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12 Airspeed indicator, artificial horizon, altimeter, turn and bank indicator, directional gyro, and vertical speed indicator.
the immediate comprehension of the problem whereas novices have to first deliberately construct a representation of the task and then generate a solution step by step. The importance of correct initial situation assessment is supported by Dörner and Scholkopf's (1991) findings that successful decision makers tend to spend more time initially assessing the situation before committing themselves to action than do less able decision makers. Shanteau (1988) observes that experts tend to make small errors rather than major mistakes, again suggesting an intuitive strategy relying on perceptual cues rather than an analytical strategy based on formal logic (Hammond, Hamm, Grassia, & Pearson, 1987).

Experts and non-experts also differ in other ways. Experts tend to have better and more complete representations of the task domain than non-experts, including a more extensive and accessible knowledge base (Ericsson & Smith, 1991). This allows them to encode new information more quickly and completely and endows them with a richer repertoire of strategies that they can bring to bear on the decision problem (Johnson, 1988). Compared to novices, experts have greater skill in producing inferences and, hence, are more likely to act in a proactive, rather than a reactive, manner. That is, experts are more likely to anticipate and prevent disturbances while novices tend to correct already existing disturbances (Cellier, Eyrolle, & Marine, 1997). For example, Cara and LaGrange (1999) reported that more experienced nuclear power plant controllers were better able to anticipate events while controlling the system. In addition experts tend to be more aware of the likely quality of their decision making, and more inclined to be self-reflective during the decision making process.

In keeping with the NDM emphasis on field studies of how people use their experience to make decisions in real-life situations, NDM researchers have studied domain experts such as fire-fighters, critical care nurses, weather forecasters, and weapons directors. Pliske, Crandall, and Klein (2004) describe five aspects of expert performance from an NDM perspective;

- noticing patterns
- seeking information
- making meaning (ie 'sensemaking')
- using visual mental representation
- employing metacognitive processes

Klein and Hoffman (1993) describe what they term the perceptual-cognitive aspects of expertise. With domain experience a person increases their ability to visualise how a situation developed, and how it is likely to evolve. That is, experts are better able to use their knowledge to 'visualise' a decision-making situation. In that way they can judge how the situation is typical of other situations that they have confronted, and
in what ways it is different. Experts are also better able to 'see' the antecedents and consequents of the situation. That enables them to imagine how a course of events is likely to unfold, and to realise when their expectations are being violated. In particular, compared to novices, experts are better at noticing the absence of something - an often difficult task. As Klein and Hoffman (1993, p. 203) state, "Novices see only what is there; experts can see what is not there."

The most common operational definition of expertise is that of seniority, in effect amount of practice. It is assumed that the greater the degree of practice the better the performance. Estimates of the time it takes to become an expert in a specific domain typically fall within the range of five to ten years (Klein & Hoffman, 1993). However, in practice, years of experience per se are only a weak predictor of an individual's level of performance in a domain (Ericsson, 1996). Twenty years of experience may be just that, or it may be one year of experience twenty times over. In situations where feedback is poor or delayed then learning may be slow or even absent. This problem is likely to be particularly marked in complex and dynamically changing environments. Hence, experience, per se, does not necessarily equate to expertise; the important thing is what is learned as a result of that experience (Shanteau, 1988).

The weight of evidence, then, is that experts are intuitive, rather than analytical, decision makers. As Hoffman (1998) states,

> [with practice] ... judgments become 'intuitions' in that one can rapidly and effortlessly associate experiences, make decisions, or perform actions.

(Hoffman, 1998, p. 84)

Indeed, one definition of an expert is someone who is,

*capable of handling a wider range of tasks nonanalytically, compared to people with less experience.*

(Klein & Hoffman, 1993)

**Expertise as rule-based knowledge compilation**

An early conceptualization of expertise drew on work from artificial intelligence that characterized problem solving as search (Newell, Shaw & Simon, 1958). A small number of heuristic methods for serial search, for example means-ends analysis and hill climbing, could be applied across a wide range of domains. The role of specific domain knowledge was considered to be minimal. Within this framework an expert was seen as someone particularly skilled at general heuristic search (Holyoak, 1991). The domain-general approach to problem solving was exemplified by the General Problem Solver created by Newell and Simon (1972). However it soon became apparent that domain-specific knowledge was a
Aeronautical decision making

crucial element of expertise. This lead to a conceptualization of knowledge compilation and expertise typified by Anderson's ACT, later ACT-R, theory (Anderson, 1983, 1993). The cognitive system on which ACT theory and many other models of human reasoning are based is the serial production system. The fundamental premise of serial production systems is that knowledge can be represented as IF–THEN rules of the form,

\[
\text{IF } <\text{antecedent}> \text{ THEN } <\text{consequent}>
\]

This relationship is termed a production rule (Giarratano & Riley, 1994). The production system model of human information processing posits that incoming stimuli trigger appropriate rules in long-term memory. Short-term memory is used for temporary storage during problem solving. Executive control, and resolving conflict between competing rules, is handled by a cognitive processor. Specific production rules could take a form such as,

\[
\text{IF } <\text{condition}> \text{ THEN } <\text{action}>
\]
or

\[
\text{IF } <\text{evidence}> \text{ THEN } <\text{hypothesis}>
\]

For example during approach and landing decision making, in which the choice is between either continuing the approach or executing a go-around, one particular compound-clause rule might be,

\[
\begin{align*}
\text{IF} & \quad <\text{circuit_leg is base}> \\
\text{AND} & \quad <\text{airspeed is high}>
\text{AND} & \quad <\text{height is low}>
\text{AND} & \quad <\text{runway is soon_to_clear}>
\text{THEN} & \quad <\text{continue_approach}>
\end{align*}
\]

Reasoning with rules is based on two rules of inference, modus ponens and hypothetical syllogism (Giarratano & Riley, 1994). Modus ponens means that when the condition of a rule is satisfied then the conclusion also follows. For example; IF \( x \) THEN \( y \), given \( x \) is true, conclude \( y \) is true. Hypothetical syllogism means that when the conclusion of one rule is the antecedent of a second rule, then a third rule can be deduced linking the antecedent of the first rule with the consequent of the second rule. For example: IF \( x \) THEN \( y \) and IF \( y \) then \( z \), conclude IF \( x \) THEN \( z \).

A knowledge base in a rule-based system consists of a set of rules and facts. The system then 'reasons' using one of two basic procedures, forward chaining or backward chaining. In forward chaining a set of data items are initially designated as being 'true', the rules are then fired sequentially, and the outcome indicates which goals can be inferred as 'true'. Backward chaining, on the other hand, starts with a particular goal in mind, and then checks whether there are data in the knowledge base.
that prove the goal to be true. Hence, reasoning by backward chaining can be related to goal directed behaviour in humans, while forward chaining can be related to stimuli directed behaviour.

Models such as Anderson's ACT theory (Anderson, 1983, 1993) see expertise as resulting from 'knowledge compilation'. The central tenet of knowledge compilation is that successful problem solving can result in new specialized production rules being formed. These new condition-action rules will have larger and more complex conditions and actions. Larger conditions allow for more precise specification of the circumstances under which the rule will fire and larger actions allow more to be accomplished by a single rule-firing. However, systems such as this soon become very complex and brittle, providing no information on what action should be taken in a slightly different situation. In other words rule-based approaches are not able to generalize. Adding further clauses to refine the scope of a particular rule can lead to undesired consequences that require further qualification by still more clauses.

The inadequacies of even a simple rule-based system soon become apparent as, for example, in the case of the 'legalistic child' (Twining & Miers, 1982). To stop him going into the pantry and helping himself to the strawberry jam the child is given the rule "Do not go into the pantry". However, he soon satisfies his sweet tooth without breaking the rule by using a broom to hook out a pot of jam. Next he is stopped by the rule from intervening when the cat enters the pantry to eat a fresh salmon, much to his parents' chagrin. Still later episodes further highlight how difficult and complex it becomes to cover all possible circumstances in a rule-based system.

It follows from the rule-base conceptualization of expertise that the performance of experts can be predicted accurately from a knowledge of the rules that they use, and that teaching those rules to non-experts should result in them acquiring expertise. However, neither of these approaches has proved fruitful. Eliciting expert knowledge from individuals is typically very difficult. People are often simply not aware of the mechanisms they employ in decision making (Johnson-Laird & Shafir, 1993). Procedural knowledge, declarative knowledge and meta-knowledge are all very important to expert performance. However, it is difficult, if not impossible, to capture declarative knowledge and meta-knowledge in condition-action rules (Edwards, 1992).

The case for improving performance by teaching abstract rules is not strong. In reviewing several major thinking-skills programmes Bransford, Arbitman-Smith, Stein, and Vye (1985) concluded that there was no convincing evidence for teaching general skills that would transfer to
other domains\textsuperscript{13}. Even proponents of rule-based approaches such as Smith, Langston, and Nisbett (1992, 1997) document only somewhat equivocal evidence for the use of prime inferential rules such as modus ponens and the law of large numbers in everyday reasoning, and even their modest claims have been disputed by other workers (Ploger & Wilson, 1991; Reeves & Weisberg, 1993). For example, Fong and Nisbett (1991) report transfer of the law of large numbers to novel problems, but as Reeves and Weisberg (1993) point out, Fong and Nisbett's own findings indicated that different-domain but not same-domain transfer was impaired after a two-week delay, a result difficult to reconcile with an abstract-rule based explanation.

The view that human reasoning is guided by abstract rules of inference has a very long history; from its origins in Plato's theories of reasoning, to the doctrine of 'formal discipline' that held that studying subjects such as Latin and geometry would serve to discipline the mind, to modern theories of cognition such as proposed by Newell and Simon (1972). However, formulating rule-based models of even simple real world systems has proved to be immensely more difficult than imagined. The inability of production systems to effect a formal representation of a large body of facts, rules, and procedures has been called the common sense knowledge problem.

As thus formulated this problem has so far turned out to be insoluble, and we predict it will never be solved.

(Dreyfus & Dreyfus, 1986, p. 316)

The failure of rule-based systems to realize their early promise has been one of the defining features of artificial intelligence over the last forty years. The production system as a metaphor of the mind has proved inadequate. An alternative approach sees case-based reasoning, rather than rule-based reasoning, as the cornerstone of human adaptive behaviour.

1.5. Case-based reasoning

Human experts are not systems of rules, they are libraries of experiences.

(Riesbeck & Schank, 1989, p. 15)

The field of case-based reasoning is founded on a view of human behaviour that sees analogy and reminding as central to the way people think and reason. The fundamental importance of analogy in human

\textsuperscript{13} Also, the limited success that has been achieved has involved extensive training and considerable practice on the part of participants. As Garnham and Oakhill (1994, p. 286) summarize, "Attempts to teach people to think leave the impression that learning to think is a long and time-consuming process - rather like learning any complex skill, in fact."
adaptive behaviour has long been recognized. Over one hundred years ago William James wrote,

*A native talent for perceiving analogies is ... the leading fact in genius of every order.*

(James, 1890/1950, p. 530)

Analogy-making is, in effect, a form of abstract recognition, a process of high-level perception. It is a central mechanism of cognition and pervades both conscious and unconscious thought (Mitchell, 1993). Work by Schank (1982) on scripts and dynamic memory forms the foundation of the field of case-based reasoning. A fundamental tenet of this approach is that in understanding and explaining everyday events and behaviours we do not use formal logic to analyse our environment, but rather we rely on reminding of past experiences to make sense of what is happening. Hence, Riesbeck and Schank (1989) argue that explanation is a process of adaptation rather than creation. That is, we explain something new by adapting a standard explanation from another situation. We don't use formal logic to find the butter, we merely recall where we saw it last. During a visit to a new restaurant we don't reason from first principles, we remember past visits to other restaurants.

*Real thinking has nothing to do with logic at all. Real thinking means retrieval of the right information at the right time.*

(Riesbeck & Schank, 1989, p. 9)

1.5.1. The case-based reasoning approach to decision making

Two premises underlie the case-based reasoning (CBR) approach to problem solving and decision making (Kolodner, 1993). The first premise is that the world is regular, that similar problems have similar solutions, and therefore a good starting point in problem solving is to look at what worked in the past in similar situations. The second premise is that the types of problems we encounter are likely to recur. Consequently, current problems are likely to resemble past problems (Leake, 1996).

In its simplest form case-based reasoning involves four steps (Marir & Watson, 1994; Watson & Marir, 1994), namely, the four REs;

- Retrieve
- Reuse
- Revise
- Retain

When a new problem is encountered the case-based reasoner searches for similar past experiences. A solution suggested by the best matching case is then implemented and tested for success. If necessary the proposed solution is revised, producing a new solution that is added to the case
base for future use. Another succinct description of case-based reasoning is given by Aamodt and Plaza (1994):

Case-based reasoning = retrieval + analogy + adaptation + learning

Adaptive learning, then, is a central focus of the case-based reasoning view of the world. As Schank (1999) highlights,

Learning is, in essence, the process of assessing new experiences and categorizing them in a way that lands them in a place in memory where they will be found again when needed.

(Schank, 1999, p 25)

The importance of adaptation and learning in the case-based reasoning cycle is emphasised by a six step conceptualisation of the process proposed by Reinartz (2001) in which additional ‘Review’ and ‘Restore’ steps relate to the ongoing maintenance of the case-based system (see Figure 8).

A case has been defined as,

a contextualized piece of knowledge representing an experience.

(Watson & Marir, 1994, p. 5)
Typically, a case comprises the problem (a description of the state of the world when the case occurred) and the solution (a description of the state of the world after the case occurred). Case retrieval starts with situation assessment. The practitioner must identify the relevant problem features and search for comparable cases based on some similarity measure. Whether a particular case warrants inclusion in the retrieval set depends not only on the case itself but also on its competitors. Once a set of plausible solution cases has been retrieved a more elaborate comparison is used to select the best candidate. Reusing prior solutions increases problem solving efficiency. It is not necessary to resolve the same problem again. Case acquisition continually adds to the body of domain knowledge. Also, storing failed solutions as well as successes ensures that the system can warn of potential problems to avoid as well as recommending a particular course of action. Expectation failure occurs when the result is better than expected as well as worse than expected. Again, this information is stored by the system for future use (Aamodt & Plaza, 1994).

Case-based reasoning only adapts cases if and when necessary, hence it is a form of 'lazy learning' (Aha, 1997). Lazy learning systems are so named because they delay computation. Rather than compiling training instances and replacing them with precise abstractions, such as a rule set, they simply store inputs for future use. In contrast, 'eager learning' systems immediately work on the data they receive, condensing the information and storing only the essence. The original raw data are discarded. By retaining specific cases, though, the CBR approach provides solutions that are more amenable to explanation and verification. Full original data are also helpful in resolving conflicting information. If two cases provide contradictory advice then they can be compared in light of the current situation in order to decide which should take precedence.

Case-based reasoning is a cyclical process; solving a problem, learning from the experience, solving a new problem. Problem solving uses the results of past learning episodes and, at the same time, provides the experience from which new learning comes (Leake, 1996). Hence, problem solving and learning are inextricably linked. In the case-based conceptualization of knowledge and expertise the same cognitive structures are used for memory storage and analytical processing. Learning can always occur because whether a problem is successfully solved or not the experience is still retained. Hence, a case-based reasoning system learns as much from its failures as from its successes. A typical rule-based system, however, does not receive any feedback about outcomes and cannot learn from experience, either success or failure.

The field of case-based reasoning has two complementary strands. From a cognitive science perspective, it is a powerful tool with which to model
human behaviour From an artificial intelligence (AI) point of view, it is a technology with promise to make AI systems more effective. As with work on rule-based (production system) models of human information processing, there is a symbiotic relationship between the cognitive science and AI perspectives. However, case-based reasoning parallels human problem solving in a number of ways that rule-based reasoning does not. For example, humans are robust problem solvers. Many day to day activities require solutions to hard problems for which there is only limited and uncertain information, and decisions must be made without knowing the underlying causal or statistical models. While a sound understanding of the principles of a domain is essential for creating a reliable rule-based system, case-based reasoning can be effective even when the principles of a domain are poorly understood (Leake, 1996).

A case-based reasoner can bootstrap, starting with a minimal amount of experience, but a rule-based reasoner requires significant seed knowledge to even get started. Moreover, a case-based reasoning system learns incrementally. Even when just a small number of cases are stored in the case library performance on those cases will be correct. Learning will then proceed in an efficient manner because cases reflecting common problems are likely to be soon encountered and entered into the knowledge base. Again, this aspect of case-based reasoning mimics human knowledge acquisition, from novice to expert (Whitaker & Thordsen, 1990). Hence, it can help in an understanding of how people develop domain expertise from their own experience and from the experience of others (Kolodner & Guzdial, 1999).

Case-based reasoning has other significant advantages over rule-based reasoning as a cognitive model. For example, it explicitly integrates memory, learning, and reasoning. It also provides a model of how experience generated through goal directed behaviour can allow an individual adapt to their environment. Hence, the notion of adaptation is an important aspect that is central to case-based reasoning in a way that is not so for rule-based models. Case-based reasoning also highlights the importance of failure in learning. Failure can focus the attention of a decision-maker on subtleties that they had not previously been aware of. (Kolodner & Guzdial, 1999).

The case-based reasoning approach also better reflects the way that people are able to reason with 'fuzzy' inputs. A case-based approach can deal with fuzzy queries because retrieval uses the complete description of a case to determine an overall similarity with existing cases. Hence the CBR system can retrieve cases that a traditional system with exact search criteria will miss. Other advantages of case-based reasoning stem from its retention of complete and intact episodes as an accurate record of prior experience. This means that no information is lost by early decisions.
about what aspects of a problem are important. Rule-based reasoning, on the other hand, first breaks down experience into constituent parts that are generalized into rules, then chains the rules together to reflect the complex nature of the problem environment. Hence, knowledge is broken down and then reassembled, with all the chance for error and distortion that brings.

In contrast to rule-based reasoning, case-based reasoning parallels human learning. Usually, it is easier to learn by retaining a concrete problem solving experience rather than having to generalize from the experience and retain some abstract representation. Case-based reasoning is also better at knowledge acquisition. While raw case data are usually readily available, extracting rules from a body of knowledge can be very difficult. Rule extraction can be time consuming and there is no certainty that the rule base will have sufficient depth and breadth to adequately deal with a wide range of problems. Experts may be unwilling or unable to supply the information necessary to formalize their knowledge (Broadbent, 1990). However as Leake (1996) suggests,

> Experts who are resistant to attempts to distil a set of domain rules are often eager to tell their 'war stories' - the cases they have encountered.

(Leake, 1996, p. 3)

The use of narrative in informal ‘on the job’ training is recognised in many work situations. For example, work by McCarl (1985) recording the occupational folklife of US urban fire fighters, documented the narrative tradition by which much occupational folk-experience was passed from experienced fire fighters to new recruits. McCarl describes how in narrative sessions in the fire house each person adds his or her personal experience to the collective pool of knowledge. As one of the fire fighters in McCarl’s study described,

> You learn a lot by listening to the stories that the guys tell in the fire house. The more you hear about things, the more that that stuff flashes in your mind when you have similar experiences on the fire ground - particularly things about timing like when or when not to do something.

(McCarl, 1985, p. 138)

In a study in the domain of intensive-care medicine, Patel, Kaufman, and Magder (1996) found that the majority of learning occurred in a ‘cognitive apprenticeship’ situation where students were closely guided by expert role models. In that setting, instructional opportunities often arose from anomalous or unanticipated events. The mentoring by senior peers that occurs in many work situations emphasises the strong relationship between case-based learning and expertise. Experts often refer to
illustrative cases or 'tell stories' when explaining their decisions (Klein & Hoffman, 1993). In fact, as Schank (1999) describes,

An expert is someone who gets reminded of just the right prior experience to help him in processing his current experiences.

(Schank, 1999, p 24)

Research evidence from a range of domains suggests that people naturally use case-based reasoning. Kolodner (1994) found that both novice and experienced car mechanics relied on their own experiences and those of others when generating hypotheses about what was wrong with a car, and when remembering how to test for different diagnoses. Kolodner (1994) also reported that physicians used previous cases extensively to generate hypotheses about patients' ailments, to interpret test results, and to choose between competing therapies. Read and Cesa (1991) found that people explained anomalous occurrences by recalling old cases, particularly when the prior experience was their own. Ross (1984) reported that when learning to use a computer text editor, participants recalled similar prior tasks when faced with a similar function. Pirolli and Anderson (1985) reported that problem solving by analogy was frequent during learning to program recursive functions.

In some fields, the use of case-based reasoning has been well established for a very long time, though not by that name. In law and medicine, in particular, case-based methods have a long tradition. Case law, where case histories are formally recorded and codified and then referred to in later judgements, forms one of the main pillars of almost all legal systems. In medicine, the important role of case histories in education and diagnosis is well accepted and documented (Hunter, 1991). From grand rounds to academic medical journals the details of particular cases play a fundamental part in the acquisition and maintenance of medical knowledge. In medicine, as in many other fields, case histories enable practitioners to record both their own experience and that of others in a way that retains the original information in its full complexity. As Hunter comments,

Because in medicine, as in the rest of life, no one person can experience everything (nor would anyone choose to experience the bad), every physician stores up cases from his of her own practice as well as journal article and accounts of other physicians' cases.... Neither biology or information science has improved upon the story as a means of ordering and storing the experience of human and clinical complexity.

(Hunter, 1991, p. 76)
Together with law and medicine, aviation is a field in which there is a rich tradition of accumulating and passing on domain knowledge in the form of cases.

1.5.2. Applications of case-based systems

Case-based reasoning systems have been developed to assist in many areas of diagnosis and problem solving, including a number of applications in aviation and related fields. For example, in a trial application Whitaker, Stottler, and King (1990) describe PROSPER, a system for choosing wing section airfoils from a database. An example of a fully developed case-based reasoning system in aviation is CASSIOPEE, a system designed to support troubleshooting of CFM 56-3 aircraft engines on Boeing 737 aircraft (Heider, 1996). Built on a case base of information from engine maintenance histories, CASSIOPEE was developed to reduce engine downtime and errors in diagnosis, and to build a knowledge base that incorporated the expertise of the most skilled maintenance specialists. The time required for diagnosing engine problems accounts for 50% of engine downtime, giving scope for significant efficiency gains.

Dattani, Magaldi, and Bramer (1996) describe another case-based engineering diagnostic tool called CaseLine, developed by British Airways. CaseLine aids Boeing 747-400 technical support engineers carrying out aircraft fault diagnosis and rectification. The case base holds records of past defects and their associated recovery and repair procedures. The system is used in conjunction with standard maintenance guidelines and operating procedures and is of particular benefit in eliminating possibly unproductive diagnostic searches and the associated lost time. In illustrating how a rich case library can be built up Dattani, Magaldi, and Bramer (1996) describe a particular incident in which an aircraft flying from London to Australia experienced a low frequency vibration after take-off. A number of possible causes were investigated over several route sectors including the possibility of a fault in the nose gear system, a problem associated with the flaps, or contact of the auxiliary power unit engine fan and door, but on each take-off the vibration re-occurred. Finally, after these incorrect diagnoses, the problem was identified as a failure of the left-hand main landing gear wheel de-spinning system. The details of the case were then added into the case library for future reference.

MacGregor and Hopfl (1993) describe another British Airways initiative, BASIS (British Airways Safety Information System). BASIS is a CBR system for the aggregation and analysis of accident and incident data. Information such as operational safety reports, maintenance quality reports, human factors information and flight data recorder data from all
flight operations are fed into the BASIS system. This currently amounts to over four gigabytes of data a day. To date over 20,000 incidents have been analysed. BASIS is in use by over 160 companies and has been chosen as the system to implement GAIN (Global Analysis and Information Network), a worldwide program to collect, analyze, and disseminate aviation safety information (GAIN, 1997).

Allendoerfer and Weber (2004) describe an application of case-based reasoning to US air traffic control ‘plays’. A play is predetermined plan for the handling of disruptions to the normal flow of air traffic due to factors such as severe weather or route congestion. Currently, plays are assessed and selected by strategic controllers using the National Playbook, a collection of over 130 plays that have worked in the past. For example, Figure 9 shows the ‘Snowbird 5’ play that reroutes southbound traffic away from the coast and over the mountains.

Figure 9. Map showing alternative air routes used in the Snowbird 5 ‘play’.

In preliminary tests, for four of the six test situations, the play recommended by the domain expert was also one of the top three plays retrieved by the case-based reasoning system (Allendoerfer & Weber, 2004).

14 Strategic controllers work with whole flows of traffic, they do not work at the individual flight level to identify or resolve conflicts.
15 The National Playbook is online at http://www.faa.gov/PLAYBOOK/pbindex.html
1.5.3. Hybrid case-based and rule-based systems

Given the significant contrasts between case-based and rule-based models, a natural extension is to combine features from both models in a hybrid system. A number of workers have developed systems of this type. One simple approach is to extend a rule-based system with a case-based module that handles exceptions to the rules. For example, Golding and Rosenbloom (1996) describe a hybrid reasoning system for the pronunciation of names. Firstly, the system rules are applied to achieve an approximate answer, but if the case data suggests that the problem is very similar to a known exception of the rules then the case data takes precedence over the rule determination. Tests showed that the hybrid system performed better than either the case-based or rule-based systems alone. Golding and Rosenbloom (1996) suggest that a hybrid case-based/rule-based approach works well for domains that are understood reasonably well.

Nakatani and Israel (1994) describe a system in which case information is used to fine tune a rule-base system, this time in the domain of cooking. Surma and Vanhoof (1995) also describe a hybrid system where rule-based reasoning is applied before case-based reasoning, in a system implemented for classification tasks. In contrast, Aamodt (1990) describes a system, CREEK (Case-based Reasoning through Extensive Expert Knowledge) where the system first attempts to solve a problem using a case-based approach but if an acceptable match is not found then a switch is made to rule-based reasoning. CREEK is based on a model of expertise in which domain knowledge, problem solving knowledge, and learning knowledge are all essential components. Knowledge about problem solving methods and knowledge about how to learn are considered as important as specific domain knowledge. While CREEK primarily learns new cases, it is also able to update its general domain model (Aamodt, 1990).

Another system that models expertise is CELIA (Kolodner, 1994; Redmond, 1997), described as "a case-based approach to the passage from novice to expert" (Kolodner, 1994, p. 89). CELIA is a hybrid system that models the task of troubleshooting a car and explores changes in problem solving performance as a reasoner learns from experience. CELIA (Cases and Explanations in Learning: an Integrated Approach) integrates case-based reasoning into a broader model of memory that solves problems using several different methods and several different kinds of knowledge (Redmond, 1997). While part of CELIA's knowledge is encoded in cases, other knowledge describes the structure of the system being reasoned about (e.g., the car's fuel system) and a model of the reasoning process itself (troubleshooting). It is assumed that novices start
with incomplete and perhaps partly incorrect knowledge about the system and the reasoning process but, with experience, they update those models as new cases are acquired. As it learns, CELIA's knowledge and performance both improve. Reasoning from cases is preferred over reasoning from rules because its models are known to be incomplete and inaccurate, while each case reflects a known instance of troubleshooting that has actually been carried out.

Experiments with CELIA allow tests of the cognitive model on which it is based and hence a greater understanding of early learning in a domain without strong knowledge. For example, experiments showed that during early learning the acquisition of cases was more useful in improving problem solving than was augmenting or refining the domain or task knowledge bases. Remembering cases was the most powerful form of learning for novices. This was due to their limited domain knowledge which made it hard for them to form explanations about what was going on. Not knowing enough about the domain also makes it difficult to decide which pieces of information are important and which are not. It is hard to identify the cues that should be indexed to activate the case in future, hence novices are more likely to put poor indices on cases.

The benefits of combining case-based and rule-based training is shown in work by Kirlik, Walker, Fisk, and Nagel (1996) who report results from two computer simulation studies, one using football game 'plays' and the other a military surveillance and attack scenario. The results supported the contention that for an individual to successfully apply abstract knowledge it is essential that they can ground it in the reality of the task situation. In practice that means recognizing the essential cues that trigger the correct application of the abstract knowledge. Hence, training must include concrete examples. Indeed, in the absence of specific cases, training may foster exactly the wrong decision making style.

*Without such concrete exposure, training focussed on abstract task knowledge might foster an increased reliance on (presumably slower) abstract reasoning and a decreased reliance on (presumably faster) perceptual and pattern-recognitional activities.*


Index cues, then, are the crucial link between abstract knowledge and real world decisions – the link between theory and practice. Without a well indexed case-base to make this connection, domain knowledge cannot be brought to bear on the problem at hand.
1.6. Aeronautical decision making

1.6.1. Definition of aeronautical decision making

The terms ‘aeronautical decision making’ and ‘pilot judgement’ are used interchangeably in this study. Some authors consider pilot judgement to be a more encompassing term. For example, Jensen (1982, 1995) considers that the term decision making refers to purely rational information processing, while the term professional judgement carries a broader meaning that includes aspects such as societal ethics. However, using similar reasoning to come to an opposite conclusion, the US FAA has preferred to use the term decision making, as opposed to the term judgement, based on a belief that experienced pilots would resist attempts to teach them ‘judgement’.

Telfer (1989) also argues that decision making is a subset of judgement, defining the latter as,

... the mental process by which pilots recognize, analyze, and evaluate information about themselves, their aircraft, and the operational environment, leading to a timely decision which contributes to safe flight.

(Telfer, 1989, p 166)

However, this would appear to be as good a definition of decision making as any. Hence, the conclusion is that using one term or the other is really a matter of choice rather than a matter of strict definition.

The FAA Advisory Circular on aeronautical decision making (FAA, 1991) defines ADM as;

[the] systematic approach to the mental processes used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances.

(FAA, 1991, p. ii)

Perhaps the best definition of aeronautical decision making is one based on aspects discussed by Green, Muir, James, Gradwell, and Green (1996). It can be paraphrased as;

The ability of a pilot to respond to cues from the environment, evaluate the situation, come to conclusions, and act on those conclusions.

(Green, Muir, James, Gradwell, & Green, 1996, p. 58-59)

The Green et al conceptualisation has the virtue of emphasising problem recognition and problem formulation, as well as problem solving. In addition, it is phrased in a way that readily embraces the notion of decision making as a complex, dynamic process. Importantly, it contains
no suggestion that decision making is primarily about choosing one course of action from a small set of alternatives.

The Green et al definition of aeronautical decision making is the one that is used in the current study.

1.6.2. Growth in aeronautical decision making research

The discipline of aeronautical decision making has grown significantly since the 1960s, both in terms of theoretical research and practical application. There is a wealth of observational evidence of the growing awareness of ADM as an important aspect of aviation safety. This has been reflected in an increasing effort to understand the decision making behaviour of pilots, and ultimately to increase the quality of aeronautical decision making in the case of both private and professional pilots.

To quantify the increasing recognition of the importance of aeronautical decision making, a search was made of the published literature to determine to what extent work in the discipline had grown. The PsycInfo database was searched for published work in the field of ADM for the period 1967 to 2003. To provide a reference point, a search was also made for published work in decision making in general over the same time period. Some work in the field of ADM may be published in aviation technical reports, journals or conference proceedings not abstracted by Psycit. However, publication in Psycit is likely to be a valid proxy of trends in ADM research output. In addition, Psycit is likely to capture the more important or theoretical ADM studies.

Figure 10 shows the publication rates for decision making and ADM for the period 1967 to 2003. Two findings are immediately apparent. Firstly, research in both decision making and ADM has grown exponentially over the last four decades. Secondly, the ADM literature is but a tiny fraction of the decision making literature in general (note different scales).

The exponential increase in decision making and ADM publications parallels the increase in research found in most scientific disciplines (Vinkler, 2000). Comparison of the growth in decision making publications in general with that for ADM in particular, indicates a greater rate of increase for ADM. During the period 1967 to 2003, published ADM work doubled approximately every 10.8 years, while that for decision making in general doubled approximately every 14.2 years.
If the data for just the ten year period 1994 to 2003 are compared, then the difference is even more marked. During that period, published ADM work doubled approximately every 7.5 years, while that for decision making in general doubled approximately every 12.0 years.

![Graph showing publication rates](image)

**Figure 10.** Publication rates for decision making and ADM research for 1967 to 2003.

While the rate of increase in ADM publications is greater than that for decision making in general, ADM still accounts for only a very small fraction of the total decision making literature. During the period 1967 to 2003, in most years less than 0.5% of the decision making publications related to ADM. At present, there are typically about 1,500 decision making publications and about 10 ADM publications recorded in Psyclit each year.

O’Hare (2003) has noted the relative lack of prominence given to ADM in the aviation psychology literature. For example, major works such as Wiener and Nagel (1988) and Garland, Wise and Hopkin (1999), give very limited coverage to decision making. A review of articles published

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10 The relatively large number of ADM publications recorded for 1997 (16) appears to be due to statistical variation.
in *The International Journal of Aviation Psychology* between 1991 and 1995 (O’Hare & Lawrence, 2000) found that the three leading topics were training, workload, and displays, and that decision making came fifteenth on the list. A popular aviation human factors textbook (Hawkins, 1993) also has a very limited coverage of decision making. Hence, the inescapable conclusion is that aeronautical decision making is a poor cousin in the world of aviation human factors.

### 1.6.3. Why aeronautical decision making is important

In the early 1970s the US FAA commissioned researchers from the University of Illinois, Jensen and Benel, to carry out a study of pilot decision making from a psychological viewpoint. The seminal report from that study (Jensen & Benel, 1977) set the scene for ADM research and training for many years to come. The first paragraph of the Jensen and Benel report succinctly outlines the problem in a way that is as relevant today as it was when it was written almost 30 years ago.

> Accident statistics reveal that approximately 50 percent of the civil aviation fatalities are in part related to poor flying judgment. What is meant by good flying judgment? Is it “professionalism” “Maturity?” “Flying experience?” Is judgment something pilots are born with or can it be taught or modified by a flight instructor? How can you tell if a pilot has good judgment?

(Jensen & Benel, 1977, p. i)

Jensen and Benel (1977) analysed data from 31,578 US general aviation accidents for the period 1970 to 1974. Accidents that involved human error were classified on the basis of three error types; procedural activities, perceptual-motor activities, and decision activities (Roscoe, 1980). Data were tabulated separately for fatal and nonfatal accidents. Table 6 reproduces the error category definitions and results presented by Jensen (1982).

The Jensen and Benel (1977) study clearly demonstrated that decision making was a significant factor in many aircraft accidents, and that decision-related accidents were likely to be serious in nature. Overall, 38.1% of all accidents involved decisional activities. In addition, the majority of fatal accidents (51.6%) involved decision making\(^{20}\). In contrast, the majority of non-fatal accidents (56.3%) involved perceptual-motor activities.

\(^{20}\) Some care needs to be taken in interpreting the Jensen and Benel (1977) data. For example, spatial disorientation accidents, of which 89.8% were fatal, are categorised under perceptual-motor activities. While that may be reasonable in one sense, from a broader perspective most spatial disorientation accidents are likely to involve a decisional activity as a precursor.
Table 6. Percentage of general aviation accidents with 'pilot error' as a factor.

<table>
<thead>
<tr>
<th>Error category</th>
<th>Description</th>
<th>Injury level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatal</td>
</tr>
<tr>
<td>Procedural</td>
<td>Management of the power plant, fuel, vehicle configuration, autopilot, displays, navigation, and communication.</td>
<td>4.6%</td>
</tr>
<tr>
<td>Perceptual-motor</td>
<td>Vehicle control, judgment of distance, speed, altitude, clearance, hazard detection, and geographic orientation.</td>
<td>43.8%</td>
</tr>
<tr>
<td>Decisional</td>
<td>Self-assessment of skill, knowledge, physical, and psychological capabilities; assessment of aircraft and ground-system capabilities; hazard assessment; navigation planning; and flight priority adjustment.</td>
<td>51.6%</td>
</tr>
</tbody>
</table>

From Jensen (1982).

O'Hare, Wiggins, Batt, and Morrison (1994) reported a similar analysis of data from New Zealand civil aviation accidents and incidents involving fixed-wing aircraft between 1983 and 1989. Each accident or incident was coded according to one of three error stages proposed by Nagel (1988); information, decision, or action. Table 7 reproduces the results presented by O'Hare, Wiggins, Batt, and Morrison (1994). Again, decision making errors were the most common cause of fatal accidents while action errors were the most common cause of mishaps that resulted in only minor or no injury at all.
Table 7. Percentage of civil aviation accidents with 'pilot error' as a factor.

<table>
<thead>
<tr>
<th>Error stage</th>
<th>Description</th>
<th>Injury level</th>
<th>Fatal or serious</th>
<th>Minor or nil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>Acquiring information from external cues and cockpit displays; exchanging, communicating and processing that information.</td>
<td>12.5%</td>
<td>23.9%</td>
<td></td>
</tr>
<tr>
<td>Decision</td>
<td>Weighing up alternatives, planning courses of action.</td>
<td>62.5%</td>
<td>30.5%</td>
<td></td>
</tr>
<tr>
<td>Action</td>
<td>Executing the chosen course of action.</td>
<td>25.0%</td>
<td>45.6%</td>
<td></td>
</tr>
</tbody>
</table>

From O'Hare, Wiggins, Batt, & Morrison (1994).

1.6.4. Major themes in aeronautical decision making research

The following section outlines some of the main themes of aeronautical decision making theory and research, and how that body of work has influenced related training programs in various operational settings. One aspect is very apparent – there has been no single unifying theme to give ADM research a coherent sense of direction. Much of the research has been disjointed, and often there has been a disconnect between theory and practical application. In fact, after 40 years of academic and applied research in ADM, it is difficult to quantify what progress has been made, or even to discern what path is being followed.

In an outline of the metaphors, models and methods of aeronautical decision making, O'Hare (2003) describes the various threads linking research and practice in the field over a period of decades. For example, the analytical approach of classical decision theory has given rise to ADM models that characterise the decision maker as being analogous to a ‘faulty computer’ or ‘rational calculator’. Another, more recent, strand has emphasised the ‘adaptive nature’ of the decision maker. Still other models have variously perceived the decision maker as being a ‘character defective’, an ‘enquiring expert’, or an ‘organisational cog’. This diversity of approach clearly indicates the field of aeronautical decision making has yet to develop an overall coherence that can effectively guide research and practice.

The question that naturally arises is: “Why has the field of aeronautical decision making been so poorly focussed?” The answer is most likely that no single approach has proved demonstrably effective. What is the
current state of play, then? Is there an emerging consensus as to the most appropriate theoretical basis for research in aeronautical decision making? To consider these questions, a brief review of the major themes in aeronautical decision making research and application is presented below.

Work in aeronautical decision making can be looked at in terms of three main models. Taken together, these three models encompass most of the significant work that has been carried out in field. The models are:

- the ‘accident prone pilot’ model of ADM
- the ‘headwork and motivation model’ of ADM
- the ‘expertise’ model of ADM

While not all research and application falls neatly into one of these categories, nevertheless much of it does and the simple characterisations apply some structure to an otherwise rather chaotic body of work. To some extent, these three models can be seen as a ‘progression’, with each one successively providing an approach to ADM that is better grounded in theory and empirical evidence. However, each model has something to offer, and in fact a full understanding of ADM probably requires aspects of each model. Again, the conclusion is that the study of ADM is a complex and difficult endeavour.

The accident prone pilot model of ADM

Early aviators didn’t think in terms of ‘decision making’ in relation to the non-technical skills of flying. If pressed, they would probably have invoked concepts like ‘professional judgment’ or ‘character’. Most would have probably agreed that flying experience played a large part in developing good aeronautical judgment.

Early studies into aspects of pilot judgment and decision making typically involved investigations into the nature of ‘pilot error’ as it related to accident involvement. A concept central to much early work was that of ‘accident proneness’. For example, in an study of 2,625 military pilots, Kalez and Hovde (1945) described an ‘accident prone’ group of non-conformist pilots that comprised just 18% of all the pilots studied and yet were responsible for 58% of the ‘pilot inaptitude’ accidents. Kunkle (1946) studied the psychological background of 200 US military pilots, half of whom had been involved in one or more ‘pilot error’ accidents and half of whom had not.21 Kunkle reported that the ‘accident prone’ group of pilots were more likely to have been involved in past accidents

21 It is interesting to note in passing the introductory paragraph to Kunkle’s report, which states an intent worthy of any ADM study today;
This report describes a search for some of the human factors which may lead to an aircraft accident. In particular, it deals with the characteristics which differentiate the safe from the unsafe pilot.
(Kunkle, 1946, p. 533)
Interest in the concept of accident proneness followed work in occupational health and safety, and research in industrial psychology, particularly during the first half of the twentieth century. In aviation, as in other industries, the attraction of the concept was that it suggested that if a particular group of workers could be identified, and weeded out, then the overall accident rate could be reduced. Over time, however, the concept of accident proneness fell into disfavour (McKenna, 1983; Haight, 2001). In particular, research indicated that the pool of ‘accident prone’ workers was not necessarily stable over time. Also, attempts to devise psychometric measures that would predict future accident involvement were not successful. Research into the role of accident proneness in motor vehicle crashes also failed to provide clear and coherent results (Grey, Triggs, and Haworth, 1989).

Over time, the general consensus that developed was that the concept of accident proneness was not helpful. For example, even statistics such as “18% of pilots were responsible for 58% of accidents” can be misleading as they are very dependent on the time-frame studied. For example, if a small time-frame is taken, say one day, then it may well be true that 0.5% of pilots were responsible for 100% of the accidents. It is clear, however, that removing that particular group of pilots would not solve the problem.

A 1993 FAA review of research into accident proneness (Rodgers & Blanchard, 1993) concluded that while it was possible that some personality factors, in combination with other factors, may play a role in the occurrence of accidents, that they were of limited usefulness in predicting accidents.

One approach related to accident proneness that has continued to attract interest is that of repeat offenders. That is, pilots who are involved in more than one accident within a given time-frame. For example, in a study of US air taxi and commuter pilots, Baker, Li, Lamb and Warner (1995) compared 20 pilots involved in repeated accidents (two or more) during the period 1983 to 1988 with 534 pilots who were each involved in a single accident during the same period. On average, ‘repeaters’ had significantly more total flight time than non-repeaters (7,016 hours vs. 5,321 hours) and significantly more flight time during the last 90 days (215 hours vs. 183 hours). In addition, a high proportion of repeaters involved accidents in Alaska, a region where the flying environment is more hazardous than normal. Both results suggest that exposure is an important aspect of accident proneness. However, a related study by Li and Baker (1995) found that pilots' prior accident and violation records were associated with an increased risk of being involved in an accident.
A group of 580 commuter or air taxi pilots who had been involved in and survived an accident during 1983 to 1988 were compared to a random sample of pilots who were flying for these commercial operations. During the three year follow-up period, the accident rate for the crash group was significantly higher than for the control group (12.4% vs. 7.2%).

**The headwork and motivation model of ADM**

Jensen and Benel (1977) concluded that there were two aspects to pilot judgment;

- the ability to derive and evaluate relevant information about a situation, to consider possible courses of action, and to determine the expected outcome for each alternative (termed ‘headwork’)
- the motivation to select and implement an appropriate and timely course of action

The Jensen and Benel report also concluded that it was possible to improve pilot decision making through teaching and evaluation. As a result, in 1978 the US FAA commissioned further research, this time by the Embry-Riddle Aeronautical University, to develop, implement, and evaluate pilot judgement training materials and methods. This subsequent work built on Jensen and Benel’s finding that there were two fundamental aspects to pilot decision making – ‘headwork’ and ‘motivation’. Initial US ADM programs were developed based on the Jensen and Benel model, and the teaching of analytical decision making skills and awareness of hazardous attitudes has dominated ADM training ever since.

The Embry-Riddle project culminated in a suite of ADM guidance and training materials aimed at pilots from all sectors of the aviation industry. Specific documents were produced for student and private pilots (Diehl, Hwoschinsky, Lawton, & Livack, 1987), for instrument rated pilots (Jensen, Adrion, & Lawton, 1987), for commercial pilots (Jensen & Adrion, 1988), for instructor pilots (Buch, Lawton, & Livack, 1987), and for helicopter pilots (Adams & Thompson, 1987). While these training materials were tailored to particular pilot groups they were developed from a common theory base. An additional volume covered aspects of crew resource management (Jensen, 1989). The material initially developed as part of the Embry-Riddle project still forms the basis of FAA ADM training as outlined in Chapter 16 of the *Pilot’s Handbook of Aeronautical Knowledge* (FAA, 2003).

Each of the training modules contained sections related to both the headwork and motivation aspects of aeronautical decision making. The headwork component outlined the five risk elements that should reviewed when evaluating potential flight hazards;
Pilot risk factors included aspects such as the pilot’s own competency, health, or level of fatigue. Aircraft risk factors included the aircraft’s power, equipment, or airworthiness. Environmental risk factors involved considerations such as the weather, air traffic control, or runways. Finally, operational risk factors related to the interaction of the pilot, aircraft and environment. The training material encouraged pilots to use this framework as a basis for carrying out a systematic risk assessment for their flight.

The training material also introduced pilots to a structured approach aimed at enhancing analytical decision-making by helping the pilot to organize their thoughts. The acronym DECIDE was used to summarize the six elements of the decision process (Benner, 1975);

- Detect
- Estimate
- Choose
- Identify
- Do
- Evaluate

The DECIDE model was designed as a way of encouraging the pilot to monitor all sources of information, recognize any relevant changes, and then select and execute an appropriate response. It was intended to help the pilot use his or her intellectual abilities to sense, store, retrieve, and integrate information.

The training material teaches pilots that the decision process is triggered by the recognition of an untoward change that could potentially affect flight safety. Hence, the detect stage relies on the pilot being vigilant at all times in seeking out and monitoring any relevant information. The pilot must then adequately interpret the information they have received. The next step is to choose a realistic goal for the safe management of the flight. In choosing a goal the pilot must establish priorities and objectives and assess the likely outcome of different courses of action. Once a goal has been selected the pilot identifies an appropriate strategy and procedures that will best implement that strategy. The pilot must then carry out the action plan in as timely and efficient a manner as possible. Finally, the pilot evaluates the effects of the action on the flight. At the end of the DECIDE cycle the process loops to the beginning again and repeats.
A small-scale investigation (N = 10) into the effectiveness of the DECIDE model in improving aeronautical decision making did not produce statistically significant results (Jensen, 1995).

A number of tools similar in nature to the DECIDE model have been developed to promote a structured and analytic approach to aeronautical decision making. FOR-DEC (Hormann, 1995) is another prescriptive model that has been used in training courses for airline pilots, including those from Lufthansa. The elements of FOR-DEC are:

- Facts
- Options
- Risks and benefits
- Decision
- Execution
- Check

Murray (1997) describes a modified decision making model called DESIDE, based on the following elements:

- Detect
- Estimate
- Set safety objectives
- Identify
- Do
- Evaluate

However, the research reported by Murray is limited to information about how many pilots who recalled receiving DESIDE educational material, or recalled the nature of the material. No study was made of the effectiveness of the DESIDE educational material.

A number of other similar models intended to teach pilots analytical decision making skills are detailed by O'Hare (2003). In all cases, however, there is a distinct lack of empirical validation for the models. In addition, the approach suffers from a number of fundamental limitations. As Adams and Ericsson (1992) have pointed out, DECIDE and other similar methods are deductive approaches based on a linear model of decision making. Therefore, they may not be the best method to use in certain operational settings. For example, a sequential consideration of alternative courses of action and possible outcomes might be quite undesirable in a complex, ambiguous, and rapidly deteriorating situation. Finally, as more became known about how expert pilots actually made decisions, it became apparent that training pilots to use models like DECIDE was in effect training them to act like novices rather than experts (Wiggins & O'Hare, 1993).

The second component of early ADM training was that of ‘motivation’. The motivation component of the FAA training materials outlined five
hazardous attitudes that could influence pilots to select inappropriate courses of action (see Table 8). The judgement training materials presented the pilot with information on how to identify and avoid each of these hazardous attitudes.

Table 8. The five hazardous attitudes.

<table>
<thead>
<tr>
<th>Hazardous attitude</th>
<th>Catch cry</th>
<th>Description</th>
<th>Antidote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-authority</td>
<td>&quot;Don't tell me!&quot;</td>
<td>Anti-authority is an attitude found in people who resent being told what to do. Pilots with this outlook may regard rules and regulations as silly and unnecessary</td>
<td>Follow the rules, they are usually right.</td>
</tr>
<tr>
<td>Impulsivity</td>
<td>&quot;Do something, quickly!&quot;</td>
<td>Impulsivity is a disposition to act immediately, without carefully thinking through all the alternatives.</td>
<td>Not so fast, think first.</td>
</tr>
<tr>
<td>Invulnerability</td>
<td>&quot;It won't happen to me.&quot;</td>
<td>Invulnerability is an attitude that accidents will only happen to other people. A belief of invulnerability can lead to a pilot increasing their exposure to risk.</td>
<td>It could happen to me.</td>
</tr>
<tr>
<td>Macho</td>
<td>&quot;I can do it.&quot;</td>
<td>Macho describes a tendency of some pilots to continually try to prove themselves better than others. They tend to be overconfident and are likely to engage in unsafe flying behaviour solely to gain esteem.</td>
<td>Taking chances is foolish.</td>
</tr>
<tr>
<td>Resignation</td>
<td>&quot;What's the use?&quot;</td>
<td>Resignation is a belief in external control, that events and outcomes are primarily the result of outside forces. Pilots who conform to this view are likely to feel that they can do little to influence what happens to them.</td>
<td>I'm not helpless. I can make a difference.</td>
</tr>
</tbody>
</table>

Adapted from Berlin, Gruber, Holmes, Jensen, Lau, Mills, and O'Kane (1982) and FAA (2003).

Lester and Bombaci (1984) studied the construct validity of the five hazardous thought patterns that were hypothesized to mediate pilot judgement (Berlin, Gruber, Holmes, Jensen, Lau, Mills, & O'Kane, 1982). Thirty five pilots completed sub-scales from the Cattell 16PF personality inventory (impulsivity, superego strength, and integration/self-concept control), as well as the Rotter 'Locus of Control'
scale. The pilots also completed the self-assessment inventory used to measure the five hazardous thought patterns. Fourteen percent of subjects displayed no predominant hazardous thought pattern. Invulnerability was found to be the most common hazardous thought pattern (43% of subjects), followed by impulsivity (20% of subjects), and macho (14% of subjects). Anti-authority and resignation patterns were noted in only a few subjects. Hence, Lester and Bombaci (1984) suggest that these three hazardous thought patterns may be sufficient to explain irrational pilot judgment. Further, the study found evidence of a relationship between the three predominant hazardous thought patterns (invulnerability, impulsivity, and macho) and the personality variables 16PF integration/self-concept control and Rotter Locus of Control.

Further work by Lester and Connolly (1987) also reported evidence for three of the hazardous thought patterns (invulnerability, impulsiveness, and macho). However, O’Hare (2003) carried out a re-analysis of the data originally published by Lester and Connolly (1987) and reported that a single principal components factor accounted for 52% of the total variance. This suggests that there is a significant redundancy in a model that incorporates five (or even three) hazardous thought patterns.

Research into aspects of the five hazardous attitudes continues. Hunter (2005) developed a Likert-type instrument to measure the five attitudes, compared to the original ipsative scales employed in earlier research. The new Likert-type Hazardous Attitude Scale (New-HAS) consisted of 88 declarative statements such as “I like to do spins”, or “I like to fly on the edge.” For each item, pilots rated themselves on a five-point scale ranging from ‘strongly agree’ to ‘strongly disagree’. In comparison, the original Hazardous Attitude Scale (Old-HAS) consisted of 10 scenarios that called for a timely decision on the part of the pilot, and a number of alternative courses of action that a pilot might take. There was one course of action associated with each of the five hazardous attitudes, and participants were required to choose the alternative that best described their likely response.

In a web-based study, 130 participants completed both the Old-HAS and New-HAS scales. Hunter (2005) reported that the Likert-type measure showed superior psychometric properties to the original ipsative version of the scale. New-HAS responses yielded a six-factor solution that

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22 A copy of the inventory is included in the FAA Advisory Circular 60-22, Aeronautical Decision Making (FAA, 1991).

23 An ipsative scale is one in which a respondent is required to express a relative preference for one item over other items, rather than indicating a preference on an absolute scale for each item.

24 A total of nine various scales, including the Old-HAS and New-HAS scales, were available for participants to optionally complete on the website. Not all participants completed all the scales.
accounted for 36% of the variance. The six factors were macho, resignation, anti-authority, worry/anxiety, impulsivity, and self-confidence. However, Hunter (2005) reported that correlations between factors of apparently similar content from the Old-HAS and New-Has were remarkably low. The largest correlation was -0.125 between the old and new versions of the impulsivity factors. Hunter made no comment on the inverse nature of this relationship.

Overall, the question of how many independent 'hazardous thought pattern' factors bring unique information to an understanding of pilot personality is unresolved. Also unresolved, is how those factors might relate to conventional personality measures, or to what extent they may be correlated with pilot involvement in accidents or incidents.

**Measuring the effectiveness of headwork and motivation ADM training**

A number of studies have sought to measure the effectiveness of training programs in aeronautical decision making in practical settings (Diehl, 1990). While in each case the investigators have argued that their findings demonstrate that pilots can, to a greater or lesser extent, successfully learn decision making skills, the results are equivocal.

Berlin, Gruber, Holmes, Jensen, Lau, Mills, and O'Kane (1982) compared the flying behaviours of two groups of student pilots, one of which had received only normal flight training and the other additional pilot judgment training. The results of an observational flight showed significantly better performance by the pilot group that had received judgment training (74% mean correct response rate), compared to the control group (58% mean correct response rate) (Berlin et al, 1982).

Further studies in Canada (Buch & Diehl, 1984) and Australia (Telfer, 1987) also found that pilot judgement training produced significant results. The Canadian study was based on two groups of young (17 to 19 years old) Air Cadets student pilots. There were 25 pilots in each group. The experimental group received additional pilot-judgment material as part of their pilot training. An observational flight at the end of their training indicated that pilots who had received judgment training performed better (83% mean correct response rate) compared to the control group (43% mean correct response rate) (Buch & Diehl, 1984).

The Australian study, involving a total of 20 pilots, followed the same format and also produced significant results. During the observational flight, pilots who had received pilot-judgment training showed a 66% correct response rate compared to a 58% correct response rate for those who had not received judgment training (Telfer, 1987).

In a simulator-based experiment with 29 pilot volunteers from an advanced flight training course, Connolly, Blackwell, and Lester (1989)
found significant gains in decision-making performance (from 41% correct pre-test to 86% correct post-test) for the experimental group of pilots who had received four hours of classroom instruction designed to enhance decision making skills. In contrast, the control group showed no improvement.

Although there is some evidence to suggest that ADM training could be effective, the authors typically tempered their findings with advice that further validation of pilot-judgment training was needed. For example, would the demonstrated effects be robust over time, and would the lessons learnt still be heeded under stress or emergency conditions? (Buch & Diehl, 1984).

A number of factors could lessen the effectiveness of programs to teach aeronautical decision making. For example, as Wiggins and O'Hare (1993) point out, programs to date make the inherent assumption that pilots will generalize and apply the judgement skills they are taught to new situations. However, a wealth of research (for example, see Anderson, 1987) suggests that there is little generalization and inter-domain transfer of skills. Alternatively, judgement training may fail because it is based on fundamentally flawed model. For example, the skills taught may not be central to the decision-making process (Wiggins & O'Hare, 1993).

Hence, given the passage of over twenty years, it is perhaps surprising that these initial and relatively small scale studies have not been followed by substantive large scale research projects to determine the effectiveness of ADM training. Such crucial points have still not been thoroughly addressed, leaving key questions about the basic principles of current aeronautical decision making programs unanswered. As O'Hare and Roscoe (1990) point out,

*In the rush to develop a judgement-training program, the actual bases of faulty pilot decision making have not been adequately researched.*

(O'Hare & Roscoe, 1990, p. 206)

**The expertise model of ADM**

Jensen and Benel (1977) first raised the issue of expertise in relation to aviation judgment training. Noting research in expertise related to stock brokers, livestock judges, and medical diagnosticians, Jensen and Benel suggested that knowledge about the cognitive processes used by experts judges could be used in general to train people in decision-making.

In the 1990s, the FAA sponsored research into the nature of expertise in the aviation domain. Published in 1997, the project was designed to formulate a model of the expert pilot that could form the basis of ADM
training intervention strategies (Kochan, Jensen, Chubb, and Hunter, 1997). Initially, semi-structured interviews were carried out with 10 'highly experienced pilots' (average total flight time of 13,500 hours), followed by structured interviews with 30 experienced pilots (average flight time of more than 5,000 hours). A problem-based flight scenario was developed that included seven events. Finally, a template was then developed of the knowledge, skills, and mental model components that it was thought a typical novice, competent, or expert pilot would bring to their handing of the events.

The scenario was presented to six pilot subjects in a classroom setting and they were asked to describe in detail how they would respond to each event in turn. Their responses were tape recorded and a verbal protocol analysis carried out on the transcripts. Kochan et al (1997) reported that pilots who achieved better overall results could be differentiated from their peers in three ways:

- they sought more quality information in a more timely manner
- they made more progressive decisions to solve a problem
- they communicated more readily with available resources

Jensen (1995) proposes an expertise model of aeronautical decision making that is based on four fundamental aspects:

- aviation experiences
- risk management
- dynamic problem solving
- attentional control

Jensen (1995) elaborates on each of these aspects. For example, the effectiveness of flight experiences will depend on five factors; their number, variety, meaningfulness, relevance, and recency. Pilots need to develop a sound approach to risk management, for example by establishing a set of 'personal minimums' and/or influencing the risk management procedures in the organisations for which they work. Jensen argues that pilots should adopt a 'satisficing' approach dynamic problem solving. This should be an iterative process, always with the safest options kept open. Finally, pilots should develop the ability to focus attention on the task at hand, leaving all other matters out of mind. They should also be alert to any indication that some aspect requires attention, and switch to that matter quickly and deliberately. They should also not allow outside pressures to influence their decisions.

25 The seven events in the scenario were: performing a weight and balance assessment and checking fuel, landing gear abnormal on take-off, icing conditions during climb-out, hypoxia at altitude, unexpected holding with moderate turbulence on arrival, reported windshear conditions on approach, and landing gear abnormal on landing.
The structure of Jensen's expertise model of expert pilot decision making is shown in Figure 11.


Figure 11. Jensen's 'Expertise' model of pilot decision making.

Jensen outlines the detail of the expertise model of the expert pilot decision maker in just two pages at the end of a 333 page book on pilot judgment. It is the culmination of over two decades of work. While the model appears to have considerable merit, the difficulty comes, as always, in specifying the detail. In elaborating on the four aspects of the expertise model, Jensen comes close to simply stating the obvious, particularly in relation to attentional control. Yes, pilots should be eternally vigilant, and yes, they should leave their worries behind them. But, oh for it to be that easy.

Other published work has also been based on an expertise model of aeronautical decision making. Adams and Ericsson (1992) considered the differences between expert and novice decision makers from a cognitive information processing perspective. Their work was prompted by a belief that while the 'first generation' ADM training programs had been of benefit to relatively inexperienced pilots, there was a need for second generation ADM training materials for use in recurrency training and to more adequately address the needs of more experienced pilots.
were required to generate alternative courses of action, as well as choose one of the options they generated. Participants were 13 inexperienced and 11 experienced pilots. The results indicated that the experienced pilots identified significantly more relevant cues, and generated significantly more response options than the inexperienced pilots. Differences were also found in terms of option selection where the experienced pilots chose the first option generated 71% of the time, compared to 53% for the inexperienced pilots.

Morrow, Miller, Ridolfo, Kelly, Fischer, and Stine-Morrow (2003) investigated the influence of pilot expertise on understanding and decision making in relation to flight scenarios of varying complexity. The expert group of pilots consisted of 37 airline and corporate pilots, while the novice group consisted of 28 GA pilots with little commercial experience. Participants read brief scenarios that described simple or more complex situations during take-off, enroute, or approach phases of flight. Their responses as to how they would deal with the problem were then rated by a panel of three airline pilot judges. Overall, the expert pilots performed significantly better than the novice pilots. However, the expertise effects were not moderated by scenario complexity in that both groups performed less well on the complex problems than on the simple problems. Morrow et al (2003) suggest that this may have been due to the fact that pilots read the scenarios at their own pace and therefore were not under any time constraint.

A number of research studies relating to expertise and aeronautical decision making specifically address the aspect of weather-related decision making. These studies are reviewed in the section on weather-related decision making below (see section 1.7).

1.6.5. Affect and aeronautical decision making

Over the last ten years there has been an increasing appreciation of the role played by affect in decision making in general. However, there has been little research to date specifically related to affect and aeronautical decision making.

Mauro, Barshi, Pederson, and Bruininks (2001) report preliminary results of a web-based study of affect, experience, and weather-related decision making. A total of 431 pilots took part in the research that utilized a system capable of reproducing simulated decision environments over the internet. The decision scenario presented to the pilots required them to decide whether to conduct the flight, and if so, how to conduct the flight. At the end of the simulation, participants provided further information including measures of behavioural activation and inhibition. Mauro et al (2001) reported that pilots' affective responses and the decisions they made were related in a number of ways. For example, participants who
reported feeling more anxious or excited were less likely to undertake the flight. In addition, pilots who chose to fly were more likely to choose a riskier option if they were happier.

The US National Aeronautics and Space Administration (NASA) has a program of research into affect and aeronautical decision making (NASA, 2004). A FactSheet describing the research states;

_Emotions can help us make good decisions. Frequently, the first indication that there is a problem is a “bad feeling in the gut”. Frequently, a good option is recognized because it “feels right.” But feelings can also be misleading. Developing ways to tell when feelings are accurate and how to train them is one goal of this project._

(NASA, 2004, p. 2)

The NASA laboratory research has demonstrated that while fear or anxiety can have a negative influence on working memory capacity, a similar decrement is not found when participants are angry or feel challenged. Hence, it is suggested that manipulating emotion in this way may be one possible means of avoiding negative effects on working memory capacity.

As Adams, Hunter, and Lubner (2003) state;

_Pilots have emotional responses. In some cases, these responses may interfere with their ability to make good decisions. In other cases, it may be possible to harness these responses and improve their ability to manage risk._

(Adams, Hunter, & Lubner, 2003, p. 29)

Hence, the possibility of significant gains through further research into the interplay of affect and aeronautical decision making would appear to be promising.

1.6.6. The 'ARTFUL' aeronautical decision maker

O'Hare (1992) has proposed a framework model aimed at capturing the structure within which different kinds of cognitive activities occur, and how they interact, during aeronautical decision making. The model is based on the premise that flying is a goal-directed activity and that only in the most extreme situations does a pilot's behaviour degenerate into completely disorganized activity. The O'Hare (1992) model includes five functionally separate components; situation awareness, risk assessment, planning, response selection, and response execution. The model is partly based on the conflict theory of decision making proposed by Janis and Mann (1977) and the acronym ARTFUL summarizes the main aspects;
Most routine decision making is seen as stemming directly from situation assessment in the way described by Klein's (1993) recognition primed model. While circumstances are such that there is no immediate threat to pursuing the current goal, then activity continues as planned, a state described as 'unconflicted adherence' (see Figure 12).

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**Figure 12. Flow chart of the ARTFUL decision-making model.**

However, if a threat to achieving the current goal appears, then the immediate question is whether or not there is time to generate an alternative course of action. If there is not, then the outcome may be 'hypervigilance or panic', with the decision maker likely to impulsively cast around for any course of action that appears to offer escape. If on the other hand there is sufficient time to consider other courses of action then
a search for an alternative goal is made. In the absence of a satisfactory alternative the likely result will be 'defensive avoidance', with such typical responses as procrastination and attempts to avoid responsibility. If, however, a viable alternative is identified then the risks of the new option must be estimated. If risk appears minimal then the alternative goal is pursued, a state of 'unconflicted change'. However, if significant risks are uncovered then the process loops back and repeats, as indicated in Figure 12.

The concept of case-based reasoning fits readily within the O'Hare (1992) model of aeronautical decision making. One of the major attributes of the model, the recognitional based process of situation assessment, is far more naturally modelled as a case-based system than as a rule-based system. Although attempts have been made to conceptualize situation assessment within a rule-based framework, it is doubtful that such a model could satisfactorily encompass the very large amount of information that even a relatively simple flight decision entails. Although the planning aspect of the ARTFUL model lends itself more readily to a rule-based expression, even here a hybrid case-based/rule-based approach would have significant advantages.

1.7. Weather-related decision making

Weather-related decision making, particularly that involving general aviation pilots, has been a particular focus of ADM studies. This research has been driven by a wealth of information documenting both the prevalence and seriousness of accidents involving weather-related decision making.

1.7.1. Weather accident statistics

The particular hazards associated with general aviation operations in poor weather have been known for many years. For example, early work by Bryan, Stonecipher and Aron (1954) highlighted the critical danger of VFR flight into IMC weather conditions.

In 1963 the US Civil Aeronautics Board published a study into 306 fatal general aviation accidents involving weather that had occurred between 1960 and 1962 (Brunstein, 1963). Data were presented showing that the majority of accidents involved private pilots flying during daylight hours and in the states with the most flying activity. However, as the report itself noted, these data were not corrected for the underlying activity rates.

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26 The Bryan, Stonecipher and Aron (1954) study is the basis of the ‘178 seconds to live’ statistic quoted in many flight safety articles that warn of the dangers of VFR into IMC (for example: FAA, 1993; CASA, 2000). The statistic refers to the average time before for a group of non-instruments pilots (flying in a simulator) lost control of the aircraft once visual reference was lost.
for the pilot groups and operation types involved. A large number of accidents were recorded for pilots in the 100-300 hours total flight time group, and for pilots with 100-300 hours instrument flight time. Pilots with fewer than 100 hours on type also figured prominently, as did pilots who had logged fewer than 10 hours instrument flight time in the last 90 days. Again, however, none of the data were corrected for exposure (Brunstein, 1963).

In the early 1970s, two further US studies were carried out as a result of concerns about the large number of weather-related general aviation accidents. A 1974 National Transportation Safety Board (NTSB) study was based on data from 2,026 fatal GA weather-related accidents between 1964 and 1972 (NTSB, 1974). Forty seven percent of the accidents involved VFR into IMC. The three most common weather phenomenon associated with accidents were low ceiling (37% of accidents), fog (23%), and rain (15%). The study found that the 41.4% of pilots who held private licences during that period accounted for 58.4% of the accidents. In contrast, the 27.8% of pilots who held student licences accounted for only 8.8% of the accidents. A relatively greater number accidents involved pilots in the 41-45 year age group (after correction for the age profile of all active pilots). The report suggests that possible factors behind that result could include physical aspects (eg, perception, reflexes), flying time, type of flying, and the sophistication of equipment. A disproportionate number of accidents were also found to occur in certain states where terrain or weather conditions were likely to pose a threat. Again, findings that many of the accident pilots had between 100 and 300 flight hours and/or less than 100 hours on type, did not allow for exposure.

A related 1976 NTSB study into 7,856 non-fatal GA weather-related accidents for the period 1964 to 1974 illustrated the different nature of the non-fatal accidents compared to the fatal accidents studied in the 1974 report (NTSB, 1976). The report found that most of the non-fatal accidents occurred during the landing phase, either during level-off and touchdown or during the landing roll. Typically, the conditions were VFR, and unfavourable wind conditions prevailed. Inadequate pre-flight planning was the most frequently cited cause in the accidents.

Two further studies of weather-related accidents, one in the US and the other in Canada, specifically studied VFR into IMC accidents. A 1989 NTSB study analysed 361 GA accidents between 1983 and 1987 in which VFR flight into IMC was listed as a possible cause or related factor. Annual data indicated that during the twelve year period the overall GA accident rate fell by 37%, while the VFR into IMC accident rate fell by
64%\textsuperscript{27}. However, very little analysis of the data was presented, and most of the accident statistics were not corrected for exposure. Some limited findings are possible based on data in the report. For example, when corrected for the number of active pilots in each age group, pilots in the 45-49 year age group were over-represented in the VFR into IMC accident statistics. Also, in terms of total flight experience, pilots in the 100-199 flight hour group and 400-499 flight hours group were relatively over-represented in the statistics. Overall, the NTSB report consisted of one and a half pages of introduction and summary, 30 pages of tables and graphs of data, no analysis, and no conclusions. In approving the report, one NTSB board member made the following comments:

*Although I concur with the information that is presented in the narrative and the tables relative to accidents involving VFR into IMC conditions, I do not believe that we have analyzed the reasons that these accidents have occurred or the reasons why the numbers of accidents have decreased over time. It was my understanding that this was the purpose of this safety study and not just a compilation of several years worth of accident data. Therefore, I will approve the compilation of data, but would have preferred that the study indicate the reasons behind these changes.*

(NTSB, 1989b, p. 33)

Unfortunately, these comments apply, to a greater or lesser extent, to much of the accident data analysis undertaken in reports concerning weather-related accidents.

A weather-related accident study that did include a significant degree of analysis was published by the Canadian Transportation Safety Board (TSB) in 1990. The study was based on the analysis of 333 Canadian accidents involving VFR flight into adverse weather for the period 1976 to 1985 (TSB, 1990). The report highlighted the serious nature of occurrences. Just over half (50.2%) of VFR into IMC accidents resulted in fatalities, compared to only 12.7% for all Canadian accidents during the same period. Few differences were found between pilots involved in VFR into IMC occurrences and all other Canadian accident pilots – pilot age, experience, and licence type were reported to be generally similar. The report highlighted the specific hazards associated with night VFR flight. While approximately 10% of flights take place at night, and a similar proportion of all accidents occur at night, approximately 30% of the VFR into IMC accidents occurred at night. Charter operations were

\textsuperscript{27} Calculations by the author based on the data presented in the NTSB report gave the following results for the decreases in GA accident rates for the twelve year period; GA total 36.8% decrease, GA fatal 25.8% decrease, VFR into IMC total 57.0% decrease, VFR into IMC fatal 49.4% decrease.
also involved in a disproportionate number of the Canadian VFR into IMC accidents.

1.7.2. Weather-related decision making research

The serious nature of weather-related aviation accidents has lead to a considerable body of research into this specific aspect of aeronautical decision making. This work has included both laboratory-based research and field studies, though the former have tended to predominate given the practical difficulties often associated the latter.

Pilot worth functions for weather information

Early weather-related ADM studies investigated whether there were differences in the weighting that pilots gave to different aspects of weather-related operational information depending, for example, on their experience and training. In a study involving 30 pilots asked to rank diversion airports, Flathers, Giffin, and Rockwell (1982) investigated the values or worth functions that pilots attributed to factors such as location, navigational aids, radar, and weather attributes. No differences were found between pilots grouped by experience as measured by total flight hours. However, differences were found when the pilot sample was grouped according to grade of pilot certificate, type of pilot training, and type of flying most commonly done.

Driskill, Weissmuller, Quebe, Hand, Dittmar, and Hunter (1997) studied the worth functions that pilots attribute to weather factors (ceiling, visibility, and precipitation) and terrain types (flat, mountainous, over-water) in making decisions about flight in a single-engine aircraft. The study found differences in pilot worth functions related to the nature of efficiency of information utilization (multiplicative compared to single variable models), and pilot demographics (age, flying experience, and aircraft ownership). In a related study, Driskill, Weissmuller, Quebe, Hand, and Hunter (1998) used regression analysis to demonstrate that pilots used either a compensatory decision strategy (compensating for poor conditions in one variable with better conditions in other variables), or a worst-factor strategy (factor standards for either ceiling, visibility, or precipitation, below which pilots become reluctant to fly).

Hunter, Martinussen, and Wiggins (2003) examined the decision-making strategies of pilots using a scenario-based judgment task based on 27 weather scenarios for each of three routes. The subjects were 326 American, 104 Norwegian, and 51 Australian pilots. The results suggested that pilots in each of the three nationality groups shared a common model for the use of weather information. In general, pilots favoured compensatory models of information utilization rather than noncompensatory models.
Risk perception and risk tolerance

Considerable recent weather-related ADM research has been aimed at understanding the relative importance of two distinct aspects of successful weather-related decision making – skill and motivation. For example, is a pilot who unwisely continues their flight into deteriorating weather simply unaware of the danger they face, or are they well aware of the existence of the hazard and yet accept the risk and continue their flight. That is, is the problem one of risk assessment or one of risk tolerance?

As Hunter (2002) points out, risk perception and risk tolerance are two related but often confounded concepts. Both can potentially impact on pilot decision making. For example, inaccurate risk perception can lead pilots to ignore or misinterpret risk-related information, while high risk tolerance can lead pilots to unnecessarily expose themselves to hazardous situations.

Goh and Wiegmann (2001) studied pilots' decisions to continue or divert from a VFR flight into IMC weather using a simulation of a cross-country flight. Thirty two non-instrument rated pilots with experience ranging from 30 to 259 hours total flight time participated in the study. Pilots who chose to continue the flight were compared with those that decided to divert, in terms of differences in situation assessment, risk perception, and motivation. Results showed that accuracy of visibility estimates, self-recognition of their own skill and judgment, and frequency of risk-taking behavior were the best predictors of pilot behaviour in the face of adverse weather. Hence, Goh and Wiegmann (2001) suggest that both overconfidence in personal ability and inaccurate assessment of visibility conditions are significant factors in VFR flight into IMC occurrences.

Hunter (2002) carried out research designed to explicate the relative significance of risk perception and risk tolerance in pilots' decision making behaviour and accident involvement. In a web-based study, a total of 402 pilots completed two risk perception and three risk tolerance measures, and provided demographic details and information about their involvement in hazardous aviation events.

The results showed that risk perception was only mildly related to risk tolerance, suggesting that the two constructs are separate. In addition, risk perception was negatively related to risk tolerance – that is, pilots who rated the weather as more risky also tended to be less tolerant of weather.

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28 This research is in line with recent approaches to studying individual behaviour in the face of risk that recognise the important of differentiating between hazard detection and threat appraisal, for example Grayson, Maycock, Groeger, Hammond and Field (2003).
risk. Self-reported involvement in hazardous aviation events was significantly related to risk perception, but not to risk tolerance. Hence, the results suggest that accident involvement is more likely related to differences in the skills or experience required for accurate risk perception than to differences in underlying personality traits related to risk tolerance. Pilot demographic variables showed a small but significant correlation with measures of risk perception, but little if any relationship to risk tolerance.

The role of pilot experience in weather-related decision making

A number of studies have researched the role of pilot experience levels in relation to weather-related decision making. For example, Wiggins and O'Hare (1995) compared the information acquisition strategies and decision-making performance of inexperienced, intermediate, and experienced pilots from a cognitive skill perspective. Data were obtained from information search patterns and verbal protocols during a series of six computer-based simulated flight scenarios. The results showed significant relationships between the effectiveness of the cognitive strategies used and the experience level of the pilots.

In a study of flight-instructor decision making involving the decision to authorise a student to conduct a cross-country flight, Wiggins and Henley (1997) found no differences between inexperienced and experienced flight instructors related to the process of information acquisition.

Wiggins, Stevens, Howard, Henley, and O'Hare (2002) compared the process of information acquisition between three groups of pilots with different levels of cross-country flight experience using a simulated study of pre-flight decision-making. The 50 pilots who participated were classified into three groups based on the number of flight hours that they had accumulated as pilot-in-command during cross-country flights – novice (less than 100 hours), intermediate (101 to 1000 hours), and expert (more than 1000 hours). The study identified qualitative difference between the information acquisition strategies employed expert pilots, compared to those of novice and intermediate level pilots. Expert pilots were better able to identify, and focus on, the most significant sources of information available to them. Wiggins et al (2002) concluded that only the expert pilots demonstrated the pre-flight decision-making skills necessary to rapidly assess the situation and formulate an efficient strategy for information acquisition.

Goh and Wiegmann (2002) compared US VFR into IMC accidents between 1990 and 1997 to other GA accidents that occurred during the same time period. For the period, a total of 409 VFR into IMC accidents involving fixed-wing general aviation aircraft were retrieved. For comparison, a stratified sample (based on year and US State of
occurrence) of 409 accidents not involving VFR into IMC flight was also sampled from the database. The results showed that VFR into IMC accidents typically involved less-experienced pilots. For example, the median flight hours for the VFR into IMC pilot group (580 hours) was significantly lower than for the comparison group (900 hours). Also, VFR into IMC pilots were less likely to have a higher grade of licence and were less likely to have an instrument rating. A larger proportion of VFR into IMC flights involved aircraft that were carrying one or more passengers in addition to the pilot. Goh and Wiegmann (2002) suggest that this finding may indicate that social pressure to continue the flight is more likely to be a factor in VFR into IMC accidents.

Other research has considered operational aspects in relation to weather-related decision making. Wiegmann, Goh and O’Hare (2002) investigated pilots’ behaviour in the face of deteriorating weather using a simulator-based scenario. Thirty six private pilots, with a broad range of flight experience (63 to 1,983 total flight hours) participated in the study. During a simulated 120 nm cross-country flight, the weather conditions degraded towards IMC either approximately 30 nm from the point of departure, or approximately 30 nm from the destination. The results showed that pilots who encountered deteriorating weather earlier in the flight flew longer into the weather prior to diverting, and had more optimistic estimates of weather conditions, than pilots who encountered the deteriorating weather later in the flight. In addition, less experienced pilots were more likely to continue the flight further into deteriorating weather. Wiegmann, Goh, and O’Hare (2002) concluded that the findings suggest that VFR into IMC flight may be more typically the result of poor situation assessment and experience rather than due to increased risk-taking behaviour as the flight progresses.

O’Hare and Owen (2002) examined 77 New Zealand GA cross-country aircraft accidents for the period 1988 to 2000. A comparison of weather-related accidents and non-weather-related accidents showed that weather-related accidents occurred further into the flight and closer to the planned destination than other kinds of cross-country accidents. In addition, pilots involved in weather-related accidents were younger and had more recent flight time than pilots involved in other crashes (even after correction for exposure).

Wiggins and O’Hare (2003a) reported that expert and novice pilots used in-flight weather-related cues differently, although that did not appear to influence their perceptions concerning the possibility of flight under VMC. Pilots were classified as ‘experts’ if they had more than 1,000 hours cross-country flying experience, and ‘novices’ otherwise. A worldwide sample of 577 pilots took part in the web-based study. Participants provided demographic information and were then asked to
indicate which of the following nine weather-related cues they considered would be useful as potential indicators that VFR flight might be no longer possible along a planned route:

- a change in the type of cloud formation
- an increase in the cloud density (concentration)
- a darkening of the cloud
- a lack of adequate terrain clearance
- a lowering cloud base
- rain showers
- a change in wind direction
- a change in wind speed
- a reduction in horizontal visibility (loss of horizon)

Participants were also asked to view a series of ten in-flight weather-related images and judge whether it was possible to continue the flight along the current track and remain in VMC. They were also asked which of the cues they used in their assessment.

The results showed a significant difference between the two groups in terms of the cues they considered important. Significantly more expert pilots nominated 'horizontal visibility' and 'cloud concentration', while more novices nominated 'wind strength'. The was also a significant effect of expertise on the pilots' perception of the cues in the weather-related images. More experts nominated 'cloud-base', 'cloud concentration', and 'cloud type' than did novices. However, notwithstanding the above results, expert and novice pilots did not differ significantly in their assessments of whether it was possible to continue the flight along the current track and still remain in VMC.

**Practical interventions to improve pilot weather-related decision making**

Research into weather-related decision making has resulted in a number of practical interventions aimed at reducing the number of weather-related accidents. For example, the FAA 'Personal Minimums' program (Kirkbride, Jensen, Chubb, & Hunter, 1996) was aimed at helping pilots to develop and use a set of self-selected, self-imposed minimums to guide them when making flight decisions. The personal minimums consist of operating criteria, procedures, or guidelines that are tailored to their own particular skills and experience, and operating environment. For example, given that the majority of pilot errors that lead to incidents are made prior to takeoff (McElhatton & Drew, 1993), a pilot may develop their Go / No-Go checklist for pre-flight decision making. An evaluation of pilot acceptance of the personal minimums training program found

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29 A version of training material based on the personal minimums concept, entitled *Setting your own standards*, has also been produced by the Australian Civil Aviation Safety Authority. http://www.casa.gov.au/avreg/pilot/minimum.htm
that pilots generally believed that the training was helpful and would recommend similar training to other pilots (Jensen, Guilkey, & Hunter, 1998).

Another practical tool developed to improve pilots' weather-related decision making skills is the Weatherwise program (Wiggins & O'Hare, 2003b). Weatherwise is a computer-based training system to provide VFR pilots with the skills necessary to recognize and respond appropriately to the cues associated with deteriorating weather conditions. In an evaluation study of Weatherwise, self-report and performance data were collected from 66 Australian pilots, all of whom had accumulated less than 150 hours flight time as pilot-in-command of cross-country flights. Analysis of the self-report data indicated that pilots' use of weather cues was amenable to training. In particular, training increased the perceived importance of two critical cues (cloud darkening and reduction in terrain clearance). Performance data were obtained during a simulated flight scenario in which participants were required to make a series of decisions concerning whether to continue the flight or divert in the face of deteriorating weather. The result showed that participants who had received cue based training were significantly less likely to continue the flight beyond the optimal decision point than were participants who had not received the training (Wiggins & O'Hare, 2003b).

1.7.3. A conceptual framework for weather-related decision making

As outlined above, research into pilots' weather-related decision making has involved a range of studies looking at a variety of possible factors of influence. To provide a unifying framework for this body of work, Johnson, Wiegmann, Goh, and Wickens (2005) have proposed a conceptual model for integrating and interpreting the results of the various studies.

The model proposed by Johnson et al (2005) considers both the factors that can lead to VFR flight into IMC, as well as interventions that may support the pilot in their decision making. The model also incorporates both human-centred and technology-centred interventions that can support the pilot in their decision making (see Figure 13).

Figure 13. Conceptual framework of pilots' weather-related decision making.

The Johnson et al (2005) model attempts to provide a framework to integrate and interpret the various studies of pilots' weather-related decision making. Pre-flight planning and individual pilot characteristics form the preconditions that may lead to VFR flight into IMC. ‘Inadvertent’ VFR into IMC occurrences are most likely to be the result of poor situation assessment or in-flight planning. In comparison, ‘intentional’ VFR into IMC occurrences are most likely to be the result of poor risk perception or pressure to continue the flight despite encountering adverse weather.

As outlined at the beginning of the Introduction, the work of this thesis falls into three parts;

- accident and incident case histories and pilot decision making
- case-based versus rule-based pilot decision training
- pilot behaviours in the face of adverse weather

Each of these areas can be related to the Johnson et al (2005) model outlined above. In particular, a pilot’s awareness of previous weather-related accident and incident case histories will potentially influence the
way in which they plan and carry out their flight. The relative effectiveness of case-based versus rule-based decision training will determine, in part, the type of training interventions best used to improve pilot performance and flight outcomes. Finally, a comparison of groups of pilots that exhibit different behaviours in the face of adverse weather will help to explain the underlying factors lead to those differences in weather-related decision making. Each of these aspects is considered in turn in the following sections of the thesis.
Part 1
Occurrence case histories and pilot decision making

The following two case histories describe accidents in which the aircraft crash-landed without power.

Case 3
On 8 January 1989, a British Midlands Airways Boeing 737-400, G-OBME, crashed near Kegworth while making an emergency approach to East Midlands Airport, Leicestershire, UK. The aircraft departed from Heathrow Airport for Belfast and while climbing through 28,300 feet a portion of a blade in the left-hand (No. 1) engine detached, resulting in a series of compressor stalls in the No 1 engine. This resulted in engine vibration, fluctuations in the engine instruments, and smoke in the cabin.

Figure 14. Accident site of Boeing 737-400 G-OBME near Kegworth on 8 January 1989.

The crew failed to adequately diagnose the situation and believed that the problem was a fire in the right-hand (No. 2) engine, which they then throttled back and shut down. As the No. 2 engine was throttled back, the noise and shuddering associated with the surging of the No. 1 engine ceased, convincing the crew that they had correctly identified the defective engine. In addition, they were not informed of the flames from the No. 1 engine which had been
observed by many on board, including three flight attendants in the aft cabin. Hence, the crew did not realize that they had shut down the wrong engine.

The aircraft made an emergency diversion to East Midlands Airport and was given radar vectors from air traffic control to position for an approach to runway 27. The approach continued normally until the No. 1 engine failed at a point approximately 2.4 nm from the runway, leading to an abrupt reduction in power and a fire warning. The crew attempted to restart the No.2 engine but were not successful and the aircraft crashed 900 metres short of the runway. The aircraft initially struck a field and then suffered a severe impact on the sloping embankment of a motorway. Forty seven of the 126 people on board lost their lives.  

The Kegworth accident (AAIB, 1990) became well known in aviation circles and was widely reported in the aviation press (Job, 1992) and in discussions of the human factors aspects of aircraft accidents and incidents (Beaty, 1991).

Case 4

On 27 December 1991, Scandinavian Airlines Flight 751, a McDonnell Douglas MD-81 registration OY-KHO, departed from Arlanda Airport, Stockholm, Sweden, bound for Copenhagen. The weather was snowy and windy, with a temperature of approximately 0°C.

Shortly after take-off, clear ice broke off the wings and was ingested by the engines, damaging the fan stages. This damage caused the engines to surge – the right one began to surge 25 seconds after lift-off, and the left one 39 seconds later. At approximately 3,200 feet both engines lost power. Grey smoked filled the cockpit and the electronic flight instrument system went blank, forcing the crew to rely on the back-up instruments.

Once the engines had lost all thrust the crew prepared for an emergency landing. The captain began to glide the aircraft in a gentle turn to the left and the first officer notified Stockholm control. The flaps were fully extended at a height of about 1,000 feet above ground level. The aircraft broke through the cloud at about 900 feet and the captain decided to attempt an emergency landing in field in the direction of flight. During the approach the captain steered the aircraft about 25 degrees to the right to avoid houses further on in the intended direction of landing. The landing gear was lowered just before the aircraft contacted the ground.

Four minutes after take-off the aircraft crash landed at Gottora, 2 miles north of Arlanda Airport. Although the aircraft broke into three pieces and was destroyed, all 129 people on board survived.  

30 This synopsis is based on information from the UK Air Accident Investigation Branch report (AAIB, 1990).
31 This synopsis is based on information from the Swedish Accident Investigation Board report (SHK, 1993).
Figure 15. Accident site of McDonnell Douglas MD-81 OY-KHO at Gottroa on 27 December 1991.

The details of the Gottroa accident are given in the report of the Swedish Accident Investigation Board (SHK, 1993). However, what is of particular interest in the context of this study, is information that subsequently came to light indicating that during the emergency the crew of the Gottroa aircraft were strongly reminded of the Kegworth accident and that they did their utmost to avoid making the same mistakes (Martensson, 1995). Hence, in some cases at least, there is strong evidence that that pilots’ exposure to aircraft accident and incident case histories has a significant effect on their thoughts and actions during flying operations. What is not known, however, is whether this is the norm or the exception, or what factors might influence the likelihood that case histories will play a part in pilots’ decision making.

The fundamental question posed in this section of the thesis is – Do pilots actually remember accident and incident reports when it counts, when the safety of their own flight may be at risk? Chapter 2 describes an initial qualitative survey of pilots to help identify the themes to be investigated. Chapter 3 describes the results of a quantitative questionnaire developed to obtain information about pilots’ beliefs about how they learn, both from their own experience and from the experience of other pilots.
2. Identifying the effect of case histories on ADM

2.1. Survey outline

A survey request form was prepared, inviting pilots to give their views as to the importance of case history material, such as accident and incident reports, in advancing aviation safety. The request form (see Appendix 1) briefly introduced the topic, describing the work as a study into how well we can learn from other peoples' experiences, and posed the question "Do we remember all those stories when it counts?" The request form then gave the example of the Gottrora crew who specifically recalled the Kegworth accident and were determined to avoid making the same mistake. The form concluded by stressing that individual reports would be kept strictly confidential unless the respondent agreed otherwise, and that a summary of the results would be made available to all pilots that contributed.

In order to obtain information from a large and diverse group of pilots the survey was distributed via the Internet. This enabled input from pilots from all over the world. It also ensured that the survey was seen by a wide range of pilots; for example, recreational and professional, civilian and military, fixed wing and rotary, experienced and novice. The survey was distributed via 19 newsgroups, eight web sites, eight mailing lists, and four Compuserve forums, as detailed in Table 10.

Table 10. Internet distribution of survey request for information.

<table>
<thead>
<tr>
<th>Newsgroups</th>
<th></th>
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<tbody>
<tr>
<td>rec.aviation</td>
<td>rec.aviation.student</td>
</tr>
<tr>
<td>rec.aviation.aerobatics</td>
<td>rec.aviation.ultralight</td>
</tr>
<tr>
<td>rec.aviation.homebuilt</td>
<td>aus.aviation</td>
</tr>
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<td>rec.aviation.ifr</td>
<td>can.aviation.rgs</td>
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<tr>
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<td>eunet.aviation</td>
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<tr>
<td>rec.aviation.military.naval</td>
<td>fido.ger.aviation</td>
</tr>
<tr>
<td>rec.aviation.misc</td>
<td>francom.aviation</td>
</tr>
<tr>
<td>rec.aviation.piloting</td>
<td>fido7.aviation</td>
</tr>
<tr>
<td>rec.aviation.rotorcraft</td>
<td>alt.aviation.fun</td>
</tr>
<tr>
<td>rec.aviation.soaring</td>
<td></td>
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### Web sites

<p>| | |</p>
<table>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aviation Safety Connection</td>
<td><a href="http://www.aviation.org">http://www.aviation.org</a></td>
</tr>
<tr>
<td>Professional Pilots Rumour Network</td>
<td><a href="http://www.pprune.org">http://www.pprune.org</a></td>
</tr>
<tr>
<td>Charlie Alpha's Aviation Page</td>
<td><a href="http://www.hiway.co.uk/aviation.html">http://www.hiway.co.uk/aviation.html</a></td>
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<td>Aviation Digest Home Page</td>
<td><a href="http://www.avdigest.com">http://www.avdigest.com</a></td>
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<tr>
<td>The Canadian Aviation Web</td>
<td><a href="http://www.cavok.com">http://www.cavok.com</a></td>
</tr>
<tr>
<td>Women in Aviation Resource Centre</td>
<td><a href="http://www.women-in-aviation.com">http://www.women-in-aviation.com</a></td>
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### Mailing lists

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<td>Flyer</td>
<td><a href="mailto:flyer@avnet.co.uk">flyer@avnet.co.uk</a></td>
</tr>
<tr>
<td>The Aircraft Discussion List</td>
<td><a href="mailto:aircraft@iubvm.ucs.indiana.edu">aircraft@iubvm.ucs.indiana.edu</a></td>
</tr>
<tr>
<td>Av Rotor</td>
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</tr>
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<td>Aeronautics &amp; Aerospace History</td>
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</tr>
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</tr>
<tr>
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### Compuserve forums

<table>
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<th>Description</th>
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</thead>
<tbody>
<tr>
<td>AVSIG</td>
<td>Aviation Special Interest Group</td>
</tr>
<tr>
<td>AWG</td>
<td>Aviation Week Group</td>
</tr>
<tr>
<td>WIAONL</td>
<td>Women in Aviation</td>
</tr>
<tr>
<td>PACFOR</td>
<td>Australia / Pacific (Aviation Forum)</td>
</tr>
</tbody>
</table>

Survey responses were received from 138 pilots. Reports varied in length from 49 words to 1,020 words, with an average length of 320 words. There were thirteen areas in which two or more pilots made similar points or comments (see Table 11).

The first seven categories of comments in Table 11 address the question of whether the details of specific accident and incident case histories are recalled by pilots at critical flight times. The latter six categories include other points that are pertinent to the current study.
Table 11. Survey report comments.

<table>
<thead>
<tr>
<th>Comments related to recalling case histories</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific case history recalled at a critical flight time</td>
<td>57</td>
<td>41.3%</td>
</tr>
<tr>
<td>Recalling case histories enables you to avoid critical incidents</td>
<td>23</td>
<td>16.7%</td>
</tr>
<tr>
<td>Case information is abstracted and integrated into memory</td>
<td>16</td>
<td>11.6%</td>
</tr>
<tr>
<td>Case histories are not recalled</td>
<td>14</td>
<td>10.1%</td>
</tr>
<tr>
<td>Archetypal case history recalled at a critical flight time</td>
<td>11</td>
<td>8.0%</td>
</tr>
<tr>
<td>Time span of critical incident affects the recall of case histories</td>
<td>7</td>
<td>5.1%</td>
</tr>
<tr>
<td>Details of case histories are recalled on later reflection</td>
<td>5</td>
<td>3.6%</td>
</tr>
<tr>
<td>Other comments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;I learned a lesson from that&quot;</td>
<td>9</td>
<td>6.5%</td>
</tr>
<tr>
<td>&quot;A good scare is worth more than good advice&quot;</td>
<td>7</td>
<td>5.1%</td>
</tr>
<tr>
<td>&quot;I'd hate to be the subject of a report&quot;</td>
<td>4</td>
<td>2.9%</td>
</tr>
<tr>
<td>Failed to learn from experience</td>
<td>2</td>
<td>1.4%</td>
</tr>
<tr>
<td>Recognition-primed decision making</td>
<td>2</td>
<td>1.4%</td>
</tr>
<tr>
<td>&quot;Accident and incident reports undermined my confidence&quot;</td>
<td>2</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

Details of typical pilot responses relating to the thirteen specific areas of comment are given below.

2.2. Survey results

2.2.1. Are accident and incident case-histories recalled at critical flight times?

Seven categories of responses addressed the issue of whether pilots recalled accident and incident case-histories at critical flight times.

Specific case history recalled at a critical flight time

Fifty seven respondents (41.3%) reported incidents where they had recalled specific case history information at a critical flight time. The exact nature of the information recalled varied between respondents in a number of ways. For example, in some cases, the information was general in character, often relating to a well known dangerous flying...
situation, while in other cases the information recalled was very specific to the particular flight operation, aircraft type, or geographical location. In some cases the recalled information had been seen only a short time before the critical incident, while in other cases the respondent had been exposed to the material many years ago.

The following examples are indicative of the reports that were received from respondents who recalled specific case histories at a critical flight time. While, in general, respondents' reports were couched in dispassionate language in several instances pilots reported vividly 'seeing' or 'hearing' the information that they recalled. In some cases a brief exposure to case history material was recalled many years later. For example one pilot recounted her childhood interest in aviation and how reading a story about a flying incident left a lasting impression.

When I was little—about 10 or so—and very much into stories about barnstormers and biplanes, I remember reading a story about how an early pilot—must've been in the post-WWI days—avoided death in an unusual way. The pilot, somewhat self-trained, had lost control of his WWI-era aircraft, and was plummeting earthward in some sort of nasty stalled condition. He had tried turning this way and that, but to no avail. Finally, not wanting to prolong the agony of watching the earth move upwards towards him, he pushed the stick forward to speed up the process of augering in. Lo and behold, the aircraft recovered. Seems the pilot had discovered what just about every pilot knows now—how to recover from a stall.

(Respondent 1)

Eighteen years later, as a trainee, the pilot was faced with loss of power during takeoff in a Grumman AA-1B. Fighting the instinctive reaction to pull back on the control column in order to gain height, a input that was likely to stall the aircraft and lead to disaster, the pilot reported,

I did for a split second, recall that story of the early aviator, and how the most ridiculous-feeling flight maneuver (at that time) was what saved his life. The mental image conjured up by a 10-year old from a dog-eared library book is pretty much what I saw in front of me, and it's spooky how, at that moment, the memory came back. I don't exactly know if it directly influenced me, but the thought was there.

(Respondent 1)

An example in which a pilot recalled the details of an earlier crash closely related to the specific emergency situation that they were facing is given by the captain of a Douglas DC-3 which ditched into Botany Bay
shortly after takeoff from Kingsford Smith Airport, Sydney, on 24th April 1994.

The aircraft's altitude and airspeed are still decreasing and it's obvious my one remaining option is a controlled ditching. As the airspeed falls towards 80 knots I take over from the first officer, extremely conscious of the fact that I must maintain control of the aircraft - to lose control would spell disaster. Determinedly, I remind myself of my responsibility for the safety of my passengers and crew - all too conscious of the tragedy that overtook a Beech Super King Air in exactly this situation at Sydney Airport in 1980, when the pilot attempted turn back after an engine failure on takeoff, but crashed into the Runway 16 seawall with the loss of all on board. I resolve that it's not going to happen to us!

(Respondent 9)

Similarly, the past accident history of a particular location was brought to mind by the pilot who made the following report. The incident involved a downwind landing on a wet runway at night. The pilot safely initiated a go-around, rather than attempting to stop the aircraft. His report stated,

I recalled two specific instances on the very same runway.... One was a Cessna 210, which ran off the end of the runway under the same circumstances. Pilot injured. Aircraft destroyed. A second involved a Piper Navajo. Aircraft destroyed, eight people died. I have no idea how long I thought about either; probably not even a second. In any case, it had the desired effect. Had I not known of those accidents, I might have attempted to stop the airplane.

(Respondent 88)

In some instances pilots recalled a 'classic' accident report that was well known within the aviation community. For example, the following report refers to an accident involving a Saudi Arabian Airlines Lockheed L-1011 TriStar in 1980 (Gero, 1993).

Shortly after takeoff, while climbing through 15,000ft, the crew was alerted by aural and visual indicators that there was smoke in the aft cargo compartment. Despite a successful emergency landing, a delay in evacuating the passengers and crew lead to the death of all 301 persons on board as fire gutted the aircraft.

A military pilot with approximately 2,000 hours on P-3C Orion aircraft reported that the Riyadh accident case history was recalled in similar circumstances.

I have very vivid memories of this incident being discussed in the air as we were making best speed for the nearest runway.
after a fire in the cabin. Everyone was very keen to land, get the engines shutdown, and 'run away' as quickly as possible.

(Respondent 19)

Figure 16. The burnt out hull of Saudi Arabian Airlines Flight 163 in Riyadh, 19 August 1980.

Similarly, the case referred to in the following report would have been well known in the professional aviation community. It relates to the crash of a USAir Boeing 737-300 near Pittsburgh on 8 September 1994, in which a rudder control system malfunction may have lead to an uncommanded rudder deflection and loss of control (NTSB, 1999). The report, from a Boeing 737-400 first officer, recounted a recent incident during an approach to London Heathrow Airport.

We received quite a violent roll while the autopilot was engaged, where the aircraft rolled substantially before we recovered it. The first thing that went through my mind was relating to the recent articles I had read about the Pittsburgh US Air crash and suggested rudder control problems with the B737. We immediately checked the serviceability of our rudder controls almost on instinct, after controlling the airplane, but then concluded that it was simply a jet upset from a preceding aeroplane. It flew fine for the remainder of the flight, and was logged as wake turbulence.

(Respondent 100)
A private pilot, who identified himself as a keen reader of accident reports, referred to a common cause of fatal light aircraft accidents, continuing a flight into deteriorating weather.

I'd read ... something like "VFR flight in marginal weather". There was one story in which a pilot was trying to get home by flying very low along a highway under a low cloud base, and mentioned that it was getting so dark that the cars were turning on their headlights... A year or two later, trying to get home in bad weather [I was flying] under increasingly lower scuddy clouds while it got darker. The sky was still murky ahead, so I couldn't yet see whether I would get through. After a while, I noticed the cars had their headlights on. This gave me a shock, and alerted me to how near dark it was. I turned around again and landed at the nearest airfield.  

(Respondent 40)

Thoughts about the dangers of manoeuvring the aircraft close to the ground were uppermost in the mind of the respondent who submitted the following report. As a trainee pilot with only several hours solo flight time, he experienced an engine failure at 300 feet while practicing touch and go landings in an ultra-light aircraft.

I recalled numerous stories I've read about accidents which occurred during similar circumstances because pilots attempted to turn back to the field. I decided to land in an area within a 60 degree arc in front of me to reduce the chance of stalling in too sharp a turn while gliding down.... I was able to do a deadstick landing onto a dirt road without incident. Admonitions from the book Stick and Rudder to "fly the plane" and to refrain from pulling back on the stick ran through my mind continuously.  

(Respondent 58)

Another typical specific case history report was given by the pilot of a Jantar Std II sailplane. Shortly into the takeoff roll he noticed that the cockpit canopy had opened slightly. His report of the incident continued,

Once airborne, I tried to relatch the canopy and could not. Thelin's column in the then current issue of 'Soaring' had concentrated on accidents that ensued following canopy openings during launch and tow. The consequences of becoming focused on the canopy problem to the exclusion of flying the sailplane ran through my head as I unsuccessfully tried to manipulate the latching mechanism.... I decided to fly the tow to pattern altitude, punch off and land. I did this with no untoward consequences.... I know that the column affected
my decision process and I think the effect was positive.

(Respondent 16)

Two other pilots reported recalling case histories in which preoccupation with minor problems such as an unlatched cabin door led to failure to monitor the flight and subsequent disaster. The first report was by a flying instructor who wrote,

I was at 11,500 feet when I encountered some moderate turbulence that popped open the cabin door ... After spending about a minute trying to close it, I recalled reading several stories about pilots killing themselves while preoccupied with open doors, windows, etc. That thought gave me the incentive to just turn up the cabin heat and devote all of my attention to flying the airplane.

(Respondent 22)

The second report was from a private pilot flying a Bonanza D-35.

The only specific case that happened to me was the door coming open after I skipped it on the checklist. Remembering a case when a solo pilot had spiraled into the ground trying to shut the thing, I just landed and shut it.

(Respondent 11)

While many reports covered common issues of flight safety some reports related to unusual and uncommon happenings. For example, while doing a pre-flight on a PA-28-236 a private pilot felt a slight puff of air coming from the fuel tank and recalled reading a story where mud daubers (an insect) had blocked the fuel tank vents, leading to fuel starvation as a vacuum developed in the fuel tank. The pilot subsequently found that a vent tube on his aircraft was blocked.

Had I not known of this story, I could easily have had the same fate as the guy I'd heard about: Engine stoppage due to fuel starvation in mid flight.

(Respondent 7)

A number of reports included details of highly specific case histories pertaining to a particular aircraft type or flight situation. For example, a US Navy F-4 pilot reported being an avid reader of Approach magazine, the Naval Aviation Safety Journal, and wrote,

Once I read an article about problems with the air data computer and landing gear in an article. One night, returning from a normal mission in the Arabian Sea (non-combat), we suffered an airspeed indicator failure. Not normally a major problem, but it failed at 300KIAS. At this speed, the air data computer would not allow the flaps to be lowered normally, which required a speed below 250KIAS.... The solution came
to me as I remembered the article on the air data computer system. I broke the glass on the rear cockpit airspeed indicator, which allowed the system to bleed off the air and reduce the airspeed to zero, and the flaps lowered normally.... You never know when your readings will come in handy!

(Respondent 99)

In a similar vein a respondent recounted an incident involving an Israeli Air Force pilot flying a damaged F-4 during the Six Day War.

*His hydraulics were going and he remembered reading in the US Navy "Approach" magazine that if you were losing hydraulic pressure and you held neutral or forward stick, you could trap some hydraulic fluid in the system and it would prevent the horizontal stab from going to full trailing edge up. He did this and hoped to make it across the Suez Canal.... Subsequently this F-4 was shot down by two missiles and the pilot captured.*

(Respondent 4)

A professional pilot reported an incident in which they were the co-pilot of an Eastern Airlines L-1049 Constellation involved in an emergency landing at Kennedy airport after the nose gear failed to extend.

*I remembered reading an article in some magazine that discussed landing Constellations without the nose gear extended. This article stated that the nose should be lowered smoothly to the runway. To hold the nose off until the elevators could no longer hold the nose up would result in the nose striking the runway with sufficient force to cause the fuselage to break between the nose and the wing.... I feel that if I had not read this article and recalled it at this critical time a decision to hold the nose off to minimum air speed may have been made which would have resulted in major structural damage and perhaps injuries to passengers or crew.*

(Respondent 95)

A US Navy flight engineer with over 12,000 flight hours reported that he had read an internal safety bulletin article about an incident in which one engine of a four engine turboprop ran out of fuel and quit on very short final, almost causing an accident due to the asymmetric thrust condition. In analysing this report he reasoned that if during a low fuel approach all engines were crossfed then any fuel tank still having fuel would supply all four engines, and that it would be better to have all engines quit at once rather than risk an outboard engine failure close to touchdown.
A year or two later I was the flight engineer on a flight returning from a combat patrol with a very low fuel state. We were beginning to wonder if we were going to make it back to the airfield.... When we were about five miles out, I opened all the crossfeed valves and left on all the fuel boost pumps.... We landed with all four engines running and taxied off of the active runway with absolutely no problems. At this time, I closed all of the fuel crossfeed valves. Both engines on the left side of the aircraft quit approximately two minutes later when the fuel lines ran out of fuel.... I believe to this day that my action saved a twenty-three million dollar aircraft and twelve fellow crew members.

(Respondent 28)

A professional pilot with 55 years flying experience and over 14,000 hours flight time described an incident during their flying training where their instructor, a person by the name of Pilot Officer Pickett, demonstrated how selecting full flap could extend the glide in an emergency. Many years later the respondent experienced an engine failure on approach to land.

It became evident to me that I would strike the sea about 100 yards short of the airfield and then possibly bounce into the sea wall.... Just before I hit the sea, with the aircraft just about fully stalled, I remembered Pilot Officer Picket’s demonstration and so I lowered full flap. The aircraft flew on and on and on and on. Finally it fell out of the sky with the main wheels between 6 and 8 feet into the perimeter road.... Some people do remember things from way back under very high stress.... Funny old thing the memory.

(Respondent 146)

A commercial pilot with thirty years experience recounted an incident where severe icing was encountered.

The pitot was not heated (legal) and as everything froze up around me, I remembered a story from Flying magazine about the suspected cause of a crash due to an unexpectedly frozen pitot tube. Flying by attitude and power we watched the airspeed do exactly as predicted during altitude changes. The approach to land was at 70% power due to no airspeed and no idea of ice induced stall speed. It is good that El Paso has long runways!

(Respondent 126)

The accident case histories that pilots reported recalling came from a wide variety of sources. While many were published in specialist aviation safety reports or bulletins others came from flying magazines or club
bulletins, or from books with an aviation theme. In the following example, a pilot reported that while attempting a takeoff from a short runway their aircraft hit a large puddle of water in a runway depression.

_Stupidly, I didn’t abort the takeoff but pressed on with the foolish determination that’s caused any number of accidents. As the end of the runway approached, I flashed back to an incident described by Ernest Gann in his excellent book “Fate is the Hunter.” He described taking off in an overloaded plane on a very hot day in India during WWII. The plane was barely airborne and was heading for the Taj Mahal. He ordered his co-pilot to dump full flaps, which increased lift enough for him to clear the building. Rapidly running out of runway, I dumped flaps and managed to become airborne. It was STUPID, STUPID, STUPID of me to continue that takeoff. Still, I’m glad that I read Gann’s book!_ (Respondent 101)

A professional pilot with 10 years experience and 1,100 hours flight time reported that they often hear a little ‘voice’ in their head read excerpts from crash reports relevant to their current flight.

_[For example] I hear the ‘voice’ read "the pilot did not do a fuel drain on the accident flight as all previous drains had been clear of water".... The ‘voice’ has often made me stop, walk back to the aircraft and do something, work something out, stop before I do something or make that little effort when you least want to, it has served me well so far._ (Respondent 26)

A CFI with about 5,000 hours of flight time over 30 years commented,

_Over the years, I have read many articles, and text on various subjects which at times of emergency have been recalled immediately and completely, and which have in some cases meant the difference between life and death._ (Respondent 47)

**Archetypal case history recalled at a critical flight time**

Eleven pilots (8.0%) reported that while they had not recalled specific case histories at a critical flight time their decision making had been influenced by general memories about prior cases relevant to their situation. In effect they recalled a archetypal composite case history that related to the situation they were experiencing. For example, a pilot flying a cross-country trip and keen to reach his planned destination so as to complete a training requirement reported,

_The weather locally was OK but as I was flying towards my destination I noticed low haze not just in front of me but_
coming up on each side, too. Although I REALLY wanted to land at the original planned airport... it reminded me of so many stories where for unknown reasons the pilot pressed on into deteriorating weather and ultimately ended up in IMC where they lost control of the plane.

(Respondent 55)

In another weather-related incident a private pilot with 500 hours flight time over 8 years reported,

As I reached the southern shore of the bay, they quit reporting the [dew point] spread and said "visibility seven miles in fog"... After the shore lights disappeared, I had no horizon, though I could see other aircraft overhead. After a few minutes, I heard the engine begin to speed up, looked at the panel, and discovered I was banking and descending. I went on the gauges and things stabilized. I spent several minutes thinking over whether to continue or not, and remembered numerous articles about "continued VFR into IMC". That made me decide to turn around.

(Respondent 57)

Another common accident scenario for light aircraft pilots, loss of control as a result of poorly coordinated manoeuvring at low altitude, was referred to by the following respondent.

In my case, I can't recall ever recollecting a previous case at critical times as such, but I have recollected the distilled information from one or more incidents as gleaned from magazine articles or accident reports. As an example, when turning from base to final on landing, I have sometimes had the thought "low altitude spin" flash through my mind, causing me to check my airspeed and ensure that my turn is coordinated. I recall having read several incidents where a pilot has come to grief from an uncoordinated stall in just such a situation.

(Respondent 120)

A similar comment was made by another pilot.

One situation that I'm sure many will identify with is the base-to-final overshoot-bank-pull-spin scenario. I have learned very well from stories I've read and heard about this. I have gone around when I've gotten into this situation - about the time I start tightening up the turn I remember thinking "Hey! People have killed themselves doing just this!"

(Respondent 34)
A gliding instructor reported that about six months before the reported incident he had been involved in a safety seminar and went on to say,

All the various incidents of the last few years were discussed, particularly the 'common cause' ones ... [including] people initiating or persisting with aerotows in unfeasible conditions. I was towing out behind a relatively weak tug on a hot day.... We were towing out towards rising ground, and the combination was not climbing - in fact, it appeared that we were in sink that the tug was having trouble combating....

As clear as a bell, the thought went through my head "I do not want to end up on one of those accident reports". So I checked the paddock I had previously planned as the emergency paddock, and released.

(Respondent 54)

On a long private flight by a group of three pilots poor fuel management resulted in the engine stopping due to fuel starvation. Changing tanks and operating the boost pump recovered the situation. None of the pilots were immediately sure exactly how much fuel was remaining in the other tank and the decision was made to err on the side of caution and land at the nearest airport. This conservative decision was confirmed when refueling required exactly the amount of usable fuel indicated in the flight manual. One of the pilots commented,

I can't say for sure if reading accident reports was on my mind at the time of the incident. I do read them regularly, and know that most bad accidents happen when people try to press on. I also knew that I, and my fellow pilots, were all exhausted from flying all day and this too is frequently listed a contributing cause of accidents. Important lessons were learned during this flight, and while specific accident reports may not have been on my mind, I think they did alter my reactions.

(Respondent 5)

A pilot who reported being a frequent reader of accident and incident reports described a time when, during a go-around, the aircraft was not climbing as fast as normal.

Thoughts of people stalling or hitting obstacles again came into my mind, as I struggled to climb and gain airspeed without introducing too much of an angle of attack that would lead to a stall. At the key position for my next landing attempt, I discovered that I had forgotten to turn off carb heat on the go around. Lesson learned, but the lessons learned from other people probably bailed me out of that one.

(Respondent 42)
An Aerostar 601 pilot reported an incident in which loss of oil pressure necessitated shutting down the right engine during an approach to Burbank, California.

I was reluctant to lower the gear for fear of being unable to maintain the glideslope on one engine, so I delayed putting the gear down. When we finally put the gear down on very short final, the left main gear did not lock. I immediately slipped the aircraft left, exposing the left main to the slipstream. This pushed it into place and it locked. I had never practiced this maneuver, and had not been trained on it, but had read about it in aviation magazine stories and in 'war stories' with other pilots.

(Respondent 63)

One pilot reported recalling case histories, but not until he had already continued the flight too far into deteriorating weather.

I flew into solid IFR and possible icing. I couldn’t climb and I couldn’t descend safely to make a difference because I picked up ice. All I could think about was things I had read in flying magazines, and how could I be so stupid.

(Respondent 85)

Fortunately, conditions improved somewhat and the pilot was able to land safely.

**Case histories are not recalled**

Fourteen respondents (10.1%) specifically stated that in their own experience specific case histories were not recalled at critical times. For example, a military pilot reported,

I can’t ever recall remembering a previous accident briefing or incident that someone else had had. Unfortunately I was involved in one T-38 bailout accident and two incidents (running off the runway in an A-1 fully loaded with bombs in Vietnam, and in a T-38 in Texas) and in all cases I did not recall previous accident briefs.

(Respondent 106)

A 300 hour flight time private pilot who reported that he had had three bad-weather related VFR experiences in Australia remarked,

I have always read all aviation and air safety magazines upon receipt and feel that I obtain great value from the experiences of others. However when I read your reports and tried to remember each of the experiences and I cannot remember making any decision based on previous written data but rather applied the hands on experience of flight.
Another private pilot reported a flight in poor weather during which he made an impromptu deviation from his planned track, very nearly with disastrous consequences. Analysing his actions later he commented,

*Flying up the wrong valley then not being able to turn around; deviating from the planned route; ignoring the deteriorating weather and showing-off to friends are all things which I have read about in the various books and magazines but it made no difference to that flight. Before the flight I would have smugly pointed out where the mistakes were. As it is I realise that observing such a chain of events is not enough and the pilot's state of mind and ego affect the decision making.*

(Respondent 86)

Another pilot commented,

*Commercial pilots need remember their training and where the emergency procedures are in their checklists. General recall of some past accident has a tendency to get you into deeper trouble if you haven't trained for the circumstances that are creating your newest emergency.*

(Respondent 104)

In a similar vein a respondent wrote,

*I believe most pilots react to inflight emergencies, etc. more from the learning provided by solid training, constant review, currency in type and large doses of plain old common-sense.... I'm sure most Navy pilots aren't thinking about "Ramp strikes and how to avoid them" when they're running night ops at sea.*

(Respondent 148)

**Time span of critical incident affects the recall of case histories**

Seven respondents (5.1%) suggested that whether or not prior case histories were recalled at a critical time depended on the time constraints of the particular situation. When time was short, for example an engine failure on takeoff, the pilot's response would be immediate and automatic, based on training drills and standard operating procedures rather than on the recollection of case histories of similar events. However, when the critical situation extended over a longer period of time, for example a flight into deteriorating weather, it would be more likely that the pilot would recall similar case histories and incorporate this information into their decision making. For example an ex-military fast-jet pilot reported,
I have been in several emergency situations.... I found that there was a greater chance of my decisions being influenced by other people’s experiences when I had time to reflect on the situation than in cases where I had no time. I had a flying accident ... where I had less than 20 seconds to attempt to save the aircraft or eject. I ended up ejecting. Thinking back I cannot remember being consciously influenced in my actions by stories.... In another emergency, I had almost 30 mins to decide on different courses of action, and here I definitely used the insight gained from talking to more experienced pilots in the pub.

(Respondent 14)

Another pilot also contrasted two emergency situations that they had experienced. Recounting an incident involving a serious engine problem shortly after takeoff he wrote,

    My thoughts went into automatic, but were centered on flight training that had been drilled over and over. I never had time nor a hint of recalling any past NTSB report.

(Respondent 60)

In contrast to this time-limited situation he describes a cross country trip during which bad weather was encountered,

    The skies were very dark and wind was shifting rather quickly to the front left. I most assuredly thought of countless reports of continued flight into poor weather with fatal results. We landed at a tiny airstrip and allowed the 50+ mph winds to pass over with the thunderstorm, leaving clear sky and sunshine in its wake.

(Respondent 60)

Another pilot with 10 years experience and 1,600 hours flight time wrote,

    We have to make a difference between incidents. For instance: emergencies that require a fast intervention (like an engine failure after takeoff or a near miss) or an incident that gives you time to think about it (like an oil leak followed by an engine shut down at cruise altitude).

(Respondent 84)

A flight instructor with 400 hours flight time commented,

    If the situation is critical, I tend to fall back to rote procedure and checklists. God willing I have time to analyze the situation with a clear head, I tend to recall past incidents or accident that are similar to situation where I happen to be.

(Respondent 66)

A private pilot with 1,400 hours flight time over 20 years reported,
**It is my untested hypothesis that as the urgency of the crisis increases, one is less likely to call on the experiences of others—you’ve already got your hands full. In a less urgent crisis, with time to think over a problem, one draws on a much greater range of knowledge.**

(Respondent 89)

In contrast to the above reports one pilot specifically made the point that they tended to recall case history information irrespective of whether time was limited or not.

*We do remember what we've read and we do apply it at critical times. ... This applies to both the heat of the moment and to larger judgment calls, such as whether to fly when icing is forecast or when thunderstorms are about.*

(Respondent 88)

**Details of case histories are recalled on later reflection**

Five respondents (3.6%) indicated that while initially their responses were influenced by information in general from the aviation safety literature, that on later reflection, after the danger had passed, they did tend to recall details of the specific case histories that may have influenced their decision making. For example a commercial pilot with 12 years experience wrote,

*I have found that when the work load in the flight deck gets busy and you are concerned about the developing flight conditions, the safety information, once in a while, gets recalled but without the details. More often they return as feelings or impressions because you have more important things to do like, "Fly The Plane" or communicate with your crewmember. It’s only afterward, over your coffee, or in the debrief, you sometimes match the situation with flight safety events you have read.*

(Respondent 29)

The pilot of a Cessna 182 recounted an incident in which a wind vortex caused the right wing to stall and drop sharply during the landing approach.

*Intuition would be to control with rudder or aileron to the left, which in fact only aggravates the situation. I didn’t even think about the problem but instinctively applied full RIGHT aileron ... and was able to unstall the wing, continue and make a faultless landing. Reflecting later ... I remembered reading an accident report from the US magazine "Flying".... The pilot was seen to drop a wing while turning onto base, stabilise momentarily, then spin into the trees (fatal). The aftermath report talked about the cause as being application*
of opposite aileron.... I wasn't playing the article over in
mind when I hit that vortex, but I'm pretty sure that
subliminally I had that incident somewhere in memory and
applied the "learning".
(Respondent 103)

Another pilot with 600 hours flight time over 3 years wrote,

_I can't say I remember specifically AT THE TIME. I think it
would be more accurate to say the experiences add to my
general knowledge and to the strength of good general
advice, e.g. be sure to identify the dead engine correctly.
AFTERWARD, in my recollection of an incident I might
associate with something specific._

(Respondent 82)

Recalling case histories enables you to avoid critical incidents

Twenty three respondents (16.7%) reported that exposure to case
histories of aircraft accidents and incidents had influenced the way in
which they planned and carried out their flying activities. In contrast to
pilots who recalled case histories at a critical flight time, these pilots
described how specific case histories helped them to avoid critical
situations in the first place. Being forewarned of potential dangers
enabled them to act prudently and avoid a similar fate. For example, a
retired airline pilot with over 30 years flying for Western and Delta
Airlines reported that lessons from accident reports had a major influence
on his flight operations. In particular he cited two well known reports.
The first involved the crash of an Eastern Airlines Lockheed L-1011
TriStar near Miami on 29th December 1972. After a nose-gear indicator
light failed to illuminate the pilots became preoccupied with this problem
and failed to adequately monitor the aircraft's instruments, resulting in the
aircraft flying into the ground (NTSB, 1973). The second crash referred
to was the collision of a Pacific Southwest Airlines Boeing 727 with a
Cessna 172 in clear weather and controlled airspace near San Diego
Airport on 25th September 1978 (NTSB, 1979a).

Referring to these accident case histories, the pilot stated,

_I read every accident I could get my hands on. Two of those
accidents played a major part in my operation of the
airplane. Other to a lesser degree. The two major ones were
the Eastern Airlines Lockheed 1011 accident in the Florida
everglades. Every time we had a problem, I reminded myself
of that accident and that someone had to fly the airplane.
Never mind the problem. The other major accident was the
PSA 727 collision with a Cessna 172 in San Diego
California. I realized that this type of accident could happen
to any pilot.... When Air Traffic Controllers pointed out
traffic (especially ones we were to follow) I made sure that
we were talking about the same aircraft.
(Respondent 97)

Figure 17. Stricken Pacific Southwest Airlines Boeing 727 after midair
collision 25 September 1978.

A pilot with 1,044 hours flight time over 13 years reported,

I read all the accident reports I can, and can often imagine
myself making the same mistake, which makes me think about
how to avoid the situation.
(Respondent 40)

Referring to a trip that involved mountain flying a private pilot with 330
hours flight time remarked,

I had heard of a number of cases in the Idaho ... backcountry
where pilots got into box canyons and couldn't climb out.
During all of the time, I kept asking myself, "Do I have a way
out?"... There is a history of people not being able to climb
out. That warned me not to get boxed into a situation where I
depended on the ability to keep going straight through the
pass without seeing the other side.
(Respondent 128)

A recently qualified pilot commented that in the early stages of flying
activities the learning curve was steep and that accident case histories
were a valuable source of information.
I have noticed that many of my procedures have been improved as a result of reading of the experiences of others in the 'crash comics'. For example, checklists - I was starting to slip into the habit of just rattling through them, and sometimes not even with the paper in my hand, just relying on memory. After reading of crashes at least partly caused by just this sort of thing, I have now altered my behaviour to always use paper and always consciously check everything on it thoroughly.

(Respondent 59)

Similarly, a student pilot with nine hours flight time reported,

The stories I've read from the ntsb reports often come back to me while we're flying, particularly the stalls-on-landing ... where, for instance, the pilot forgot to raise the flaps and consequently died. Before I read that one, I almost always forgot to do so myself, but this last flight (after reading the reports) it was no problem, and I'm sure that those stories were in the back of my mind when I did so.

(Respondent 129)

A private pilot with 330 hours flight time wrote,

I don't believe I will ever hear a small voice saying "Remember what so-and-so did (or didn't do) in this situation." What I do get out of them is the motivation to think through what I would do in an engine out situation, a no-lights-at-night situation or a flight into deteriorating weather condition. Sometimes the articles even provide enough motivation to get me to go out and practice simulated emergencies.

(Respondent 130)

A professional pilot of 30 years attested to being influenced many times by accident reports relevant to their flight operations. The particular accident referred to was the crash of an American Airlines Boeing 757-223 on December 20, 1995, while on approach to land at Cali, Colombia, with the loss of 159 lives (ACRC, 1996). Under time pressure the pilots failed to fully appreciate the consequences of course changes entered into the computerized Flight Management System (FMS), leading to a lack of situational awareness and controlled flight into terrain.

The most recent example is the AA accident at Cali. I currently fly an aircraft with a fairly sophisticated FMS and that accident drove home the fact that even a single digit entered in error can have disastrous results if the flight crew is more occupied with programming the computer than
Identifying the effects of case-based histories on ADM

flying the aircraft.
(Respondent 78)

A military pilot with 2,000 hours flight time described how a systematic recording and analysis of accidents and incidents in their organisation was used to build up a store of corporate knowledge that was available to all pilots.

Each incident that occurs has a report written on it. These were pretty much required reading, and the corporate knowledge that existed... was extensive.... In every case, it seemed that someone had either done it before, or heard of someone else doing it. Obviously every case had its own quirks, but there was normally a large information base to draw upon when needed.
(Respondent 19)

Another military respondent, a Navy F-14 pilot, commented,

I think that most of the time it comes from pre-flight planning, and thinking to yourself "hey, this is what killed those guys last year." that saves your life before you ever make the bad decision which may jeopardize your own life.
(Respondent 51)

A pilot with instructor and helicopter ratings reported,

I tend to use "hangar flying" stories, as we call them here in the States, to AVOID critical situations.... For the most part, we're taught what to do in case of common emergencies. I tend to find the hangar flying stories just help to make these emergency checklist steps more memorable by putting them into a realistic scenario.... Knowing a good story related to a failure to follow that procedure seems to make it easier to remember - even if I didn't personally suffer the results of the failure.
(Respondent 115)

A private pilot with approximately 700 hours flight time accumulated over 8 years wrote,

The classic stall/spin while turning to the final leg of a landing pattern. I know I make a conscious effort while in the pattern to keep the nose down and the speed well controlled, and I do specifically think of the many accident reports regarding collisions with the ground short of the runway!
(Respondent 5)

An instructor reported recalling a specific and rather uncommon case history and then acting accordingly.
I was teaching a particularly ham-fisted student how to do
stall recoveries. During the lesson, I recalled reading a story
in Flying called "Out Spinning With Jules" about a student
who repeatedly put the airplane in a spin during a similar
exercise, despite his CFI's best efforts. It made me sit up and
be ready to grab the yoke.

(Respondent 79)

Case information is abstracted and integrated into memory, details
are not retained

Sixteen of the pilots (11.6%) surveyed stated that reading case histories
about aircraft accidents and incidents had added to their store of aviation
knowledge in general, rather than resulting in them remembering
individual cases. The important information from many interrelated case
histories was remembered in an abstract and integrated form. The pilots
reported that this knowledge subsequently affected the way in which they
carried out their flying activities, although the details of particular case
histories were not recalled at critical times. For example a pilot with over
35 years experience in aviation including military, test flight, regulatory
and instructional flying, commented,

I can honestly say that I have never actually recalled an
individual accident report or flight safety article at a time
when I found myself in a situation I would have preferred to
avoid. However, I think that a continued indoctrination with
the above has led me to the situation where the alarm bells
ring because of generalities rather than specifics.... With
deteriorating wx - so much has been published that individual
stories don't matter - the big picture is that with no IFR
rating and a non IFR aircraft deteriorating wx is not a good
scene.

(Respondent 8)

Similarly, a former commercial pilot wrote,

Rather than recall a relevant story at a critical time, I think
we tend to incorporate the stories, along with our own
experiences, into something that becomes a component of
judgment. There, experience fights it out with goals and
personality to determine the outcome of any given situation,
routine or emergency.

(Respondent 10)

Another pilot made the point that the insights and judgements derived
from case histories are incorporated into training programs and standard
operating procedures.

Having heard of an experience, you may well include such
things in a training program.... Although the incident itself
Identifying the effects of case-based histories on ADM may not be recalled at the time of an emergency, the training scenarios and resulting procedures/reactions may have saved the situation. Thus the indirect effect may be felt, but not by remembering the specific incident.

(Respondent 87)

A professional pilot with 3,500 hours flight time including airline and instructing experience wrote,

In general many of those informations coming from reports - like accident reports or information from NTSB - are stored in a pool called know how and experience.

(Respondent 73)

A military helicopter pilot with both fixed wing and rotary wing time commented,

From our own experience and the experience of others, we learn how to recognize a deteriorating situation. We often spend time thinking about what action to take and how to avoid the situation in the first place. By studying the experiences of others, it helps us to recognize when we are faced with similar circumstances. As a pilot in one article put it to his copilot, "I see a rather unhealthy chain of events developing here".

(Respondent 12)

Another pilot made the point that case histories were effective in reinforcing the importance of correct operating procedures.

Personally I can recall only a very few of these tales with any detail. However, reading lots of these Crash Comic stories does instill a respect for certain procedures that pure instruction often fails to do. The most useful tales ... are those whose themes instill more respect for simple things like fuel draining, fuel calculations, pre-flight inspections, weather briefings, watching for traffic, low ceilings and how to spot a bad infection of get-home-itis.

(Respondent 45)

A private pilot with 150 hours flight time over 5 years wrote,

I am an avid reader of incident reports and "I learned about flying from that" type stories.... I believe this has had an impact on my attitude - I consciously try to make rational, conservative decisions about flying.

(Respondent 20)
2.2.2. Other issues raised in survey responses

In addition to the seven categories of responses that addressed the issue of whether or not accident and incident case histories were recalled at critical flight times, a further six categories of responses expressed other relevant points of view.

**A good scare is worth more than good advice**

Seven respondents (5.1%) made the point that the anxiety or fear resulting from actual exposure to a risky or dangerous situation meant that personal experience was very much more effective in modifying attitudes and behaviour than was reading about the experiences of others. For example one pilot wrote,

*Personal experience of a life threatening situation is not easily forgotten, while to a reader or listener it is just a story, and only an excellent narrator would be able to convey the feelings aroused in such a situation. I once spent 45 minutes flying through the mountains in Norway in cloud and turbulence. I was forced to stay at 7000 feet because of severe icing, even though I knew that the mountain tops extended to 7500 feet.... That was about 15 years ago, but I remember every detail of that flight like no other.*

(Respondent 67)

Similarly another respondent commented,

*We seem to have slight or no ability to learn of others mistakes. I think one has to experience the anguish of real life before you can apply your logical solutions.*

(Respondent 6)

A professional pilot with a particular interest in aviation safety concurred, but also added the point that a frightening mistake alone is not sufficient to ensure that a lesson is well learnt - later reflection and analysis is needed to ensure that the experience leads to future modification of flying behaviour.

*A personal feeling is we learn best from our own mistakes.*

*Quoting Ed Howe: “A good scare is worth more to a man than good advice.” We also need to learn how to learn from mistakes. ... the error needs to be acknowledged, analyzed and the lesson converted into a personal guideline that can be noted and referenced from time to time.*

(Respondent 80)

A private pilot reported that, after gaining his licence at 19 years of age, he experienced several very close calls during the next few years of
Identifying the effects of case-based histories on ADM 123

flying. He then ceased flying for a long period, returning only recently. In light of this experience he reported,

Until a tragedy becomes personally close, it has very little impact on most folks. Until one gains a realization of their own personal mortality (usually attained by living a long time, ie age), other's tragedies have little impact on ones behavior.... The two barriers to internalizing tragedies is immaturity and distance. This is not to say that education of the do's and don'ts lessons are not useful, for they indeed are, but their impact is usually limited on the immature and uninvolved.

(Respondent 41)

A pilot with 75 hours flight time over three years wrote,

My own adrenaline experiences have altered my future actions - we all know the feeling of "Geeezzzzz, I won't do THAT again" when you give yourself a fright.

(Respondent 59)

I learned a lesson from that

Nine respondents (6.5%) described experiencing a critical flying incident that left a deep and lasting impression on them and significantly influenced their subsequent flying behaviour. For example, a flight instructor with 7,000 hours flying experience recalled an incident early in his flying career when he was caught by deteriorating weather and forced to climb above cloud in an Auster with limited instrumentation. Eventually they were able to descend and land safely.

That episode has turned me into almost a meteorological 'freak' - it is now a very interesting hobby of mine and I thoroughly enjoy lecturing on Met. to our many students - always relating this story to them. I am now very careful about every detail of flight planning.... In other words it taught me a very valuable lesson that lives with me every day I fly.

(Respondent 2)

In another report, a professional pilot with 5,500 hours flight time over 40 years recounted how the fatal crash of another aircraft made an indelible impression on him. The respondent described how the accident aircraft arrived at it's destination but was unable to land because of localized bad weather. Rather than waiting for conditions to improve or making a precautionary landing the VFR pilot decided to divert to another airfield that it was not possible to reach before dark or with the available fuel.
The end result was that in the dark east of Daly Waters he ran out of fuel and all on board perished. I heard all of this on VHF and listened to six people die and it has made a lasting impression on me.... That accident happened about 30 years ago and still to this day, when the going gets tough I remember that night in the NT and I am a better pilot for it. I wish those people had not died but I have learnt from their misfortune.

(Respondent 135)

A pilot with approximately 700 hours flight time on single engined aircraft described a cross-country flight during which poor fuel management very nearly resulted in the aircraft running out of fuel. The pilot commented,

The flight altered forever the way I flightplan and the way I manage my aircraft's systems on long flights.

(Respondent 5)

A professional pilot with 30 years in the industry also described a situation that left a lasting impression. He wrote,

[An] experience which I recall each time I am sequenced behind a large aircraft close in to the airport is the encounter I had with the wingtip vortices of a Lockheed Electra immediately after my takeoff as an instructor in a Cherokee 140. No groundschool instructor or "how to fly" book could have possibly prepared me for the complete lack of control I had over my aircraft.

(Respondent 78)

I'd hate to be the subject of a report

Four respondents (2.9%) specifically mentioned that their flying behaviour had been moderated by their thought that they didn't want to become the subject of some future accident report or cautionary tale. For example a flight instructor wrote,

I personally don't recall any specific previous accident come to mind when faced with a critical situation in flight. Perhaps, for me it was more of a "Geez, I'd better get -real- careful now. I'd hate to be in one of Flying magazine's Aftermath columns."

(Respondent 79)

A pilot with 185 hours flight time over two years reported,

Often it's not remembering a specific story, or even as much the general type of story, that's a source of helpful guidance; it's the idea that if you mess up, especially in some novel or particularly dumb way, someone *IS* going to write about it
somewhere and everyone's going to wonder how you could've been such an idiot.

(Respondent 55)

A student pilot with 20 hours flight time wrote,

I always try to read those stories as much as I can, or always listen to pilots saying "Do you remember that idiot who did ..." (to make sure I'm not the next idiot :-).

(Respondent 108)

A private pilot with 180 hours flight time over three years reported,

When faced a go or no-go decision, I find myself writing (mentally) my own accident report....this on many occasions has led to me realise something that perhaps I wouldn't have otherwise.

(Respondent 134)

Failed to learn from experience

Two respondents (1.4%) commented about the marked lack of learning that is sometimes evident. A flight instructor with 7,000 hours flight time wrote,

I have seen ... pilots who have made some very stupid and foolish mistakes/errors who seem to simply repeat the same mistake over and over again.... 'Learning from one's mistakes' varies greatly from person to person. Those that seem to learn the most are those who have the higher degree of 'personal discipline'. The other types who also seem to learn from their mistakes are the types who are forever questioning the reasons for what ever they do.

(Respondent 2)

A former commercial pilot commented,

There were times when I read the feature in Flying magazine and thought it should have been called "I Didn't Learn a !@#$%^&* Thing about Flying from That". Case in point, the guy who had a generator belt come apart, lost his radios, got lost, wandered around until he was almost out of gas, got lucky and found a runway ahead of him. He concluded that he'd never again take only a cursory glance at the generator belt on his pre-flight. Nary a word about learning how to navigate without radios (he'd been VFR the whole time). The thing he'd missed is that there are a lot of ways to lose the radios, and he can't check them all, so what's his backup plan _before he starts the flight_.

(Respondent 10)
Recognition-primed decision making

Two pilots (1.4%) made comments in their reports that appeared to describe aspects of Klein's (1993) recognition-primed decision (RPD) model of decision making. In the RPD model, correctly assessing the situation is seen as a crucial step in decision making. In this regard expert decision makers have the advantage of recognitional skills developed over long experience in their domain of expertise. For example, a US Navy helicopter pilot with 1600 hours total time, including a tour as instructor in SH-2F helicopters and 25 combat missions during Desert Storm commented,

"You might remember the story of a senior pilot on a fighter squadron who had a bad cat shot and ejected. Now, he had less than a second to assess the situation and make his decision, and was asked by one of the junior pilots how he was able to do that. "You had less than a second to react, when did you make the decision to eject?" The older pilot replied: "I made that decision 18 years ago."

(Respondent 12)

Another military pilot commented,

"I had a flying accident almost 8 years ago where I had less than 20 seconds to attempt to save the aircraft or eject. I ended up ejecting.... My decision to eject under certain circumstances had been taken years before on the ground after evaluating other pilots' successful and unsuccessful ejections. The fact that I knew beforehand when to call it quits saved my life."

(Respondent 14)

Accident and incident reports undermined my confidence

An indication of the powerful effect of accident case histories on some pilots is shown by comments from two respondents (1.4%). In these two cases the desire of the aviation safety authorities to make pilots aware of potential flying dangers by the use of dramatic and vivid accident scenarios clearly had a marked effect. For example, one private pilot attributed an 18 year interruption to their flying activities to reading accident reports.

"As a direct result of the crash comic scenario, low hours pilot blah blah ended fatally etc, I stopped flying until I could resume with some continuity."

(Respondent 50)

Another pilot also reported a strong negative reaction to reading accident reports after subscribing to Aviation Safety.
By the end of the 6 months I had no confidence left at all. I would beg instructors to fly with me for even the easiest of trips. The reason - If these high hour professional pilots would make such simple stupid mistakes, what mistakes was I making that I didn't even know about! It took a while for me to regain my confidence but eventually it did come back.

(Respondent 61)

A discussion of the work outlined in this chapter is included in Chapter 8.
3. Quantifying the effect of case histories on ADM

3.1. Questionnaire outline

To complement the qualitative survey data outlined in Chapter 2 a short questionnaire was developed to obtain additional data suitable for quantitative analysis (see Appendix 2). The questionnaire first asked for basic demographic information (age, sex, nationality, and education level) and for details of the respondents' flying history and experience (years and hours of experience, licences and ratings held, flying training, types of aircraft flown, types of flying activities undertaken, and attitude to flying). The next section asked respondents to give details of the particular sources of case-based aviation accident and incident information that they read, and how recently they had last read that type of material. Finally, a series of questions asked whether respondents agreed or disagreed with some common points made by pilots in the original survey study.

The questionnaire was initially emailed to 123 of the 138 original survey respondents (six were not pilots and nine were no longer at the same email address). Eighty-eight questionnaires were returned from this group, a response rate of 71.5%. As the original survey respondents were a self-selected sample that replied to a post about aviation safety, it would be expected that the pilots in this group would be more safety aware than average. To extend the study to a more general sample of pilots, the questionnaire was also emailed to all people who listed as pilots on the US Four 11 online directory service, to pilots from the Women in Aviation Resource Centre, and to UK pilots listed on the Charlie Alpha web site. The uniform resource locator (URL) for each of these web sites and the number of email addresses obtained from each source are detailed in Table 12.

Table 12. Source of pilot email addresses.

<table>
<thead>
<tr>
<th>Source and URL</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four 11 directory service <a href="http://www.Four11.com">http://www.Four11.com</a></td>
<td>444</td>
</tr>
<tr>
<td>Women in Aviation Resource Centre <a href="http://www.aircruise.com/aca/wia">http://www.aircruise.com/aca/wia</a></td>
<td>73</td>
</tr>
<tr>
<td>UK Charlie Alpha web site <a href="http://www.hiway.co.uk/aviation/aviation.html">http://www.hiway.co.uk/aviation/aviation.html</a></td>
<td>626</td>
</tr>
</tbody>
</table>
Of the 1,143 questionnaires emailed to pilots from these three sources, 302 were returned (26.4%). An additional 19 questionnaires were returned by pilots who became aware of the study by other means. Hence, a total of 409 questionnaires were received for analysis.

3.2. Questionnaire results

3.2.1. Demographic profile of pilots

By far the majority of pilots who completed the questionnaire were men. Only 29 responses (7.1%) were from women. Most pilots who completed the questionnaire were from Britain (192, 47.1%) or from North America (173, 42.4%). Eighteen pilots (4.4%) were from Australia or New Zealand, there were five each from France and Germany, three from Belgium, two each from Holland and Denmark, and one each from Ireland, Switzerland, Sweden, Norway, Czechoslovakia, Italy, Spain, and South Africa. The pilots were predominantly middle-aged, with two thirds between the ages of 30 and 50 inclusive. The youngest was 18 years of age and the oldest was 75 (mean 41.3 ± 10.9 SD). The frequency distribution of ages is shown in Figure 18.

![Age distribution for all pilots](image)

Figure 18. Age distribution for all pilots.

A large majority (341, 83.6%) of the pilots had received some form of tertiary education, while for 65 pilots (15.9%), their highest educational level was secondary, and two pilots (0.5%) had received only a primary education.
3.2.2. Flying history and experience

The majority of respondents to the questionnaire were private pilots (257, 63.1%). A small number were student pilots (15, 3.7%), 80 (19.7%) were commercial pilots, and 55 (13.5%) held an airline transport pilot's licence (ATPL). The proportion of pilots in each licence category is shown in Figure 19.

![Figure 19. Proportion of pilots in each licence category.](image)

Pilots' total number of years of flying experience ranged from three months to 55 years (mean 11.9 yrs ± 9.9 SD). The total number of flying hours that pilots had accumulated over this time ranged from three hours to 24,000 hours (mean 1,720 ± 3,290 SD). The grand total flying experience of all pilots who responded to the questionnaire was 703,422 hours. The frequency distribution of total hours flown is shown in Figure 20.
A new variable 'average hours flown per year' was computed by dividing a pilot's total flying time by their number of years of experience. Hours flown per year ranged from 6 to 778 (mean 110 ± 131 SD). The frequency distribution of the average number of hours flown per year by the pilots is shown in Figure 21.
Over half of the pilots (238, 58%) held one or more additional ratings. In particular, 215 pilots (52.6%) held an instrument rating, 130 pilots (31.8%) held a multi-engine rating, 81 pilots (19.8%) held a flight instructor rating, and 26 pilots (6.4%) held a helicopter rating. Most pilots (328, 81.2%) had received all of their flight training with an aero club, civilian flight school, or fixed base operator (FBO). Fifty four pilots (13.4%) had received some or all of their training with the military, and 38 pilots (9.4%) had received airline training.

The types of aircraft flown by pilots who responded to the questionnaire are shown in Figure 22. Almost all pilots had flown light single-engined aircraft. The seventeen pilots (4.2%) who had not flown a light single were solely glider (sailplane), ultralight, or helicopter pilots. A large number of pilots (173, 42.3%) had flown light twin-engined aircraft, with lesser numbers flying aircraft in the medium weight category (79 pilots, 19.3%) and the heavy aircraft category (39, 9.5%). Nearly a quarter of pilots (95, 23.2%) had flown a jet or turboprop aircraft of some type, either fixed-wing or rotary-wing. Approximately one third of pilots (131, 32%) had flown a glider. Finally, 54 pilots (13.2%) had flown an ultralight aircraft.

![Figure 22. Types of aircraft flown by all pilots.](image-url)

Pilots responding to the questionnaire engaged in a wide range of flying activities. Almost all pilots (395, 96.6%) listed recreational flying as one of their activities. Nearly a quarter of pilots (98, 24%) reported flying for business, for commuter or charter work, or in corporate employment. Forty three pilots (10.5%) had flown for airlines, and 60 pilots (14.7%) had experience in military aviation. Ninety seven pilots (23.7%) had
given flight instruction and 82 (20%) had performed some other form of aerial work, such as agricultural flying, emergency services flying, or test flying. The kinds of flying activities that pilots had been involved in are shown in Figure 23.

![Figure 23. Flying activities engaged in by all pilots.](image)

A composite measure of pilots' flying experience was constructed from the relevant data fields. The composite metric was based on the premise that no single measure of pilot experience could adequately reflect the full breath and depth of experience levels across the group of pilots. The metric was composed of six elements;

- number of years flying experience
- total hours flying time
- highest licence type held
- number of ratings held
- experience with different aircraft types
- experience related to different types of flying activity

The formula used to calculate a ‘flying experience’ score for each pilot computed a score within an arbitrary range of approximately 0 to 100\(^32\). The frequency distribution of scores for all pilots is shown in Figure 24.

---

\(^32\) The different individual measures of flying experience were converted to z-scores before combining to avoid any particular subscale having undue influence on the combined result.
By inspection of individual cases within each of the flying experience groups it was possible to build up a picture of the typical pilot within each of the groups (see Table 13). The six flying experience groups can be seen as approximating the six of the ‘guild’ levels of expertise described by Hoffman, Shadbolt, Burton, and Klein (1995) – novice, initiate, apprentice, journeyman, expert, and master. However, the characterisations between the flying experience groups are somewhat arbitrary and any analysis based on them should to be treated with caution.

33 Hoffman, Shadbolt, Burton, and Klein (1995) also describe an additional level of expertise, naivette (one who is totally ignorant of a domain). However, that level is not relevant to the grouping of individuals who have had some exposure, however limited, to the domain in question.
Table 13. Typical pilot characteristics for each level of flying experience.

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Pilot group</th>
<th>Expertise level</th>
<th>Characteristics of typical pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>student pilot</td>
<td>novice</td>
<td>approx 35 hrs TT gained over a period of 18 months, student licence, endorsed on single engine aircraft only</td>
</tr>
<tr>
<td>2</td>
<td>private pilot</td>
<td>initiate</td>
<td>approx 135 hrs TT gained over a period of 4 years, private licence, single engine aircraft, no additional ratings</td>
</tr>
<tr>
<td>3</td>
<td>advanced private pilot</td>
<td>apprentice</td>
<td>approx 350 hrs TT gained over a period of 10 years, private licence, light-twin endorsement and instrument rating</td>
</tr>
<tr>
<td>4</td>
<td>professional pilot</td>
<td>journeyman</td>
<td>approx 1,200 hrs TT gained over 15 years, CPL, medium-twin endorsement, instrument rating, additional rating and experience (e.g., flight instructor, aerial work etc)</td>
</tr>
<tr>
<td>5</td>
<td>experienced professional pilot</td>
<td>expert</td>
<td>approx 4,000 hrs TT gained over 20 years, ATPL, multiple ratings and endorsements, experience with various aircraft types and flying activities, possibly including turboprop or jet aircraft</td>
</tr>
<tr>
<td>6</td>
<td>master professional pilot</td>
<td>master</td>
<td>approx 10,000 hrs TT gained over 30 years, ATPL, multiple ratings and endorsements, very extensive experience with different aircraft types and flying activities, including heavy jet aircraft</td>
</tr>
</tbody>
</table>

As indicated in Figure 24, only a small number of pilots (13, 3.2%) fell within the group of least experienced pilots, characterised as the ‘student pilot’ group. The ‘private pilot’ group included 108 pilots (26.7%). The ‘advanced private pilot’ group was the largest group with 140 pilots (34.7%). The ‘professional pilot’ group included 72 pilots (17.8%), the ‘experienced professional pilot’ group 50 pilots (12.4%), and the ‘master professional pilot’ group 21 pilots (5.2%).

The final history and experience variable considered in the study was aimed at quantifying pilots' level of engagement in aviation-related matters. To this end, the questionnaire asked pilots, "How passionately do you feel about flying?" Responses were given on a five point scale that ranged from very high interest to very low interest. The descriptive captions for the five points on the scale were;
Quantifying the effects of case-based histories on ADM 137

- What else is there? It's my life.
- It's always been one of my prime interests, I'm very involved.
- It's important to me.
- Just a job really (or) A pleasant hobby.
- It's a minor interest.

The pilots in this study reported a high degree of interest in flying with two thirds of pilots (270) choosing one of the top two rating points as their response. Almost all pilots (375, 92.4%) rated flying as "It's important to me" or higher. The frequency distribution for level of engagement for all pilots is shown in Figure 25.

![Figure 25. Level of engagement in aviation for all pilots.](image)

**Pilot response group**

Two groups of pilots completed the questionnaire. The first group of pilots received the questionnaire as a follow-up to the original survey study, while the second group of pilots were sent the questionnaire without prior contact. As the first group was entirely self-selected it might be expected that they would have a particular interest in aviation safety, the topic of the original survey. However this potential difference between the groups was confounded by the markedly different questionnaire response rates, 71.5% and 26.4% respectively. The lower return rate for the second group is likely to also bias that group towards safety-aware pilots.

The two groups differed in a number of aspects. Pilots in the original survey group had flown significantly more hours (mean 2,694 ± 472 SE versus 1,453 ± 159, F(1,407) = 10.04, p = 0.002) over a significantly
longer time (14.9 ± 1.33 years versus 11.0 ± 0.50 years, F(1,404) = 10.75, p = 0.001). Pilots in the original group were also significantly more likely to hold a commercial or ATPL licence (51% versus 28%, F(1,405) = 16.49, p = 0.000). However, there was no significant difference between the two groups of pilots in how recently they had read case-based aviation safety material or in terms of hours flown per year, age, sex, or education level.

3.2.3. Exposure to safety related aviation material

The next section of the questionnaire was designed to ascertain how regularly each respondent read case-based aviation safety material. Specific behavioural information was requested rather than having respondents give their own responses which could result in data that were ambiguous or difficult to compare. Firstly, a number of aviation safety reports and periodicals were listed and respondents were asked to indicate which, if any, they read. Respondents were also asked to list any other sources that they made use of that were not specifically listed on the questionnaire. The aim of requesting this information was to prime respondents for the question which followed, "How recently did you read any of the air safety reports, periodicals or magazine columns that you listed?" Answers were given by choosing one of the following alternatives:

- In the last two days
- In the last week
- In the last month
- In the last three months
- In the last year
- More than a year ago

Pilots reported a high degree of exposure to case-based accident and incident information from air safety reports and periodicals. Seventy four pilots (18.6%) had read this kind of information in the last two days, and altogether nine out of ten respondents (356 pilots) had viewed such material within the last month. The distribution of 'time since reading' scores for all pilots that answered the questionnaire is shown in Figure 26.
3.2.4. **Are accident and incident case-histories recalled at critical flight times?**

In the final section of the questionnaire, respondents indicated whether they agreed or disagreed with seven statements relating to the role of accident case histories in aviation safety awareness. The statements related to common survey responses as outlined in Chapter 2. The statements rated by respondents are listed below. The headings are those used in Chapter 2 to summarize common responses.

**Specific case history recalled at a critical flight time (SCH)**

*Yes we do recall those stories when it counts. The specifics of accident and incident reports do come to mind at critical flight times, often in surprisingly vivid detail.*

**Archetypical case history recalled at a critical flight time (ACH)**

*I would say that similar sorts of accident case histories tend to merge into one, and it is this composite picture that we recall at a critical moment, rather than remembering any individual story.*

**Time span of critical incident affects the recall of case histories (TS)**

*Depends on how much time you have. If time is short, say an engine failure on take-off, then your response is based on standard drills and procedures rather than on the recollection of prior cases. With longer time though, say a flight into deteriorating weather, it’s more likely that you’ll remember specific accident reports that you have read.*

![Figure 26. Recency of reading case-based aviation safety material.](image)
Details of case histories are recalled on later reflection (DRL)
At the time you don't remember particular case histories but on later reflection, after the danger has passed, you tend to recall details of the specific cases that may have influenced you.

Recalling case histories enables you to avoid critical incidents (ACI)
Exposure to aircraft accident and incident reports has influenced the way I plan and carry out my flying activities. Recalling specific case histories has enabled me to avoid critical situations in the first place.

Case information is abstracted and integrated into memory, details not retained (IAI)
Reading the case histories adds to our store of aviation knowledge in general. The important information is remembered in an abstract and integrated form, but the details of particular cases are not recalled.

A good scare is worth more than good advice (AGS)
A good scare is worth more than good advice.

For each statement participants chose one of the following alternatives, coded as scores of 1 to 5 respectively;

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

The mean ratings for all pilots for the seven statements are shown in Table 14. Overall pilots agreed with three of the statements, showed marginal agreement with one other statement, and neither agreed nor disagreed with the remaining three statements.

On the central question as to whether specific case histories were recalled at critical flight times (SCH), the response from pilots overall was neutral. There was slightly more support for the related proposition that archetypical case histories were recalled at critical flight times (ACH). The statement that received the greatest support was the one suggesting that recalling case histories enabled pilots to avoid critical incidents (ACI). There was agreement with the statement that prior cases may be recalled when there was time for reflection, as compared to when time was limited (TS). There was also agreement with the statement that recalling case histories enabled a pilot to avoid critical incidents occurring in the first place. Pilots in general responded neutrally to the suggestion that details of case histories were recalled on later reflection (DRL).

The last two questions related to suppositions other than the direct recall of case-histories. The IAI statement, in effect, presents a rule-based
model in which the essential information from case-based safety material is distilled, and added to the pilot's store of aviation knowledge as an abstract rule. Overall, pilots agreed with this suggestion that case history information was integrated and abstracted into memory, while details were not retained. Finally, pilots were neutral on the suggestion that "A good scare is worth more than good advice" (AGS). That statement can be construed as suggesting that personal experience, as opposed to hearing about the experiences of other pilots, is the prime motivator of pilots' flying behaviours.

Table 14. Mean ratings for case-history statements.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Code</th>
<th>Mean ± SD</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Case History</td>
<td>SCH</td>
<td>3.40 ±0.94</td>
<td>neutral</td>
</tr>
<tr>
<td>Specific case history recalled at a critical flight time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Archetypical Case History</td>
<td>ACH</td>
<td>3.54 ± 0.91</td>
<td>neutral / agree</td>
</tr>
<tr>
<td>Archetypical case history recalled at a critical flight time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Span</td>
<td>TS</td>
<td>3.93 ± 0.88</td>
<td>agree</td>
</tr>
<tr>
<td>Time span of critical incident affects the recall of case histories</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Details Recalled Later</td>
<td>DRL</td>
<td>3.34 ± 0.89</td>
<td>neutral</td>
</tr>
<tr>
<td>Details of case histories are recalled on later reflection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avoid Critical Incidents</td>
<td>ACI</td>
<td>4.05 ± 0.94</td>
<td>agree</td>
</tr>
<tr>
<td>Recalling case histories enables you to avoid critical incidents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information Abstracted and Integrated</td>
<td>IAI</td>
<td>3.72 ± 0.95</td>
<td>agree</td>
</tr>
<tr>
<td>Case information is abstracted and integrated into memory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Good Scare</td>
<td>AGS</td>
<td>3.38 ± 1.38</td>
<td>neutral</td>
</tr>
<tr>
<td>A good scare is worth more than good advice</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 27 shows the distribution of the rating scores for each of the seven statements. One frequency distribution, that for the statement "A good scare is worth more than good advice" (AGS), stands out from the others. Opinion about this assertion was more evenly divided across the scale range (see (g) in Figure 27) than was the case for the other statements. In contrast, for three of the statements the modal category had a response frequency of over 50%. This was true for the statement suggesting that
archetypal case histories are recalled at critical flight times (ACH), the statement that the time span of critical incidents affects recall (TS), and the statement that case information is abstracted and integrated into memory (IAI), see (b), (c), and (e) in Figure 27 respectively.

Figure 27. Frequency distributions for pilots' ratings of case history statements.

3.2.5. Pilots’ beliefs about learning from experience

Three of the rating statements concerning the role of accident and incident case histories in aviation safety can be seen as relating to specific
beliefs about how people learn from experience. For example, agreement with the SCH (specific case history) statement suggests a belief that pilots can learn from the experience of others by building up a case library based on accident and incident reports. Alternatively, agreement with the IAI (information abstracted and integrated) statement suggests a rule-based approach to how we can learn from the experiences of others. That is, the experience of other pilots is used to develop rules and guidelines that a pilot can then apply in their own operations. Finally, agreement with the AGS (a good scare) statement suggests a belief that pilots learn primarily from their own personal experience, rather than from the experience of other pilots. The three models of how pilots learn from experience can be described as:

- case-based
- rule-based
- personal experience based

Pilots in the study were classified into three groups depending on whether they agreed most strongly with the SCH, IAI, or AGS statements (see Table 15). For example, pilots who gave a higher rating to the SCH statement that to either the IAI statement or the AGS statement were included in the ‘case-based experience’ group. Similarly, pilots who rated the IAI statement the highest where included in the ‘rule-based experience’ group, and pilots who rated the AGS statement the highest were included in the ‘personal experience’ group. Pilots were only assigned to one of the three ‘learning experience’ groups if they expressed a clear preference for one of the three statements over the other two. If that was not the case, then a missing value was entered for that pilot (see Table 15).

Table 15. Characterisation of pilots beliefs about learning from experience.

<table>
<thead>
<tr>
<th>Characterisation of experience</th>
<th>Code</th>
<th>Membership rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-based</td>
<td>CASE</td>
<td>SCH rating &gt; IAI rating AND SCH rating &gt; AGS rating</td>
</tr>
<tr>
<td>rule-based</td>
<td>RULE</td>
<td>IAI rating &gt; SCH rating AND IAI rating &gt; AGS rating</td>
</tr>
<tr>
<td>personal experience</td>
<td>PER</td>
<td>AGS rating &gt; SCH rating AND AGS rating &gt; IAI rating</td>
</tr>
<tr>
<td>&lt;not coded&gt;</td>
<td>NULL</td>
<td>ELSE IF none of the above rules apply</td>
</tr>
</tbody>
</table>
Overall, it was possible to classify 248 pilots (60.6% of the total) on the basis of the three learning experience group membership rules. The number of pilots in each group is shown in Figure 28.

![Figure 28. Pilots' beliefs about learning from experience.](image)

3.2.6. Factors affecting pilots' beliefs about learning from experience

Analyses were carried out to determine whether any of the measures derived from the questionnaire had a significant influence on pilots’ beliefs about learning from experience. In general, no major effects of significance were found. Primarily, the three ‘learning experience’ groups of pilots did not differ significantly in terms of experience, either as measured by the composite experience variable, or by the specific measures of years of flying experience or total hours flown. In addition, the three learning experience groups did not differ significantly in terms of age, sex, or hours flown per year.

Factors affecting pilots' ratings of specific case history statements

Several minor effects of significance were found in relation to the seven specific case history statements in the questionnaire.

For pilots' attitudes to the SCH statement, there was a significant two-way ANOVA for total flight time and how recently the pilot had read case-based safety material ($F(3,391) = 3.21, P = 0.023$). In particular, the main effect of recency of reading was significant ($F(1,391) = 7.81, p = 0.005$), with pilots who had read case-based safety material in the last two days rating the SCH statement higher than those who had not. The main
effect of total flight time was not significant. However, there was a significant interaction between the two factors \( F(1,391) = 3.81, p = 0.052 \). Less experienced pilots (0 - 200 hours total time) who had read case-based safety material within the last two days gave significantly higher SCH ratings than pilots who had not (Tukey HSD, \( \alpha = 0.05 \)). In contrast, more experienced pilots (more than 200 hours) were not influenced in their SCH ratings by having recently read safety material (see Figure 29). The significant interaction effect of total time and recency of reading was not due to differential exposure to case-based material as there was no significant effect of total time (below or above 200 hours total time) on the likelihood of pilots having read safety material in the last two days, \( \chi^2(1) = 0.016, p = 0.901 \).

Age was a significant factor in determining TS rating, \( F(2,401) = 3.92, p = 0.021 \), with relatively young pilots (less than 30 years old) giving the statement a significantly higher rating \((\text{mean } 4.16 \pm 0.106 \text{ SE})\) compared to pilots between 30 and 50 years \((3.85 \pm 0.056)\), and pilots older than 50 years \((4.01 \pm 0.084)\). However, in all three cases, the average result was ‘agree’.

Two factors significantly influenced pilots' ratings of the DRL statement. Firstly, there was a significant difference between male and female pilots in their ratings, \( F(1,402) = 6.93, p = 0.009 \), with female pilots giving the statement a higher rating. Secondly, age was also a determining factor. Relatively young pilots (less than 30 years) and relatively old pilots (older than 50 years) rated the DRL statement higher than did other pilots.
(30 - 50 years), $F(2,401) = 6.73, p = 0.001$. The details of significant DRL results are shown in Table 16.

Table 16. Factors significantly affecting pilots' DRL statement ratings.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sub-group</th>
<th>Mean ± SE</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>male</td>
<td>3.31 ± 0.046</td>
<td>neutral</td>
</tr>
<tr>
<td></td>
<td>female</td>
<td>3.76 ± 0.162</td>
<td>agree</td>
</tr>
<tr>
<td>Age (years)</td>
<td>&lt; 30</td>
<td>3.58 ± 0.119</td>
<td>neutral/agree</td>
</tr>
<tr>
<td></td>
<td>30 - 50</td>
<td>3.22 ± 0.054</td>
<td>neutral</td>
</tr>
<tr>
<td></td>
<td>50 +</td>
<td>3.54 ± 0.097</td>
<td>neutral/agree</td>
</tr>
</tbody>
</table>

Recency of reading case-based aviation safety material significantly affected pilots' attitudes to the ACI statement. Pilots who had read case-based material in the last week rated the statement significantly higher than those who had not (mean $4.20 ± 0.062$ SE and $3.91 ± 0.070$ respectively, $F(1,393) = 10.06, p = 0.002$). In both cases, however, the average result was 'agree'.

There was a significant difference between male and female pilots in their ratings of the IA1 statement, $F(1,401) = 4.33, p = 0.038$. Male pilots agreed with this statement (mean $3.74 ± 0.048$ SE) while female pilots were neutral ($3.36 ± 0.201$).

Pilots' responses to the AGS statement were significantly influenced by two factors; total number of flying hours and hours flown per year. Pilots with less experience (below 200 hours total time) rated the AGS statement significantly lower (mean $3.17 ± 0.130$ SE, 'neutral') than did other pilots ($3.48 ± 0.080$, 'neutral/agree'), $F(1,406) = 4.35, p = 0.038$.

The effect of the average number of flying hours per year on pilots' rating of the AGS statement is shown in Figure 30. Pilots carrying out only a limited amount of flying (less than 15 hours per year on average) rated the AGS statement significantly lower (mean $2.09 ± 0.286$ SE, 'disagree') than did pilots who flew a greater number of hours per year ($3.46 ± 0.069$, 'neutral/agree'), $F(1,406) = 21.31, p = 0.000$. 


Summary of factors affecting pilots' beliefs about learning from experience

Overall, there was little, if any, evidence that pilots' beliefs about the importance of accident and incident case histories in aviation safety varied significantly with any of the pilot demographic or flying history variables studied.

Most importantly, pilots with different levels of experience did not differ in their reported beliefs about how pilots learn from experience. When respondents were classified into three groups depending on their views about how pilots typically learn from experience, the groups did not differ significantly in terms of the composite experience variable, or by the specific measures of years of flying experience or total hours flown. One possible interpretation of this result is that pilots' views about learning from experience stem from some innate belief, rather than being shaped in the course of their flying careers. However, it is also possible that the explanation is associated with other influences not controlled for in this study.

A number of individual findings in relation to the specific case history statements were significant, and these are summarised in Table 17. However, when a Bonferroni adjustment is applied to correct for the total number of multiple pairwise comparisons in the table (42 tests, adjusted p = 0.001), only the significant effect of hours flown per year on the AGS rating statement can be reliably accepted. However, the data in Table 17 are presented from an exploratory point of view as they may be of benefit in suggesting future lines of research.
Table 17. Factors significantly affecting pilots’ ratings of case history statements.

<table>
<thead>
<tr>
<th>Factor</th>
<th>SCH</th>
<th>ACH</th>
<th>TS</th>
<th>DRL</th>
<th>ACI</th>
<th>IAI</th>
<th>AGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td>&lt; 30 years</td>
<td>&lt; 30 and &gt;50 years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td>female</td>
<td>male</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total flying hours</td>
<td>&lt; 200 hrs*</td>
<td></td>
<td></td>
<td>&gt; 200 hrs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years flying experience</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours flown per year</td>
<td></td>
<td></td>
<td></td>
<td>&gt; 15 hrs/yr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recently read safety material</td>
<td>&lt; 2 days</td>
<td></td>
<td>&lt; 1 week</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Significantly greater support for statement by indicated sub-group.**
- **Significant after Bonferroni correction**
- * Significant interaction with ‘Recently read safety material’, not significant main effect.

A discussion of the work outlined in this chapter is included in Chapter 8.
Part 2
Case-based versus rule-based pilot decision training

The following two case histories describe two types of common general aviation accidents.

Case 5.
The aircraft was carrying out a private VFR flight from King Island to Moorabbin. Weather conditions were poor with cloud cover across most of western Bass Strait. A squall-line passing across the coast near Cape Otway at 9.30 am resulted in areas of driving rain, cloud in excess of 5/8's cover down to 500 feet, with lower patches, and visibility down to 500 metres.

At 10.07 am the pilot reported to Melbourne Flight Service that he was coastal in the Queenscliff area, requesting radar vectoring to Moorabbin. He subsequently advised that he was "trying to find" his way and again requested radar vectoring. He did not declare an emergency. Melbourne Radar observed the aircraft to be south of Geelong, outside the radar area of responsibility. The pilot was unaware of the discrepancy between his reported position and his position observed on radar. Melbourne Flight Service attempted to advise the pilot but received only a broken transmission from an unidentified station. Melbourne Radar observed a brief radar return of the aircraft carrying out left orbits at about 800 feet over in the Anglesea area. Shortly after this observation, the aircraft flew into the sea.

Figure 31. Aircraft wreckage from a weather-related accident
The wreckage and the bodies of the pilot and his three passengers were recovered the following day. Damage to the aircraft indicated that it impacted with the sea in a wings-level, slightly nose-down attitude with the engine operating at a low power setting. The subsequent accident investigation report concluded that the following factors were responsible for the crash; the weather was unsuitable for visual flight, the pilot did not declare an in-flight emergency.\textsuperscript{34}

Case 6.

The aircraft was being flown on a cross-country flight to an open day during which the aircraft was to be displayed on the ground and in the air. Witnesses at the departure airfield observed the aircraft take off and conduct a circuit before flying low along the strip in the takeoff direction. The aircraft then pulled up to about 75 degrees nose up, levelled at about 350 ft, and descended again while travelling in the same direction. It then accelerated, turned right, climbed to about 500 ft and departed the area.

Witnesses at the destination airfield saw the aircraft over-fly the main runway, and then approach the airfield at low level before abruptly entering a very steep climb. At an altitude estimated by some witnesses as between 200 and 400 ft above ground level, the aircraft rolled right before diving vertically towards the ground and disappearing behind trees. A short time later, the sound of impact was heard and smoke was seen rising above the trees\textsuperscript{35}.

\textbf{Figure 32.} Aircraft wreckage from a low flying accident.

\textsuperscript{34} This synopsis is based on information from a Bureau of Air Safety Investigation accident report (APAS, 1993).

\textsuperscript{35} This synopsis is based on information from a UK CAA General Aviation Safety Information Leaflet (GASIL, 1995).
Examination of the accident site revealed that the initial impact occurred when the aircraft struck 8m high trees. This ruptured the right fuel tank, providing the fuel source for the fire. The aircraft struck the ground with about 7 degrees of left bank, a level nose attitude and low horizontal speed. The engine was operating at low power at the time of impact. The investigation concluded that following the pull-up from about tree height, the aircraft probably stalled and entered an incipient spin to the right. Control of the aircraft was then lost at a height insufficient to effect a safe recovery.

The two case histories outlined above are typical of accidents that befall general aviation pilots. They are typical in that the root cause in both cases is not aircraft mechanical failure but a shortcoming in aeronautical decision making. The first case involves flight into adverse weather. A private pilot trained only under Visual Flight Rules (VFR) continues their flight into Instrument Meteorological Conditions (IMC). The second case describes another common general aviation accident scenario, inappropriate low-level flying. In both of these accidents, the pilot ultimately faced a situation beyond their flying skill and experience. Yet the root cause in each case was a deficiency in aeronautical decision making, an error of judgement that placed them in a situation beyond their ability. The outcome was then predictable.

**The prime causes of general aviation fatal accidents**

This section of the thesis focuses on the two areas that are responsible for the majority of fatal general aviation accidents, flight into adverse weather and low-flying. A study by the Air Safety Foundation of the US Aircraft Owners and Pilots Association (AOPA) of accidents involving fixed-wing general aviation light aircraft in the United States during 1995 found that weather-related factors accounted for 26% of fatal accidents (AOPA, 1996). Most weather-related accidents involved either controlled flight into terrain, or crashing out of control after the pilot became spatially disoriented. In some cases, the aircraft suffered pilot-induced catastrophic structural failure. As the report states,

*The high impact forces experienced in these types of accidents make them the deadliest accidents of all.*


A similar study by the Transportation Safety Board (TSB) of Canada into weather-related aircraft accidents in Canada between 1976 and 1985 also found that VFR-into-IMC accidents accounted for a disproportionate number of fatalities (TSB Canada, 1990). While VFR flights into adverse weather accounted for only 6% of accidents in total they accounted for 23% of fatal accidents, and took the lives of 418 persons over the ten year period. The extremely serious consequences of VFR flight into adverse weather are shown by the fact that fully half of this type of accident resulted in fatalities. In comparison only 13% of accidents overall
involved loss of life. The pilots involved in these accidents were generally similar in age and experience to non-accident pilots. While pilots with less than 1,000 hours total flying time accounted for 56% of the accidents studied, almost one fifth of the accidents involved pilots with more than 3,000 hours total time. This highlights the fact that years of flying experience does not necessarily equate to expertise, or prevent a pilot being involved in a safety-related accident or incident (Lubner, Markowitz, & Isherwood, 1991).

Reporting a US study of VFR-into-IMC accidents, Landsberg (1996b) relates that two-thirds of the pilots had received a weather briefing indicating that VFR flight was not recommended. This suggests that far from being a surprise, the encounter with bad weather followed from a deliberate decision in the face of cautionary evidence. While most aircraft were lost en route, 15% crashed during take-off or initial climb, where the danger was obvious before even leaving the ground.

Low flying is another major cause of fatal general aviation accidents. As Landsberg (1996a) states in pithy style,

*Mix ignorance with arrogance at low altitude and the results are almost guaranteed to be spectacular.*

(Landsberg, 1996a, p. 1)

The AOPA Air Safety Foundation (1996) study found that for single-engined aircraft, low-level flight accounted for 31% of fatal accidents. The majority of low-flying accidents occurred during flights described as 'personal' and involved activities such as unauthorized aerobatics, low passes, 'buzzing', and sharp pull-ups. Typically, the aircraft collided with terrain, wires, or towers, or crashed out of control. The AOPA (1996) report comments,

*Many involved a degree of recklessness that makes it difficult to term them 'accidents' in a true sense.*

(AOPA Air Safety Foundation, 1996, p. 12)

Other dangerous low flying situations include turns to reverse direction, such as a box canyon type manoeuvre, or after engine failure during take-off where the pilot attempts to reverse course for landing. In other cases, the pilot is distracted from flying the aircraft. For example, looking for an animal or object on the ground, discussing something with a photographer, or trying to close an open door are regular factors in low flying accidents. After describing a crash that occurred while scouting for moose during a hunting trip, Landsberg (1996a) comments,

*This type of animal distraction is so common in Alaska that locals refer to them as 'moose stalls'.*

(Landsberg, 1996a, p. 2)
Not all low flying incidents involve light aircraft, as the following report indicates,

*The FAA is investigating reports that on Aug. 16 a Boeing 737 on a test flight flew between Haystack Rock and Canyon Beach on the Oregon coast... Police Chief Dave Rouse said "witnesses say it was flying at or below the top of Haystack Rock." The top is about 250 feet high and accessible during low tide. Boeing admitted they are aware of the incident and that "there are some serious issues with that particular flight" and that they are "working with the FAA and other federal officials."

(AVweb, 1997)

Although the above example is extreme, a study of air transport pilots (ATPs) in general aviation accidents (Salvatore, Stearns, Huntley, & Mengert, 1986) found that while ATPs were involved in fewer general aviation accidents overall than private pilots, they were over-represented in accidents involving aerobatics. In fact, nearly 50% of ATP pilot-induced fatal general aviation accidents occurred during aerobatics.

In general, little if any work has been specifically carried out into pilot decision making in relation to low flying behaviours. The one specific study to consider low flying accidents concentrates on perceptual and attentional factors and is based on military flying (Haber, 1987).

The aim of this section of the thesis was to investigate the relative effectiveness of case-based or rule-based training, or both, in improving aeronautical decision making skills. An experiment based on a weather-related decision making scenario is presented in Chapter 4, and an experiment based on a low flying scenario is presented in Chapter 5.
4. **When To Turn Back**

The *When To Turn Back* experiment was designed to examine whether exposure to accident and incident case histories alone could be an effective form of flight safety instruction. That is, whether case-based training by itself would be a sufficient agent to modify behaviour. The effect of training was measured by way of a flight simulation task presented by computer. The *When To Turn Back* scenario was designed to measure actual behaviour in a simulated setting, not factual knowledge or stated intent. Computer-based simulation has the advantage of being able to present a rich decision making environment that mimics the complex, uncertain and dynamic aspects found in real-life problem situations (Dörner & Scholkopf, 1991). It also allows full control over the decision making scenario, and enables the recording of a wide range of decision making data.

While participants were also tested on the extent to which they retained factual information from the training material, this was only of secondary interest. The important question was whether participants would be able to successfully perceive, elaborate, and integrate the training information so that the 'experience' would positively influence their simulated flying behaviour. None of the participants who took part in the experimental studies were pilots or had had significant exposure to aviation other than as passengers on airline flights. Non-pilot participants were chosen as pilots would have brought varying degrees of existing case-based and rule-based knowledge to the study. It would not have been possible to accurately measure and control for these differences in pilot experience, and, therefore, any effect of the training intervention would have been confounded with prior experience.

Fifty seven university undergraduate students took part in the experiment that consisted of four parts. Initially, participants received either no training, case-based training, or rule-based and case-based training in bad weather flying decision making. Secondly, all participants completed the flight simulation task in which they were the pilot in command of a light aircraft flying into deteriorating weather. Participants who had initially received training were then tested on the material that they had received. Finally, all participants completed the Need for Cognition Scale (Cacioppo, Petty & Kao, 1984).

Firstly, it was hypothesized that participants who received case-based training will make significantly more conservative flight decisions than participants who received no training at all. However, converging evidence from studies of expert and novice decision makers (Ericsson & Smith, 1991; Cellier, Eyrolle, & Marine, 1997), and cognitive modelling...
of how expertise is acquired (Kolodner, 1994; Redmond, 1997), suggests that novice decision makers are likely to have difficulty correctly identifying and indexing retrieval cues from case-based information. Therefore, it is likely that prior rule-based training will provide a framework within which case-based material can be better assimilated. Therefore, the second hypothesis was that participants who received both rule-based and case-based training will make significantly more conservative flight decisions than participants who received case-based training alone.

4.1. Method

4.1.1. Bad weather flying training material

Participants in the *When To Turn Back* experiment were randomly assigned to one of three training groups; no training, case-based training, or rule-based and case-based training. All training material was presented by computer using a program written for that purpose by the author – Training Presentation And Analysis (TPAA). The TPAA program incorporated six training modules for either rule-based or case-based training in relation to bad weather flying or low flying (the *How Low To Go* experiment described in Chapter 5)\(^{36}\). The main screen of the TPAA program is shown in Figure 33. The computer code of the TPAA program is detailed in Appendix 3.

![Training Presentation And Analysis](image)

*Figure 33. Main screen of the Training Presentation And Analysis Program (TPAA).*

\(^{36}\) An additional module that included training based on the DECIDE analytical decision method was not used in this study.
Using a computer program to present the training material allowed the automatic recording of the time that participants spent viewing the training material. Computer presentation also enabled the easy mixing of text and graphics in the training modules. The type of accident-related safety material that pilots are typically exposed to often consists of both text and accompanying photographs. In reports based on accident case histories, the pictorial content is frequently a very graphic and salient component of the information. When preparing the training material used in this experiment, a mix of text and graphics was used in both the case-based and rule-based modules so as to ensure a similar presentation for both training methods. While the case-based module included pictures of aircraft crashes, the graphics used in the rule-based module consisted of neutral images such as pictures of aircraft on the ground or in flight. Both training modules consisted of sixteen main information screens with a total of approximately 1,100 words of text.

The case-based training module presented brief information about four aircraft accidents or incidents related to bad-weather decision making. The case histories on which the material was based were drawn from a range of flight safety publications issued by the civil aviation safety authorities of different countries. The main sources were *Flight Safety* (CAA, New Zealand), *Asia-Pacific Air Safety* (BASI, Australia), *Aviation Safety Reflexions* (TSB, Canada), *Aviation Safety Letter* (TCA, Canada) and *GASIL* (CAA, UK). As the *When To Turn Back* experiment was conducted in New Zealand, case material from other countries was adapted by substituting New Zealand place names and flight details to ensure that the material was readily understandable by participants. All four cases involved light aircraft pilots flying under VFR flight conditions, and were chosen to be representative of typical GA weather-related safety occurrences. The bad-weather flying case-based training module is shown in Appendix 4.

In the first case, the pilot began a flight from Hamilton to Wellington in good weather but encountered a band of heavy showers south of Raetihi and misjudged how rapidly the front was moving. Suddenly finding himself enveloped in cloud the pilot contacted Ohakea air traffic control for assistance. The controller was able the reassure the pilot and guide him back to VFR conditions. The training module that described this scenario to subjects consisted of four screens of information. A screen shot of one of the screens is shown in Figure 34.
"Being suddenly enveloped in cloud produced an incredible feeling of isolation and inadequacy. Fortunately though expert help was only a radio call away. When I contacted the Ohakea controller and requested help it was immediately forthcoming. His instructions to me were to concentrate on keeping my wings level, assuring me that I had ample ground clearance, and that my groundspeed was good."

Figure 34. A screen shot from one of the *When To Turn Back* case-based training scenarios.

In the second case, the pilot left Dunedin for Christchurch via the coast. On passing Moeraki, the weather began deteriorating, with light drizzle and a lowering cloud base. The pilot considered turning back but was distracted by a problem with the directional gyro. The aircraft began to diverge from its intended flight path and the pilot lost visual contact with the coast. While turning to return to Dunedin the aircraft struck a tree and crashed. Although the aircraft was destroyed on impact the pilot survived and was able to walk to a nearby farmhouse for help.

The third case involved a flight from Wellington to Christchurch in poor weather. The pilot reported being coastal in the Woodend area and requested radar vectoring to Christchurch, but did not declare an emergency. The aircraft's position, as observed on radar, did not accord with his reported position but when Christchurch Flight Service tried to advise the pilot of this discrepancy they were unable to establish contact. Shortly afterwards, the aircraft crashed into the sea at Pegasus Bay with the loss of all four people on board.

In the final case, the pilot took off from the beach at Horseshoe Bay on Stewart Island, intending to complete one circuit before landing and tying
down for the night. However, during the circuit the aircraft encountered fog. The pilot continued, expecting to quickly regain clear conditions, but the fog and low cloud was more extensive than expected. The pilot decided to divert to Invercargill but the aircraft became completely enveloped in cloud and crashed in bush covered country near Halfmoon Bay. The wreckage was not located until the following morning when the seriously injured pilot and passenger were rescued by helicopter.

The bad-weather flying rule-based material was prepared using information from a range of pilot training manuals and reference books including Wagendonk (1994), Buck (1988), Collins (1978), Job (1994), Dyson-Holland (1977a) and Diehl, Hwochinsky, Lawton and Livack (1987). The training material began with a brief introduction outlining the importance of sound aeronautical decision making. ADM was described as a process of recognizing and analyzing all relevant information, followed by the evaluation of alternative courses of action, and finally, the execution of the chosen course in a timely manner. The next section emphasized the importance of weather-awareness for VFR pilots of light aircraft and described how pilots without instrument training are very likely to become disorientated and lose control if they suddenly find themselves in cloud.

If a pilot without instrument training suddenly finds him or herself in cloud then typically disorientation and loss of control will occur within a matter of minutes. Once visual reference is lost sensory illusions occur that make it very difficult to determine the aircraft’s attitude. Instrument pilots are trained to ignore these false sensations and rely entirely on the aircraft’s instruments. However this is very hard to do without proper training.

Figure 35. A screen shot from the When To Turn Back rule-based training module.
The rule-based module then referred to the need to obtain a thorough preflight weather briefing and the importance of the early recognition of deteriorating weather to allow a safe diversion or backtrack to be made. The deadly combination of a lowering cloud-base and rising terrain was described, with the emphasis that a decision to turn back must be made quickly, before the aircraft is trapped by the valley walls. The nature of a precautionary landing was outlined and presented as a far better alternative to uncontrolled flight into terrain. The possibility of social or financial pressures on the pilot to continue their flight were referred to and the point made that pilots must make flying decisions purely from a flying point of view. Finally, the items outlined above were briefly noted in a summary screen. The bad-weather flying rule-based training module is shown in Appendix 5. A screen shot of one of screens from the When To Turn Back rule-based training module is shown in Figure 35.

4.1.2. Bad weather flying test material

Participants in the When To Turn Back experiment who received case-based training subsequently completed a test questionnaire to assess their retention of the material that they had viewed. The questionnaire consisted of sixteen items, four relating to each of the accident or incident case histories described in the training module. The questions were predominantly multiple choice, with some direct recall items. The bad weather flying case-based questionnaire is shown in Appendix 6. Participants who completed the rule-based training module were given a similar questionnaire relating to the information that they had viewed. The rule-based test questionnaire is shown in Appendix 7.

4.1.3. The Icarus flight simulation program

A number of commercial flight simulator programs were assessed for their suitability for use in the weather-related decision making scenario. These included Microsoft Flight Simulator, Flight Assignment ATP, and Flight Unlimited. However, the commercial flight simulator programs available at this time, while suited for use in skill-based flight training and testing, had major limitations for use in decision-based training or testing. These limitations can be summarised in four main points.

Firstly, the commercial programs were based on realistic simulations of aircraft flight dynamics and required a certain level of flying skill to be developed before participants could successfully carry out routine flying activities. As the participants in this experiment were specifically chosen to have no prior aviation experience, the need for some flying skill was a significant disadvantage. Secondly, the commercial programs did not allow the weather to vary in a dynamic and structured way that would enable all participants to be accommodated and yet still maintain the weather conditions within set boundaries. Also, the programs could not
When To Turn Back

record changing weather conditions in relation to other data from the flight simulation. Thirdly, the commercial simulations had limited opportunity for displaying a secondary 'motivational' task to act in tension with the decision-making task. Without pressure to continue, it would be likely that most participants would simply err on the side of caution when faced with a decision in an uncertain situation. Fourthly, even though the programs had a prime emphasis on the control aspects of flying they had only very limited, if any, provision for recording instrument readings and control inputs, essential for a thorough analysis of participants' behaviour in the experiment.

As none of the commercially available flight simulators were found to be suitable a computer program was purpose written by the author. The prime aim was to provide a flight simulation program that placed less emphasis on the skill-based aspects of flying and more emphasis on the decision-making aspects. In particular, the four limitations of the commercial programs, as outlined above, were addressed. The program, Icarus, was written in Visual Basic and used the Global Majic Software Aircraft Instrument Custom Control VBX and had 2,240 lines of code in 67 main modules (see Appendix 8) and was designed to run on a Windows based computer.

The Icarus program presented a simulation of flying a light aircraft under Visual Flight Rules (VFR). There were three main functional aspects to the program. Firstly, Icarus provided a full screen interface to give a realistic simulation of flying a light aircraft, including controls and basic VFR instruments. In addition, the weather as viewed from the cockpit window could be varied under program control. Secondly, the program provided a means of presenting a motivational task to participants that could be used to structure the flight and provide a realistic task goal. Thirdly, Icarus enabled a full recording to be made of all the required experimental data.

Icarus screen interface

The Icarus screen interface viewed by participants consisted of three main sections; the view from the cockpit window, a VFR instrument panel, and the flight director (see Figure 36). The view from the cockpit window depicted a scene about five thousand feet above ground level, with snow capped mountains in the far distance and tree-covered ridges in the middle distance. The scene was one of good weather with only a small amount of cloud present, mainly to the left of the aircraft's field of view.
Figure 36. Icarus flight simulation program screen interface.

The Icarus instrument panel incorporated six main flight instruments; an airspeed indicator, an artificial horizon, an altimeter, a turn and bank indicator, a directional gyro, and a vertical speed indicator (see Figure 37). At the start of the simulation, the aircraft was in straight and level flight at an altitude of 7,500 feet above sea level and on a north-easterly heading (45°). The flight instruments were under program control. A complex cyclical disturbance was added to the altimeter and directional gyro readings to simulate the usual buffeting that an aircraft would encounter during normal flight. Monitoring and correcting for this altitude and heading disturbance was the basic flight control task of the Icarus simulation. The cycle lengths of the altitude disturbance and the heading disturbance were different to ensure that the control task was not at all predictable. The altitude disturbance ranged over ±400 feet with a cycle time of approximately twelve minutes while the heading disturbance ranged over ±18 degrees with a cycle time of approximately eight minutes. In addition, a small amount of random jitter was added to all instrument readings for realism.
The control interface for the Icarus flight simulator was the flight director\textsuperscript{37} (see Figure 38). The flight director was designed to fulfil three functions. Firstly, the control pad was used to command the aircraft to climb, descend, turn left, or turn right. Participants clicked on the appropriate arrow with the mouse button and the aircraft responded at a constant rate. Clicking on the centre dot of the control pad returned the aircraft to straight and level flight. Hence, participants did not directly manoeuvre the aircraft via the cursor keys or a joystick as was the case for the commercial flight simulation programs. Rather, they indicated their control objectives via the control pad and the flight director implemented their requests. By breaking the direct link between control input and outcome, the simulation was far more stable and participants were able to fly the aircraft without any need for practice. This method of controlling the aircraft reduced the skill-based component of the simulation, allowing a greater emphasis on decisional aspects.

\textsuperscript{37} To date flight management systems have been available only on larger aircraft. However, their use in small single-engined aircraft as a 'virtual co-pilot' decision aid has been discussed (Miller, 1997).
The second function of the flight director was to act as a communications tool. The screen panel was designed to simulate radio transmissions between the aircraft and air traffic control and other aircraft. Participants typed in their messages via the computer keyboard and pressed the 'Enter' key to transmit them. Similarly, incoming messages from other stations were also displayed on the flight director screen panel. Using a text-based system had the advantage that the Icarus program could monitor and interpret participants' communications and respond accordingly. The third functional area of the flight director was the indicator panel. Here, the current set altitude and set heading, as assigned by air traffic control, were displayed. The indicator panel was also used to display warning messages when either altitude or heading varied too greatly from their set values.

In addition to the cockpit view, main instrument panel, and flight director, the Icarus flight simulation program main screen also included functioning gauges for fuel, alternator current, and oil pressure, as well as a control toggle and indicator lights for the nose and main landing gear. Figure 36 shows a view of the main Icarus screen in which there are communications from air traffic control, a flight director heading warning, and control input commanding a bank to the left to regain the set heading.

**Icarus flight task programming**

The Icarus simulator could be programmed to present any required flight scenario by means of a structured task file. The task file was a plain ASCII text file that listed a sequence of data values and text that were read by the Icarus program at varying time intervals and used to construct an interactive task environment.
Figure 39 shows an example excerpt from an Icarus task file. Task segments were formed by pairs of lines in the task file. The first line of each pair listed a series of parameter values and control codes while the second line stored the accompanying radio transmission text, if any.

```
  atc, 8500, 45, altcheck_off, 30, y, "8500"
  WHISKEY GOLF LIMA Descend to 8,500 feet. Please confirm 8500.
  atc, 8500, 45, altcheck_on, 30, n
  / 
  atc, 8500, 45, headcheck_off, 30, y, ""
  WHISKEY GOLF LIMA Please orbit left for positive identification.
  atc, 8500, 45, headcheck_on, 30, y, ""
  WHISKEY GOLF LIMA Identified. Maintain set altitude and heading.
  atc, 8500, 45, pos_check, 20, n
  / 
  atc, 8500, 45, disturb_on, 10, n
  / 
  atc, 8500, 355, ack_1, 10, y, "355"
  WHISKEY GOLF LIMA Turn left heading 355 degrees. Please confirm 355.
```

Figure 39. Example excerpt from an Icarus task file.

For example, a task file segment might consist of a pair of lines that altered the displayed set altitude value and presented a radio transmission from air traffic control directing the pilot to climb or descend to the newly assigned altitude. Task segments could be set to require a response that included certain key information, for example the correct read-back of an assigned altitude or heading. If the participant failed to reply correctly they were informed of their mistake and the original transmission was repeated. Alternatively, task segments could be set to require any response, or no response at all. If no response was received when one was required, a warning and repeat transmission were sent. Other functions under task file control included the time between task elements, altitude and heading disturbance and checking, and the form of acknowledgment made to a participant's transmission. In Figure 39 the fields in the first line of each task segment are, from left to right; the sender, the set altitude, the set heading, program codes, the time until the next task segment is executed (in seconds), whether a response is required, and the required response if any.

**Icarus flight data recording**

The Icarus simulation was programmed to act as a 'Black Box' Flight Data Recorder (FDR). At a set interval of five seconds, the program recorded the aircraft's current altitude and heading as displayed by the
panel instruments. The set altitude and heading as assigned to the pilot by air traffic control were also recorded, as were all control inputs by the pilot, the current cloud position, and control codes related to aspects of the flight task.

<table>
<thead>
<tr>
<th>time</th>
<th>alt</th>
<th>aset</th>
<th>head</th>
<th>hset</th>
<th>cloud</th>
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<td>7500</td>
<td>47.7</td>
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<tr>
<td>8:31:03</td>
<td>7526</td>
<td>7500</td>
<td>48.2</td>
<td>45</td>
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</tr>
<tr>
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<td>7525</td>
<td>7500</td>
<td>49.4</td>
<td>45</td>
<td>9.20</td>
<td></td>
</tr>
<tr>
<td>8:31:09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ATC &quot;WHISKEY GOLF LIMA This is Christchurch Air Traffic Control. To avoid conflicting traffic climb to 8,000 feet. Please confirm 8000.&quot;</td>
</tr>
<tr>
<td>8:31:13</td>
<td>7520</td>
<td>8000</td>
<td>51.1</td>
<td>45</td>
<td>9.25</td>
<td></td>
</tr>
<tr>
<td>8:31:18</td>
<td>7514</td>
<td>8000</td>
<td>50.2</td>
<td>45</td>
<td>9.25</td>
<td></td>
</tr>
<tr>
<td>8:31:23</td>
<td>7506</td>
<td>8000</td>
<td>48.3</td>
<td>45</td>
<td>9.25</td>
<td></td>
</tr>
<tr>
<td>8:31:28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SUBJ &quot;8000&quot;</td>
</tr>
<tr>
<td>8:31:28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ATC &quot;Roger&quot;</td>
</tr>
<tr>
<td>8:31:32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;Climb&gt;</td>
</tr>
<tr>
<td>8:31:34</td>
<td>7520</td>
<td>8000</td>
<td>53.1</td>
<td>45</td>
<td>9.50</td>
<td></td>
</tr>
<tr>
<td>8:31:36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;Climb again&gt;</td>
</tr>
<tr>
<td>8:31:37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[Heading warning]</td>
</tr>
<tr>
<td>8:31:40</td>
<td>7590</td>
<td>8000</td>
<td>52.5</td>
<td>45</td>
<td>9.75</td>
<td></td>
</tr>
<tr>
<td>8:31:40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;Turn left&gt;</td>
</tr>
<tr>
<td>8:31:46</td>
<td>7660</td>
<td>8000</td>
<td>52.0</td>
<td>45</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>8:31:52</td>
<td>7730</td>
<td>8000</td>
<td>51.6</td>
<td>45</td>
<td>10.25</td>
<td></td>
</tr>
<tr>
<td>8:31:57</td>
<td>7800</td>
<td>8000</td>
<td>48.3</td>
<td>45</td>
<td>10.50</td>
<td></td>
</tr>
</tbody>
</table>

Figure 40. Example excerpt from Flight Data Recorder / Cockpit Voice Recorder log-file.
The Icarus program also acted as a Cockpit Voice Recorder (CVR), in this case recording all radio communications between the aircraft and other stations.

Figure 40 shows an excerpt from a flight log-file. At time 8:30:57 the 'pilot' subject is initially maintaining altitude but gradually drifting off heading to the right. At that stage of the flight 8.71% of the view from the aircraft's front windscreen is obscured by cloud. The pilot is then given an instruction by ATC to change altitude. Nineteen seconds later they read back their assigned altitude to ATC, who confirm the receipt of the transmission. Four seconds later the subject initiates a climb, and four seconds after that they increase the rate of climb. At time 8:31:37 the aircraft has drifted off course sufficiently for the Flight Director to issue a warning to the pilot, which they respond to three seconds later by initiating a turn to the left. By 8:31:57 the aircraft has climbed to 7,800 feet, has a heading of 48.3 degrees, and 10.5% of the pilot's view is obscured by cloud. A typical complete subject data file is shown in Appendix 9.

The *When To Turn Back* weather-related decision making scenario

The *When To Turn Back* scenario required participants to carry out three concurrent tasks; fly the aircraft, relay radio messages to help survivors at a crash site, and continually monitor the weather. The first task provided a moment to moment skill-based activity for participants to engage in, while the tension generated by the conflicting demands of the latter two tasks was the key element in the *When To Turn Back* weather-related decision making scenario.

The flight control task required participants to maintain an assigned altitude and heading. While the set heading remained constant during the full course of the experiment, the assigned altitude was changed from time to time by air traffic control. It was necessary for participants to maintain their altitude and heading values within certain limits of the set values; for altitude the allowed margin of error was ±150 feet and for heading the allowed margin was ±7 degrees. If the actual values of altitude or heading fell outside these limits, then a warning was displayed briefly on the flight director indicator panel and a single short tone sounded. The flight control task, while reasonably demanding, was well within the skill limits of all participants. On average, participants were within the allowed altitude margin 95% of the time and within the heading margin 90% of the time. Participants were not required to attend to instruments other than the altimeter and the directional gyro.

At the start of the *When To Turn Back* simulation, the weather conditions were entirely suitable for VFR flying; visibility was good and there was just some light cloud to the left of the aircraft and scattered wisps of
cloud in the distance. As the flight progressed, however, the weather slowly deteriorated. This was simulated by a gradual increase in the proportion of the view from the cockpit window that was obscured by cloud. While at the beginning of the flight there was only 6% cloud cover, if the flight was allowed to continue, cloud eventually totally obscured the view from the cockpit window. Figure 41 shows example views from the cockpit window corresponding to a low amount of cloud (10% of the view obscured by cloud), moderate cloud (40% obscured) and heavy cloud (70% obscured).

Figure 41. Low (a), moderate (b), and high (c) final cloud in the When To Turn Back scenario.
The *When To Turn Back* scenario was introduced as follows. Participants were told that during their flight another aircraft had crashed in an area near to them. The survivors at the crash site had only a weak emergency radio and their transmissions could not be received by air traffic control. However, because the participant's aircraft was in the vicinity and at a reasonable altitude, they were able to pick up the radio transmissions from the crash site and could help the survivors by relaying their messages to and from air traffic control. This part of the task provided participants with a motivating force to continue their flight for as long as possible; by doing so they could continue to help the survivors at the crash site. The instructions to participants then stated,

*At the same time though the weather is gradually deteriorating. You are pilot in command of your aircraft and it is your responsibility to make sure that your flight is conducted safely in all respects. You need to be aware of the weather at all times and if you think that it is deteriorating to the extent that it is not safe to continue your flight then you must say so. You are flying by visual reference so you must stay out of cloud, you can't fly just by looking at the instruments. From time to time you will be specifically asked by air traffic control if it is safe for you to continue and you have to reply yes or no. You have to make your decision just on the basis of what you can see out the cockpit window. The only information that you have is from the outside view. Air traffic control, for example, can't give you any more information because they are in a different area. You just have to make a decision as best as you can from what you can see.*

It was then emphasised to participants that the essence of their task was to weigh up these two conflicting goals. On one hand, by continuing their flight for as long as possible, they could continue to help the survivors at the crash site by relaying messages. On the other hand, they did not want to jeopardize the safety of their own flight by flying into bad weather. Hence, the point at which participants decided to turn back was the crucial decision-related measure in *When To Turn Back*.

The details of the *When To Turn Back* scenario are shown in full in the associated Icarus task file (see Appendix 10). The scenario was comprised of sixteen sections; an initial introductory section followed by fifteen task sections. The introductory section simply required participants to successfully communicate with air traffic control and read-back their assigned altitude and heading. This section took approximately two minutes to complete and all participants were able to accomplish it without problem, indicating that they were proficient in the basic skill of flying the aircraft while receiving and sending radio messages.
The fifteen task sections all followed the same structure as the first section. Firstly, participants received a direction from air traffic control, either to change altitude or to maintain their current altitude. The task file then allowed sufficient time for the aircraft to climb or descend if necessary. Participants then received a radio message, either from air traffic control or from the survivors at the crash site, and they had to relay the message to the other party. Finally, after another short break participants were asked by air traffic control, "Are you able to safely continue your flight and relay information received from the crash site?", to which they were required to answer yes or no.

After making their decision, participants were asked by the experimenter, "What were you thinking when you gave that answer?". If their response was incomplete or ambiguous additional probes such as "In what way?", or "How do you mean?" were used. If no reference was made to the prevailing weather conditions participants were specifically asked "Do you think the weather is OK?". A tape recording was made during the full experimental period and participants' explanations for their decisions were transcribed after the session. An example transcript of one participant's responses to successive decision probes is given in Appendix 15.

A summary of the assigned altitudes and messages to be relayed in each section of the When To Turn Back scenario is shown in Table 18.

Table 18. Summary of set altitudes and relay messages in the When To Turn Back scenario.

<table>
<thead>
<tr>
<th>No.</th>
<th>Altitude (ft)</th>
<th>Message from air traffic control or crash site</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7500</td>
<td>WHISKEY GOLF LIMA This is Christchurch Air Traffic Control. Do you receive?</td>
</tr>
<tr>
<td>2</td>
<td>8000</td>
<td>WHISKEY GOLF LIMA We have received information that a helicopter has crashed in your vicinity. Please monitor for radio transmissions from the crash site and report any information you receive.</td>
</tr>
<tr>
<td>3</td>
<td>8500</td>
<td>WHISKEY GOLF LIMA Have you received any information from the reported crash site?</td>
</tr>
<tr>
<td>4</td>
<td>8500</td>
<td>MAYDAY MAYDAY MAYDAY This is helicopter CHARLIE FOXTROT MIKE We have crashed west of Queenstown. Our emergency radio cannot reach Christchurch Air Traffic Control. Please relay our MAYDAY call immediately.</td>
</tr>
<tr>
<td>5</td>
<td>8000</td>
<td>This is CHARLIE FOXTROT MIKE We have two injured crew members and require medical assistance as soon as possible. Please relay this information to Christchurch Air Traffic Control.</td>
</tr>
</tbody>
</table>
When To Turn Back

<table>
<thead>
<tr>
<th>No.</th>
<th>Altitude (ft)</th>
<th>Message from air traffic control or crash site</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>7500</td>
<td>WHISKEY GOLF LIMA An air ambulance will be dispatched to the crash site. Please relay this information to CHARLIE FOXTROT MIKE.</td>
</tr>
<tr>
<td>7</td>
<td>7000</td>
<td>This is CHARLIE FOXTROT MIKE Pilot has suspected broken leg and copilot has burns to hands and arms. Please relay this information to Christchurch Air Traffic Control.</td>
</tr>
<tr>
<td>8</td>
<td>7000</td>
<td>WHISKEY GOLF LIMA Injured crew members should be treated for shock as per instructions in aircraft First Aid manual. Please relay this information to CHARLIE FOXTROT MIKE.</td>
</tr>
<tr>
<td>9</td>
<td>7500</td>
<td>This is CHARLIE FOXTROT MIKE The crash site is on the east side of a large lake. Please relay this information to Christchurch Air Traffic Control.</td>
</tr>
<tr>
<td>10</td>
<td>8000</td>
<td>WHISKEY GOLF LIMA If possible the crew at the crash site should prepare a smoke beacon to show their position. Please relay this information to CHARLIE FOXTROT MIKE.</td>
</tr>
<tr>
<td>11</td>
<td>8500</td>
<td>This is CHARLIE FOXTROT MIKE We have lit a smoke beacon near the crash site. Please relay this information to Christchurch Air Traffic Control.</td>
</tr>
<tr>
<td>12</td>
<td>9000</td>
<td>This is CHARLIE FOXTROT MIKE There is an open area suitable for a helicopter to land on a ridge about half a kilometre from the crash site. Please relay this information to Christchurch Air Traffic Control.</td>
</tr>
<tr>
<td>13</td>
<td>9000</td>
<td>WHISKEY GOLF LIMA The crew should stay at the crash site until help arrives. Please relay this information to CHARLIE FOXTROT MIKE.</td>
</tr>
<tr>
<td>14</td>
<td>8500</td>
<td>This is CHARLIE FOXTROT MIKE Injured crew members are in a serious but stable condition. Please relay this information to Christchurch Air Traffic Control.</td>
</tr>
<tr>
<td>15</td>
<td>8500</td>
<td>WHISKEY GOLF LIMA The air ambulance should arrive at the crash site in approximately 10 minutes. Please relay this information to CHARLIE FOXTROT MIKE.</td>
</tr>
<tr>
<td>16</td>
<td>9000</td>
<td>This is CHARLIE FOXTROT MIKE The battery power of our emergency radio is fading. Please relay this information to Christchurch Air Traffic Control.</td>
</tr>
</tbody>
</table>

Each section took approximately four minutes to complete. Hence, if run to completion, the full *When To Turn Back* scenario lasted for approximately one hour. The experiment concluded when a participant indicated that they felt that it was no longer safe to continue. Although they could discontinue their flight at any time by informing the experimenter, almost all participants terminated their flight at one of the air traffic control announced decision points.
4.2. Data analyses

4.2.1. Experimental variables

Data were compiled for eighteen variables in the *When To Turn Back* weather-related aeronautical decision making scenario. The principal dependent variable was **final cloud**. The seventeen independent variables were grouped as follows; three training variables, two decision variables, two demographic variables, one psychological variable, and nine flight performance variables (see Table 19). Data from the nine flight performance variables were subsequently combined to form a single flight performance grouping variable.

Table 19. *When To Turn Back* independent variables.

<table>
<thead>
<tr>
<th>Training variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training group</td>
</tr>
<tr>
<td>Training time</td>
</tr>
<tr>
<td>Training score</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision response time</td>
</tr>
<tr>
<td>Decision response time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demographic variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Gender</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Psychological variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need for cognition</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flight performance variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation from set altitude</td>
</tr>
<tr>
<td>Deviation from set heading</td>
</tr>
<tr>
<td>Correct control inputs</td>
</tr>
<tr>
<td>Incorrect control inputs</td>
</tr>
<tr>
<td>Time changing altitude</td>
</tr>
<tr>
<td>Time changing heading</td>
</tr>
<tr>
<td>Time concurrent control</td>
</tr>
</tbody>
</table>

4.2.2. Dependent variable - Final cloud

During the *When To Turn Back* flight simulation task, participants were required to monitor the outside weather conditions to determine if it was
safe to continue the flight. Participants’ bad-weather decision making ability was measured by recording how far they continued their flight into deteriorating weather. The percentage of the view from the cockpit window that was obscured by cloud at the point that the participant decided to discontinue the flight was automatically recorded by the Icarus computer program. It should be noted that the final cloud variable does not correspond to the measurement of cloud cover in OKTAs.

4.2.3. Training variables

Training group
Participants in the weather-related aeronautical decision making experiment were randomly assigned to one of three training groups. The first group (n = 20) did not receive any training at all, the second group (n = 19) received case-based training in the dangers of bad-weather flying, and the third group (n = 18) received both rule-based training and case-based training in this domain. The case-based training material is shown Appendix 4 and the rule-based training material is shown in Appendix 5.

Training time
The time spent by participants in viewing the case-based or rule-based training modules was automatically recorded by the training presentation computer program in decimal minutes. For participants who received both rule-based and case-based training, the time spent viewing each of the two training modules was recorded separately. The training time variable was not applicable to participants in the no-training group. Training times for the case-based material ranged from 2.37 to 15.31 minutes (mean 5.59 ± 2.20 SD), while training times for the rule-based material ranged from 3.76 to 9.49 minutes (mean 5.96 ± 1.67 SD).

Training score
After viewing the training modules and completing the When To Turn Back flight simulation, participants completed a pencil and paper test to assess their retention of the information that they had been shown. Participants who received both rule-based and case-based training were scored separately for questions relating to each of the two modules. The training score variable was not applicable to participants in the no-training group. The case-based test questionnaire is shown in Appendix 6 and the rule-based test questionnaire is shown in Appendix 7. Training scores for the case-based material ranged from 0 to 16 (mean 12.9 ± 2.98 SD). Training scores for the rule-based material ranged from 7 to 15.

38 In aviation, the amount of overall cloud cover is measured in OKTAs, where an OKTA is one eighth of the celestial dome. Hence, cloud cover can range from 0 to 8 OKTAs (i.e., from clear sky to sky totally obscured by cloud).
(mean 11.8 ± 2.24 SD). The maximum possible score in both cases was 16.

4.2.4. Decision variables

Decision response time

At approximately four minute intervals, participants were specifically asked by air traffic control if it was safe to continue; "WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?" As all communications were recorded by the Icarus computer program, it was possible to calculate the elapsed time in seconds from the receipt of this transmission until the time that the participant responded. This elapsed time will reflect, in part, the time that the participant took to decide on whether or not to continue the flight. The median, rather than the mean, of these times was used because at some points a high concurrent flight control workload meant that a response was delayed. Median decision response times ranged from 2.50 to 21.50 seconds (mean 7.89 seconds ± 4.20 SD).

Decision response time increase

From observations during the running of the When To Turn Back experiment, it was apparent that some participants tended to take longer to respond to the "Safe to continue?" prompt once they felt that they were nearing the point at which they should discontinue their flight. Often their final decision was quite deliberative. This trend was confirmed for data averaged over all participants (see Figure 42).

![Figure 42. Mean response time data for all participants (N = 57).](image-url)
However, many participants did not show this increase in decision response time and, in fact, some participants made their final decision more quickly than their earlier decisions. Hence, the variable *decision response time increase* was calculated to capture this information. For each participant, the reference value was the median of all their decision times except the last. If the final decision was taken more slowly than the median then *decision response time increase* was calculated as final decision time divided by the median time for all others. If, on the other hand, the final decision was taken more quickly, the score was calculated as the median time divided by the final decision time, and expressed as a negative number. *Decision response time increase* values ranged from -13.0 to 6.92 (mean -0.15 ± 3.33).

4.2.5. Demographic variables

Age

The age of participants, from date of birth to date of experiment, was recorded in decimal years. The age range was from 18.9 to 34.3 years (mean 22.1 ± 2.7 SD).

Gender

Twenty seven males and thirty females participated in the *When To Turn Back* scenario.

4.2.6. Psychological variable

Need for cognition

Cognitive motivation was measured using the standard short-form of Cacioppo, Petty, and Kao's (1984) Need for Cognition Scale (NCS). Need for cognition refers to "an individual's tendency to engage in and enjoy effortful cognitive endeavors" (Cacioppo, Petty, & Kao, 1984, p306). NCS scores ranged from 4 to 18 (mean 12.9 ± 3.4 SD), out of a maximum possible score of 18.

4.2.7. Flight performance variables

During the *When To Turn Back* flight simulation task, the Icarus computer program acted as a Flight Data Recorder and a Cockpit Voice Recorder. After the flight the log-file data were analyzed to extract nine flight performance variables, as described below.

Deviation from set altitude

*Deviation from set altitude* measures the ability of the pilot to maintain their assigned altitude as set by air traffic control. The variable was calculated as the root mean square (RMS) deviation of the aircraft's actual altitude from the corresponding set altitude for all data points in the flight recorder log, and expressed as a percentage of the set altitude.
margin (± 150 feet). Deviation from set altitude values ranged from 24.9% to 94.7% (mean 46.2 ± 15.2 SD).

The assigned altitude was changed by air traffic control at regular intervals. This particularly focused the pilots’ attention on this aspect of the flight control task and, hence, maintaining set altitude was considered to be the primary control task. Figure 43 shows the actual altitude trace, compared with the assigned altitude, for two participants (Participant 41 and Participant 10). In the first case (‘a’ in Figure 43) the pilot was able to accurately maintain their assigned altitude, while in the second case (‘b’ in Figure 43) the pilot had difficulty in correctly flying the required altitude profile. The RMS deviation from set altitude was 30.3% (a) and 94.7% (b) for these accurate and inaccurate flying cases respectively.

Figure 43. Low (a) and high (b) RMS deviation from set altitude during the When To Turn Back task.
Deviation from set heading

*Deviation from set heading* measures the ability of the pilot to maintain their assigned heading as set by air traffic control. Calculated in a similar way to *deviation from set altitude*, it is expressed as a percentage of the set heading margin (± 7 degrees).

![Graph of heading deviation](image)

**Figure 44.** Low (a) and high (b) RMS deviation from set heading during the *When To Turn Back* task.

*Deviation from set heading* values ranged from 35.0% to 122.2% (mean 63.1 ± 18.9 SD). The same assigned heading was in force for the full duration of the flight and maintaining set heading was considered to be...
the secondary control task. Figure 44 shows the actual heading trace, compared with the assigned heading, for two participants. In one case ('a' in Figure 44) the pilot was able to accurately maintain their assigned heading, while in the other case ('b' in Figure 44) the pilot showed greater deviation from the set heading. The RMS deviation from set heading was 35.0% (a) and 81.1% (b) for these accurate and inaccurate flying cases respectively.

Correct control inputs altitude

*Correct control inputs altitude* gives the mean number of correct climb and descend control inputs per minute calculated over the duration of the flight. Correct control inputs in this case are 'climb' when the aircraft is below the current set altitude and 'descend' when the aircraft is above the set altitude. The range of *correct control inputs altitude* was from 0.82 to 3.44 inputs min$^{-1}$ (mean 2.09 ± 0.63 SD).

Correct control inputs heading

*Correct control inputs heading* gives the mean number of correct turn left and turn right control inputs per minute calculated over the duration of the flight. Correct control inputs here are 'turn left' when the aircraft is to the right of the current set heading and 'turn right' when the aircraft is to the left of the set heading. The range of *correct control inputs heading* was from 0.72 to 4.02 inputs min$^{-1}$ (mean 2.31 ± 0.77 SD).

Incorrect control inputs altitude

*Incorrect control inputs altitude* gives the mean number of incorrect climb and descend control inputs per minute calculated over the duration of the flight. Incorrect control inputs are 'climb' when the aircraft is not below the current set altitude and 'descend' when the aircraft is not above the set altitude. The range of *incorrect control inputs altitude* was from 0 to 0.83 inputs min$^{-1}$ (mean 0.22 ± 0.17 SD).

Incorrect control inputs heading

*Incorrect control inputs heading* gives the mean number of incorrect turn left and turn right control inputs per minute calculated over the duration of the flight. Incorrect control inputs are 'turn left' when the aircraft is not to the right of the current set heading and 'turn right' when the aircraft is not to the left of the set heading. The range of *incorrect control inputs heading* was from 0 to 1.06 inputs min$^{-1}$ (mean 0.29 ± 0.26 SD).

Time changing altitude

*Time changing altitude* gives the percentage of total flight time during which the aircraft was climbing or descending. The range of *time changing altitude* was from 19.3% to 44.5% (mean 30.9% ± 4.70% SD).
Time changing heading

*Time changing heading* gives the percentage of total flight time during which the aircraft was turning left or turning right. The range of *time changing heading* was from 5.30% to 37.9% (mean 20.5 ± 5.45 SD).

Time concurrent control

*Time concurrent control* gives the percentage of control time during which the aircraft's altitude and heading were changing at the same time. It was intended as a measure of the extent to which the pilot controlled altitude and heading in parallel, that is concurrently, as opposed to controlling them serially. Hence, *time concurrent control* is expressed as a percentage of total control time (time during which the aircraft is changing altitude, or changing heading, or both), in contrast to the *time changing altitude* and *time changing heading* variables, where the base comparison is total flight time. The range of *time concurrent control* was from 0% to 44.7% (mean 17.9% ± 7.54% SD).

4.2.8. Flight performance group

The flight performance of each participant was measured in terms of the nine variables described above. These data were then used to categorize participants into groups of individuals who displayed similar flight performance behaviour. It was decided to do this grouping purely on statistical grounds, rather than on the basis of any a priori assumptions about the nature of the variables or their inter-relationships, for the following reason. For many of the variables it would seem clear which particular flying skills are being tapped; however for other variables the factors influencing a participant's score appear to be more complex. For example, while it would seem clear that *deviation from set altitude* reflects a fundamental tracking skill, shown here in the ability to accurately maintain an assigned altitude, the interpretation of *correct control inputs altitude* and *correct control inputs heading* scores is less obvious. For example, a high number of *correct control inputs altitude* might reflect very accurate altitude control on the part of a skilled pilot, or else it might reflect a frantic over-controlling on the part of a pilot having difficulty flying the aircraft.

A cluster analysis employing K-means clustering (Romesburg, 1984; Spath, 1980) was carried out using the data from the nine flight performance variables for all of the participants in the experiment. The results indicated that, on the basis of their flight performance scores, the participants could be categorized into three distinct groups. There was

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39 Clustering is a statistical technique that groups cases based on similarity. K-means clustering classifies cases by minimizing the sum of the squares of distances between data and the corresponding cluster centres.
one main group with 31 of the participants as members (54.4% of the total sample), and two smaller groups, one with 15 members (26.3%) and the other with 11 members (19.3%). To characterize these three flight performance groups, the scores of the members of each group on the nine flight performance variables were considered in detail. Analysis of the results indicated that there were significant differences between the flight performance groups for all nine variables (see Table 20). A series of post hoc tests (Tukey HSD, $\alpha = 0.05$) were then used to characterize the three flight performance groups as being either 'low', 'medium' or 'high' in terms of the nine flight performance variables. For seven of the nine variables the significant difference was between one of the extreme groups (i.e. low or high) and the other two groups, hence the descriptions for the three groups were either 'low, low, and high', or 'low, high, and high', as appropriate.

<table>
<thead>
<tr>
<th>Flight performance variable</th>
<th>Flight performance variable by flight performance group</th>
<th>Flight performance group</th>
</tr>
</thead>
</table>
| Deviation from set altitude | $F(2,53) = 13.305$  
$p = 0.000$ | high  
high  
low |
| Deviation from set heading  | $F(2,52) = 22.194$  
$p = 0.000$ | high  
high  
low |
| Correct control inputs altitude | $F(2,54) = 22.043$  
$p = 0.000$ | low  
high  
high |
| Correct control inputs heading | $F(2,54) = 41.175$  
$p = 0.000$ | low  
high  
medium |
| Incorrect control inputs altitude | $F(2,54) = 3.446$  
$p = 0.039$ | low  
high  
medium |
| Incorrect control inputs heading | $F(2,54) = 27.221$  
$p = 0.000$ | low  
high  
low |
| Time changing altitude | $F(2,54) = 8.341$  
$p = 0.001$ | low  
high  
low |
| Time changing heading | $F(2,52) = 16.622$  
$p = 0.000$ | low  
high  
low |
| Time concurrent control | $F(2,54) = 16.317$  
$p = 0.000$ | low  
high  
low |

In the case of two variables, correct control inputs heading and incorrect control inputs altitude, the post hoc tests indicated that the significant difference was between the two extreme groups and hence the three terms
When To Turn Back

low, medium and high were used. A summary of these results is given in Table 20. The participants in Group 1 (n = 15) used a low number of control inputs during the flight simulation and achieved poor results in terms of flying accuracy. Deviation from set altitude and deviation from set heading were high, while control inputs, both correct and incorrect, were low for both altitude and heading (see Table 21). This suggests that their poor performance may have been due largely to a lack of application to the flight task, rather than to a lack of ability per se. Instead of accurately monitoring the flight instruments and making precise and timely corrections the participants in Group 1 tended to respond only when altitude or heading deviated widely from their assigned values. Hence Group 1 can be characterized as the 'inattentive' group.

Table 21. Flight performance scores (mean ± SE) for each flight performance group.

<table>
<thead>
<tr>
<th>Flight performance variable</th>
<th>Group 1 Inattentive</th>
<th>Group 2 Attentive but unskilled</th>
<th>Group 3 Skilled and attentive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation from set altitude</td>
<td>55.1 ± 3.31</td>
<td>56.9 ± 6.06</td>
<td>38.3 ± 1.63</td>
</tr>
<tr>
<td>Deviation from set heading</td>
<td>78.6 ± 4.19</td>
<td>75.8 ± 7.92</td>
<td>52.0 ± 1.52</td>
</tr>
<tr>
<td>Correct control inputs altitude</td>
<td>1.39 ± 0.068</td>
<td>2.25 ± 0.158</td>
<td>2.36 ± 0.096</td>
</tr>
<tr>
<td>Correct control inputs heading</td>
<td>1.37 ± 0.086</td>
<td>3.00 ± 0.208</td>
<td>2.52 ± 0.085</td>
</tr>
<tr>
<td>Incorrect control inputs altitude</td>
<td>0.154 ± 0.038</td>
<td>0.325 ± 0.067</td>
<td>0.223 ± 0.026</td>
</tr>
<tr>
<td>Incorrect control inputs heading</td>
<td>0.148 ± 0.030</td>
<td>0.654 ± 0.090</td>
<td>0.223 ± 0.030</td>
</tr>
<tr>
<td>Time changing altitude</td>
<td>28.9 ± 1.35</td>
<td>35.3 ± 1.47</td>
<td>30.2 ± 0.59</td>
</tr>
<tr>
<td>Time changing heading</td>
<td>18.0 ± 1.50</td>
<td>28.0 ± 1.67</td>
<td>19.6 ± 0.57</td>
</tr>
<tr>
<td>Time concurrent control</td>
<td>13.7 ± 1.90</td>
<td>26.9 ± 2.22</td>
<td>16.7 ± 0.86</td>
</tr>
</tbody>
</table>

The participants in Group 2 (n = 11) used a high number of control inputs and yet also performed poorly as measured by deviation from set altitude and heading. Time spent changing altitude and heading was also high for this group, suggesting that the high number of correct control inputs was due to erratic over-controlling rather than to precise altitude and heading correction. This is supported by the high number of incorrect control
inputs made by the group. Hence in contrast to Group 1 the poor performance of Group 2 was due more to lack of ability that to lack of application. Group 2 can be described as the 'attentive but unskilled' group.

Group 3 (n = 31) accurately controlled altitude and heading with a medium to high level of control input. The low amount of time spent changing altitude or heading suggests that these inputs were well considered and applied accurately to minimize deviation from set altitude and heading. This is supported by the low to medium level of incorrect control inputs (see Table 21). Group 3 can be characterized as the 'skilled and attentive' group.

![Figure 45. Proportion of participants in each of the three flight performance groups.](image)

As indicated above, there were 15 members in Group 1, 11 members in Group 2, and 31 members in Group 3. Figure 45 shows the proportion of participants in each of the three flight performance groups.

### 4.3. Results

In the *When To Turn Back* scenario the weather-related decision making of participants was determined by the extent to which they continued their flight into deteriorating weather, as indicated by their final cloud score.

#### 4.3.1. Distribution of final cloud scores

*Final cloud* values ranged from 13.5% to 97.7% (mean 41.1% ± 22.2 SD) out of a maximum possible range of 6% to 98%. The distribution of final cloud scores for all participants is shown in Figure 46. Overall, the final cloud scores fell into three distinct groups, suggesting that there were differences in kind, rather than just degree, between the participants in...
terms of their tendency to continue flying into deteriorating weather. A bootstrap analysis\(^{40}\) (Mooney & Duval, 1993; Robertson, 1991) confirmed that the final cloud scores fell into three significantly different groups, rather than being continuously distributed (1,000 resamplings, \(p < 0.01\)). The first and largest of the three final cloud groups consisted of 43 participants (75.4% of the total sample) with a low-to-moderate tendency to continue on into deteriorating weather, with final cloud scores ranging from 13.5% to 48.1%.

![Figure 46. Distribution of final cloud scores for all participants.](image)

The second group of 11 participants (19.3%) had a strong tendency to continue, with final cloud scores between 60.5% and 79.6%, while a small third group (3 participants, 5.3%) exhibited an extreme tendency to continue their flight with final cloud scores ranging from 92.7% to 97.7%.

4.3.2. The effect of training group on weather-related decision making

For participants with no training in weather-related decision making the mean final cloud score was 47.9% (± 5.81 SE), while for those participants in the case-based training group the mean final cloud score was 41.8% (± 4.73), and for participants who received both rule-based and case-based training the mean final cloud was 32.9% (± 3.99), see Figure 47.

\(^{40}\) A bootstrap analysis is a computer-based resampling procedure that can be applied in situations that are not amenable to traditional statistical methods of analysis (Efron & Tibshirani, 1994).
However, the effect of training in weather-related decision making on the extent that participants continued their flight in to deteriorating weather was not significant at the 5% level, $F(2,54) = 2.28, p = 0.112$.

### 4.3.3. The effect of training on skilled and attentive participants

While training in weather-related decision making did not have a significant effect on the outcome of the *When To Turn Back* scenario for participants as a whole, there was, however, a significant training effect for participants in one of the three flight performance groups. Participants who were judged to be skilled and attentive in terms of their flight performance were amenable to training in bad-weather decision making, as shown by a significant training group effect, $F(2,28) = 3.906$, $p = 0.032$. Skilled and attentive participants who received no training continued on average until final cloud was 57.0% ($\pm$ 7.88 SE), those that received case-based training alone until 41.5% ($\pm$ 4.97), and those that received both rule-based training and case-based training until average final cloud was 29.2% ($\pm$ 3.13), see Figure 48.

Tukey HSD post hoc tests indicated that, for the skilled and attentive group, the difference between the final cloud scores for the no training group and rule-based plus case-based training group was significant ($\alpha = 0.05$), while the other pairwise comparisons were not. In contrast to the skilled and attentive group, there was not a significant final cloud by training group effect for either the inattentive flight performance group, $F(2,12) = 0.522$, $p = 0.606$, or for the attentive but unskilled flight performance group, $F(2,8) = 1.040$, $p = 0.397$. 

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**Figure 47. The effect of training group on final cloud score (mean ± SE).**
Figure 48. The effect of training for skilled and attentive *When To Turn Back* participants (mean ± SE).

From Figure 48, it appeared that for the skilled and attentive flight performance group, the variability in final cloud scores was greatest for the no training group, intermediate for the case-based training group, and least for the rule-based plus case-based training group. A Levene test of homogeneity of variance confirmed that this effect was significant, $F(2,28) = 4.886$, $p = 0.015$. Pairwise comparisons of the group variances indicated that there was a significant difference between the rule-based plus case-based training group and both the no-training group, $F(10,5) = 11.629$, $p = 0.007$, and the case-based group, $F(13,5) = 5.874$, $p = 0.031$.

The distribution of final cloud scores by training group for participants in the skilled and attentive flight performance group is shown in Figure 49. Participants with no training in weather-related decision making fell across the full spectrum in terms of their tendency to continue their flight into deteriorating weather.

In contrast, participants with case-based training were represented in only the low-to-moderate and strong tendency to continue groups, and participants with both rule-based and case-based training in weather-related decision making all fell within the low-to-moderate tendency to continue group.
4.3.4. The effect of training time and training score on weather-related decision making

The time that participants spent viewing training material had no significant effect on their weather-related decision making as reflected in their final cloud scores. This was true for both for case-based training material, \( r(55) = -0.046, p = 0.788 \), and for rule-based training material, \( r = 0.003, p = 0.992 \). Similarly participants' final cloud scores were not significantly affected by their training scores for either case-based material, \( r(55) = -0.152, p = 0.368 \), or for rule-based material, \( r(55) = 0.071, p = 0.779 \).

4.3.5. The effect of decision variables on weather-related decision making

The extent to which participants continued their flight into deteriorating weather was significantly affected by the variable decision response time, the time taken to respond 'yes' or 'no' when asked by air traffic control if it was safe to continue the flight. Participants with short decision response times discontinued their flight on average at 54.0% final cloud, significantly later than the average end-point for participants with medium decision response times (34.9% final cloud) or long decision response times (35.4% final cloud), \( F(2,53) = 5.22, p = 0.009 \), see Figure 50. Post hoc pairwise comparisons of means (Tukey HSD, \( \alpha = 0.05 \)) indicated that the short decision response time group was significantly different from both the medium and long response time groups.
The variable *decision response time increase* did not have a significant effect on participants' final cloud scores, $F(1,51) = 0.024, p = 0.876$. *Decision response time increase* reflected whether or not participants spent a longer time making their final *When To Turn Back* decision (see page 174).

**4.3.6. The effect of demographic variables on weather-related decision making**

There was no significant effect of either age, $F(1,54) = 0.484, p = 0.489$, or gender, $F(1,55) = 0.597, p = 0.443$, on participants' weather-related decision making as indicated by their final cloud scores.

**4.3.7. The effect of Need for Cognition score on weather-related decision making**

The extent to which participants continued their flight into deteriorating weather was not significantly effected by their score on Cacioppo, Petty, and Kao's (1984) Need for Cognition Scale, $r(55) = 0.188, p = 0.161$.

**4.3.8. Interactions between variables affecting final cloud scores**

There were no significant interactions between any of the variables studied in relation to final cloud scores.
5. **How Low To Go**

The *How Low To Go* experiment was designed to study the effectiveness of case-based training and rule-based training on low flying decision making. Fifty seven university undergraduate students took part in an experiment that consisted of four parts. Initially participants received either no training, case-based training, or rule-based and case-based training in low flying decision making. Secondly all participants completed a flight simulation task in which they were the pilot of a light aircraft in a situation involving low flying. Participants who had initially received training were then tested on the material that they had received. Finally, all participants completed the Need for Cognition Scale (Cacioppo, Petty & Kao, 1984). The *How Low To Go* experiment was similar in design to the *When To Turn Back* experiment except that the training material and simulation task related to low flying rather than bad weather flying.

Firstly, it was hypothesized that participants who received case-based training will make significantly more conservative flight decisions than participants who received no training at all. Secondly, it was hypothesized that participants who received both rule-based and case-based training would make significantly more conservative flight decisions than participants who received case-based training only.

### 5.1. Method

#### 5.1.1. Low-flying training material

Participants in the *How Low To Go* experiment were randomly assigned to one of three training groups; no training, case-based training, or rule-based and case-based training. As in the *When To Turn Back* scenario, all training material was presented by computer and consisted of both text and graphics. Again, the case-based module included pictures of aircraft crashes while only neutral images were used in the rule-based module. Both training modules consisted of sixteen main information screens with a total of approximately 1,000 words of text.

The case-based training module presented brief information about four aircraft accidents related to low flying decision making. The case histories on which the material was based were drawn from flight safety publications including *Flight Safety* (CAA, New Zealand), *Asia-Pacific Air Safety* (BASI, Australia), *Aviation Safety Reflexions* (TSB, Canada), *Aviation Safety Letter* (TCA, Canada) and *GASIL* (CAA, UK). The four

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41 The students that took part in the *How Low To Go* experiment were a different group to those that participated in the *When To Turn Back* experiment.
case histories presented in the training material were chosen to be typical of GA light aircraft low-flying accidents. If necessary, the case histories were modified by substituting New Zealand place names and flight details. The low flying case-based training module is shown in Appendix 11.

The first case involved an aircraft that was owned by a farmer and operated from a grass strip. After taking off, the pilot flew low over the strip and adjoining areas and then attempted a manoeuvre at low level which resulted in the aircraft apparently stalling before crashing in a near vertical attitude through the branches of a large tree. The pilot was killed on impact but his passenger survived.

The second case occurred at an aero club fly-in. At the end of the day several departing aircraft carried out minor aerial displays prior to their final departure. The accident aircraft then took off and at a height of less than 50 feet commenced a steep climb, combined almost immediately with a steeply banked turn. By a height of about 200 feet the aircraft appeared to have stalled. It then descended into a steep spiral and hit the ground at an angle of more than 45 degrees, killing both occupants. The training module that described this scenario to subjects consisted of four screens of information. A screen shot of one of the screens is shown in Figure 51.

By the time the aircraft had turned through 180 degrees and reached a height of about 200 feet it appeared to have stalled. From the point of stall the aircraft pitched downwards just past the vertical and descended steeply into a spiral, beginning a recovery from the vertical attitude less than 100 feet above ground.

The aircraft hit the ground at an angle of more than 45 degrees, impacting with the left wingtip and nose first. Both occupants were killed on impact.

Figure 51. A screen shot from one of the How Low To Go scenarios.
In the third case, the pilot arranged to hire an aircraft to fly a work colleague over the area near where he lived. The aircraft was circling at a moderately low height when the pilot lost control and a spin developed. Recovery was made at a low height but, almost immediately after levelling, the aircraft collided with a tree and cartwheeled to the ground. The pilot was killed while his passenger survived.

In the final case, the pilot landed on a strip near a lake and visited a group of friends on the shore with his passenger. It was arranged that the pilot would fly past for some photographs to be taken. After a first run past the group on the shore, the aircraft flew over the observers at less than 50 feet and began to turn and start a steep climb with the speed reducing rapidly. The aircraft then dropped the right wing, dived into the water and sank rapidly. The passenger managed to extricate himself from the wreckage. The body of the pilot was recovered after the aircraft had been towed to shore.

The low flying rule-based material was prepared using information from a range of pilot training manuals and reference books including Freeman (1995), Thom (1992), Collins (1978), Job (1994), Dyson-Holland (1977b) and Diehl, Hwoschinsky, Lawton and Livack (1987). The training material began with a brief introduction outlining the importance of sound aeronautical decision making (ADM). This material, the first four information screens, was the same as the initial screens of the bad weather flying training module. The remaining twelve screens focussed on specific low flying information. The potentially destabilizing effect of wind and turbulence on light aircraft was outlined. Whereas such minor disturbances are likely to be inconsequential when the aircraft is at a safe height, they may be significant at low level where there is little room to recover. It was explained that a tailwind will increase the aircraft's speed over the ground, creating a false impression of higher than normal airspeed and the possibility that the pilot may mistakenly reduce airspeed to a dangerously low level. The next section mentioned the many potential collision hazards in low flying, pointing out that they may be hidden by the background or obscured by sun glare. The rule-based module then referred to the three activities that cause the majority of low flying accidents; beat-ups, impromptu aerobatics, and circling to observe something on the ground.
A common element in many low level crashes is a desire to perform to the gallery. Particularly in the case of beat-ups and impromptu aerobatics the pilot's actions are often carried out to impress someone known to them. Enthusiasm, however, needs to be tempered with self-discipline. If sound aeronautical decision making is abandoned then the result is likely to be serious injury or death.

Figure 52. A screen shot from the *How Low To Go* rule-based training material

The next section mentioned a common element in many low level crashes; the pilot's desire to impress someone known to them. Finally, the module concluded with a screen summarizing the points outlined above. The low flying rule-based training module is shown in Appendix 12.

5.1.2. Low flying test material

Participants in the *How Low To Go* experiment who received case-based training subsequently completed a test questionnaire to assess their retention of the material that they had viewed. The questionnaire consisted of sixteen items, four relating to each of the accident case histories described in the training module. The questions were predominantly multiple choice with some direct recall items. The low flying case-based questionnaire is shown in Appendix 13. Participants who completed the rule-based training module were given a similar questionnaire relating to the information that they had viewed. The rule-based test questionnaire is shown in Appendix 14.
5.1.3. The How Low To Go low-flying decision making scenario

The How Low To Go scenario presented a low-flying decision making task. Participants were required to decide how low it would be safe for them to fly their aircraft at its present position. The scenario was relatively unstructured. Participants were not directed in their decision making and they were not restricted in the time that they spent on the task. The outcome for each participant was the final altitude of their aircraft, the height above the ground that they considered to be the minimum safe altitude given the view from the cockpit window.

In practice, the simulation began at a relatively high altitude and required participants to descend so that the nature of the terrain directly beneath their aircraft became apparent. It was explained that the aircraft's altimeter was set to read zero at sea level rather than at ground level below the aircraft, and as such could not be used as a decision aid. Participants made their judgement solely on the basis of what they could see from the cockpit window. They were not penalised for descending to a very low altitude and then climbing back up to a safer height. In fact they were informed that they could fly down and up again to whatever extent they thought necessary to make a fully informed decision. It was also permissible for participants to remain at a constant height for a period of time while they considered their decision.

The How Low To Go simulation was static rather than dynamic in nature. In effect, the aircraft was frozen in time as opposed to moving forward through the landscape visible from the cockpit window. This was done to standardize the judgement task for all participants as the time taken to make a decision varied. Hence, if the aircraft moved through the landscape during the simulation, participants would not have been making their judgements in relation to the same environment. For the same reason, the aircraft was constrained from moving to the left or right of its current heading. Participants were instructed that they should choose the lowest altitude at which they thought it safe to fly at their current position. To motivate them to consider low altitudes rather than simply making a very conservative and safe decision, participants were told that a $20 bonus would be paid to the person who chose the lowest final altitude that was nevertheless equal to or greater than the actual minimum safe altitude as predetermined by the experimenter.

To present the How Low To Go scenario, the Icarus flight simulator was modified in two ways. Firstly, the weather did not deteriorate as was the case in the When To Turn Back scenario. In the How Low To Go simulation, the sky was initially completely clear and remained so during the full course of the simulation. Secondly, while in the When To Turn Back task the view from the cockpit window remained static, even when
the aircraft was climbing or descending, in the *How Low To Go* task the scenery panned vertically to simulate the changing outlook that would be seen from the aircraft at different altitudes. Figure 53 shows the view from the cockpit window at three different altitudes.

(a) 7,000 feet

![Image of high altitude view](image)

(b) 5,000 feet

![Image of middle altitude view](image)

(c) 3,000 feet

![Image of low altitude view](image)

**Figure 53.** High (a), middle (b), and low (c) altitude views in the *How Low To Go* scenario.

At the start of the simulation, the aircraft was at an altitude of 7,500 feet above sea level. A far range of snow capped mountains filled the top half of the view from the cockpit window. The lower half of the view showed a series of hills and valleys in the middle distance. As participants directed the aircraft to descend, the view from the cockpit window panned upwards, revealing the nature of the terrain at lower altitudes. When the aircraft had descended to 5,000 feet, the hills and valleys in the
middle distance appeared in the top half of the window and a close tree covered ridge could be seen in the lower part of the view. By 3,000 feet, the ridge filled the entire window except where the tops of very close large trees were visible in the bottom quarter of the view. During the How Low To Go scenario, the Icarus simulator recorder the aircraft's altitude at five second intervals. All control inputs by the pilot were also logged.

5.2. Data analyses

5.2.1. Experimental variables

Data were compiled for eleven variables in the How Low To Go low flying decision making scenario. The principal dependent variable was final altitude. The ten independent variables were grouped as follows; three training variables, two demographic variables, one psychological variable, and four decision variables (see Table 19). Data from the four decision variables were subsequently combined to form a single decision grouping variable.

Table 22. How Low To Go independent variables.

<table>
<thead>
<tr>
<th>Training variables</th>
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<tbody>
<tr>
<td>Training group</td>
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<tr>
<td>Training time</td>
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<tr>
<td>Training score</td>
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<tr>
<td>Decision variables</td>
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<tr>
<td>Flight time</td>
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<tr>
<td>Total altitude excursion</td>
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<tr>
<td>Altitude reversals</td>
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<td>Control inputs</td>
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<td>Demographic variables</td>
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<td>Psychological variable</td>
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<td>Need for cognition</td>
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5.2.2. Dependent variable - Final altitude

The How Low To Go scenario required participants to judge and report the altitude that they considered to be the minimum safe altitude for their aircraft, given its current position. During the simulation, participants commanded their aircraft to climb and descend to the extent that they thought necessary to make a fully informed decision. There was no time
limit on the low flying decision task and no requirement to follow a particular flight path. The simulation concluded when participants brought their aircraft to level flight at their chosen minimum safe altitude and informed the experimenter of their decision. The aircraft's final altitude was recorded automatically by the Icarus flight simulation program.

5.2.3. Training variables

Training group
Participants in the low flying decision making experiment were randomly assigned to one of three training groups. The first group (n = 21) did not receive any training at all, the second group (n = 18) received case-based training in the dangers of low flying, and the third group (n = 18) received both rule-based training and case-based training in this domain. The case-based training material is shown in Appendix 11 and the rule-based training material is shown in Appendix 12.

Training time
The time spent by participants in viewing the case-based or rule-based training modules was automatically recorded by the training presentation computer program in decimal minutes. For participants who received both rule-based and case-based training, the time spent viewing each of the two training modules was recorded separately. Training times for the case-based material ranged from 3.25 to 10.78 minutes (mean 5.30 ± 1.44 SD), while training times for the rule-based material ranged from 3.98 to 10.63 minutes (mean 6.54 ± 1.76 SD).

Training score
After viewing the training modules and completing the How Low To Go flight simulation, participants completed a pencil and paper test to assess their retention of the information that they had been shown. Participants who received both rule-based and case-based training were scored separately for questions relating to each of the two modules. The case-based test questionnaire is shown in Appendix 13 and the rule-based test questionnaire is shown in Appendix 14. Training scores for the case-based material ranged from 3 to 15 (mean 9.49 ± 2.72 SD). Training scores for the rule-based material ranged from 4.5 to 15 (mean 11.47 ± 2.94 SD). The maximum possible score in both cases was 16.

5.2.4. Decision variables

During the How Low To Go flight simulation task, the Icarus computer program recorded the aircraft’s altitude every five seconds as well as all pilot control inputs. The log-file data for each participant were used to construct a flight profile and to extract four decision variables. The How Low To Go simulation was relatively unstructured and did not require
participants to perform any time dependent or skill related secondary task concurrently with the primary decision making task. This was in contrast to the When To Turn Back scenario during which participants were required to maintain a set altitude and heading against outside disturbance. The low flying scenario allowed participants to follow whatever flight profile they wished and to make their minimum safe altitude judgement in the own time, undistracted by any other task demands. Hence, the behavioural data relate to decision making aspects of the scenario and not to timed skills such as tracking ability, as was the case for the logged data in the When To Turn Back scenario. The flight profiles obtained during the How Low To Go simulation varied considerably. Figure 54 shows two particular examples.

Figure 54. Example flight profiles from the How Low To Go scenario.
In the first example ('a' in Figure 54), the pilot adopted a very cautious approach and made all changes in altitude in small increments. After two minutes they had descended to approximately 6,000 feet and from this point on they made relatively minor changes in altitude for the next ten minutes, before announcing their minimum safe altitude decision.

In contrast, the pilot in the second example ('b' in Figure 54) carried out a more detailed investigation of the terrain beneath the aircraft before making their decision. After descending to 3,500 feet they paused briefly before continuing their descent to approximately 2,000 feet. They then climbed rapidly to above 6,000 feet before settling on a minimum safe altitude of approximately 5,500 feet.

Four decision variables were extracted from the flight profile data in an attempt to quantify the different approaches that participants used during the How Low To Go simulation. The decision variables were,

**Total time**
The total time (in decimal minutes) taken to complete the How Low To Go scenario was measured from the start of the simulation until the pilot announced to the experimenter that they had levelled their aircraft at their chosen minimum safe altitude. Although it was influenced partly by the aircraft's programmed maximum rate of descent, total time primarily reflected the speed with which participants made their low flying judgement. **Total time** ranged from 1.87 minutes to 12.18 minutes (mean 5.76 ± 2.61 SD).

**Total altitude excursion**
The variable **total altitude excursion** represents the total vertical distance that the aircraft traversed, both climbing and descending, while the pilot investigated the terrain in their immediate vicinity. It is a measure of the 'information content' on which participants based their minimum safe altitude decision. A low **total altitude excursion** score indicates that the pilot did not fully explore the terrain before making their decision, while a high score indicates a thorough approach to the low flying judgement task. **Total altitude excursion** was calculated as the sum of the point to point absolute differences in altitude. Values ranged from 1,492 feet to 16,347 feet (mean 6,630 ± 415 SD).

**Altitude reversals**
The variable **altitude reversals** gives a measure of the total number of times that the pilot changed from climbing to descending, or vice versa, throughout the simulation. A low **altitude reversals** score indicates that the pilot tended to go straight to what they considered to be the minimum safe altitude, while a high score suggests that they were inclined to check
and recheck available information before making a final decision. 

*Altitude reversals* ranged from 0 to 21 (mean 3.9 ± 3.8 SD).

**Control inputs**

*Control inputs* gives a measure of the mean number of control commands per minute calculated over the duration of the simulation. Because the *How Low To Go* task did not include any timed or skill based component *control inputs* in this instance does not act as a performance variable, as was the case in the *When To Turn Back* scenario, but rather reflects the degree of fineness of control that a participant displayed. A low control inputs score indicated that the pilot made many fine adjustments to the aircraft's altitude, while a high score indicated that the pilot tended to make changes in larger increments. For example, a slow, cautious descent would result in a relatively high *control inputs* score compared with traversing the same vertical distance at the aircraft's maximum descent rate. During the *How Low To Go* simulation the aircraft was constrained to move only in the vertical plane, hence *control inputs* included 'climb', 'descend' and 'straight and level' control commands. *Control inputs* ranged from 0.78 to 8.29 inputs min⁻¹ (mean 3.49 ± 1.61 SD).

### 5.2.5. Decision group

The data from the four decision variables were used to categorize participants into 'decision' groups, using K-means clustering (Romesburg, 1984; Spath, 1980). The results indicated that participants could be categorized into three groups on the basis of the decision variables. There was one main group with 35 members (61.4% of the total sample), a second group with 17 members (29.8%), and a third group with 5 members (8.8%). To characterize the three decision groups the scores of the members of each group on the four decision variables were considered in detail. Analyses indicated that there were significant differences between the flight performance groups for all four variables (see Table 23).

A series of post hoc tests (Tukey's HSD, α = 0.05) were used to characterize the three flight performance groups as being either 'low', 'medium' or 'high' in terms of four decision variables (see Table 24). The first group (n = 35) was characterized by low values for *total time*, *total altitude excursion*, and *altitude reversals*, and medium values for *control inputs* (see Table 24). Hence, the participants in Group 1 could be described as making quick decisions on the basis on minimal information and with little rechecking. This group was designated the 'quick decision' group.
Table 23. Characterization of decision groups by decision variables.

<table>
<thead>
<tr>
<th>Decision variable by decision group</th>
<th>Decision group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1</td>
</tr>
<tr>
<td>Total time</td>
<td>F(2,54) = 31.047</td>
</tr>
<tr>
<td></td>
<td>p = 0.000</td>
</tr>
<tr>
<td>Total altitude excursion</td>
<td>F(2,54) = 31.073</td>
</tr>
<tr>
<td></td>
<td>p = 0.000</td>
</tr>
<tr>
<td>Altitude reversals</td>
<td>F(2,54) = 41.052</td>
</tr>
<tr>
<td></td>
<td>p = 0.000</td>
</tr>
<tr>
<td>Control inputs</td>
<td>F(2,54) = 29.853</td>
</tr>
<tr>
<td></td>
<td>p = 0.000</td>
</tr>
</tbody>
</table>

Participants in the second group (n = 17) scored high on total time and total altitude excursion indicating that they tended to spend more time and gather more information before making their decision. However, in common with the participants in Group 1, they also scored low on altitude reversals and control inputs. Hence, this group sought out information in a straightforward and definite manner, and then came to a conclusion with relatively little ‘wavering’ in terms of altitude reversals. Group 2 was described as the ‘considered and definite’ decision making group.

Table 24. Decision variable scores (mean ± SE) for each decision group.

<table>
<thead>
<tr>
<th>Decision variable</th>
<th>Group 1 Quick decision</th>
<th>Group 2 Considered and definite</th>
<th>Group 3 Considered and wavering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time</td>
<td>4.28 ± 0.27</td>
<td>7.95 ± 0.42</td>
<td>8.78 ± 1.45</td>
</tr>
<tr>
<td>Total altitude excursion</td>
<td>4,878 ± 300</td>
<td>9,871 ± 649</td>
<td>7,874 ± 1,297</td>
</tr>
<tr>
<td>Altitude reversals</td>
<td>2.77 ± 0.38</td>
<td>3.53 ± 0.50</td>
<td>13.40 ± 2.14</td>
</tr>
<tr>
<td>Control inputs</td>
<td>3.59 ± 0.20</td>
<td>2.34 ± 0.23</td>
<td>6.74 ± 0.65</td>
</tr>
</tbody>
</table>

As indicated above, there were 35 members in Group 1, 17 members in Group 2, and 5 members in Group 3. Figure 55 shows the proportion of participants in each of the three decision groups.

Finally, the third group (n = 5) was characterized by high scores on all four decision variables. That is, they also took a considered approach to the task and sought out information, but in contrast to the second group their search strategy was characterised by a more wavering approach as indicated by the high number of altitude reversals they made. This
behaviour may have reflected a relatively conservative 'risk averse' approach to the task, or simply a degree of indecisiveness on their part, or a combination of both. Group 3 was designated the 'considered and wavering' decision making group.

Figure 55. Proportion of participants in each of the three decision groups.

5.2.6. Demographic variables

Age
The age of participants, from date of birth to date of experiment, was recorded in decimal years. The age range was from 18.7 to 31.2 years (mean 21.7 ± 2.3 SD).

Gender
Twenty males and thirty seven females participated in the How Low To Go experiment.

5.2.7. Psychological variable

Need for cognition
Cognitive motivation was measured using the standard short-form of Cacioppo, Petty, and Kao's (1984) Need for Cognition Scale (NCS). NCS scores ranged from 1 to 18 (mean 11.7 ± 4.0 SD), out of a maximum possible score of 18.

5.3. Results

In the How Low To Go scenario, participants' low flying decision making ability was measured by their final altitude score, reflecting their judgement as to how low they could safely fly their aircraft at its current position.
5.3.1. Distribution of final attitude scores

*Final attitude* values ranged from 6,447 feet down to 1,637 feet (mean 4,612 feet ± 1,039 SD). The distribution of *final attitude* scores for all participants is shown in Figure 56. The majority of participants (80.7%) returned *final attitude* scores in the range from 3,000 feet to 6,000 feet. At one extreme, nine participants (15.8% of the sample) made relatively conservative decisions, deciding on a minimum safe altitude between 6,000 feet and 6,500 feet. At the other extreme, two participants (3.5%) chose a relatively risky minimum safe altitude below 3,000 feet.

![Figure 56. Distribution of final altitude scores for all participants.](image)

5.3.2. The effect of training group on low flying decision making

For participants as a whole, training in the dangers of low flying had no significant effect on the outcome of their minimum safe altitude judgement task, $F(2,54) = 1.60, p = 0.211$. Mean (± SE) *final attitude* scores were 4,530 ± 206 feet for the no-training group, 4,364 ± 245 feet for the case-based training group, and 4,957 ± 261 feet for the group that received both rule-based and case-based training (see Figure 57).
5.3.3. The effect of training for the quick decision group

While for participants as a whole low flying training did not have a significant effect on the outcome of the *How Low To Go* scenario, there was, however, a significant training effect for members of the quick decision group, $F(2,32) = 4.05, p = 0.027$. Participants in the quick decision group that received no training in the dangers of low flying decided on average on a minimum safe altitude of 4,337 (± 251 SE) feet, those that received case-based training alone indicated 4,499 (± 249) feet on average, and those that received both rule-based training and case-based training chose 5,262 (± 3.13) feet on average, see Figure 58.

---

*Figure 57. The effect of training group on final altitude score (mean ± SE).*
Tukey HSD post hoc tests indicated that the only significant ($\alpha = 0.05$) pairwise comparison was between the no training group and the group that received both case-based and rule-based training. The distribution of final altitude scores by training group for participants in the quick decision making group is shown in Figure 59.

Figure 58. The effect of training for quick decision making *How Low To Go* participants (mean ± SE).

Figure 59. Quick decision making group participants final altitude scores by training group.
In contrast to the quick decision making group, there was not a significant training group effect for either the intermediate calibre decision making group, $F(2,14) = 0.013, p = 0.988$, or for the high calibre decision making group, $F(2,5) = 11.77, p = 0.078$.

5.3.4. **The effect of training time and training score on low flying decision making**

The time that participants spent viewing the case-based training material had a significant effect on their low flying decision making as reflected in their final altitude scores, $r(55) = 0.343, p = 0.041$. However closer inspection of the data revealed that this effect was due entirely to two outliers, Participants 81 and 82 (see Figure 60). If either outlier was removed from the data set, the significant training time effect was abolished. With both outliers removed, the resulting correlation between training time and final altitude was $r(55) = 0.118, p = 0.508$.

![Figure 60. Scatter plot of final altitude by case-based training time.](image_url)

There was no significant effect of time spent viewing the rule-based training material on participants' final altitude scores, $r(55) = 0.175, p = 0.488$. Final altitude scores were not significantly affected by training scores for either case-based material, $r(55) = 0.124, p = 0.470$, or for rule-based material, $r(55) = -0.034, p = 0.895$.

5.3.5. **The effect of demographic variables on low flying decision making**

There was no significant effect of age on participants' low flying decision making as indicated by their final altitude scores, $r(55) = -0.072, p = 0.596$. There was, however, a significant effect of gender, $F(1,55) = 9.29,$
The mean minimum safe altitude chosen by males was 4,080 feet (± 242 SE) while the mean value for females was 4,900 feet (± 149 SE), see Figure 61.

**Figure 61.** The effect of gender on final altitude score (mean ± SE).

### 5.3.6. The effect of Need for Cognition score on low flying decision making

Participants' scores on Cacioppo, Petty, and Kao's (1984) Need for Cognition Scale did not significantly relate to their judgement of their aircraft's minimum safe altitude, \( r(55) = -0.043, p = 0.753 \).

### 5.3.7. Interactions between variables affecting final altitude scores

There were no significant interactions between any of the variables studied in relation to final altitude scores.

A discussion of the work outlined in this chapter is included in Chapter 8.
Part 3
Pilot behaviours in the face of adverse weather

The following two accident case histories illustrate that the final outcome of a safety-related occurrence rests with the interplay of a myriad of factors, and that in the final analysis chance can play a significant part.

Case 7.

The aircraft was on a private flight from Shepparton to Moorabbin with the pilot and three passengers on board. Before departing from Shepparton, the pilot had obtained an enroute weather forecast that indicated that VFR flight via the Kilmore gap was perhaps possible but that conditions were likely to be marginal. On departure from Shepparton, there was scattered cloud at 2,500 feet with a ceiling of approximately 4,000 feet. Visibility was approximately 8km, with occasional rain showers.

As the flight approached Mangalore, the hills to the east and south west were shrouded in low stratus. Abeam Seymour, the weather ahead appeared to be closing in and the pilot began a left turn onto a reciprocal heading for Mangalore. However, the weather had closed in from behind, and soon after completing the turn the aircraft was enveloped in cloud.

Figure 62. An aircraft in marginal VFR weather conditions.

The pilot contacted Melbourne ATC and reported that they were in cloud with nil visibility. ATC advised the pilot to concentrate on keeping the wings level, and provided radar vectors to ensure that the aircraft remained clear of high terrain in the vicinity. Abeam Mangalore the aircraft broke free of cloud and the pilot was able to resume their own navigation. The flight then continued to Shepparton where the aircraft landed safely.
The aviation safety incident described above involved VFR flight into IMC, a potentially very hazardous occurrence, and yet the pilot emerged unscathed because, luckily, advice and guidance were at hand. In contrast, the pilot involved in the accident described below, while initially slow to recognize the deteriorating weather, made a wise decision to carry out a precautionary landing. In spite of this, the aircraft was destroyed and the pilot and one of his passengers were injured.

Case 8.
The planned flight was from Bendigo to Albury. The area forecast indicated that the weather enroute would be suitable for VFR flight. A cold front was moving slowly through the region from the south-east, but was not forecast to reach the area of the planned route until after the completion of the flight. The private pilot did not hold an instrument rating but had completed 3 hours of instrument flight training.

The aircraft departed Bendigo at 11 am with the pilot, his wife, and their two children on board. As the flight progressed it became clear that the front was moving much more quickly than forecast and that the weather along the planned route may deteriorate below that required for VFR flight. The pilot decided to return to Bendigo and advised ATC of his intentions. A short time later the pilot again contacted ATC and advised that the weather had deteriorated further and that he was intending to carry out a precautionary landing in the Rushworth area.

![Image of an aircraft substantially damaged as a result of a precautionary landing.](image)

The pilot identified a suitable landing area and carried out a low speed pass to confirm that the area was free of obstacles. The pilot configured the aircraft for
a precautionary landing and made a slow-speed approach to the field. However, shortly after touch-down the pilot noticed a drainage ditch running across the field perpendicular to the aircraft’s path. The ditch was concealed by long grass and reeds growing in the waterway. The nose gear contacted the bank of the ditch and was sheared off. The aircraft then continued for some distance before it ground looped and overturned before coming to rest. The pilot and the front seat passenger were restrained by their lap-sash seat belts, but the pilot suffered a fracture to his left arm due to impact forces on the control column. One of the passengers in the rear of the aircraft received minor injuries.

The above two cases illustrate that in aeronautical decision making, as in any field of human activity, there is never a perfect link between intent and outcome. A pilot may accurately assess the situation they face, decide on a suitable course of action, and yet it is still possible for things to go wrong in the process of putting the plan into action. While sometimes a pilot lives to tell their story, despite their foolhardy actions, at other times events can conspire against a pilot and continually test his resolve to conduct his flight in a safe manner. Hence, trying to understand pilot decision making by simply focussing on the outcome of an occurrence is likely to be imprecise at best, and at worst fundamentally in error.

This approach is in line with thinking that acknowledges that, in the final analysis, the difference between final outcomes (for example, an accident or incident) will involve an element of chance. What is important is understanding the underlying circumstances and immediate events that combined to produce an unsafe situation (Reason, 1997). While the final outcome of an occurrence can range from a ‘free lesson’ to disaster, all can provide an equally valuable learning experience (Maurino, Reason, Johnston, & Lee, 1995).

Following this line of argument, the work described in this section of the thesis differs from previous work in that it concentrates on process rather than outcome. The emphasis is not on flight outcome (for example, accident or non-accident) but rather on measures of pilot behaviour, and by inference, pilot cognition. For example, in considering a weather-related occurrence, the fundamental question is - “How did the pilot come to be in that position?” Was it because of the type of pilot he was? Or could it have happened to anyone? What was going on in the pilot’s mind. What was he thinking as events progressed? Did he misjudge the weather situation he faced? Or did he realise that the weather was deteriorating significantly, and yet consciously decide to press for reasons best known to him? These are questions about process, about how the situation had it genesis, and how it developed over time.

The work reported in this section is based on a set of aviation accident and incident occurrences that reflect different pilot behaviours in the face of adverse weather conditions. The study draws on material that was gathered during the course of air safety investigations by the Australian
Transport Safety Bureau (ATSB) and, as such, is not normally available for analysis. In using information from actual air safety occurrences, this work is aimed at supplementing other work in this thesis based on survey and experimental work.

The three weather-related decision making behaviours that are compared in this study are:

- VFR into IMC
- a weather-related precautionary landing
- some other significant weather avoidance action

Chapter 6 is based on quantitative information from ATSB database of occurrences. Chapter 7 is based on qualitative information from ATSB investigation files.
6. **Identifying pilot weather-related behaviours**

This chapter of the thesis compares three groups of pilots that exhibited different behaviours in the face of adverse weather. The three groups are compared in terms of a number of quantitative variables.

6.1. **Weather-related decision making group dataset**

The weather-related decision making dataset that forms the basis for this work includes accidents, incidents, and 'normal operations'. However, this 'outcome' based categorisation is not the basis for the analyses. Each of the three weather-related decision making groups includes occurrences with different outcomes. The data are drawn from the Australian Transport Safety Bureau aviation occurrence database.

6.1.1. **The Australian Transport Safety Bureau database**

The ATSB is the government body responsible for investigating accidents, incidents, and safety deficiencies involving civil aircraft operations within Australia. The ATSB also conducts investigations and studies of the aviation system to identify and rectify underlying factors that can affect safety and potentially become significant factors in accidents. The ATSB performs its functions in accordance with International Civil Aviation Organisation (ICAO) standards and recommended practices as set out in Annex 13 to the *Convention on International Civil Aviation - Chicago 1944*.

All accidents and serious incidents which affect the safety of aircraft in Australia must be reported to the ATSB. This information is recorded in a database, OASIS (Occurrence Analysis and Safety Information System), for use in investigation and safety analysis work. The OASIS database includes accident and incident reports from all types of aviation operations and all aviation industry sectors. Currently, the ATSB records approximately 105 accident reports and 1,600 incident reports each year. The OASIS database holds a total of over 180,000 occurrences for the period from 1969 to 2003. Because of confidentiality requirements, much of the information in the OASIS database is not available publicly. For that reason, together with resource constraints within the ATSB, relatively little study and analysis has historically been made of the wealth of safety-related information contained within the OASIS database.

42 For example, an occurrence in which a pilot diverts or turns back, in a timely manner, in the face of deteriorating weather would not necessarily constitute an air safety incident.
OASIS database architecture

The OASIS database comprises gigabytes of data stored on a Unix based server. OASIS is an Oracle database consisting of over 380 main tables, with a total or more than 2,300 variables. An Oracle Forms interface is used for data entry and simple data queries. For more extensive data analysis a SAS/SQL front-end is used to interrogate the underlying Oracle database. Data queries are formulated in SQL syntax and then submitted for remote processing via SAS. This is a relatively specialised and complex task and again this has militated against full use being made of the information contained within OASIS.

6.1.2. Selection of weather-related decision making occurrences

Initial ‘general aviation VFR’ dataset

The current study focuses on general aviation weather-related decision making. Therefore, an initial dataset was created that excluded certain types of occurrences that were not relevant. Occurrences in the following categories were excluded:

- high-capacity regular public transport (‘airline’) operations
- sport aviation, including gliding and ballooning
- aerial work, including agriculture flying
- military operations
- rotary wing operations
- IFR operations

Rotary-wing operations were excluded as the very different performance capabilities and operating environment of rotary-wing aircraft (eg helicopters) means that any direct comparison with fixed-wing operations is complex and difficult. Occurrences where the flight was conducted under IFR (instrument flight rule) procedures were excluded as, by definition, the pilot and aircraft would have been capable of operating in IMC (instrument meteorological conditions).

The initial dataset contained 20,598 occurrences for the period 1973 to April 2003. In many cases, only limited information was recorded in the database for occurrences prior to the early 1990s.

Weather-related decision making dataset

The OASIS database includes a number of fields that were relevant to selecting occurrences involving some aspect of weather-related decision making. For example, some variables include descriptive values such as ‘Due To Weather’ and ‘Weather Related Event’ or even specifically

43 Some OASIS tables and variables relate to ATSB investigation management.
44 The ATSB does generally not investigate sport aviation occurrences unless they involve a VH-registered aircraft and a fatality or serious injury. Relevant sporting bodies, such as the Gliding Federation or the Hang Gliding Federation, may carry out an investigation.
Identifying pilot weather-related behaviours 213

‘VFR Aircraft in Non VMC’. However, a close inspection of the database indicated that because of serious limitations in the way that data had been recorded it was not possible to rely solely on such variables to identify all potentially relevant occurrences.

Preliminary work indicated that the only reliable way to ensure that all potentially relevant weather-related decision making occurrences were retrieved was to also make use of the information in the free text narrative of the ‘Occurrence Summary’ field. This was done by a combination of both ‘manual’ and ‘automatic’ means. Firstly, approximately 5,000 individual occurrence summaries were read in order to select those relevant to weather-related decision making. These occurrences represented a significant proportion (approximately one quarter) of the initial ‘general aviation VFR’ dataset. Secondly, using this ‘seed’ group of occurrences, a set of selection rules was developed that could be applied automatically to the entire dataset.

The set of case selection rules that was developed was intentionally broad. That is, it was intended to err on the side of false positives (identifying occurrences as relevant when they were not) while minimising false negatives (failing to identify relevant cases). This was because the dataset created by the automatic selection process was subsequently reviewed case by case to identify occurrences that were not relevant. The rule base used to create the initial weather-related dataset employed a list of single terms and combinations of terms as outlined in Table 25. If any of the terms or combination of terms appeared within the Occurrence Summary text, then the occurrence was selected for inclusion in the weather-related dataset.
Table 25. Single terms and combinations of terms used to search Occurrence Summary text.

<table>
<thead>
<tr>
<th>Single terms</th>
<th>Any of the terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>cloud</td>
<td>encountered IMC</td>
</tr>
<tr>
<td>non VMC</td>
<td>conditions of IMC</td>
</tr>
<tr>
<td>non-VMC</td>
<td>VFR on top</td>
</tr>
<tr>
<td>non - VMC</td>
<td>rising terrain</td>
</tr>
<tr>
<td>other than VMC</td>
<td>radar assistance</td>
</tr>
<tr>
<td>not in VMC</td>
<td>press on</td>
</tr>
<tr>
<td>entered IMC</td>
<td>pressed on</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Combination of terms</th>
<th>Any of the terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>The term</td>
<td>VFR</td>
</tr>
<tr>
<td>weather</td>
<td>visual flight rules</td>
</tr>
<tr>
<td>AND any of the terms</td>
<td>VMC</td>
</tr>
<tr>
<td></td>
<td>visual meteorological conditions</td>
</tr>
<tr>
<td></td>
<td>AND any of the terms</td>
</tr>
<tr>
<td></td>
<td>IMC</td>
</tr>
<tr>
<td></td>
<td>instrument meteorological conditions</td>
</tr>
<tr>
<td></td>
<td>marginal</td>
</tr>
<tr>
<td></td>
<td>less than</td>
</tr>
<tr>
<td></td>
<td>not exist</td>
</tr>
<tr>
<td></td>
<td>unable to maintain</td>
</tr>
<tr>
<td></td>
<td>unable to remain</td>
</tr>
<tr>
<td></td>
<td>in and out</td>
</tr>
<tr>
<td></td>
<td>not possible</td>
</tr>
<tr>
<td></td>
<td>not be possible</td>
</tr>
<tr>
<td></td>
<td>adverse conditions</td>
</tr>
<tr>
<td></td>
<td>below the requirements</td>
</tr>
<tr>
<td></td>
<td>visibility</td>
</tr>
</tbody>
</table>

A combination of selecting cases by values in OASIS descriptive fields and automatic searching for relevant terms in the Occurrence Summary field returned a dataset of 1,307 occurrences. The initial dataset was, by design, very broad in its scope. For example, any occurrence simply with the word ‘cloud’ in the summary field was automatically added to the
Identifying pilot weather-related behaviours

Therefore, many occurrences in the initial dataset were not relevant.

The types of occurrences that were removed from the dataset included those related to:

- mechanical problems
- aircraft mishandling
- navigation difficulties not primarily due to weather
- VCA (violation of controlled airspace) not primarily a weather-related occurrence
- precautionary landing not due to weather per se (eg lost, low on fuel)
- effect of turbulence or wind (eg headwind, crosswind) alone
- occurrence involving person or agency other than pilot (eg ATC etc)
- birdstrike
- radio failure
- MBZ/CTAF procedures
- pilot incapacitation

In addition, a small number of ‘night VFR’ weather-related occurrences were omitted because of the different nature of night VFR operations. After screening, a total of 491 occurrences fell within the three weather-related decision making categories (see Table 26). Categorisation into the three decision making groups was carried out by two raters with 95% initial agreement. Differences were then resolved by discussion.

Table 26. Weather-related decision making groups.

<table>
<thead>
<tr>
<th>Weather-related decision making group</th>
<th>Number of cases</th>
<th>Percent of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>VFR into IMC (V)</td>
<td>280</td>
<td>57%</td>
</tr>
<tr>
<td>Precautionary landing (WP)</td>
<td>60</td>
<td>12.2%</td>
</tr>
<tr>
<td>Weather avoidance (WA)</td>
<td>151</td>
<td>30.8%</td>
</tr>
<tr>
<td>Total</td>
<td>491</td>
<td>100%</td>
</tr>
</tbody>
</table>

All other data were extracted directly from the ATSB occurrence database in quantitative form without further manipulation. The data had been entered into the ATSB database by trained and experienced air safety investigators. For a small number of variables where the numeric data represented values labels, for example ‘serious injury’, the codes represented international standard definitions established by ICAO and promulgated in documents such as Annex 13.
No conclusions can be drawn from the absolute number of cases in each group because this will depend on the reporting rate for each type of occurrence. It is likely that the reporting rate will vary for the different occurrence types, due to factors such as the possible repercussions of reporting the occurrence, or the likelihood that the occurrence will come to the attention of a third party.

Details of the selection criteria for each group of weather-related occurrences, and representative examples, are given below.

6.1.3. VFR into IMC occurrences

Typical VFR into IMC scenarios included the following:

- occurrences where the aircraft entered cloud, but subsequently regained VMC
- accidents where the aircraft was trapped by bad weather and rising terrain
- pilot requests for assistance when the aircraft was already in IMC
- aircraft crashes in circumstances indicative of VFR in IMC

The implication in each of these types of scenarios is that the pilot was unable or unwilling to take necessary action to avoid the aircraft entering flight conditions for which the pilot was not equipped to handle. By definition, VFR into IMC occurrences resulted in a situation well beyond 'normal operations'. At that point, the final outcome most likely depended on chance in many cases. Possibly only seconds, or at most minutes, separated a safe outcome from an accident - safety assurance had been lost.

Figure 64 shows an example of the typical weather conditions associated with VFR into IMC accidents. Low cloud and mist shrouds the ranges, hiding the full extent of the height of the terrain, evident in the upper left corner of the figure.

Examples of VFR into IMC occurrences included:

**Occurrence 289**

The aircraft departed Ocean View Farm, near Esperance, for Jandakot at 0850. Shortly after 1100 the aircraft was observed flying in and out of cloud at a very low height, less than 100 feet above ground level, as it circled Narrogin townsite. At approximately 1115 the aircraft crashed in a farm paddock between Narrogin townsite and Narrogin airstrip. There were no witnesses to the crash. The weather condition at the time of the accident was poor with fog and low cloud in the area. The aircraft collided with the ground in a near vertical attitude.

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45 Occurrence numbers refer to the dataset of cases in this study, not to ATSB OASIS occurrences numbers. Some occurrence summaries have been edited for brevity.
Figure 64. Local weather conditions at the time of a fatal VFR into IMC accident.

**Occurrence 451**
The VFR pilot contacted ATS and advised operating in IMC conditions. ATS identified the aircraft and provided navigational assistance for visual tracking. The pilot regained visual contact and proceeded to the destination without further incident.

**Occurrence 442**
The pilot of the VFR flight reported to the tower that he was in cloud and was advised that the weather conditions at the airfield were unsuitable for a visual approach. ATC declared a distress phase and the pilot elected to divert to Ayers Rock where the weather was reported as being more favourable. The aircraft was climbed to 6,500 ft, became visual and with the use of a GPS was able to track to Ayers Rock. The aircraft made an uneventful landing and the distress phase was cancelled.

**Occurrence 392**
The aircraft, on a VFR flight, entered cloud inadvertently. While the pilot was manoeuvring to regain visual conditions, the aircraft struck the top of a tree, damaging the landing gear. The pilot declared an emergency and diverted to Bathurst. An experienced pilot on the ground at Bathurst inspected the landing gear during a flypast and advised the pilot that it appeared to be in reasonable condition. The aircraft landed without further incident.

**Occurrence 446**
The aircraft departed on a visual flight on climb to 9,500 ft. Shortly after reaching this altitude the pilot encountered cloud which he inadvertently entered and then the aircraft started to collect ice. The pilot began a descent and the ice...
started to melt, he then received advice from another pilot that cloud conditions were clear to the north. He then exited the cloud and was able to conduct the rest of the flight in VMC.

Figure 65. VFR into IMC accident site.

Figure 65 shows a fatal VFR into IMC accident site. The initial point of impact can be seen in the foreground of the figure. A wreckage trail extends along the ground scar, with the remains of the rear fuselage and tail section visible in the mid left of the figure.

Occurrence 459

The aircraft departed Swan Hill at approximately 1600. The pilot had arranged to phone a contact on arrival at Goulburn. At about 1735 a radar trace consistent with the flight path of the aircraft was identified approaching Goulburn from Yass. The aircraft disappeared from radar 7 NM west of Goulburn at 1744, which was consistent with the flight profile of a planned descent to Goulburn. The pilot did not report to the contact by phone as planned and a search for the aircraft commenced the next morning. The aircraft wreckage was found 4 NM to the south-west of the aerodrome. The accident was not survivable. The circumstances of the accident were consistent with the pilot attempting to continue the flight into non-visual meteorological conditions.

Occurrence 457

During the cruise, the pilot contacted the tower advising he was inbound, 26 NM from Rockhampton at 2,000 ft. ATC queried the pilot regarding his altitude as the minimum safe altitude (MSA) for that area was 2,300 ft. The pilot then declared that he was in cloud. ATC initiated an uncertainty phase and instructed

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Accident photographs are for general illustrative purposes only. They should not be taken as relating to any particular accident discussed in this study.
the pilot to climb to 3,500 ft (MSA at 25 NM from Rockhampton). The pilot subsequently became visual and the approach and landing continued without further incident.

**Occurrence 419**
The pilot was advised by ATC when 95 nm NW of Melbourne that the cloud cover at Melbourne and Moorabbin was solid overcast at 1,200 ft. The pilot continued until he found himself in non-VMC conditions. The pilot was instructed and guided by ATC to climb above cloud and maintain a level attitude and constant heading. The pilot became visual at 4,900 ft and insisted he needed to get to Moorabbin. ATC informed the pilot that this was not possible. The pilot then elected to return to Swan Hill and was vectored to Bendigo where he was able to resume his own navigation.

6.1.4. **Precautionary landing occurrences**
For the purposes of this study, a precautionary landing was defined as a premeditated emergency landing where further flight was possible but inadvisable (FAA, 2004). The type of landing sites typically used for a precautionary landing include any sufficiently large open area such a paddock or other cleared area, or a suitable stretch of road. A precautionary landing can be contrasted with a 'normal' landing at a place specifically intended as an aircraft landing area, and also from an off-aerodrome 'forced landing' due to a mechanical problem.

A precautionary landing is a prudent course of action in the face of significantly adverse weather. The alternative of 'pressing on' may well place the aircraft and its occupants into a potentially very risky situation. However, the fact that a precautionary landing was necessary will, in most cases, indicate that the VMC assurance had been lost. Perhaps the situation can best be summed up by the colloquial observation that it was 'a close call', an experience likely to leave a lasting impression on the pilot (and any passengers).

Occurrences in which the pilot carried out a precautionary landing covered a range of situations and outcomes. In some cases, the weather was worse than forecast, or deteriorated rapidly, but in other cases, the weather was 'as forecast'. In some cases carrying out a precautionary landing occurred after the pilot had initially diverted, or turned back, to avoid adverse weather. Some precautionary landings involved damage to the aircraft, while others did not.

Examples of precautionary landing occurrences included;

**Occurrence 111**
The aircraft made a precautionary landing on an ALA [authorised landing area] due to adverse weather on track ahead. Weather was as per forecast. Pilot made diversion to remain in VMC, landed after deciding would not be able to continue in VMC.
Occurrence 359
The stream weather was worse than forecast. A diversion west of track to follow a highway to Charters Towers was conducted. The weather deteriorated further, forcing the pilot to make a precautionary landing at Merricourt Station. At the end of the landing roll the aircraft encountered a soft area resulting in the nose gear breaking the surface. Subsequently the propeller blades struck the ground.

Occurrence 166
Whilst enroute, cloud base lowered and showers became more frequent. On receipt of advice on weather ahead from another aircraft, pilot elected to divert and land in a paddock suitable as an ALA.

Occurrence 372
Due to poor weather in the area of the intended track, the pilot decided to fly his aircraft down the Macleay River to Kempsey, however, the weather deteriorated rapidly. He chose to carry out a precautionary search and landing in a paddock at Temagog, landing in a southerly direction on a downslope. The brakes were ineffective and the aircraft continued on into a creek. The pilot escaped without injury; however, the aircraft sustained substantial damage.

Occurrence 467
The pilot reported that he made a safe precautionary landing in a paddock, due to severe approaching weather conditions. The aircraft departed Nowra in CAVOK conditions. As the flight progressed, the pilot noticed the weather rapidly deteriorating and realised that he would not be able to proceed to Bathurst. The pilot then decided to divert firstly to Orange and secondly to Cowra, but rapidly deteriorating weather forced him to abandon these intentions. He decided against attempting to return to Nowra as this would have involved flight over mountainous terrain that was unsuitable for landing in the event of the front reaching the aircraft's location. He finally decided to land in a paddock while over suitable terrain in VMC conditions.

Occurrence 415
When the pilot failed to cancel SARTIME for Rowland Flat by the nominated time of 1300 CSUT, communication checks were commenced. No contact could be made with the pilot by radio or telephone, despite extensive checks. At 1315 an Uncertainty Phase was declared. At 1320 Brisbane Flightwatch advised that the pilot had made a precautionary landing 5 NM west of Dutton due to poor weather. SARTIME and the phase were cancelled.

Occurrence 452
The pilot informed the controller that he was making a precautionary landing on the road due to low cloud. An uncertainty phase was declared by ATC. After the pilot had landed and confirmed his position, he departed for Esperance aerodrome and landed safely.

6.1.5. Weather avoidance occurrences
The significant aspect that weather avoidance occurrences in the dataset have in common is that the pilot's behaviour indicated a degree of situational awareness, and a willingness to take appropriate action when confronted with adverse weather. Conversely, if the pilot had not acted in
a timely manner then it was possible that the situation could have escalated and that VMC assurance\(^\text{47}\) might have been lost.

Typical weather avoidance scenarios included the following:

- the pilot turned back, or diverted to an alternate destination
- the pilot requested assistance to avoid adverse weather, in a timely manner

Typically, the request for assistance was to ATC and involved the pilot being given navigation guidance to ensure that the flight remained in VMC. In a number of cases the fact that the pilot had taken some action to avoid adverse weather only came to light indirectly, for example when they failed to cancel a SARTIME\(^\text{48}\). That in itself, however, does not detract from the appropriateness of their prudent weather-related action.

Examples of weather avoidance occurrences included:

**Occurrence 288**
The pilot reported that he was unsure of his position, was approaching inclement weather, and was requesting navigational assistance. The Alert Phase was declared and the pilot was given assistance to locate Dalby by the SARO, Oakey ATC and the pilot of another aircraft. The aircraft landed safely at Dalby at 1751 EST.

**Occurrence 266**
The pilot did not cancel his SARTIME by the nominated time. The aircraft was tracking around frontal weather passing through south east Queensland and was unable to fly to the intended destination, St George. It was eventually landed at Roma without incident.

**Occurrence 65**
Student on solo navex was authorised by an instructor in spite of forecast indicating marginal VMC enroute. Pilot encountered marginal VMC near Kingston and diverted to Naracoorte.

**Occurrence 320**
While en route to Latrobe Valley, destination weather reports deteriorated. The pilot elected to return to Albury but weather there also deteriorated. A diversion to Wagga was then commenced but on receiving Holbrook weather the pilot elected to land there.

**Occurrence 360**
Approaching Oberon, the student pilot noticed cloud build up on track and closing behind. The pilot requested radar assistance around the cloud, which was given. The flying school was informed by FIS which requested the pilot to return to Bankstown. The pilot was then given radar assistance for his safe return to Bankstown.

\(^{47}\) 'VMC assurance' refers to the confidence that VMC conditions can be maintained at all times during the flight. VMC assurance is a similar concept to 'separation assurance' in air traffic control (Airservices, 2004) and 'continuing airworthiness assurance' in aircraft certification and maintenance (ATSB, 2002).

\(^{48}\) SARTIME is the time nominated by a pilot for the initiation of search and rescue action if an arrival report has not been received by that time.
6.2. Weather-related decision making group data analyses

Quantitative analyses comparing the three weather-related decision making groups were carried out in the following areas;

- occurrence outcome
- pilot demographics
- operational factors
- aircraft characteristics
- geographical and environment factors
- absolute and relative flight distances

6.2.1. Occurrence outcome

The following factors were analysed to determine if there were significant differences in outcomes for the three weather-related decision making groups;

- whether the outcome was an accident or incident
- the severity of injury to the pilot or passengers
- the degree of damage to the aircraft

**Accident or incident**

Overall, 13% of the occurrences in the weather-related decision making dataset involved accidents, and 87% involved incidents (see Figure 66). Generally speaking, an accident is defined as any occurrence that results in death or serious injury to the pilot or passengers, or in which the aircraft is destroyed or seriously damaged. An incident is defined as an
occurrence, other than an accident, which affects or could affect the safety of the flight\(^{49}\).

There were significant differences between the three weather-related decision making groups in terms of whether the outcome of the occurrence was an accident or an incident (chi-square(2) = 20.49, \(p = 0.000\)).

![Figure 66](image)

**Figure 66.** Percentage of accidents and incidents in each weather-related decision making group.

The highest proportion of accidents (23.3%) occurred within the precautionary landing group, followed by the VFR into IMC group (16.1% accidents), and the weather avoidance group (3.3% accidents).

**Severity of injury to pilot or passengers**

There were significant differences in terms of the maximum severity of injury received by either the pilot or passengers for occurrences in each of the three weather-related decision making groups (chi-square(6) = 30.6, \(p = 0.000\)), see Figure 67.

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\(^{49}\) For specific definitions of accident and incident see, for example, ICAO Annex 13, *Aircraft Accident and Incident Investigation*, and the Australian Transport Safety Investigation Act 2003.
Almost all injuries to pilot or passengers occurred within the VFR into IMC group. Of the occurrences within this group, 12.1% involved a fatality, 1.4% involved serious injury, 0.7% resulted in minor injury, and 85.7% did not involve any injury to the aircraft occupants. One occurrence in the precautionary landing group involved serious injury, and one occurrence in the weather avoidance group involved minor injury.
The very serious nature of VFR into IMC accidents\textsuperscript{50} was apparent in that 75.6\% of cases involved a fatality, 8.9\% involved serious injury, 4.4\% resulted in a minor injury, and in only 11.1\% of cases did the pilot, and passengers if any, escape injury entirely.

**Aircraft damage**

Overall, of the aircraft involved in the weather-related occurrences studied, 7.8\% were destroyed, 5.3\% received substantial damage, 1.4\% minor damage, and 85.4\% received no damage at all.

There were significant differences between the three weather-related decision making groups in terms of the degree of damage that the aircraft sustained as a result of the occurrence (chi-square(6) = 61.1, p = 0.000), see Figure 69.

\textsuperscript{50} Note. These statistics relate to accidents only, while all other statistics are for accidents and incidents.
Two main findings were apparent in the relation to the aircraft damage data. Firstly, the likelihood of the aircraft incurring some form of damage was greatest for the precautionary landing group (28.8%), intermediate for the VFR into IMC group (17.4%), and least for the weather avoidance group (4.0%).
Secondly, where damage did occur, the likely severity of the damage was greatest in the VMC into IMC group (13.0% destroyed), followed by the precautionary landing group (20.3% substantial damage), and lastly the weather avoidance group (3.3% substantial damage).

6.2.2. Pilot demographics

Age

The age of the pilot was recorded in the OASIS database for a total of 89 of the cases in the dataset. The overall age distribution for pilots in all three weather-related decision making groups is shown in Figure 71.
The age of pilots within the three weather-related decision making groups did not differ significantly\(^{51}\) \((F(2,86) = 1.04, p = 0.358)\).

**Flying experience**

The two measures of amount of flying experience were analysed, total flying time and total time on type. Total time on type refers to the total flying time that the pilot had accumulated on the type of aircraft make and model that they were flying when the accident or incident occurred. Two further measures of flying experience were considered for analysis, total time flown in the last 90 days and time on type during the last 90 days. However, there were insufficient data available for these two variables, with total time in last 90 days for only 52 cases (11\% of all occurrences in the dataset) and time on type in last 90 days for 18 cases (3.7\% of occurrences).

**Total flying time**

The total number of hours flown by pilot was recorded for a total of 132 cases in the dataset (see Figure 72). Total flying time ranged from 53 to 19,400 hours (mean 776 ± 1,860 SD).

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\(^{51}\) The pilot age variable was transformed by Log10 as the original distribution was non-normal (positively skewed). However, the ANOVA result was non-significant both before and after transformation.
Identifying pilot weather-related behaviours

There were no significant differences between the three weather-related decision making groups in terms of the pilot's total flying hours\(^{52}\) (F(2, 129) = 0.182, p = 0.834).

**Time on type**
The total number of hours flown by pilots on the make and model of aircraft involved in the occurrence was recorded for a total of 89 cases in the dataset (see Figure 73). Time on type ranged from 1 to 1,625 hours (Mean 198 ± 312 SD).

---

\(^{52}\) Pilot flying time variables were transformed by Log10 as the original distributions were non-normal. However, the ANOVA results were non-significant both before and after transformation.
Figure 73. Time on type for pilots in all weather-related decision making groups.

There were no significant differences between the three weather-related decision making groups in terms of the pilot's time on type ($F(2, 86) = 0.068, p = 0.934$).

**Pilot licence type**

The type of flying licence held by the pilot was recorded in a total of 233 cases. There was no significant difference in terms of licence type between the three weather-related decision making groups (chi-square(8) = 5.19, $p = 0.737$). The overall proportion of licence holders in each category is shown in Figure 74.
The majority of pilots held a private pilot's licence (81.5%). A commercial pilot’s licence was held by 14.6% of pilots, and a student pilot’s licence by 3.8%.

**Pilot ownership status**

Pilot ownership status was recorded in a total of 85 cases. The majority of pilots (72%) did not own the aircraft that they were flying at the time of the occurrence (see Figure 75).
There were no significant differences between the three weather-related decision making groups in terms of flying operation type (chi-square(10) = 6.72, p = 0.752). The overall distribution of operation types is shown in Figure 76.

**Type of airspace**

The type of airspace within which the weather-related decision making accident or incident occurred was recorded in a total of 428 cases. In 23.1% of cases, the occurrence took place within some form of controlled airspace.
The age of pilots within the three weather-related decision making groups did not differ significantly\(^5\) (F (2,86) = 1.04, p = 0.358).

**Flying experience**

The two measures of amount of flying experience were analysed, total flying time and total time on type. Total time on type refers to the total flying time that the pilot had accumulated on the type of aircraft make and model that they were flying when the accident or incident occurred. Two further measures of flying experience were considered for analysis, total time flown in the last 90 days and time on type during the last 90 days. However, there were insufficient data available for these two variables, with total time in last 90 days for only 52 cases (11% of all occurrences in the dataset) and time on type in last 90 days for 18 cases (3.7% of occurrences).

**Total flying time**

The total number of hours flown by pilot was recorded for a total of 132 cases in the dataset (see Figure 72). Total flying time ranged from 53 to 19,400 hours (mean 776 ± 1,860 SD).

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\(^5\) The pilot age variable was transformed by Log10 as the original distribution was non-normal (positively skewed). However, the ANOVA result was non-significant both before and after transformation.
Figure 72. Total flying time for pilots in all weather-related decision making groups.

There were no significant differences between the three weather-related decision making groups in terms of the pilot’s total flying hours\(^{52}\) (F(2,129) = 0.182, p = 0.834).

**Time on type**

The total number of hours flown by pilots on the make and model of aircraft involved in the occurrence was recorded for a total of 89 cases in the dataset (see Figure 73). Time on type ranged from 1 to 1,625 hours (Mean 198 ± 312 SD).

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\(^{52}\) Pilot flying time variables were transformed by Log10 as the original distributions were non-normal. However, the ANOVA results were non-significant both before and after transformation.
There were no significant differences between the three weather-related decision making groups in terms of the pilot's time on type ($F(2,86) = 0.068, p = 0.934$).

**Pilot licence type**

The type of flying licence held by the pilot was recorded in a total of 233 cases. There was no significant difference in terms of licence type between the three weather-related decision making groups (chi-square(8) = 5.19, $p = 0.737$). The overall proportion of licence holders in each category is shown in Figure 74.
The majority of pilots held a private pilot’s licence (81.5%). A commercial pilot’s licence was held by 14.6% of pilots, and a student pilot’s licence by 3.8%.

**Pilot ownership status**

Pilot ownership status was recorded in a total of 85 cases. The majority of pilots (72%) did not own the aircraft that they were flying at the time of the occurrence (see Figure 75).
There was no significant difference between the three weather-related decision making groups in terms of pilot ownership status (chi-square(6) = 6.58, p = 0.362).

6.2.3. Operational factors

Type of flying operation
The type of flying operation was recorded in a total of 368 cases. The majority of occurrences involved private flights (77.2%). There were a small proportion of business flights (4.1%), flying training flights (10.1%), and commercial operations (8.7%). The commercial operations consisted primarily of charter flights.
There were no significant differences between the three weather-related decision making groups in terms of flying operation type (chi-square(10) = 6.72, p = 0.752). The overall distribution of operation types is shown in Figure 76.

**Type of airspace**

The type of airspace within which the weather-related decision making accident or incident occurred was recorded in a total of 428 cases. In 23.1% of cases, the occurrence took place within some form of controlled airspace.
Figure 77. Type of airspace in which occurrence took place by decision making group.

The distribution of occurrences either within controlled airspace or outside controlled airspace (OCTA) for each weather-related decision making group is shown in Figure 77. There was a significant difference between the three groups in this regard (chi-square(2) = 15.43, \( p = 0.000 \)). Almost all (96%) of precautionary landings took place outside controlled airspace (OCTA). In comparison, 79% of weather avoidance occurrences, and 71% of VFR into IMC occurrences took place outside controlled airspace.

6.2.4. Aircraft characteristics

It is possible that high performance light aircraft may be over-represented in weather-related accidents and incidents due to the fact that it may be harder for the pilot to ‘stay ahead of the aircraft’. That is, because the pilot has less time in which to perceive and analyse potentially relevant information, it may be harder for them to maintain adequate situational awareness.

Although there is no universal definition of what constitutes a ‘high performance’ light aircraft, typical aspects would include larger aircraft size, a more powerful engine or engines, a higher cruising speed, and
more complex equipment such as retractable landing gear or a variable pitch propeller\(^{53}\).

The following aircraft type characteristics where analysed to determine if there were any significant differences between the three weather-related decision making groups;

- maximum certificated takeoff weight (MTOW)
- number of engines
- type of landing gear
- type of propeller

**Maximum certificated takeoff weight**

Aircraft maximum certificated takeoff weight data was available for 488 cases. Typical aircraft types within each maximum takeoff weight range are shown in Table 27\(^{54}\).

The type of weather-related decision making behaviours observed did not vary significantly for operations involving aircraft types of different maximum takeoff weights (\(F(2, 483) = 1.762, p = 0.173\)).

**Number of engines**

The majority of the aircraft (89\%) in the weather-related occurrence dataset were single-engined. The remaining aircraft were twin engined. There was no significant difference between the three weather-related decision making groups in terms of whether the aircraft in question was single-engined or twin-engined (chi-square(2) = 4.43, \(p = 0.109\)).

**Type of landing gear**

The type of landing gear of the occurrence aircraft was recorded for 465 cases in the dataset. A majority (56.2\%) of the aircraft had fixed landing gear, rather than retractable landing gear. There was no significant difference between the three weather-related decision making groups in terms of aircraft landing gear type (chi-square(2) = 3.28, \(p = 0.194\)).

**Type of propeller**

The propeller type of the occurrence aircraft was recorded for 222 cases in the dataset. A majority (59.0\%) of the aircraft for which propeller type was recorded had a variable pitch, rather than a fixed pitch, propeller. There was no significant difference between the three weather-related decision making groups in terms of propeller type (chi-square(2) = 3.49, \(p = 0.175\)).

\(^{53}\) The FAA defines “high performance” as an airplane that has an engine with greater than 200 horsepower or that has retractable landing gear, flaps, and a controllable pitch propeller (14 Code of Federal Regulations, FAR Part 61.31 (e)).

\(^{54}\) This study did not use the MTOW breakpoints typically used by aviation regulatory bodies (2,730 Kg, 5,670 Kg, 13,610 Kg) as they were not suitable given the range of aircraft types in the current dataset.
Table 27. Typical aircraft types in maximum certificated takeoff weight ranges.

<table>
<thead>
<tr>
<th>MTOW range</th>
<th>N(^a)</th>
<th>Examples of aircraft types in MTOW range</th>
<th>Typical aircraft characteristics(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 to 1000 Kg</td>
<td>51</td>
<td>Cessna C150 Vicla Airtourer</td>
<td>2 seat, 90-110 HP, 100-110 kts</td>
</tr>
<tr>
<td>1000 to 1250 Kg</td>
<td>202</td>
<td>Cessna 172 Skylhawk Piper PA-28 Cherokee</td>
<td>4 seat, 140-180 HP, 110-140 kts</td>
</tr>
<tr>
<td>1250 to 1500 Kg</td>
<td>85</td>
<td>Cessna 182 Skylane Piper PA-24 Comanche Mooney M20</td>
<td>4 seat, 230-280 HP, 140-180 kts</td>
</tr>
<tr>
<td>1500 to 1750 Kg</td>
<td>102</td>
<td>Cessna 210 Centurion Piper PA-44 Seminole Beech 36 Bonanza</td>
<td>4-6 seat, 260-300 HP (single) or 2 x 160-180 HP (twin), 180-200 kts</td>
</tr>
<tr>
<td>1750 to 2000 Kg</td>
<td>13</td>
<td>Beech 76 Duchess Piper PA-30 Twin Comanche</td>
<td>4-6 seat, 2 x 180-200 HP, 160-180 kts</td>
</tr>
<tr>
<td>2000 to 2500 Kg</td>
<td>23</td>
<td>Beech 58 Baron Piper PA-34 Seneca Cessna 310</td>
<td>6 seat, 2 x 220-300 HP, 180-210 kts</td>
</tr>
<tr>
<td>above 2500 Kg</td>
<td>10</td>
<td>Cessna 402 Piper PA-31 Navajo</td>
<td>6-8 seat, 2 x 300-350 HP, 210-230 kts.</td>
</tr>
</tbody>
</table>

Note.  
(a) Number of aircraft in this MTOW range for all weather-related decision making groups.  
(b) Seating capacity, engine horse-power, and cruise speed.  
  Indicative values only for common aircraft types in this MTOW range.

6.2.5. Geographical and environment factors

Geographical location

Australia spans many different geographical and climatic regions; from tropical northern areas, through remote outback regions, to temperate midlands, and to relatively cold and wet southern areas. The physical geography and typical weather environment of a region can have a significant influence of the aviation accident and incident rates in that region (Braithwaite, 2001). It is possible, therefore, that regional environmental factors might influence the weather-related decision making behaviour of pilots.

The latitude and longitude at which the weather-related accident or incident occurred was recorded for 287 cases. KMeans clustering (SPSS 11.5) was employed to classify the cases into 10 groups. However, four of the geographical groups, in remote areas of Australia, included only 5,
3, 3, and 3 cases respectively. Hence, these 14 cases were combined into a single ‘Remote area’ group. The geographical distribution of the cases throughout Australia is shown in Figure 78.

The number of cases within each geographical area in shown in Table 28. No significance can be given to the relative number of occurrences in each area as this will be influenced by many factors including the size of the geographical area, the population distribution, and local flying activity.
Table 28. Approximate geographical areas for all weather-related decision making occurrences.

<table>
<thead>
<tr>
<th>Approximate geographical area</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW and ACT, including Sydney, Canberra, Wagga Wagga, Goulburn</td>
<td>75</td>
<td>26</td>
</tr>
<tr>
<td>VIC and TAS, including Melbourne, Ballarat, Echuca, King Island, Wynyard</td>
<td>70</td>
<td>24</td>
</tr>
<tr>
<td>Southern QLD, including Brisbane, Coolangatta, Maroochydore</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>South West WA, including Perth, Albany, Bunbury</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td>Far North QLD, including Townsville, Cairns, Mackay, Rockhampton</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>South East SA, including Adelaide, Port Augusta</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>Remote areas, including NT, remote WA, and inland Australia</td>
<td>14</td>
<td>5</td>
</tr>
</tbody>
</table>

Note. (a) Description of geographical areas is indicative only. For some groups, not all cases fall within the States described. (b) Number of cases in each geographical area.

There was no significant difference in the types of weather-related decisions made in each of the geographical areas (chi-square(12) = 12.32, p = 0.420).

City versus country flying

Latitude and longitude are not the only geographical variables that can influence the flying environment and, hence, possibly affect the character of flying operations. Another distinction is between that of 'city' and 'country' flying. It is possible that there is a difference between these two flying environments, and perhaps a different ethos among pilots in the two groups.

City flying can be characterised as occurring within a relatively controlled environment. A typical example might be a 'weekend warrior' hiring an aircraft from a local flying school to take family or friends on a cross country flight. In that situation, the flight may be under informal oversight of the flying school CFI, and the flight may be partly within controlled airspace. In comparison, a typical example of a country flight might be a local grazier flying his own aircraft from the ALA (authorised landing area) on his property to attend a sale at a regional town. The flight may be less likely to be under supervision, or to involve flight in controlled airspace.
The distinction between city and country flying is a generalisation. There will be many counter-examples, as well as examples that combine aspects from both areas. Nevertheless, it is an distinction that may be useful when comparing different aspects of pilots’ flying behaviour, such as the weather-related decision making comparisons in the current study. No aspect of the comparison between city flying and country flying should be taken as suggesting that either is any more or less likely to be conducted in a professional manner.

![Distribution of city flights and country flight for occurrences in all groups.](image)

For the purposes of this study, an occurrence was coded as being either a ‘city flight’ or a ‘country flight’ depending on whether either one, or both, of the point of departure or intended destination was a State capital city\(^{55}\). While this categorisation will not be appropriate in all cases – for

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\(^{55}\) The following locations were taken as capital city points of departure and/or destination - Sydney, Bankstown, Hoxton Park, Camden, Melbourne, Moorabbin, Essendon, Brisbane, Archerfield, Adelaide, Parafield, Perth, Jandakot, and Hobart (Cambridge).
example, some country flying will involve flights to or from large regional centres—it would appear to be appropriate for the majority of occurrences given the Australian population distribution.  

Figure 79 shows the overall distribution of flights to or from a State capital city for occurrences in all three decision making groups.  

Overall, occurrences in the weather-related decision making dataset were approximately equally divided between ‘city flying’ and country flying’ (see Table 29).

Table 29. Proportion of all occurrences that were city flights or country flights.

<table>
<thead>
<tr>
<th>Flying environment</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>232</td>
<td>52.1%</td>
</tr>
<tr>
<td>Country</td>
<td>213</td>
<td>47.9%</td>
</tr>
<tr>
<td>Total</td>
<td>445</td>
<td>100%</td>
</tr>
</tbody>
</table>

There were significant differences between the three weather-related decision making groups in relation to city flying or country flying (chi-square(2) = 8.943, p = 0.011). For the VFR into IMC and weather avoidance groups, the proportion of occurrences between city flying and country flying were similar (56% vs 44% and 52.5% vs 47.5% respectively). However, for the precautionary landing group there was a far greater proportion of occurrences in the country flying group (66%) as compared to the city flying group (34%) (see Figure 80).

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Australia has a vast landmass, and yet it is among the most urbanized countries in the world. Almost 40% of the population lives in Melbourne or Sydney, and another 20% in Brisbane, Perth, and Adelaide.
The question arises as to whether the greater proportion of precautionary landings within the country flying group simply reflects the greater proportion of precautionary landings that took place outside controlled airspace. However, there was not a significant difference between the proportion of city or country occurrences either within controlled airspace or OCTA (chi-square(1) = 2.13, p = 0.145). Hence, the greater proportion of precautionary landing occurrences within the country flying group cannot be ascribed solely to the influence of airspace type.

Another confounding factor that could possibly influence the precautionary landing result is that of 'exposure'. The result may simply reflect the greater average time and distance associated with country flights. However, the average planned flight distance did not differ significantly between city flights (mean 410 ± 41.8 SE) and country flights (361 ± 33.6 km) (t (79) = 0.904, p = 0.369). Therefore, the precautionary landing result is not likely to be due to differences in exposure.

**Time of day of occurrence**

The local time of day at which the accident or incident occurred was recorded for a total of 488 cases. The distribution of occurrence times is shown in Figure 81, compared to the distribution of all occurrence times.

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57 See section 6.2.6 for details of calculation of flight distances.
for similar flying activity during the day\textsuperscript{58} (shaded area). The two distributions were similar, except that the weather-related decision making dataset showed a smaller proportion of occurrences during the period from approximately 2 pm to 4 pm.

![Distribution of local time (24 hr) of occurrences in comparison to flying activity.](image)

There was a significant difference between the three weather-related decision making groups in relation to the time of day at which the accident or incident occurred ($F(2,485) = 3.731$, $p = 0.025$). For occurrences in the VFR into IMC and precautionary landing groups the mean local time was approximately 12.45 pm. For the weather avoidance group the mean local time was approximately an hour later, 1.40 pm. Post hoc tests (Tukey’s HSD) indicated that the only significant pairwise comparison was that between the V and WA groups ($p = 0.022$).

\textsuperscript{58} The distribution of occurrence times estimated from the time of occurrence of the 20,598 ATSB reports from which the weather-related decision making dataset was derived. This distribution was used to approximate flying activity by time of day.
Table 30. Statistics for time of day (24 hr) of weather-related decision making occurrences.\textsuperscript{59}

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>SEM</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>VFR into IMC (V)</td>
<td>277</td>
<td>12:43</td>
<td>00:13</td>
<td>12:13</td>
</tr>
<tr>
<td>Precautionary landing (WP)</td>
<td>60</td>
<td>12:44</td>
<td>00:23</td>
<td>12:25</td>
</tr>
<tr>
<td>Weather avoidance (WA)</td>
<td>151</td>
<td>13:40</td>
<td>00:19</td>
<td>13:52</td>
</tr>
<tr>
<td>All groups</td>
<td>488</td>
<td>13:01</td>
<td>00:10</td>
<td>12:30</td>
</tr>
</tbody>
</table>

Inspection of the time of day distributions for the three weather-related decision making groups indicated that the distribution for the weather avoidance group differed in being bimodal (see Figure 82). As well as a peak during the morning, at approximately 9 am, a second distinct peak occurred late in the afternoon, at about 5 pm.

![Figure 82. Distribution of occurrences by local time of day for each group (V, WP, WA).](image)

Hence, there were a relatively low number of weather avoidance occurrences during the middle part of the day (approximately 11 am to 1 pm). In comparison, the distribution for VFR into IMC occurrences

\textsuperscript{59} All calculations were done using decimal hour values. Times are reported as 24 hour "hrs:min" values for convenience.
peaked at approximately 11 am, and that for precautionary landings at about 12 midday.

**6.2.6. Absolute and relative flight distances**

It is possible that different types of weather-related decision making behaviours may be associated with different absolute or ‘relative’ flight distances. For example, are certain pilot behaviours more evident on shorter flights as compared to longer flights, or will there be an increasing propensity for pilots to “press on” into deteriorating weather as they approach their destination?

Detailed flight plan information was not available for most of the cases in this study. However, the OASIS database contained several data fields that could be used to calculate approximate measures of absolute and relative flight distances. The information available included the point of departure of the flight, the destination, and the location at which the accident or incident occurred.

The OASIS data fields for point of departure and destination contained text descriptions (e.g., Bankstown, NSW or Payne’s Lagoon QLD) while the actual point at which the accident or incident occurred was recorded in degrees latitude and longitude. Therefore, in order to calculate absolute and relative distances, it was necessary to derive the latitude and longitude of all the descriptive place names relevant to the data set. This was done using the Geoscience Australia Gazetteer of Australia 2002 (http://www.ga.gov.au) compilation of Australian geographic names. The latitude and longitude for a total of 177 place names was determined in this way. Where applicable, the latitude and longitude of the associated aerodrome, airfield, or ALA (authorised landing area) was taken, while in other cases the latitude and longitude of the town or homestead, for example, was used. In combination, the point of departure, destination, and occurrence location were available for a total of 191 cases (see Table 31).

The dataset described in Table 31 does not include 18 cases where the point of departure and the destination were the same location. In those cases, in the absence of any more detailed flight plan information, it was not possible to calculate flight distances.

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60 The term ‘relative’ flight distance refers to measures such as the proportion of the total flight distance completed at the point that the accident or incident occurred.
Table 31. Number of valid cases for location variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude and longitude of accident or incident</td>
<td>287</td>
</tr>
<tr>
<td>Point of departure</td>
<td>204</td>
</tr>
<tr>
<td>Destination</td>
<td>233</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>191</td>
</tr>
</tbody>
</table>

**Calculation of flight distances**

For the calculation of flight distances, it was assumed that flights were planned over the shortest distance between ‘point A’ and ‘point B’. While this will not be true in all cases, experience and anecdotal evidence suggests that it is a reasonable assumption for many of the general aviation type flights typical of this study. Importantly, there is no a priori reason to believe that the assumption will apply differentially to the three weather-related decision making groups compared in the study.

Flight distances were calculated from the latitude and longitude of the relevant locations using the great circle distance formula. The great circle distance ($D$) between two points, $(\text{lat}_1, \text{long}_1)$ and $(\text{lat}_2, \text{long}_2)$, is given by,

$$D \text{ (km)} = 1.852 \times 60 \times \text{Arcos} (\sin(\text{lat}_1) \times \sin(\text{lat}_2) + \text{Cos}(\text{lat}_1) \times \text{Cos}(\text{lat}_2) \times \text{Cos} (\text{long}_2 - \text{long}_1))$$

where:
- latitude and longitude are given in degrees
- south latitudes are negative, and east longitudes are positive
- 1 minute of arc is 1 nautical mile
- 1 nautical mile is 1.852 km

The great circle distance between two points is a calculation based on spherical trigonometry. That is, it calculates the shortest distance between two points on the surface of a sphere. As such it is an approximation that does not allow for the fact that the earth is not a perfect sphere. However, the great circle formula is estimated to have an accuracy of approximately 1 km over a distance of 500 km, well sufficient for the purposes of this study.\(^6\)

**Absolute flight distances**

The following absolute distances (in kilometres) were calculated for the purposes of this study,

\(^6\) More accurate methods are based on approximations of the earth as a spheroid or an ellipsoid. For example, Vincenty’s formulae (Vincenty, 1975) produce results with millimetre accuracy over thousands of kilometres.
Total planned flight distance

The total planned flight distance (FLIGHT_DIST) for all flights in the dataset ranged from approximately 30 kilometres to over one thousand kilometres (4 cases). The frequency distribution of total flight distances is shown in Figure 83. The mean flight distance was approximately 400 km, and the median flight distance was approximately 350 km.\(^\text{62}\)

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\(^{62}\) Approximate flight distance estimates for all private general aviation flights based on data from the Australian Government AVSTATS 2002 flying activity survey (John Streeter, private communication) were as follows: range of flight distances from 30 km to 1,148 km, mean 227 km, median 193 km, \(N = 1,568\). The estimated mean and median flight distances will be shorter in this case as the data includes circuit training and training area flights, as well as cross-country flights.

\(^{63}\) The variables FLIGHT_DIST, FROM Pod and TO_DEST were transformed by the square root function to normalise their respective distributions. However, the same pattern of ANOVA results was obtained using non-transformed variables.
flight had any differential influence on pilots' weather-related decision making behaviour.

**Distance from point of departure**

The distance from the point of departure at which the occurrence took place (FROM_POD) ranged from 0 to over 1,000 kilometres (one case). The median distance was 138 km and the mean distance 205 km.

Figure 84 shows the distribution of 'point of departure to occurrence' distances relative to the number of flights of that distance or longer. Without such a correction for baseline activity the apparent percentage of flights would decrease across the distance groups simply because there were less flights of longer distances. That is, it would predominantly reflect the underlying frequency distribution of flight distances shown in Figure 83, rather than any relationship between weather occurrences and distance from point of departure.

![Figure 84](image.png)

Figure 84. Distance from point of departure to occurrence location for all occurrences.

Although Figure 84 suggests a somewhat greater representation of occurrences in the 0-100 km distance group, the overall variation across distance groups was not significant (chi-square(6) = 10.02, p=0.124). Closer inspection of the 0-100 km group in 20 km increments did not reveal any significant variation. Further inspection of the 0-20 km sub-group in 5 km increments showed 12 cases in the 0-5 km sub-group and
approximately 3 cases in each of the other three sub-groups (5-10, 10-15, and 15-20 km).

A comparison of the three weather-related decision making groups (V, WP, and WA) in relation to the distance from the point of departure to the occurrence location did not indicate any significant difference between the three groups ($F(2,201) = 1.415$, $p = 0.245$).

**Distance to planned destination**

The distance from the planned destination at which the accident or incident occurred (TO_DEST) ranged from 0 to over 1,000 kilometres (2 cases). The median distance was 96 km and the mean distance 168 km.

Figure 85 shows the distribution of ‘point of occurrence to destination’ distances relative to the number of flights of that distance or longer. That is, the proportion of flights in each group is corrected for the underlying frequency distribution of overall flight distances (see Figure 83).

![Figure 85. Distance from occurrence location to planned destination for all occurrences.](image)

The overall variation of across ‘distance to destination’ groups was significant ($\chi^2(6) = 42.65$, $p = 0.000$). As shown in Figure 85 there was a greater representation of weather-related occurrences within the 0-100 km and > 750 km groups. The result of a greater number of weather-related occurrences in the 0-100 km group can be taken as robust as this represents an actual total of 120 cases (more than in any other
group). The result for the > 750 km group should be treated with caution as this represents a total of only 6 cases before correction for flight distance frequency.

Closer inspection of the 0-100 km group in 20 km increments did not reveal any significant variation across sub-groups. Similarly, further inspection of the 0-20 km sub-group in 5 km increments did not reveal any significant variation across sub-groups.

A comparison of the three weather-related decision making groups (V, WP, and WA) in relation to the distance from the occurrence location to the planned destination showed a significant difference between the three groups ($F(2,230) = 3.258, p = 0.040$). The data indicated that the location of weather avoidance occurrences was furthest from the planned destination, followed by VFR into IMC occurrences, with precautionary landing occurrences being closest to the planned destination (see Table 32). However, post hoc tests (Tukey’s HSD) did not produce significant pairwise comparisons at the 5% level, the highest level achieved being that between WA and WP ($p = 0.061$). This result follows from the considerable variation within the groups, as indicated by the standard error of the mean values shown in Table 32.

Table 32. Statistics for TO DEST (km distance from point of occurrence to planned destination).

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>SEM</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>VFR into IMC (V)</td>
<td>149</td>
<td>161</td>
<td>16.5</td>
<td>79.7</td>
</tr>
<tr>
<td>Precautionary landing (WP)</td>
<td>21</td>
<td>102</td>
<td>43.8</td>
<td>86.7</td>
</tr>
<tr>
<td>Weather avoidance (WA)</td>
<td>63</td>
<td>208</td>
<td>25.3</td>
<td>152</td>
</tr>
<tr>
<td>All groups</td>
<td>233</td>
<td>168</td>
<td>13.2</td>
<td>96.3</td>
</tr>
</tbody>
</table>

The median distance values for the V and WP groups were similar, in contrast to the median for the WA group which was far greater. Hence, overall, it can be concluded that pilots in the weather avoidance group took action much further from their destination than pilots in either of the other two groups.

**Relative flight distances**

As well as absolute distance measures, as analysed in the preceding section, it is possible that a pilot’s decision making behaviour could be influenced by what can be described as ‘relative’ distance measures. For example, what proportion of the total flight has been completed at a particular point, or whether the flight has passed the half-way point of the planned journey.
To some degree, a pilot is likely to mentally measure their progress in terms of the proportion of the journey completed, irrespective of the absolute distance covered. For example, as the flight progresses the focus of the pilot’s thought and attention will shift gradually from the point of departure to the planned destination. Indeed, the half-way point of the flight may feel like a psychological 'turning point' that assumes a greater relevance than would be expected simply due to the distance in absolute terms from either the point of departure or the destination.

The following relative distances were calculated for the purposes of this study,

\[
\begin{align*}
\text{HALFWAY} &= 0 \text{ if } \text{PCNT\_FD} < 50 \text{ (less than half-way)} \\
&= 1 \text{ if } \text{PCNT\_FD} \geq 50 \text{ (more than half-way)} \\
\text{PCNT\_FD} &= \text{ 'percent of flight distance' travelled at point of occurrence} \\
&= 100 \times \text{FROM\_POD} / \text{FLIGHT\_DIST}
\end{align*}
\]

**Point of occurrence before or after the mid-point of the flight**

The variable HALFWAY was constructed to investigate whether pilots' weather-related behaviour varied significantly before or after the psychological 'half-way' point of their planned flight.

**Table 33. Proportion of all occurrences before and after mid-point of flight.**

<table>
<thead>
<tr>
<th>Location of occurrence</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before mid-point of flight</td>
<td>74</td>
<td>38.7%</td>
</tr>
<tr>
<td>After mid-point of flight</td>
<td>117</td>
<td>61.3%</td>
</tr>
<tr>
<td>Total</td>
<td>191</td>
<td>100%</td>
</tr>
</tbody>
</table>

Overall, the majority of occurrences (approximately 61%) occurred during the second half of the flight (see Table 33). This result was statistically significant (chi-square(1) = 9.68, p = 0.002).
There were significant differences between the three weather-related decision making groups in terms of the occurrence location before or after the mid-point of the planned flight (chi-square(2) = 7.86, p = 0.020). The greatest difference was for the precautionary landing group, where 74% of the occurrences were during the second half of the flight. VFR into IMC occurrences also occurred predominantly during the second half of the flight (66%). However, in contrast, for the weather avoidance group the majority of occurrences (55%) took place during the first half of the flight (see Figure 86).

**Proportion of planned flight completed at point of occurrence**

The significant HALFWAY results were examined in further detail by analysis of the PCNT_FD variable, the proportion of the planned flight that had been completed at the point of the occurrence.

PCNT_FD values ranged across the full spectrum, from 0 to 100% of the planned flight distance. The distribution of occurrences showed a slight over-representation in the 0-10% distance group, less than expected occurrences across the range 10 to 50%, and a greater than expected proportion of occurrences during the second half of the flight (see Figure 87), as indicated by the HALFWAY results described above.
A comparison of the three weather-related decision making groups (V, WP, and WA) in relation to the percent of flight distance completed at point of occurrence indicated a significant difference between the three groups ($F(2, 188) = 6.133, p = 0.003$). The same pattern of results was also shown for median values (see Table 34).

Table 34. Statistics for PCNT FD (percent of flight distance completed at point of occurrence).

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>SEM</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>VFR into IMC (V)</td>
<td>123</td>
<td>57.6%</td>
<td>2.60%</td>
<td>60.8%</td>
</tr>
<tr>
<td>Precautionary landing (WP)</td>
<td>19</td>
<td>63.8%</td>
<td>6.62%</td>
<td>71.4%</td>
</tr>
<tr>
<td>Weather avoidance (WA)</td>
<td>49</td>
<td>42.2%</td>
<td>4.12%</td>
<td>39.9%</td>
</tr>
<tr>
<td>All groups</td>
<td>191</td>
<td>54.3%</td>
<td>2.74%</td>
<td>59.8%</td>
</tr>
</tbody>
</table>

Post hoc tests (Tukey’s HSD) indicated a significant difference between the weather avoidance group (WA) and the other two groups (V and WP). On average, weather avoidance action was taken during the first half of the flight while VFR into IMC and precautionary landing accidents or incidents occurred during the second half of the flight.
Figure 88 shows in detail how pilot flying behaviour varied as a function of the proportion of planned flight distance that had been completed. The pattern for each of the three weather-related decision making groups was distinctly different. The VFR into IMC graph (top right panel) shows that relatively few cases of this type of occurrence were associated with the early part of the flight. The lowest percentage in any group was 12.2% of occurrences in the 20-40% flight distance group. However, as the flight then progressed the chances of a VFR into IMC encounter increased until they reached a maximum of 27.6% during the final 20% of the flight distance. This pattern suggests an increasing tendency on the part of pilots to 'press on' as they near their goal. To turn back or divert when the destination seemed ever closer became progressively more difficult.

Figure 88. Percent of flight distance completed at point of occurrence by group (All, V, WP, WA).
The distribution of precautionary landing occurrences across the flight profile was very distinct (Figure 88, bottom left panel). Over half of this type of occurrence (52.6%) occurred within the 60-80% flight distance group. The proportion of occurrences before this point was low - 10% or less in each group. This pattern suggests these pilots initially postponed taking action in the face of adverse weather, as did those in the VFR into IMC group, but that as pressure to resolve the situation grew they finally took positive action rather than just pressing on and hoping for a favourable outcome.

The distribution of occurrences across flight distance for the weather avoidance group (bottom right panel) was markedly different to the other two groups. Weather avoidance was the only group in which the largest proportion of occurrences took place early in the flight - 30.6% in the 0-20% flight distance group. From that point onwards, the proportion of occurrences in each distance group decreased or stayed constant at a low level (16.3% for each of the 40-60%, 60-80%, and 80-100% distance groups). Hence, in contrast to the VFR into IMC and precautionary landing groups, pilots in the weather avoidance group were distinguished by taking action in a timely manner.

A discussion of the work outlined in this chapter is included in Chapter 8.
7. Understanding pilot weather-related behaviours

The previous chapter outlines the identification of three groups of pilots that exhibited different behaviours in the face of adverse weather. As outlined, the three weather-related decision making groups varied significantly in a number of ways. To complement the quantitative data analyses, an examination was made of any accident investigation files that had been raised in relation to the occurrences in the weather-related decision making dataset. This was done to obtain any relevant qualitative information that could supplement and help explain the quantitative results.

7.1. Investigation file source material

The principle types of information held on investigation files that were likely to be relevant to the current study were:

- pilot interview or report
- investigator comment, information and/or analysis
- assessment/description of the pilot by CFI, instructor or other pilot
- witness reports of conditions at the time of the occurrence
- passenger interviews or reports

However, OASIS file management records showed that an investigation file had been raised for only 36 of the occurrences in the weather-related decision making dataset. These related mainly to the more serious occurrences – accidents and particularly fatal accidents (see Table 35).

Table 35. Occurrences with information held on investigation file.

<table>
<thead>
<tr>
<th>Weather-related decision making group</th>
<th>Investigation files</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal accident</td>
</tr>
<tr>
<td>VFR into IMC (V)</td>
<td>13</td>
</tr>
<tr>
<td>Precautionary landing (WP)</td>
<td></td>
</tr>
<tr>
<td>Weather avoidance (WA)</td>
<td></td>
</tr>
</tbody>
</table>

In nine cases, although an investigation file had been raised, the file could not be located in the archives. Hence, a total of just 27 investigation files were available.
Any qualitative information that might aid in the understanding of the pilot's decision making processes was extracted and assessed. Only 18 available files contained relevant information, and the majority of these files related to VFR into IMC occurrences. This reflects the fact that these occurrences are more likely to result in an accident, and possibly a fatal accident, than a weather avoidance or precautionary landing occurrence. Therefore, more investigation resources are typically applied to a VFR into IMC occurrence, leading to more factual information being gathered, and the information being analysed in greater depth.

Excerpts from the information held on the investigation files are given below. Because of the paucity of qualitative information, it was not possible to carry out a systematic comparison of the three weather-related decision making groups. However, the material presented is illustrative and raises a number of issues which are discussed in Chapter 8.

7.1.1. VFR into IMC occurrences

Occurrence A

In this occurrence, the pilot and his two passengers were lucky to survive a VFR into IMC encounter. Information obtained from the pilot during the investigation points to a number of issues. It would appear that the pilot did not have the experience necessary to adequately assess the weather conditions he faced, and that in general, he had a poor appreciation of the how the situation developed and of his own decision making behaviour.

It is possible that the small amount of instrument training that the pilot had done may have given him a false sense of his own proficiency in that regard. Also, the pilot might have learned the wrong lesson from a recent encounter with weather that had a successful outcome. In that situation, the pilot also climbed above cloud, and after requesting assistance from ATC was able to complete the flight safely.

The pilot was training for a CPL and had done a small amount of basic instrument flying. During the flight the pilot could see signs of developing cloud and amended the planned route. When asked for specifics on the cloud he could see the pilot was unable to say, other than there was some cloud above, which in summary was probably broken cover.

A climb was initiated and the pilot called the radar advisory service. His recollection of critical events from then was very

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64 Some excerpts have been edited for clarity and to preserve anonymity.
65 To ensure the confidentiality of restricted file information, the occurrence numbers used in this section have been altered to negate the possibility of matching information presented here with the occurrence summaries given earlier in this chapter.
vague. He said he applied climb power. He does not know how it happened but he became aware he was descending and in cloud. At one stage he saw the VSI was on or near 2000 FPM. A head set and boom mike were worn and he made a broadcast that he was upside down. He used the turn and slip to level the wings and closed the throttle. They came out of cloud with the nose well down, IAS about 130 kts. There were trees not far below and he thought he would crash into these. The nose was raised and power applied to regain safe level flight.

On another flight about three months previously he had encountered some cloud when tracking south of the [A] area. He had climbed to 9,000 feet and on request was given tracking assistance to fly on top of cloud to its destination.

(Occurrence A investigation file)

Occurrence B

In this fatal VFR into IMC occurrence, the aircraft was trapped by a combination of bad weather and the rising terrain of a river valley. It is possible that the pilot mis-identified the valley into which he flew because of the deceptive appearance of the valley entrance. The forecast weather for the flight did not preclude VFR flight. The pilot had flown through the same area in good weather at least once before.

The CFI described the pilot as a very dedicated young flyer who held down two jobs to pay for his flying training. His next objective was the Commercial Licence. He was also attending TAFE studying the ATPL subjects. The CFI said that he did not understand why the pilot had not telephoned him when the flight was delayed due to weather.

It would reasonably be expected that the pilot would contact his instructor. This would include the concept of a flight to check the accuracy of the weather forecast. Why the pilot failed to contact his instructor is not known, but it may reflect upon his confidence in his own ability to make weather judgements.

(Occurrence B investigation file)

As the flight into the river valley progressed the pilot was faced with a situation most likely beyond his capability and experience.

At some point the pilot proceeded beyond a point of no return, a point beyond which the aircraft could not safely conduct a 180 degree turn and retrace its path. That point varied with airspeed; radius of turn being proportional to the square of TAS. Given the rugged nature of the mountainous
terrain this point along the flight path would have been a very difficult assessment for even an experienced pilot.

The configuration of the aircraft at the time of impact was gear and flap retracted. This indicated the pilot did not appreciate the importance of flying at a reduced IAS in conditions of poor visibility to increase manoeuvrability. The rapidity with which the situation deteriorated for the pilot is indicated by the absence of flap selection. It would appear, however, that the pilot had sufficient time to close the throttle and pull up to reduce speed.

(Occurrence B investigation file)

The speed with which the situation overtook the pilot was most likely exacerbated by his inexperience on a relatively high performance aircraft type. This would have been a particular problem once the flight entered a region of deteriorating weather.

The pilot had very limited experience. He completed his endorsement on the aircraft type two days before the accident and had less than three hours flight time on type prior. Operation of the Trinidad represented a major step up in aircraft performance for the pilot whose prior experience was confined to C172 and PA 28 types. The Trinidad cruised about 50% faster than types the pilot had previously flown. In conditions of VMC where an aircraft is cruising at moderate altitudes well clear of terrain, the increased ground speed would be relatively insignificant. However, in marginal weather conditions and mountainous terrain, the increased cruise speed becomes a major factor in the safe operation of the aircraft.

(Occurrence B investigation file)

**Occurrence C**

In the following fatal VFR into IMC occurrence, there was evidence that the pilot may have been attempting a precautionary landing at the time of the accident but lost control of the aircraft at low level.

A witness reported that the aircraft was flying in and out of the mist and behind trees as it orbited. At one stage the aircraft tightened the orbit, 45 degrees of bank, and appeared to be making an approach to the paddock next to their house. The pilot eventually gave it away. A short time later they heard a thud that sounded like a large branch on a tree breaking.

The mode of impact indicated that the loss of control had occurred at low altitude. The fact that the accident site was located in a large grassed paddock may indicate that the
pilot lost control whilst manoeuvring for a landing in the paddock. An inspection of the wreckage indicated that the landing gear and flap were extended, the battery and generator switches had been selected off and although the engine was producing power it was throttled back. These selections are also an indication that the pilot was preparing to land and he was unsure of the final result so he had attempted to reduce the risk of fire after impact.

(Occurrence C investigation file)

Again, evidence was found that the pilot had a history of VFR into IMC flight.

The CFI said that the pilot had demonstrated a more than adequate technique in the aircraft. He said that although the pilot was very fastidious with his preparation and maintenance on the aircraft he had a tendency to be over-confident. It was known that if he thought that he could get to the destination by flying through cloud he would, providing he knew that he could find his way safely to below cloud at the end of the flight.

(Occurrence C investigation file)

A final investigator comment on the file gives an insight to the approach often taken in relation to general aviation VFR into IMC accidents. Once the basic facts of the accident have been established it is often considered that there is little safety benefit to be gained from further investigation.

There are no new significant safety aspects to this accident.

(Occurrence C investigation file)

Occurrence D

In this occurrence, a relatively inexperienced pilot, training for a commercial licence, was nearing the end of an extended journey of cross country flights through several States and lasting a number of days.

The pilot was on an extended cross country flight over several days with the object of achieving the minimum 100 hours pilot-in-command time required for the issue of a Commercial Pilot Licence. The pilot contacted FIS and requested clearance to climb from 3,000 to 6,000ft. The aircraft was later cleared by Adelaide Approach to descend when ready and maintain 1,000ft AMSL. The pilot advised that they were commencing descent immediately although over 50km from the airport. The aircraft was observed on radar to level at about 1,000 ft then commence a steepening descending left turn until it was lost from the radar at about 300ft AMSL. The accident appears to be a loss of control at too low a level for recovery when an inexperienced VFR pilot
become disorientated when entering IMC at the end of a relatively long and difficult flight.

(Occurrence D investigation file)

**Occurrence E**

A combination of fatigue and pressure to make the flight so that the aircraft would be available for another booking possibly contributed to the following fatal VFR into IMC accident in which the aircraft was destroyed but the pilot survived.

The pilot was aware that the aircraft was booked for flying over the weekend and was probably under some pressure to deliver the aircraft. The pilot reported for work at 0900 and worked until 1500. He obtained weather briefings at 2330 at which time he went to sleep. He then woke at 0230 and drove to the airport. In effect, at best the pilot was awake a period of 16.5 hours (from 0700 to 2330) then rested for 3 hours before initiating a journey of 12 hours.

(Occurrence E investigation file)

**Occurrence F**

The pilot involved in the following fatal VFR into IMC accident had reportedly flown in poor weather conditions on a number of previous occasions, and had not lodged a flight plan for years. A passenger, who survived, was also a private pilot.

The passenger could not remember seeing any flight planning information (such as weather or flight plan or map for visual navigation) on the aircraft. The passenger said that start, taxi and takeoff appeared normal. They then headed south along the coast just below the cloud. The passenger recalled that at this stage the aircraft was heading for the hill at [X]. He could see that there was cloud on the top section of the hill. There was slight wispy cloud ahead but he could see the ocean clearly out on the left side of the aircraft.

The passenger said that he was concerned at what was happening and considered taking control of the aircraft and turning towards the ocean. However, at the same time, he was aware that the pilot was very experienced and did not appear in any way troubled. The pilot seemed very calm throughout the flight, showing no apparent concern as the flight progressed. The passenger said that the last thing he clearly remembered was seeing trees 30 feet below the aircraft. He had a vague recollection of the pilot pulling back on the control column at the very last instant but could not be certain that this happened.

(Occurrence F investigation file)
Occurrence G

The pilot involved in the following VFR into IMC flight had survived a previous loss of control incident when he allowed his aircraft to enter conditions that he was not equipped to handle. It is possible that a contributing factor in this subsequent, and fatal, accident may have been that the pilot became psychologically ‘locked in’ to flying a particular track that he had entered into the GPS.

A friend of the pilot reported that on one occasion they were trapped above cloud and were forced to climb to 11,000ft to stay visual above the cloud. During the descent through cloud, the horn sounded on a number of occasions and he thought that they had been on their back before regaining control. He was aware that the pilot did not have an instrument rating. This episode demonstrates a willingness on the part of the pilot to continue flight into IMC and a degree of overconfidence.

The pilot had scheduled business in [A]. The crash site was situated below the direct IFR track between [B] and [C]. It is possible that the pilot had this route entered in the GPS.

(Occurrence G investigation file)

Occurrence H

In the following fatal VFR into IMC occurrence, the aircraft crashed in reported heavy rain and low cloud with lightening and thunder observed. In his final radio transmission, the pilot reported to FIS that he was descending to 3500 due to cloud. Pilot did not sound stressed during the transmission. A witness reported hearing the aircraft circling for about ten minutes before the crash.

The instructor who carried out the pilot’s last BFR said that the pilot was a quiet type but sometimes indicted that he thought he knew more than others. He probably had to watch his money and had objected to doing a NAVEX as part of the BFR on the grounds of cost. His paperwork was well done and his flying okay. They only talked about IMC and did no IFR flying. He said that after seeing the ARFOR, he did not think the pilot would fly in such poor weather conditions. He had talked with the pilot about the autopilot and IF flying but did not know if he used the autopilot or the GPS and would be surprised if he deliberately flew into cloud. They had talked about getting weather and NOTAMs and he had heard someone say that the pilot had bought a fax for that purpose.

(Occurrence H investigation file)
Occurrence I
In the following incident, the VFR pilot inadvertently entered cloud, and while manoeuvring to regain visual conditions the aircraft struck the top of a tree, damaging the landing gear. The aircraft subsequently landed safely. It is not entirely clear what lesson the investigator of the incident felt that the pilot had learnt from his near escape.

The pilot who advised that this incident was not one of the aircraft inadvertently flying into cloud but was really one of cloud forming around the aircraft. He advised that he was in a valley and was what he believes well clear of cloud, when he became disoriented because he suddenly lost all outside reference. He realises now that the safest option would have been to climb on instruments, but as was not an instrument pilot, he natural reaction was to descend to get out of the cloud. He has learned a valuable lesson from this incident.

(Occurrence I investigation file)

Occurrence J
Fatigue and the use of prescription drugs may have been a factor in the following fatal VFR into IMC accident.

The flight instructor who taught the pilot to fly about 10-12 years ago said that he was an average pilot. The instructor believes the pilot has not done a BFR since receiving his licence. Suggested that pilot may not be flying legally - no current BFR.

The pilot was a medical practitioner in private practice as well as being ‘on call’ part-time at [X] Hospital with a high workload. It was reported that the pilot did not sleep at all the night prior to the accident, and gained only poor sleep the night before to that. Post-mortem toxicological results indicated the presence of the drugs Diazepam and Norpropoxyphene. Fatigue, together with the effects of the drugs detected in the pilot’s blood, may have impaired his ability to make appropriate decisions during the flight, or to recognise a dangerous situation developing.

(Occurrence J investigation file)

Occurrence K
In the following fatal VFR into IMC occurrence the pilot had initially departed in the morning but returned a short time later due to low cloud along the planned route. The aircraft was subsequently refuelled and departed again that afternoon.

The pilot phoned an automatic weather service twice for information and a friend called him shortly before the flight
with an appreciation of the weather at the destination and what could be seen along the flight path. The decision to commence the flight with the weather information was not unreasonable, with a continuing possibility of returning if the weather had been found to be unsuitable en route. An escape route was available to the pilot until almost immediately before he entered cloud.

(Occurrence K investigation file)

A report from a passenger that survived the accident indicated that the aircraft entered cloud only a short time before the crash.

The passenger said that they had been going 10 degrees to the left to avoid cloud, and then suddenly entered cloud. They had gone through some rain for about 15 minutes earlier in the flight, but they were not in rain just before they entered cloud. They had been flying up the right side of a valley before they entered cloud. The aircraft appeared to go quiet after they had entered cloud, and then they saw the trees, and the pilot said that he couldn't keep it up, and then they hit the trees. They had seen a valley, and a clearing and he thought that they were going through there, and they crashed soon after. He said that they were in cloud for only a very short period before he saw the trees.

(Occurrence K investigation file)

**Occurrence L**

Weather conditions at the time of the following VFR into IMC fatal accident were reported as low visibility with cloud and mist. A witness reported hearing the aircraft circle twice in a left turn with the second orbit lower than the first and with the engine noise louder. Following that, there was a distinct sound of impact and then silence.

There were conflicting reports about the pilot's attitude to flying in poor weather and his previous behaviour in that regard.

The instructor who had conducted most of the pilot's flying training said that he was a pilot that flew within his limitations of competency and experience. He did not think he was the type to push weather. The pilot had previously aborted flights due to weather and had landed short of his destination on a previous occasion due to poor weather.

(Occurrence L investigation file)

In contrast, information supplied by the CFI and a report by two other pilots painted a somewhat different picture.

The CFI said that since the accident he had taken the opportunity to speak to some of the pilot's work associates.
Most agreed that he was thorough and safety conscious. However, one person commented that he was a determined sort of person. The CFI wondered if by that he may have meant he was single-minded and not likely to be swayed from a course of action once he had decided upon it.

It was reported that two experienced private pilots that had flown with the pilot concerned considered his flying to be extremely dangerous at times. They felt that the pilot concerned would kill himself and anyone else that may be airborne with him.

(Occurrence L investigation file)

This accident raises the issue of the adequacy of cross-country flight training that is conducted almost entirely in good weather. If a pilot has never had the opportunity to confront poor weather in a supervised and structured manner then they may not be equipped with the necessary skills and knowledge to adequately deal with hazardous weather situations they may encounter.

It was possible that the pilot did not realise just how bad conditions were until after he entered the area of rain approaching [B]. By then he was already in hilly terrain and probably busy trying to remain in visual contact with the ground, fly the aircraft and navigate.

The pilot's training was reported to have been conducted in mostly ideal weather conditions. It was reported that navigation training was such that poor weather could interfere with an exercise and frustrate the student, as well as add to the cost if a navex had to be repeated. Ab-initio training was carried out away from the hills and was unlikely that the pilot would have known about the existence of landing grounds in the [B] area.

This may well have been the pilot's first encounter with marginal VMC weather and his recognition of the deteriorating conditions may not have been adequate to respond appropriately.

(Occurrence L investigation file)

Occurrence M

The pilot and his passenger were killed in the following fatal VFR into IMC accident. The weather at the time was reported to include extensive areas of low cloud, estimated at 6-7 OKTAS, at a height of about 300-500 ft, with scattered lower patches. The tops of the low hills in the region were completely obscured by low cloud. Visibility was about 6,000 metres, reducing to about 500 metres in rain showers and mist.
Two independent witnesses reported that the pilot had flown in poor weather in the past.

A pilot colleague said that he felt that if the pilot inadvertently encountered IMC, he would approach the problem logically, and not encounter an immediate accident. He felt that the pilot would push through a limited quantity of IMC, if he felt that this was his best option. He suspected that if the pilot had arrived at [A] in marginal weather, then he would have held in the area for a while, waiting for an improvement in the weather. The colleague said that the aircraft had a moving map GPS and that the pilot normally flew the aircraft using the autopilot. He said that the pilot had grumbled recently because he used to get weather information for free from AVFAX, but it now cost. He hadn't got a phone card yet for getting weather.

Another friend of the pilots who had flown regularly with him interstate said that they had flown through poor weather in the past, once accidentally getting into the middle of a storm which he didn't like, but the pilot seemed to handle OK.

(Occurrence M investigation file)

Again, the investigation file concludes that no safety benefit would be gained by additional investigation.

No further benefit could be identified from further investigation, so the report will contain the story identified here, with no intent for future safety action.

(Occurrence M investigation file)

**Occurrence N**

The aircraft in the following VFR into IMC accident crashed in inaccessible mountainous country. The pilot survived the impact and was fortunate that searchers located the accident site before he died from injuries and exposure.

The report of a witness provides a classic description of an accident scenario that is repeated many times.

The witness said that he caught a glimpse of the aircraft as it went between clouds or fog. The aircraft was turning west toward the mountain. He hoped that the pilot knew that the escarpment rose approximately 500 meters ahead of him. He thought that the aircraft would turn east toward the coast. He indicated that he heard the engine revs increase and approximately five seconds later he heard the sound of a crash. There was no explosion just the sound of a quick thud.

(Occurrence N investigation file)
7.1.2. Precautionary landing occurrences

Occurrence O
The following occurrence illustrates one of the dilemmas of carrying out a precautionary landing. The pilot initially delayed making a decision to divert or turn back, but then decided that carrying out an immediate precautionary landing was the safest course of action, even if it resulted in an accident, which it did in this case. They rightly considered that risking a precautionary landing was preferable to pressing on into adverse weather, with the likelihood of an even more serious result involving death or serious injury.

Prior to departing the pilot waited for the weather to clear before attempting the flight. En route he obtained a favourable weather report for his destination. However, the weather en route deteriorated and he made a decision to land. During the approach the pilot decided that it was better to continue the approach than risk a go-around in poor weather conditions and the possibility of entering IMC. The outside conditions did not improve on final and the drizzle on the windscreen made it difficult to see but was able to make out the length of the landing area. The ground was rough and the landing gear collapsed and the left wing and engine were torn out. The cabin area of the aircraft remained intact and the pilot was uninjured. The decision to land appears sensible in the circumstances, although it would have been prudent for the pilot to have taken a decision to discontinue the flight earlier rather than continuing into inclement weather.

(Occurrence O investigation file)

Occurrence P
The following occurrence illustrates a number of successive weather-related decision making behaviours, culminating in a precautionary landing that resulted in some damage to the aircraft but no injury to the pilot or passengers. In the successive stages of the flight the pilot;

1. obtained up-dated weather information during the flight
2. varied the planned route as a result of the new weather information
3. landed to refuel to increase flight endurance for turning back or diverting
4. varied the planned route as a result of the weather enroute
5. landed and waited for the weather to improve
6. planned the next stage of flight to assess the weather ahead
(7) turned back when non-VMC conditions were encountered
(8) carried out two 360 degree orbits to assess the situation
(9) configured the aircraft for a low speed bad-weather circuit
(10) carried out a precautionary landing

As I reached a point about thirty five miles abeam [A], I called flight watch for a weather update for area 20. Upon receiving this new information I decided to approach the ranges ahead from the area of [B]. I landed in [A] for more fuel since the weather situation allowed for the possibility that may necessitate turning back or further diversion.

I took off from [A] and tracked towards [B]. About thirty miles from [B], I saw that the weather over the ranges looked better further south, so flew in that direction. I had to track further south due to weather in the north of my position; and after a uneventful crossing of the ranges came out on the eastern side near the [D] area. I decided to land at [D] aerodrome and wait for a while as the weather looked bleak to the north along the coast. After about forty minutes at the [D] aero club I observed the weather to the north clearing. I looked south and saw that the weather was not deteriorating, nor was there any sign that the weather would deteriorate at [D] and decided to take off for [E] and go that far at any rate and see how things were further north and east from that point.

Twelve miles south of [E] I made a 180 degree turn and tacked back to [D] as had I gone further, I would not have been able to maintain flight VMC. At a point of approximately fifteen miles north of [D] the weather started to close in in all directions. The ceiling in the vicinity also became much lower. I made a complete 360 degree turn to survey the weather in all quarters to find that there was no place to go. I made another 360 degree turn bringing my aircraft down to a slower speed with 20 degrees of flaps so that things didn’t happen too quickly. In other words so that I could manoeuvre safely. At this point any direction that I would have chosen to fly would have caused me to fly into IMC.

I made a turn to align the plane with the paddock I had chosen to land in and set up for a precautionary landing. The paddock had long green grass and looked safe. As I touched down the plane nosed in and flipped over on it’s back. I got out and helped my passengers out. Nobody was hurt, only shaken. We made our way to a farm house about
one kilometre away. The going was very hard as we found that under the grass which was about half a metre long there was water about half a metre deep. This hidden water was probably what caused the plane to nose in.

(Occurrence P investigation file)

The report of this occurrence indicates that the pilot was continually assessing the weather enroute and modifying their flight plan accordingly. However, not withstanding this proactive decision making, the flight ended in a precautionary landing, and from the pilot’s own description, could just have easily ended as a VFR into IMC occurrence. The result could easily have been a fatal accident, and an investigation report that described the pilot’s behaviour as being typical of VFR into IMC occurrences.

This example emphasises the dynamic nature of weather-related decision making. A pilot may make a series of good decisions, but that is no automatic protection against a subsequent poor decision putting the safety of the flight at risk. The flight is only ever as safe as the pilot’s last decision.

7.1.3. Weather avoidance occurrences

Occurrence Q

In the following weather avoidance occurrence, the pilot climbed to above 10,000 feet to avoid cloud, using supplemental oxygen. When weather conditions did not improve, the pilot contacted Flight Service for information, and subsequently diverted and descended in VMC. While this occurrence had a safe outcome, the conditions were such that it was possible that the flight may not have been completed safely. Again, this occurrence illustrates the sometimes tenuous connection between action and outcome.

The pilot indicated that he was initially operating VFR at 8,500 ft when it became necessary to climb to remain above cloud. He stated that the cloud tops were forecast at 8,500 and he had not expected the cloud to develop above this level. The pilot stated that although he was able to maintain his aircraft in VMC there was some wispy cloud about at his operating level.

His aircraft was equipped with supplemental oxygen and this was used for the entire time the aircraft was above 10,000 ft. The pilot became concerned when the weather conditions had not improved and a light frost appeared to be forming on the airframe. His windscreens were partially obscured and icing was starting to form on the leading edge of the wing and wing strut. He requested information on the extent of the
cloud cover as he was concerned about the prospect of descending in IMC. Upon receiving the report of broken cloud in the vicinity of [A], he elected to divert and descend in VMC. This was accomplished without further incident.

(Occurrence Q investigation file)

**Occurrence R**

In the following occurrence the pilot decided to land at a landing strip enroute when the weather deteriorated. The aircraft suffered some damage due to stock on the landing area. This outcome illustrates the increased risk of landing at an unfamiliar landing area, a consideration that pilots are likely to factor into any decision to land enroute when they encounter adverse weather.

The pilot said that he departed [A] to return to [B] about 1615. He had checked the weather and determined it was VFR all the way but continued to get updates as there was a front coming in from the west. The weather progressively worsened although [C] kept telling him it was OK VFR. Overhead [D] he decided it would be best to land till the front had moved through. He descended and made a circuit to check the wind and noticed livestock on the strip. The aircraft scared them off the strip at the upwind end and he then continued for an approach and landing. During the landing roll out some livestock moved back onto the strip in front of him. He applied full power and ballooned over them but the aircraft settled back onto the strip and he ran off the end shutting off the power but the aircraft collided with a fence bending the prop and denting the wing.

(Occurrence R investigation file)

A discussion of the work outlined in this chapter is included in Chapter 8.
8. Discussion

This thesis draws on a range of data sources and methods in order to approach the topic of aeronautical decision making from a number of different perspectives. The three main parts of the thesis report studies in the following areas:

- the role of accident and incident case histories in pilot decision making
- the effectiveness of case-based versus rule-based pilot decision training
- a comparison of different pilot behaviours in the face of adverse weather

The primary results from each of these areas are summarised below. The Discussion then attempts to draw out any themes that are common to one or more parts of the thesis. Finally, there is a brief discussion of the principal findings in terms of how they may inform future theorising, research, and/or training in aeronautical decision making.

8.1. Accident and incident case histories and pilot decision making

Accident and incident case histories feature strongly in both formal and informal aviation safety training, but there has been little analysis of the role and importance of case-based material in influencing pilots' attitudes and behaviour. One aspect of the current study, then, was to investigate the part played by case histories in pilot decision making. For example, do pilots typically recall relevant prior cases, as the Gottrora crew reported, when confronted by a critical flight situation? Alternatively, perhaps the information contained in accident and incidents reports is abstracted and integrated into pilots' store of aviation knowledge, enabling them to avoid critical incidents in the first place? The current study sought both qualitative and quantitative information to answer these questions.

8.1.1. Survey results

A wide range of pilots were surveyed for their views on the function and significance of case-based material in aviation safety and training. The survey form was distributed via the Internet and responses were received from 138 pilots around the world. The respondents were from all areas of flying, and ranged in experience from student pilots to senior professional

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66 When faced with an emergency involving both engines shortly after takeoff, the Gottrora crew reported that they recalled a previous accident in which the crew had mistakenly shut down the wrong engine (AAIB, 1990; SHK, 1993; Martensson, 1995).
pilots with thousands of hours of experience. Responses to the survey request were unstructured and the background material that they provided was used to develop a questionnaire to obtain further quantitative information, again via the Internet. Questionnaire responses were received from 409 pilots worldwide, with a combined experience of over 700,000 hours flying time.

**Evidence for the role of case-based information**

The survey results provided strong support for the theory that case-based accident and incident material plays a crucial role in pilot decision making. Overall, 66% of pilots who took part in the survey reported either that they had recalled case-based safety information at a critical flight time, or that such material had enabled them to avoid critical incidents in the first place. In addition, almost half (49%) of the pilots who responded to the survey reported recalling case-based safety information, in either a specific or general form, at a critical flight time.

The nature of the case-based information recalled by pilots varied considerably. In some cases, pilots recalled information specifically related to their particular flight operation, aircraft type or geographical location. For example, when faced with engine failure soon after take-off from Kingsford Smith Airport, Sydney, a pilot recalled a similar case in which the pilot attempted to return to land but crashed into the seawall at the end of the runway, with fatal consequences. With this vivid picture in mind, the second pilot elected instead to carry out a controlled ditching, resulting in no loss of life. In another case, a pilot who initiated a go-around during a downwind landing on a wet runway at night reported that his decision was influenced by his recollection of two previous accidents at the same location in similar circumstances.

Other pilots reported that they had recalled a 'classic' accident case history at a critical time. For example, one particular case that was cited was that of the Saudi Arabian Airlines Lockheed L-1011 TriStar accident in which all passengers and crew died from fire, when after a successful emergency landing the pilot failed to order an immediate evacuation of the aircraft. A number of pilots reported that recalling case histories reinforced the importance of 'flying the aircraft' as their number one priority. Cases that came to mind in these instances included pilots preoccupied with minor problems such as an unlatched cabin door or canopy. Some reports included details of highly specific case histories related to a particular aircraft type. For example, the pilot of a US Navy F-4 Phantom in which the airspeed indicator failed while showing a high reading, preventing the flaps from being lowered, recalled reading about a similar case and applied the same solution (breaking the glass of the
rear cockpit airspeed indicator) to enable the aircraft to be landed safely.67

While, in general, pilots' reports were described in neutral terms, in several instances, pilots reported vividly 'seeing' or 'hearing' the information that they recalled. Sometimes a brief exposure to case history material was recalled many years later, as in the case of the pilot who recalled a childhood memory of how to recover an aircraft from a spin. Eleven pilots (8%) reported that they had been influenced by general memories of prior cases relevant to their situation, in effect recalling an archetypal case history. Typically, those reports centred on common accident scenarios such as VFR flight into IMC weather or low flying. For example, several pilots reported that when faced with deteriorating weather conditions they recalled accidents that had occurred in similar circumstances and then took appropriate action such as diverting or turning back. Similarly, other pilots recalled accident case histories that highlighted the dangers inherent in flight at lower levels, again saving them from falling into the same trap.

The powerful influence that case-based material can have on pilots was clearly demonstrated by two respondents (1.4%) who described how exposure to this type of material resulted in them interrupting or curtailing their flying activities. Four other pilots (2.9%) reported that their flying behaviour had been tempered by the thought that if they didn't act in a considered and prudent manner then they may end up as the subject of a future accident case history.

The influence of timing

Seven pilots (5.1%) argued that whether or not specific case histories were recalled depended on the time frame of the critical incident that the pilot was facing. If time was very short, say in the case of engine failure on take-off, then a pilot's reaction would be based solely on training drills and standard operating procedures (SOPs). On the other hand, if there was more time for reflection, for example during a flight into deteriorating weather, then it would be more likely that recollection of past cases would influence a pilots' actions. One possible interpretation of this comparison between 'fast' and 'slow' incidents could be in terms of Rasmussen's (1983) distinction between knowledge-based, rule-based and skill-based performance.

Incidents that occur over a short time period are, by their nature, likely to be relatively well defined, rather than open-ended; for example, an engine fire, or a decision whether to eject or not. Emergency situations such as these lend themselves to solutions based on set procedures that can be

67 The Phantom has a safety interlock that prevents the flaps being deployed at an indicated airspeed above V_{FE} (the maximum airspeed for flap deployment).
well rehearsed beforehand. Hence, it is predominantly the 'fast' incidents for which pilots undertake training drills and practice SOPs. In comparison, critical incidents occurring over a longer period of time, for example a system malfunction that does not immediately disable the aircraft, or a flight in adverse weather, are less likely to be covered by a pilot's repertoire of skill-based responses.

Although this distinction between 'fast' and 'slow' events appears plausible the suggestion that a skill-based response precludes case-based input does not stand up to scrutiny. As detailed in section 2.2.1, the distinction between 'fast' and 'slow' incidents in terms of recalling prior case histories was only true for some pilots. Other pilots reported that they instantly recalled specific case histories, often with notable clarity and detail, in situations where they had just seconds to react. Analysis of the reports suggests that in these situations the case-based information supplemented, rather than replaced, the skill-based response. For example, in the case of the pilot faced with an engine failure after take-off from Kingsford Smith Airport, their immediate actions would have followed well rehearsed skill-based procedures, such as correcting for asymmetric thrust and feathering the windmilling propeller. At the rule-based level they would have been aware of the dangers of attempting to return to the runway they had just left. However, it was the case-based information that they reported strongly influenced their split second decision to ditch ahead rather than turn back. The vivid memory of the loss of an aircraft in similar circumstances was a key factor in their situation assessment, and mental simulation of the available courses of action. Hence, case-based material can be of critical importance even when the primary response is at the skill-based level.

**Proactive effect of accident and incident case histories**

As outlined above, many pilots reported that they recalled previous accident or incident case histories when faced with a critical flight situation. In those cases, the resultant behaviour of the pilots could perhaps be characterised as partly an instinctive reaction. That is, behaviour that was not under conscious control. In contrast, a number of pilots reported a more proactive effect of accident and incident case histories on their flying behaviour. In particular, 23 pilots (16.7%) reported that exposure to case-based aviation safety information had influenced the way in which they planned and carried out their flying activities. In many of those cases, pilots were consciously aware of the proactive effect of the case histories on their flying behaviour.

Some of the case histories that pilots said had influenced the way they operated involved well known "classic" accidents often used in aviation publications or in safety-related training material. For example, one case
Discussion

in point was the crash of an Eastern Airlines Lockheed L-1011 TriStar near Miami after the pilots became preoccupied with a minor malfunction and failed to adequately monitor the aircraft's height, resulting in controlled flight into terrain (NTSB, 1973). Another example cited was the crash of an American Airlines Boeing 757-223 while on approach to land at Cali, Colombia, in which errors in data entry to the flight management system were a contributing factor (ACRC, 1996).

Other pilots reported that reading case-based material had made them more wary in potentially dangerous situations, such as when manoeuvring at low altitude or when flying in a mountain pass. Some pilots reported that they had been motivated to consider, in advance, their responses to emergency situations that might arise, such as engine failure, or loss of instrument lighting at night. A number of respondents mentioned that case histories added a personal dimension to aviation safety material, hence increasing the chance that they would recall the information at the appropriate time. Finally, some pilots reported the benefits they obtained from case-based material prepared by organisations such as the armed forces and airlines from specialized databases of accidents and incidents.

Case histories not recalled

In contrast to the examples cited above, fourteen pilots (10.1%) specifically stated that in their own experience, case histories were not recalled at critical times. In several cases, respondents emphasized instead the importance of constant training and review, and of relying on standard operating procedures (SOPs) in times of emergency. In another instance, a pilot involved in a weather-related incident made the point that they were well aware of previous accidents in similar circumstances and yet, as a result of non-flying factors, still made the same mistakes. A small number of reports indicated that, for some pilots, exposure to case-based safety material did not appear to be of significant benefit to them at critical flight times. For example, one pilot stated that they regularly read aviation safety material and yet also reported that they had been involved in three weather-related incidents, during none of which did they recall being influenced by the relevant case history information.

Rule-based knowledge compilation

Sixteen pilots (11.6%) reported that, for them, the important information from case-based safety material was abstracted and integrated into their store of aviation knowledge in general, rather than being retained as individual cases. This knowledge subsequently influenced the way that they planned their flying activities or how they reacted in an emergency situation. In effect, this is a rule-based 'knowledge compilation' model of aviation expertise. Experience, both a pilot's own and that of other pilots
in the form of case-based material, results in ever more specialized production rules that cover a greater number of possible circumstances. In its most formal expression, this process codifies this safety information as changes to training drills or standard operating procedures. Overall, 20.3% of pilots reported either that in their experience case histories were not recalled, or that the information from that type of material was abstracted and integrated in a pilot's store of aviation knowledge, but that specific details were not retained.

**The importance of personal experience**

Nine pilots (6.5%) recounted a personal flying experience that had a notable effect on their subsequent flying behaviour. For example, one pilot reported an experience where they encountered bad weather and were forced to climb above cloud in an aircraft with limited instrumentation made them an avid student of meteorology. In another case, a pilot very nearly ran out of fuel during a cross-country flight and emphasized how the experience altered forever the way they planned and managed such flights. These examples demonstrate the powerful effect of personal experience as compared to simply reading about the experiences of others.

Seven pilots (5.1%) argued that the apprehension or fear resulting from actual exposure to a risky or dangerous situation made a far greater and longer lasting impression than did reading about the experiences of other pilots. As one pilot stated, reading or hearing a story about another person's experiences is unlikely to arouse the same strong feelings as being personally involved. However, as another respondent emphasized, to learn from past mistakes requires reflection and analysis. A highly experienced flight instructor observed that certain pilots tended to repeat the same errors over and over again, while others were quick to learn from their mistakes. In his opinion the pilots who learnt quickly were those with high personal discipline or a questioning attitude.

**Recognition-primed decision making**

The reports from two pilots (1.4%) described aspects of decision making that appeared to be in line with Klein's (1993) recognition primed decision model. In each case, the critical incident involved a decision to eject. Both pilots stressed the very short amount of time available in this emergency situation, and described the decision making process as one of situation assessment based on many years experience. Once the pilot had recognized crucial details of the situation they faced, the correct course of action was very clear.

However, as noted above, only a very small number of respondents volunteered this type of description of the decision making process, with its emphasis on the crucial nature of situation assessment. This was true
even though many of the respondents had accumulated vast aviation experience. Whether this result is a true reflection of the importance of the recognitional aspects of expert decision making, or whether it simply reflects some artefact of the questionnaire materials or procedure, is unclear.

8.1.2. Questionnaire results

The survey data indicated that for many pilots case-based knowledge plays an important role in aeronautical decision making. To further investigate this finding, a questionnaire was developed to elicit more detailed information about the role played by accident and incident case histories in aviation safety. Responses to the questionnaire were received from 409 pilots who varied widely in terms of aviation background and experience and demographic details. Some pilots were just learning to fly, while others had many years and thousands of hours of experience. Two thirds held a private or student licence while the remainder held commercial or ATPL licences. Participants had flown aircraft of all types and had participated in many and varied flying activities. Almost all reported a keen interest in aviation and almost all had read some form of case-based aviation safety material within the last month. Details of the variables related to pilot demographics, flying history and experience, and exposure to safety-related aviation material are given in section 3.2.

Are accident and incident case-histories recalled at critical flight times?

To investigate whether pilots recalled accident or incident case histories at a critical flight time, the questionnaire asked participants to indicate (on a five point scale) whether they agreed or disagreed with seven statements that summarized common points made in survey responses. The questionnaire statements, their related short descriptions, and the overall result, are outlined in Table 36.

Three of the statements put to pilots were strongly endorsed by the group as a whole. The statement receiving greatest support was the assertion that recalling case histories enables pilots to avoid critical incidents in the first place (avoid critical incidents). A substantial majority of pilots (81%) agreed or strongly agreed with this statement, providing strong evidence that the widespread use of case-based safety material in aviation is an effective strategy. Only a small proportion (7.9%) of pilots disagreed or strongly disagreed with the avoid critical incidents statement.
Table 36. Questionnaire ‘learning from experience’ statements.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Overall result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Case History</td>
<td>neutral</td>
</tr>
<tr>
<td>Specific case history recalled at a critical flight time</td>
<td></td>
</tr>
<tr>
<td>Archetypical Case History</td>
<td>neutral / agree</td>
</tr>
<tr>
<td>Archetypical case history recalled at a critical flight time</td>
<td></td>
</tr>
<tr>
<td>Time Span</td>
<td>agree</td>
</tr>
<tr>
<td>Time span of critical incident affects the recall of case histories</td>
<td></td>
</tr>
<tr>
<td>Details Recalled Later</td>
<td>neutral</td>
</tr>
<tr>
<td>Details of case histories are recalled on later reflection</td>
<td></td>
</tr>
<tr>
<td>Avoid Critical Incidents</td>
<td>agree</td>
</tr>
<tr>
<td>Recalling case histories enables you to avoid critical incidents</td>
<td></td>
</tr>
<tr>
<td>Information Abstracted and Integrated</td>
<td>agree</td>
</tr>
<tr>
<td>Case information is abstracted and integrated into memory</td>
<td></td>
</tr>
<tr>
<td>A Good Scare</td>
<td>neutral</td>
</tr>
<tr>
<td>A good scare is worth more than good advice</td>
<td></td>
</tr>
</tbody>
</table>

A high rating was also given to the statement that the time span of critical incidents affects whether or not specific case histories are recalled (time span). A total of 80% of pilots either agreed or strongly agreed with this statement. However, as indicated above, some survey pilots reported very definitely recalling specific cases at certain critical times. Therefore the effect of time span must be seen as influencing, rather than absolutely determining, the recall of case histories.

The third statement to receive substantial support was the assertion that case information is abstracted and integrated into memory, while specific details are lost (information abstracted and integrated). This statement was rated ‘agree’ or ‘strongly agree’ by a total of 71% of pilots. However, the proportion of respondents disagreeing or strongly disagreeing was also higher (15%). Hence, there was also strong support for a rule-based conception of the way in which case-based material influences pilots' attitudes and behaviour.

The remaining four statements received less support. The assertion that archetypical case histories were recalled (archetypical case history) was rated ‘agree’ or ‘strongly agree’ by 62% of pilots and ‘disagree’ or ‘strongly disagree’ by 15%.
Just over half the pilots completing the questionnaire agreed or strongly agreed with the *specific case history* statement, while 20% disagreed or strongly disagreed. Hence, there was only moderate support for the proposition that specific case histories from accident and incident reports were recalled at critical flight times (*specific case history*). Again, however, any conclusions from this result must be tempered with the knowledge that many pilots who contributed to the original survey did report recalling specific case histories. Nevertheless, the strong indication is that the beneficial effect of case-based safety material will most likely occur through the prevention of accidents and incidents, rather than by helping pilots to deal with critical events that have already developed. Partly this reflects the statistically low aviation accident rate; many pilots will not face a serious incident in a lifetime of flying.

The statement that details of case histories are recalled on later reflection (*details recalled later*) was not strongly supported, with 47% of pilots for and 19% of pilots against this assertion. The statement that a good scare is worth more than good advice (*good scare*) received a very mixed response. Overall, there was marginal support for the statement, with 55% of pilots indicating agreement or strong agreement. However, disagreement was much higher, with a total of 30% of pilots disagreeing or strongly disagreeing with the assertion. The *good scare* statement polarised pilots far more than any of the other statements. A total of 40% of pilots expressed an extreme view in their *good scare* rating, either strongly agreeing or strongly disagreeing, while the average proportion of pilots expressing an extreme view in relation to the other statements was 18%. The *good scare* statement apparently tapped a significant difference of opinion amongst pilots on the importance of intense personal experience in determining flying behaviour.

**Factors affecting pilots' beliefs about learning from experience**

As outlined in section 3.2.5, three of the rating statements concerning the role of accident and incident case histories in aviation safety can be seen as relating to specific beliefs about how people learn from experience. Agreement with the *specific case history* statement supports a belief in a case-based view of how pilots can learn from the experience of others. Alternatively, agreement with the *information abstracted and integrated* statement suggests a belief in a rule-based conceptualisation where the experience of other pilots is encoded in rules that a pilot can then apply to their own operations. Finally, agreement with the *good scare* statement suggests a belief that pilots learn primarily from their own personal experience, rather than from the experience of others. These three models of how pilots learn from experience can be described as;
Pilots who demonstrated an unambiguous preference for one of the three relevant statements (specific case history, information abstracted and integrated, or a good scare) were allocated to one of three 'beliefs about learning experience' groups. The largest group consisted of pilots with a rule-based view of experience (38% of respondents that could be categorised), followed by the personal experience group (37%), and lastly the case-based experience group (25%).

It is possible that pilots' beliefs about the nature and role of experience in determining flying behaviour may be influenced by factors such as their own level of flying experience, or factors such as age, sex, or hours flown per year. However, analysis of the questionnaire data did not support this view. The three 'learning experience' groups did not differ significantly in terms of any of the variables studied.

Factors affecting pilots' ratings of specific case history statements

While there were no significant differences between the three learning experience groups in terms of any of the questionnaire variables, there were a number of significant differences between pilots' ratings of the seven learning experience statements. However, when a Bonferroni correction for multiple pairwise comparisons was applied, only one result remained significant at the 0.05 level. The significant result related to the effect of hours flown per year on pilots' rating of the good scare statement.

Pilots who only flew infrequently (less than 15 hours per year on average) disagreed with the good scare statement. In comparison, pilots who flew more regularly, to whatever degree, rated the statement as 'neutral' to 'agree'. In analysing this result, it seems possible that at the responses of pilots who only fly infrequently may be more a reflection of how they would like to learn, as opposed to a judgment of what method of learning they think is the most effective. Pilots who only fly infrequently are perhaps likely to feel less confident about flying and to be more fearful about possible incidents that they might be involved in. In addition, the skills of low currency pilots are likely to deteriorate, potentially leading them to be involved in more accidents or incidents than average, hence further undermining their confidence. In these circumstances they may well feel somewhat apprehensive about flying at all, and are unlikely to agree that a good scare is just what they need to improve their flying.

Overall, it was possible to categorise 248 pilots (60.6% of the total) in this way.
As indicated above, a number of other results were initially significant at the 0.05 level, but then failed to reach that level of significance after Bonferroni correction. However, it is felt that discussion of these results is justified in that they may be helpful in suggesting future lines of research.

While the specific case history statement was not strongly supported overall, there was greater support from pilots who had read case-based safety material within the last two days. While this might be expected, as reading case histories and a belief in their worth will reinforce one another, a closer inspection of the data shows that the stronger support for the specific case history statement by pilots who had recently read case-based material was entirely due to pilots with less than 200 hours total flying time. For more experienced pilots, there was no significant difference between the specific case history ratings for pilots who had recently read safety material and for those who had not.

Hence, inexperienced pilots who had read safety material in the last two days rated its worth as higher than average, but those who had not read the material recently rated its worth lower than average. As total flight time increased, though, this difference lessened, and by 200 hours flying time there was no significant effect of recency of reading. Perhaps this result can be interpreted by saying that experienced pilots seem better able to judge the true worth of case-based safety material. Inexperienced pilots who had greater exposure to case-based material tended to over-estimate its worth, while inexperienced pilots with less exposure to case-based material tended to under-estimate its worth. In that respect, the finding can be seen as reflecting the greater meta-knowledge of experienced pilots in the sense that they are better able to judge the relative worth of different sources of information in relation to their existing store of aviation knowledge.

Ratings of the most strongly supported questionnaire statement, avoid critical incidents, were also influenced by how recently pilots had read case-based safety material. Pilots who had read such material within the last week gave the statement a higher rating. As in the case of the specific case history statement, the effect of recency of reading can be explained by a two-way relationship between attitude and behaviour. On one hand, pilots who consider that case-based aviation safety material has worth are more likely to read such material. Conversely, pilots are likely to attach greater worth to an activity that they have recently engaged in because that will minimize cognitive dissonance between their beliefs and actions.

In addition to currency, pilots' ratings of the a good scare statement were also influenced by total flying time. Relatively inexperienced pilots (less than 200 hours total time) rated this statement lower than did other pilots.
Again, one would surmise that this result reflects differences in pilot confidence. Low-time pilots are likely to be less confident of their abilities, more tentative in their approach to flying, and therefore less convinced of the worth of potentially dangerous experiences.

Overall, in considering pilots’ ratings of the seven case history statements, the general theme was one of considerable similarity rather than difference. In fact, pilots with very different flying histories and experience often gave very similar ratings to the seven statements. As an illustration, Participants 67, 265, and 313 gave the same pattern of responses and yet came from quite diverse aviation backgrounds. Participant 67, a US pilot, had accrued 1,700 hours flying time over 17 years. He held a commercial licence and flight instructor rating, and had worked as a flight instructor, flying light single-engine aircraft only. Participant 265 was from Britain. As a private recreational flyer he had accumulated 320 hours in light-single and light-twin aircraft over five and a half years. Participant 313 was a US military pilot with a commercial licence and a total of 1,300 hours military jet helicopter experience. Notwithstanding their very different backgrounds and flying experience, these three pilots gave the same ratings to the questionnaire statements. This result adds weight to the view that pilots’ beliefs about the importance of case histories in aviation safety is due to more than just their particular flying background or experiences.

8.2. Case-based versus rule-based pilot decision training

The experimental studies that form the second part of this thesis were based on two common scenarios that account for a majority of general aviation fatal accidents; VFR flight into adverse weather and low flying. Statistics show that these two areas together account for approximately 57% of fatal general aviation accidents (AOPA Air Safety Foundation, 1996).

Participants in the When To Turn Back and How Low To Go experiments viewed either case-based training material, rule-based training material, or both. A cognitive flight simulator, Icarus, was developed to present the decision making scenarios used in these experiments, and to record a wide range of behavioural data for later analysis. The participants in the two experiments had no flying experience and, hence, did not come to the experiments with different levels of case-based or rule-based aviation knowledge, as would have been the case if they had been active pilots. Hence, they were complete novices in the field of aviation.

Simulation studies (Kolodner, 1993; Redmond, 1997) have shown that for novices the acquisition of new cases is the most powerful form of learning. However, it has also been found that novices have difficulty in
identifying the important cues by which cases should be indexed. Hence, cases potentially provide the best form of learning for novices, but without guidance novices may not be able to make good use of the information presented to them. The first question that the experimental studies sought to answer was whether the case-based training material alone would provide an 'experience' sufficient to modify the flying behaviour of novice participants. Would the participants be able to successfully interpret the cases they viewed in a way that allowed them to correctly identify the important cues with which to index the cases for later retrieval and reuse? The second question of interest was, given the suggestion that novice participants may well have difficulty indexing cases, would prior rule-based training assist them to accurately interpret and index the case-based material?

8.2.1. When To Turn Back

The When To Turn Back scenario presented participants with two conflicting objectives during a simulated flight task. On the one hand, extending their flight meant that they could continue to help the survivors of an aircraft crash by relaying radio messages. On the other hand, flying into deteriorating weather would eventually risk their own safety and that of their passengers.

Participants were randomly assigned to one of three groups and received either no training, case-based training, or rule-based and case-based training in weather-related decision making. The main outcome variable for the experiment was the degree to which participants continued their flight into deteriorating weather, as expressed by the percentage of the view from the cockpit window that was obscured by cloud (final cloud scores).

Flight performance data were also recorded during the simulation, enabling participants to be characterised in terms of variables that reflected how skilled and/or attentive they were to the task at hand. On that basis, participants were divided into three flight performance groups; one group that performed well (skilled and attentive), and two groups that did not perform well (attentive but unskilled and inattentive).

Distribution of final cloud scores

A majority of participants (75%) demonstrated a low-to-moderate tendency to continue their flight into deteriorating weather, discontinuing their flight before half of the view from the cockpit window was obscured by cloud. A second group of participants (19%) exhibited a stronger tendency to continue, with final cloud scores in the approximate range of 60% to 80%. A final group of three participants (5%) continued their flight until over 90% of the cockpit view was obscured by cloud.
The effect of training on simulated weather-related decision making

Overall, the effect of the training manipulations on simulated weather-related decision making was not significant in the When To Turn Back scenario. Although there was a clear trend among the three groups, variability within the groups meant that the differences were not significant ($\alpha = 0.05$). However, the results for the three groups were in the direction that would be expected. On average, the group that had received no training in weather-related decision making discontinued their flight when the view from the cockpit window was almost half obscured (48% cloud). In comparison, the group that had received case-based training discontinued their flight at 42% cloud, and the group that had received both rule-based training and case-based training discontinued their flight when a third of their view was obscured (33% cloud).

While the behaviour of the three weather-related decision making groups was not significantly different for participants as a whole, there was a significant difference between the groups for the subset of participants characterized as being skilled and attentive. The same trend observed for participants as a whole was also seen for this subset of participants. In particular, participants who had received no training tolerated the largest amount of cloud (57%), followed by the case-based training group (42% cloud), and then the group that had received both rule-based and case-based training (29% cloud).

In contrast to the skilled and attentive group, there was not a significant final cloud by training group effect for either the inattentive flight performance group or the attentive but unskilled group. While this result for the inattentive group can most likely be explained by that group being insufficiently motivated to fully engage with the experimental task, it is harder to explain why the training had little effect on the group of participants who were characterised as being attentive but unskilled. Why a relative lack of sensorimotor skill in a tracking task would predispose participants to be unreceptive to training in weather-related decision making is unclear.

Decision response time

For participants as a whole there was a significant effect of decision response time on bad weather decision making. Participants who tended to make quick judgements about whether or not to continue their flight into deteriorating weather took greater risks on average than participants who were more measured in their decision making. Compared to real-life situations the training sessions were very brief. The average time that participants spent viewing the training material was 5.6 minutes for the
case-based module and 6.0 minutes for the rule-based module. However, average test scores for case-based material and rule-based material were 75% and 81% respectively, suggesting that lack of training effectiveness was not due to participants not attending to, or not understanding, the training material. Participants remembered the information they had seen, but it did not necessarily influence their behaviour.

**Analysis of decision probe responses**

The *When To Turn Back* simulation protocol allowed participants to discontinue their flight at any time. In addition, participants were specifically asked at regular intervals whether they wished to continue their flight, and after they had indicated ‘yes’ or ‘no’, they were further asked “What were you thinking when you made that decision”. Transcripts of participants’ decision probe responses were studied to establish whether they provided any insights into their decision making processes. No formal procedure was used to analyse the decision probe responses. An example transcript of one participant’s responses to successive decision probes is given in Appendix 15.

Information from the decision probe transcripts supported the suggestion that novice decision makers may have difficulty making best use of the information contained in case-based material, most probably due to difficulties in appropriate cue indexing. In effect, they are less able to tell what information in the stories is important and what information is not.

One very clear example of this problem was shown in the transcript of Participant 14, a member of the group that received just case-based training. At a point late in the *When To Turn Back* scenario, with 71% of the view obscured by cloud, when queried as to whether it was safe to continue the participant replied,

>*I was thinking that because I've got contact with air traffic control if I do get in some cloud they should be able to help me out a bit and tell me where I am.*

It would appear very likely that this mistaken belief was fostered by the first case history given in the training material. In that example, a VFR pilot misjudged the weather and entered cloud but was helped back to safety by air traffic control. Although the episode had a happy ending it was, none the less, an object lesson in how not to conduct a flight. However, without the benefit of guidelines or prior experience the participant coded the case in exactly the wrong way. From the lucky escape of the pilot in the case history, they mistakenly assumed that air traffic control would always be able to guide a VFR flight that enters IMC weather back to safe conditions. In a similar example, Participant 6, also from the case-based training group, made the following comment
early in their flight (17% cloud) when justifying their decision at that point,

The examples they gave, the weather was pretty bad when they, sort of lost it, no visibility at all.

They then continued on for approximately another 20 minutes before finally discontinuing their flight with almost half the windscreen obscured by cloud.

On the other hand not all participants misconstrued the case-based material. Participant 40 promptly decided that the weather conditions had deteriorated to an unsafe degree at 17% cloud, commenting,

I don't want to make the mistake those other pilots did.

In contrast, participants who had not received any training at all, although aware of the deteriorating weather, were uncertain what to make of it. Excerpts from the decision making transcript of one of the no training group (Participant 56) included the following comments;

At 29% cloud,

I'm not sort of actually in that cloud as yet, so I'm going to wait to see.

At 43% cloud,

The cloud is obviously a lot closer and it's probably a bit thicker than I thought but I can still see the mountains, it doesn't seem to be stopping me from being able to stay in the area.

At 55% cloud,

OK the cloud cover is definitely thickening and I'm probably the most worried I've been throughout the test so far, but I'm still going to continue.

At 63% cloud,

OK it's definitely getting worse but I'm still able to fly in relative safety.

The participant finally discontinued the flight at 71% cloud.

8.2.2. How Low To Go

The How Low To Go scenario presented participants with a low flying task in which they were required to judge and report the altitude that they considered to be the minimum safe altitude for their aircraft, given its current position. To motivate participants to fly to a low altitude rather than simply making a very conservative and safe decision, a small monetary reward was promised to the participant who recorded the
lowest final altitude above a predetermined minimum safe altitude calculated by the experimenter.

Participants were randomly assigned to one of three groups and received either no training, case-based training, or rule-based and case-based training in low-flying decision making. The main outcome variable for the experiment was the final altitude of their aircraft, the height above the ground that they considered to be the minimum safe altitude.

Four 'decision' variables were extracted from participants' How Low To Go flight profile data in an attempt to quantify the different approaches that participants used during the simulation. The decision variables were, total time, total altitude excursion, altitude reversals, and control inputs. The data from the four variables were used to categorize participants into three groups that were described as the quick decision, the considered and definite, and the considered and wavering decision making groups (see section 5.2.5).

**Distribution of final altitude scores**
The majority of participants (81%) recorded final altitude scores in the range of 3,000 feet to 6,000 feet, while 16% made relatively conservative decisions (above 6,000 feet) and two participants (3.5%) made relatively risky decisions (below 3,000 feet).

**The effect of training on simulated low-flying decision making**
Overall, the effect of the training manipulations on simulated low-flying decision making was not significant in the How Low To Go scenario. However, the group that received both rule-based training and case-based training did, on average, make more conservative decisions. That is, they judged the minimum safe altitude to be higher than that estimated by the other two groups.

However, training in low-flying decision making did have a significant effect on the flying behaviour of participants in the quick decision group. In particular, participants who received both case-based and rule-based training made significantly more conservative decisions that did participants in either the case-based training group, or the no training group. A similar effect was not found for either the considered and definite or the considered and wavering decision making groups. Participants in the quick decision group tended to make their decisions on the basis of minimal information, and with little rechecking. The training effect may have been most pronounced with this group as their relatively poor decision making skills left a good deal of room for improvement.

In the How Low To Go scenario, male participants made significantly more risky decisions than did female participants. Greater risk taking by males compared to females has been widely documented, particularly in
relation to driving behaviour and related injuries (Turner & McClure, 2003; WHO, 2002; Byrnes, Miller, & Schafer, 1999). Similarly, in aviation Vail and Ekman (1986) found that male pilots had a higher rate of accidents than female pilots, and a higher portion of the male accidents resulted in fatalities or serious injuries than for females. The gender result of the How Low To Go scenario accords with these findings.

In comparison to the low flying scenario, there was not a significant effect of gender in the bad weather scenario. Given that gender is a well established marker for risk-taking propensity, the significant effect of gender on decision making in the How Low To Go scenario but not the When To Turn Back scenario can perhaps be taken as evidence that participants in the former saw their task as more obviously representing an immediate risk-based choice than did participants in the latter. One factor influencing this aspect may have been that the time frame of the two risk assessment situations varied considerably. The average time spent for the entire How Low To Go simulation was 5.8 minutes, while the average total time for the When To Turn Back decision task was 24.1 minutes. The How Low To Go scenario can perhaps be characterised as a static one-off decision situation, while in comparison the When To Turn Back scenario represented a dynamic ongoing decision situation.

**Static versus dynamic decision making**

In the low flying simulation, participants knew that they were required to make a one-off risk assessment. If they made the ‘wrong’ decision they would not have a chance to reconsider. In comparison, in the bad weather simulation participants knew from the description of the scenario that they would be required to make a series of decisions over a longer period of time. They understood that the situation would unfold gradually and that they could discontinue their flight at any time. Hence, while the How Low To Go scenario primarily involved a one-off ‘static’ decision, the When To Turn Back scenario presented participants with a ‘dynamic’ series of related decisions. This aspect may have influenced how participants perceived the risk-based choice they faced in the two scenarios, and hence influenced their behaviour.

It is possible that a dynamic decision making task may leave the decision maker susceptible to a ‘ratcheting effect’ in which the risk they accept is increased in small increments, each of which alone is insufficient to trigger a fundamental reappraisal of the situation. This is because the ‘context’ of each successive decision will be the decision taken before. Hence, the decision reference point will gradually increase and partially disguise the fact that the ‘absolute’ level of risk is also increasing. Perhaps this situation could be characterised as ‘individual groupthink’ in that although only one person is involved in the decision making process,
their past decisions will tend to influence their future decisions in the same way that other group members might (Janis & Mann, 1977).

Support for this argument was given by information from the When To Turn Back decision probe transcripts. There was evidence that, for some participants, the gradual way in which the weather deteriorated tended to mask the true nature of the danger they faced. As conditions worsened, they would note that the situation had changed but take comfort from the fact that their flight had so far not suffered any dire consequences. For example, in response to a decision probe at 43% cloud, Participant 14 commented,

*I haven't crashed yet.*

The risk of being unaware of the stealthy increase in danger is illustrated by the decision probe responses by Participant 46 who eventually continued until their view from the cockpit window was entirely obscured by cloud.

At 47% cloud they stated,

*I mean I seemed to get through it safely last time, although it's getting a bit trickier, I lost 400 feet last time and yeah, that could cause an accident.*

At 71% cloud,

*I'm in control. Mmm I shouldn't really be flying into this cloud, it's kind of dangerous.*

At 82% cloud,

*Still in control.*

This response is suggestive of a form of gradualism where escalating risk goes unchecked.

### 8.3. Pilot behaviours in the face of adverse weather

Weather-related general aviation accidents remain one of the most significant causes for concern in aviation safety. The approach of previous studies of this type of occurrence has been to compare accident and non-accident cases. However, in the final analysis, the outcome of a particular encounter with bad weather will often depend simply on chance. Therefore, the foundation on which much previous research of this type is based would appear to be somewhat shaky. The current study took a new approach and concentrated instead on the different behaviours that pilots exhibited in the face of adverse weather and, by inference, on the decision making processes that underpinned those behaviours.

A set of 491 ATSB occurrence reports were analysed to compare the following three weather-related decision making behaviours;
• VFR into IMC
• a weather-related precautionary landing
• some other significant weather avoidance action

The cases in these three groups reflected different levels of threat to flight safety. At one extreme, VFR flight into IMC is very risky; at the other extreme, proactive weather avoidance is the safest action to take.

8.3.1. VFR into IMC – a deadly scenario

Previous studies of general aviation accident and incident data have clearly demonstrated the significant dangers associated with VFR flight into IMC (NTSB, 1989b; TSB, 1990; AOPA, 2002).

US data for the period 1975 to 1986 indicated that VFR into IMC accidents were more than four times likely to prove fatal than general aviation accidents as a whole – 72% of VFR into IMC accidents were fatal, compared with 17% for all general aviation accidents. Hence, while VFR into IMC accidents comprised only 4% of general aviation accidents, they accounted for 19% of the total fatalities (NTSB, 1989b).

Similar figures were obtained for Canadian data for the period 1976 to 1985. Approximately 13% of all Canadian accidents during this period involved fatalities, but 50% of VFR into IMC accidents were fatal – again, approaching a four-fold difference. In Canada, VFR into IMC accidents were 6% of the total, but accounted for 23% of all fatalities (TSB, 1990).

More recent US statistics include a study by Goh and Wiegmann (2001) that reports an average VFR into IMC fatality rate of approximately 80% for the period 1990 to 1997. The 2002 Nall Report (AOPA, 2002) indicates that VFR flight into IMC continues to be the most deadly weather-related scenario. While occurrences of that type resulted in only 2.2% of all US general aviation accidents during 2001, 84% of those accidents were fatal.

The results of the current study confirmed previous findings. For VFR into IMC accidents, 76% of cases involved a fatality, 8.9% involved serious injury, 4.4% a minor injury, and in only 11.1% of cases was no injury recorded. Figure 89 compares the fatal accident rate for VFR into IMC accidents found in previous studies with the results found in the current study.

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69 The Nall Report is published each year by the US Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation and is based on US National Transportation Safety Board (NTSB) reports of accidents for the previous calendar year involving fixed-wing general aviation aircraft weighing less than 12,500 pounds.
Figure 89. Fatality rate for VFR into IMC accidents.

The similar result for VFR into IMC accident fatality rates found in the current study compared with previous work suggests a common point of reference that can anchor the more general comparison of VFR into IMC occurrences with the other weather-related decision behaviours that form the basis of this study.

There was clear evidence of significant differences in severity of outcome for each of the three weather-related behaviour groups. The severity of injury or aircraft damage in the VFR into IMC group was much greater than for the other two groups. For example, while approximately 12% of VFR into IMC occurrences were fatal, only one occurrence in the precautionary landing group involved serious injury, and only one occurrence in the weather avoidance group involved minor injury.

Almost all injuries to pilots or passengers occurred within the VFR into IMC group. However, the likelihood of the aircraft incurring some degree of damage was greatest for the precautionary landing group. Combining these results, it is possible to map out a progression of weather-related decisions that finally results in a pilot continuing a VFR flight into IMC. In the early part of the flight, when the weather is deteriorating but still acceptable for VFR flight, the pilot may weigh up the alternatives of continuing or discontinuing the flight in terms of losses. In that framework, they may compare the certain loss of diverting or turning back (e.g. inconvenience and cost) with the uncertain, though potentially much more serious, consequences of continuing the flight (O'Hare and Smitheram, 1995).
Further into the flight, when the weather has deteriorated even more, the pilot may wish that they still faced the original alternatives. However, by then the options available to the pilot have changed – the stakes have been raised and they are now faced with a more difficult dilemma. By this stage, the safest course of action may be a precautionary landing, but there is a distinct chance that a precautionary landing will end in an accident. As the results above show, the proportion of precautionary landing occurrences that involved some form of aircraft damage (29%) is actually higher than that for VFR into IMC occurrences (17%). While a VFR into IMC accident is likely to be much more serious, it is possible that the realisation that a precautionary landing may well involve aircraft damage will dominate the pilot’s decision making. Hence, they may again decide to continue the flight into deteriorating conditions in the hope that the situation may improve and that this potential loss may be avoided.

8.3.2. Comparison of results with previous ‘outcome’ based studies

The risk factors for involvement in aviation accidents have been reviewed by Li (1994) and O’Hare (1999). An overview of previous findings relevant to the variables considered in the current study is given in Appendix 16. In summary, the following results have been reported for the influence of demographic factors on pilot involvement in aviation accidents;
• Age - conflicting results - accident risk increases, decreases, or stays the same, with increasing age.
• Total flying time - accidents rates have generally been found to decrease with total hours flown.
• Licence category - accidents rates have generally been found to decrease for pilots with higher licence qualifications.
• Time on type and pilot ownership status - descriptive information for accidents pilots only, no information comparing accidents pilots with non-accident pilots.

Early work in this field typically did not control for 'exposure' – for example, the total number of pilots across particular age groups, total flying time groups, or other similar categories being studied. More recent studies typically remedied this shortcoming by employing a case-control methodology in which matched accident and non-accident cases are compared.

In contrast to studies based on flight outcome (e.g. accident or non-accident), this study found no significant differences among the three weather-related behaviour groups on the basis of pilot demographics. In particular, there were no significant differences among the three groups in terms of:

- age
- total flying time
- time on type
- type of licence
- pilot status (owner, renter etc).

This study also found no significant difference among the three weather-related decision making groups in terms of the type of flying operation or in terms of the following characteristics of the occurrence aircraft:

- maximum certificated takeoff weight (MTOW)
- number of engines
- type of landing gear
- type of propeller

Hence, the results do not suggest that a pilot flying a high performance general aviation aircraft is at any greater risk of a VFR into IMC encounter. The aircraft in the dataset ranged from types such as the Cessna 150 with a cruising speed of approximately 90 knots, to aircraft such as the Cessna 402 with a cruising speed of up to 175 knots\textsuperscript{70}. Hence, the time taken by these aircraft to cover a distance of 10 nautical miles at cruise speed would be of the order of six minutes and three minutes respectively. The results suggest, therefore, that within that time-frame

\textsuperscript{70} Knots = nautical miles per hour.
pilots had an adequate opportunity to appraise the immediate weather situation and decide on an appropriate course of action.

Overall, nearly a quarter of occurrences (23%) took place within controlled airspace. The proportion of occurrences within controlled airspace varied significantly between groups, with relatively few precautionary landings (4%) taking place within controlled airspace. This would appear to reflect the nature of operations within a more structured flying environment. Pilots encountering adverse weather when flying in controlled airspace would perhaps be more likely to ask for ATC guidance, for example to a nearby landing area, rather than carrying out a precautionary landing entirely of their own accord.

This study found no significant differences among the three weather-related behaviour groups in terms of the geographical location of the occurrence, despite the large variations in terrain and weather environment across the Australian continent. This suggests that environment itself was not a major influence on pilots’ decision making. In contrast, studies based on outcome data have reported significant regional differences (Baker and Lamb, 1989; NTSB, 1974; NTSB, 1976). Those results may simply reflect the fact that some flying environments are less forgiving of error, rather than providing evidence that pilots’ weather-related decision making varies with flight environment.

When flights were categorised as being either a ‘city flight’ or a ‘country flight’ a significantly greater proportion of precautionary landing occurrences took place during country flights. This result is of interest, as an understanding of why pilots on country flights may be more willing to carry out a precautionary landing could be helpful in understanding the factors that influence pilot decision making in general. It is possible, for example, that country pilots may in general be more practical and self-reliant, and less daunted by the possible difficulties and risks of ‘improvising’ a precautionary landing. However, such a premise could only be tested by measuring and comparing the attitudes of city and country pilots (Urban, 1983).

The influence of airspace type was ruled out as a significant determinant of the country precautionary landing result. Also, it would seem unlikely that the result was simply due to physical differences between the natural or built environment over which city or country flights are conducted. In fact, the greater proportion of both city and country flying will typically occur over a non-urban landscape. It is unlikely, therefore, that the environments will differ significantly in terms of the availability of areas suitable for a precautionary landing.

The time of day distribution for weather avoidance occurrences differed from that of the other two groups. It is possible that the peak in weather
avoidance action near 5 pm may have been partly due to the onset of darkness. For locations between 15 and 45 degrees south latitude, the end of evening civil twilight occurs between approximately 5 pm and 8.30 pm, depending on the time of year. The realisation that the end of daylight was approaching may have been an added factor in influencing pilots not to continue their flight into adverse weather conditions.

8.3.3. Measures of absolute and relative flight distance

Measures of both absolute distance (e.g. distances in km) and relative distance (e.g. proportion of planned flight completed) have the potential to shed light on the influence of psychological and social pressures on a pilot's decision to continue a flight into adverse weather. The theory of 'sunk cost' (Arkes and Blumer, 1985) suggests that pilots will be more likely to 'press-on' into deteriorating weather as a flight progresses because of the increasing amount of time and effort that they have already invested in the flight.

This study found that there was no significant difference among the three weather-related behaviour groups with respect to the planned flight distance. Hence, there is no evidence that the length of the planned flight had any differential influence on pilots' weather-related decision making behaviour.

The likelihood of an occurrence did not vary significantly with distance from point of departure, either for all occurrences, or differentially for the three weather-related behaviour groups. While overall there was a significant difference among the three weather-related behaviour groups as a function of distance to the planned destination, none of the pairwise comparisons between groups were significant.

The influence of the halfway point milestone

Overall, the majority of occurrences took place during the second half of the planned flight. This suggests that, in general, pilots' thoughts and actions became more focussed on weather-related aspects of their flight once they had passed the mid-point of their journey. This finding suggests that psychological aspects, rather than specific operational considerations, are the primary influence on pilots' decision making in these situations. This is because the halfway point may relate, for example, to an absolute distance of 5 miles, 50 miles, or 500 miles. Therefore, the halfway point has standing only as a psychological construct.

The influence of the halfway point milestone on pilot behaviour differed significantly across the three weather-related behaviour groups. The majority of pilots in the weather avoidance group took action before the halfway point of the flight, whereas the majority of pilots in the
precautionary landing and VFR into IMC groups took action during the second half of the flight. The significant 'before and after halfway' results demonstrate that pilots' decision making can be influenced by psychological factors that do not directly equate to any particular operational aspect of the flight.

The VFR into IMC and precautionary landing results are similar to those of O'Hare and Owen (2002) who, in an analysis of 77 New Zealand general aviation accidents involving aircraft on cross-country flights, found that, on average, VFR into IMC and precautionary landing accidents occurred during the second half of the flight.

**Proportion of the planned flight distance at the point of occurrence**

A detailed analysis of the proportion of the planned flight that had been completed at the point of occurrence further illustrated the significant differences among the three weather-related behaviour groups. Weather avoidance occurrences were concentrated in the earlier part of the flight, with the pattern of behaviour for this group apparently reflecting both an awareness of the weather conditions, and a willingness to take appropriate and timely action.

In contrast, the distribution pattern for VFR into IMC occurrences approximated a mirror image of that for the weather avoidance group, with an increasing likelihood of occurrence as the relative flight distance increased. This pattern suggests an increasing tendency on the part of pilots to 'press-on' as they increasingly invested more time and effort in reaching their destination.

The distinction between the weather avoidance and VFR into IMC groups in terms of relative distance was very clear. The evidence suggests that the weather avoidance group were paying heed to weather conditions and alternative courses of action relatively early in the flight. Perhaps this mindset can be characterised as: “Should I continue the flight as planned or not?” In contrast, the VFR into IMC group apparently did not focus on weather conditions until relatively later in the flight. The focus of this group can perhaps be characterised as: “Can I reach my destination or not?”

The third weather-making decision group, precautionary landing, also showed a distinct distribution pattern of relative distance values, with occurrences highly clustered within the 60%-80% relative distance group. This result would seem to reflect an eventual, albeit delayed, realisation on the part of the pilot that the situation had deteriorated and that definite action was required.
The most salient result of the flight distance data was that the weather avoidance group took action in a timely manner. That is, they were proactive in their decision making. Their approach can be summarised by the maxim ‘Take control of the situation before the situation takes control of you’. Hence, one of the principal findings of this research is that a safe pilot is a proactive pilot.

What is it, then, that makes some pilots more willing or able to plan and think ahead during their flight than other pilots? Is it an inherent trait, or an aspect that has been developed through training and/or flying experience? Future research could investigate this aspect by comparing pilot behavior with scores on psychometric measures such as the ‘Planning and Thinking Ahead’ subscale of the AT-SAT test used by the US Federal Aviation Administration in selecting air traffic controllers (Ramos, Heil, & Manning, 2001).

8.3.4. Information from investigation files

An examination was made of available investigation files related to the occurrences in the weather-related decision making dataset. However, this aspect of the study was severely restricted by the limited amount of information held on file.
A number of themes emerged from the qualitative information obtained from the VFR into IMC investigation files. In particular, the issues noted a number of times were:

- a history of poor decision making (5 cases)
- lack of knowledge or experience (4 cases)
- overconfidence (4 cases)

The most common theme to come from the qualitative information on file for VFR into IMC occurrences was evidence that the pilot had previously behaved in a similar fashion. That is, the pilot had displayed a history of poor weather-related decision making. In some cases, the pilot had barely survived such an encounter, however this experience had still not tempered their later behaviour.

Another common aspect concerned a lack of knowledge or experience on the part of the pilot. For example, the pilot may not have had the experience necessary to adequately assess the weather conditions they faced, or they may have lacked specific local knowledge. This aspect may reflect shortcomings in the weather-related training that pilots typically receive. For example, cross-country flight training conducted in good weather may not adequately prepare pilots for the conditions they encounter in later flights. In some cases, the VFR into IMC occurrence in the dataset may have been the pilot’s first encounter with poor weather.

Much dual cross country training is deliberately carried out in good weather to ensure that the exercise can be completed and to avoid the extra cost of further flights. The emphasis is likely to be primarily on navigation and the opportunity for the student pilot to receive realistic instruction in identifying and dealing with adverse weather may occur infrequently or not at all.

Overconfidence on the part of the pilot was also cited in a number of investigation files – for example, reports by instructors or colleagues that the pilot appeared overconfident, or was very determined by nature. In some cases a little knowledge may be a dangerous thing. For example, a small amount of instrument training may give a pilot a false sense of their own proficiency.

As well as the more common themes from investigation reports, a number of other issues were raised that are worthy of consideration. In one particular occurrence, it appeared that the pilot had 'learned the wrong lesson' from a previous encounter with bad weather. On that occasion they had climbed above cloud and, with assistance from air traffic control, had been able to safely conclude the flight in VMC. That
successful outcome may have influenced the pilot to 'chance' it once again.\textsuperscript{71}

In two cases the pilot in question currently held a private pilot licence (PPL) but was carrying out training to obtain a commercial pilot licence (CPL). There was some evidence that the pilots may have been under pressure, perhaps self-imposed, to complete the flight as part of their training program. This is an area that is worthy of further study. It is possible to imagine a situation where a young, relatively inexperienced, pilot is keen to progress in their profession and, as a consequence, may tackle situations that extend them to the limit of their abilities, or beyond.

\section*{8.4. Major themes}

A number of common themes emerged from the survey and questionnaire, experimental, and occurrence data analysis parts of the thesis. These aspects are addressed below.

\subsection*{8.4.1. The importance of case-based information in aviation safety and training}

Almost all theoretical discussion of aeronautical decision making (ADM) has to date been based on a traditional ‘analytical’ view human decision making. This approach has, in turn, influenced the nature of practical interventions aimed at improving pilots' skills in decision making. However, there is mounting evidence that the traditional conceptualisation of decision making bears little resemblance to the way in which practitioners actually make decisions in the real world (Johnson-Laird & Shafir, 1993; Holyoak & Thagard, 1995; Klein, 2003; Slovic et al. 2004). In contrast, there is much evidence to suggest that humans are fundamentally ‘libraries of experiences’ and that a case-based reasoning model is a far better way to view practical decision making (Riesbeck & Schank, 1989; Kolodner, 1993; Leake, 1996). This is particularly so in the case of complex real-world problem situations that typically do not have clear goals, well defined alternatives to choose from, or information about the likelihood and values of the possible outcomes (Pretz, Naples, & Sternberg, 2003; Jonassen, 2004; Evans & Thompson, 2004).

The case-based reasoning (CBR) approach to problem solving and decision making rests on two premises – that similar problems are likely to have similar solutions, and that the types of problems we encounter are likely to recur. (Kolodner, 1993; Aamodt & Plaza; 1994; Watson & Marir, 1994; Leake, 1996). Hence, case-based reasoning is a form of adaptive learning (Schank, 1999).

\textsuperscript{71} A similar result was found in the case of one participant in the When To Turn Back experimental study.
The case-based reasoning model would appear to have particular relevance to domains such as aviation, medicine, and law that have a rich tradition of ‘learning by example’ (Hunter, 1991; Klein & Hoffman, 1993; Patel, Kaufman, & Magder, 1996). Although case-based reasoning systems have been employed successfully in a number of operational and maintenance areas in aviation (Whitaker, Stottler, & King, 1990; Dattani, Magaldi, & Bramer, 1996; Allendoerfer & Weber, 2004), there has been no attempt, to date, to apply the theory of case-based reasoning to aeronautical decision making. Hence, one of the prime aims of this thesis was to investigate to what extent, if any, a case-based reasoning approach could be usefully applied to the study of aeronautical decision making.

**CBR meets ADM**

Evidence from all three parts of the thesis clearly demonstrates the important role of case-based information in aviation safety and training. Hence, the long tradition of drawing on accident and incident case histories in aviation safety is complemented by the more recent theoretical underpinning provided by case-based reasoning. This suggests that knowledge gained from the study of case-based reasoning in general can be applied to reinforce and refine the application of case material in aviation safety.

However, while the results of the thesis provide strong evidence that the role of case-based reasoning in aeronautical decision making is important, the results also show that the way in which case-based information influences pilot behaviour is multifaceted and is often difficult to identify and isolate.

Information from accident and incident case histories influences pilot decision making in a number of interrelated ways. From the evidence of the survey and questionnaire studies, the most important function of case-based material is that it enables pilots to proactively plan and monitor their flying activities so as to avoid accidents and incidents in the first place. For example, a pilot may develop their own personal SOPs or minimums as a result of reading case-based material. In that way, the case-based information becomes partly codified into a rule-based form – for example, a pilot’s ‘rule’ not to fly into a valley shrouded with low cloud. However, the encoding of the abstract rule is still likely to be associated in memory with relevant exemplar cases. Consequently, in the final analysis, the distinction between case-based and rule-based information becomes blurred.

The survey and questionnaire results also clearly demonstrated the very powerful influence of personal experience in shaping subsequent flying behaviour. This raises the fundamental question: Why does personal experience often play a more prominent role in aeronautical decision
making than the experience of pilots relayed in the form of accident and incident case histories? One possible answer may lie in the pivotal role of affect, encapsulated in the adage that “a good scare is worth more than good advice”.

The importance of affect in relation to many aspects of cognition has been increasingly recognised in psychology (Isen & Labroo, 2003; Slovic, Finucane, Peters, & MacGregor, 2004). One important way in which affect can influence decision making is by attaching a powerful ‘marker’ that increases the salience of particular information to the decision maker. Hence, a pilot’s decision making can be influenced not only by what they think about the situation they are facing, but also by what they feel about the situation.

In general, memories of personal experience are more likely to be imbued with strong affect, and therefore are more likely to be recalled, than less salient memories based on stories about the experiences of others. This suggests that the effectiveness of case-based safety material could be increased by presenting the information in a form that includes sufficient affective content to strongly engage the reader. This could be done by including a judicious amount of (possibly fictitious) personal information in the case history report, and by using language that is not entirely devoid of emotion. Finally, there is evidence that the role of affect can be particularly important for novices, as compared to experts (Bhattacharjee & Moreno, 2002). Hence, a focus on maximising the benefit of affective content could be particularly useful in the early stages of aviation training.

**8.4.2. The bootstrapping problem**

The conclusion that the roles played by both case-based and rule-based material are closely linked was supported by the results of the two experimental studies. For both the bad weather scenario and the low flying scenario, the results showed that a combination of case-based and rule-based instruction was more effective than case-based instruction alone. In particular, there was strong evidence that, for novices, rule-based information was important in providing a framework by which case-based information could be interpreted. Without such a framework to guide them, novices are likely to have difficulty in being able to successfully interpret the information embedded in case-based material. This can be characterised as a bootstrapping problem in that for novices to learn from example they need a framework to start coding cases, but

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72 The term bootstrapping alludes to a German legend about Baron Münchhausen, who was able to pull himself out of the sea by pulling himself up by his own bootstraps.
the information to develop that framework comes in part from case-based information.

One clear example of how a novice pilot may learn the 'wrong' lesson from case-based material was shown in the decision probe transcript of one particular participant in the bad weather scenario. The participant had been exposed to case-based training material that included an example where a VFR pilot misjudged the weather and entered cloud but was helped back to safety by air traffic control. When the experimental training material was developed, the intended lesson of the particular case history was that VFR flight into IMC conditions was a risky course of action. The added information about air traffic control providing assistance was intended as an incidental postscript, mainly to round out the story. However, rather than focussing on the risks of VFR flight into IMC, one of the participants taking part in the study focussed on the role that air traffic control played in the incident and identified that aspect of the case history as the 'take home message'.

Hence, without the benefit of prior experience, the participant coded the case in exactly the wrong way. To understand why this might have happened, it is instructive to look in detail at the wording of the particular case history that was misinterpreted. The scenario in question consisted of four paragraphs of text. The first two paragraphs set the scene and described the weather as deteriorating. The second paragraph of the scenario ended with the pilot flying in to cloud. The last two paragraphs of the scenario text read as follows;

> Being suddenly enveloped in cloud produced an incredible feeling of isolation and inadequacy. Fortunately though expert help was only a radio call away. When I contacted the Ohakea controller and requested help it was immediately forthcoming. His instructions to me were to concentrate on keeping my wings level, assuring me that I had ample ground clearance, and that my groundspeed was good.

> The feeling of being alone had already gone, and concentrating on the job in hand became a priority. It was like having an instructor sitting with you while flying. The controller told me that my heading was good and that I would soon see Wanganui, which was 15 miles away. As quickly as I had entered cloud I burst out of it, with a great debt of gratitude to the Ohakea controller.

In retrospect, it seems quite clear why the scenario might have been open to misinterpretation. Not only did half of the narrative concern the help provided by air traffic, but in addition, that aspect was contrasted with the pilot’s initial predicament in quite emotive terms. Being caught in cloud
was described as producing “an incredible feeling of isolation and inadequacy”. In contrast, the controller was a source of “expert help” that was close at hand and “immediately forthcoming”. The pilot no longer felt alone, and was left with a “great debt of gratitude” to the controller. Hence, the rich affective content of the narrative would have tended to focus attention on the role played by air traffic control. Without rule-based guidance to the contrary, it was not surprising that the participant concluded that they could rely on air traffic control to rescue them.

Hence, without proper ‘priming’ or guidance, a novice pilot may wrongly interpret case-based material. In effect, they are less able to tell what information in the case histories is important and what information is not. What was lacking in the above example was a supporting rule-based framework that would have warned the participant that assistance from air traffic control would not always be available and should not considered a substitute for adequate flight preparation and prudent in-flight decision making.

As a counterpoint, the following case history describes a VFR into IMC accident in which air traffic control assistance was not provided to best effect.

Case 9
The aircraft was being flown on a private VFR flight from Lightning Ridge to Caloundra by a non-instrument rated pilot with 220 hours flying experience. The weather on departure was suitable for VFR flight but by the time the aircraft was overhead Goondiwindi the weather had deteriorated significantly. A short time later the aircraft entered the Amberley Military Control Zone without a clearance. The Amberley approach controller contacted the pilot and instructed him to immediately conduct a left orbit to provide separation with an incoming military aircraft. During the orbit, the pilot advised the controller that the aircraft was “caught in cloud” and that he was “in trouble”. During the next eight minutes the controller issued the pilot with a number of air traffic control instructions. Radar data then indicated that during a turn to the right the aircraft’s ground speed and rate of descent increased. Radio contact with the pilot was lost after that time. Based on witness reports and evidence at the accident site, the aircraft was in a spiral dive before impacting the ground. The aircraft was destroyed and both occupants were fatally injured.

The investigation determined that the strategy adopted by the controller in responding to the in-flight emergency situation was not consistent with the guidance provided in the relevant air traffic control manuals. In particular, the pilot was placed in a situation where he was turning and descending the aircraft at the same time. In addition, the pilot was also required to respond to questions from ATS while performing these manoeuvres. It was unlikely that the pilot had the skills or experience that were required to enable him to cope with these demands. Although the controller’s communication style was in accordance with standard phraseology, the authoritative and interrogative style was inappropriate in the circumstances and was unlikely to have instilled confidence in or reassured the pilot.73

73 This synopsis is based on information contained in the Australian Transport Safety Bureau report of the accident (ATSB, 1999).
8.4.3. A case-based and rule-based model of aeronautical decision making

One of the main conclusions of this research is that aeronautical decision making can be best understood in terms of a model that combines both case-based and rule-based reasoning. Both aspects are equally important – they work in tandem and complement one another. Rule-based material provides a basic framework of standard procedures and recommended practices, particularly for novices, while case-based material adds detail and salience to the framework, particularly in the form of affective markers linked to particular case histories (see Figure 93) – a fusion of ‘cold cognition’ and ‘hot cognition’ (Kunda, 1999).
The conclusion that the best model of aeronautical decision making combines aspects of both case-based reasoning and rule-based reasoning is in accord with recent developments in information science where such hybrid models have been described by a number of researchers (Kolodner, 1994; Nakatani & Israel, 1994; Bartsch-Sporl, 1995; Golding & Rosenbloom, 1996; Redmond, 1997). In particular, hybrid systems are a good way to model the interplay of theory (rules) and practice (cases). Such an approach is particularly helpful in studying the progress of practitioners from novice to expert. This is because the relative utility of case-based and rule-based techniques will depend on the level of experience of the practitioner at a particular time in their career.

Hence, theoretical modelling using hybrid systems has the potential to shed light on ways to maximise the effectiveness of case history material in aviation safety and training. For example, a hybrid modelling approach could be used to investigate aspects such as the bootstrapping problem, where insufficient rule-based domain knowledge makes it difficult for
novices to determine what cues embedded in case history information are important and what cues are not.

8.4.4. The dynamic nature of aeronautical decision making

One of the main findings of this study is that, in many ways, aeronautical decision making is best characterised as a dynamic ongoing process, rather than as a static one-off decision. For example, in bad weather decision making, a pilot must often continually adapt their flying behaviour in response to changing conditions. The process is one of continual monitoring and feedback, where mistakes can be identified and (hopefully) corrected in time. These are all aspects that have been identified as characterising dynamic decision making in complex situations (Brehmer, 1999). Other aspects that are typical of dynamic decision making situations include ill-structured problems, shifting goals, and possibly time stress (Orasanu & Connoly, 1993). The opportunity for adapting and revising goals and strategies in many dynamic decision making situations is conducive to a ‘take a look and see’ approach (Dominguez, Flach, McDermott, McKellar, & Dunn, 2004). Again, in the aviation domain, this reflects the reality of much bad weather decision making.

The complexity of many dynamic decision making situations means that there are a multitude of different paths to success. Hence, models of the dynamic decision making process are typically based on stored instances of ‘action’ and ‘outcome’ pairs that are generated by the decision maker as they gain experience with the system (Dienes & Fahey, 1995; Gonzalez, Lerch, & Lebiere, 2003). That is, the models describe a form of case-based reasoning in which cases consist of information about the decision making situation, the action taken, and the resulting outcome. This suggest that ongoing research in the field of dynamic decision making has the potential to be of considerable benefit to the study of aeronautical decision making.

As outlined above, success in a dynamic decision making situation can only be gauged by the final outcome. In many ways, this places a considerable burden on the decision maker in that they can never rest on their laurels and must always remain vigilant to the risks they face. However, many pilots rise to this situation admirably, as the following example shows.

8.4.5. A singular case

One particular occurrence from the study of different pilot behaviours in the face of adverse weather provided a very graphic illustration of the principle that any flight is only as safe as the last decision that the pilot makes. In this occurrence, it was possible to identify ten separate steps in
an ongoing process in which the pilot obtained and analysed information, decided on and carried out a course of action, and then re-appraised the situation. This cycle was completed four times during which the pilot successively; varied the planned route, landed and waited for the weather to improve, turned back and assessed the situation, and carried out a precautionary landing.

In the successive stages of the flight the pilot;

1. obtained up-dated weather information during the flight
2. varied the planned route as a result of the new weather information
3. landed to refuel to increase flight endurance for turning back or diverting
4. varied the planned route as a result of the weather en route
5. landed and waited for the weather to improve
6. planned the next stage of flight to assess the weather ahead
7. turned back when non-VMC conditions were encountered
8. carried out two 360-degree orbits to assess the situation
9. configured the aircraft for a low speed bad-weather circuit
10. carried out a precautionary landing.

This succession of decisions and actions clearly illustrates that dealing with adverse weather is not a one-off decision but a continuously evolving process. At each of the four stages described above, there was the possibility that the pilot’s decision, and the outcome of the occurrence, may have been significantly different.

The report of this occurrence indicates that the pilot was continually assessing the weather en route and modifying their flight plan accordingly. However, notwithstanding this proactive decision making, the flight ended in a precautionary landing, and from the pilot’s own description, could just have easily ended as a VFR into IMC occurrence. The result could easily have been a fatal accident, with an investigation report that described the pilot’s behaviour as being typical of VFR into IMC occurrences.

This example emphasises the dynamic nature of weather-related decision making. A pilot may make a series of good decisions, but that is no automatic protection against a subsequent poor decision putting the safety of the flight at risk. The flight is only ever as safe as the pilot’s last decision.
A parallel can be drawn between the importance of a pilot, at an individual or 'micro' level, being continually mindful of the situation they face and similar concepts that have been advocated at a systems safety or 'macro' level. At the macro level, this concept has variously been described by Weick and Sutcliffe as 'organisational mindfulness' (2001), by Reason as 'chronic unease' (1997), and by Westrum as 'requisite imagination' (1993). A guiding tenet of this approach is that 'the price of safety is eternal vigilance', the idea that no system can guarantee safety for once and for all. The application of this approach to the level of the individual pilot would include aspects such as the importance of a pilot not flying to the limit of their abilities, and of not letting past success breed complacency.
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List of Tables

Table 1. Nomenclature of reasoning systems.................................19
Table 2. Inducement of intuition or analysis by task conditions........20
Table 3. Properties of intuition and analysis................................21
Table 4. Characteristics of associative and rule-base systems...........22
Table 5. Domains of good and poor decision performance...............43
Table 6. Percentage of general aviation accidents with 'pilot error' as a factor.................................................................65
Table 7. Percentage of civil aviation accidents with 'pilot error' as a factor.................................................................66
Table 8. The five hazardous attitudes...........................................72
Table 9. Characteristics of expert decision making relevant to advanced ADM training.......................................................79
Table 10. Internet distribution of survey request for information........99
Table 11. Survey report comments..............................................101
Table 12. Source of pilot email addresses.....................................129
Table 13. Typical pilot characteristics for each level of flying experience.................................................................136
Table 14. Mean ratings for case-history statements.........................141
Table 15. Characterisation of pilots beliefs about learning from experience.................................................................143
Table 16. Factors significantly affecting pilots' DRL statement ratings.......................................................................................146
Table 17. Factors significantly affecting pilots' ratings of case history statements.................................................................148
Table 18. Summary of set altitudes and relay messages in the When To Turn Back scenario...............................................................170
Table 19. When To Turn Back independent variables........................172
Table 20. Characterization of flight performance groups by flight performance variables........................................................180
Table 21. Flight performance scores (mean ± SE) for each flight performance group.................................................................181
Table 22. How Low To Go independent variables..............................195
Table 23. Characterization of decision groups by decision variables..............................................................................................200
Table 24. Decision variable scores (mean ± SE) for each decision group.......................................................................................200
Table 25. Single terms and combinations of terms used to search Occurrence Summary text .................................................. 214
Table 26. Weather-related decision making groups .................. 215
Table 27. Typical aircraft types in maximum certificated takeoff weight ranges .............................................................. 236
Table 28. Approximate geographical areas for all weather-related decision making occurrences ........................................ 238
Table 29. Proportion of all occurrences that were city flights or country flights ............................................................... 240
Table 30. Statistics for time of day (24 hr) of weather-related decision making occurrences ............................................... 243
Table 31. Number of valid cases for location variables ............... 245
Table 32. Statistics for TO_DEST (km distance from point of occurrence to planned destination) ....................................... 249
Table 33. Proportion of all occurrences before and after mid-point of flight ................................................................. 250
Table 34. Statistics for PCNT_FD (percent of flight distance completed at point of occurrence) .................................... 252
Table 35. Occurrences with information held on investigation file .. 255
Table 36. Questionnaire ‘learning from experience’ statements .... 278
List of Figures

Figure 1. Passengers are evacuated from Aloha Flight 243 after landing.................................................................2
Figure 2. Accident site of Bandeirante registration [XXX], near [destination], [date].........................................................3
Figure 3. Street Calculus.................................................................14
Figure 4. American Airlines Flight 191 just prior to impact at Chicago O'Hare International Airport.................................16
Figure 5. Different display templates for decision-related information.................................................................28
Figure 6. Recognition Primed Decision model..........................................35
Figure 7. The problem-detection process........................................40
Figure 8. Application and maintenance phases of case-based reasoning.............................................................52
Figure 9. Map showing alternative air routes used in the Snowbird 5 ‘play’...........................................................58
Figure 10. Publication rates for decision making and ADM research for 1967 to 2003.........................................................63
Figure 11. Jensen’s ‘Expertise’ model of pilot decision making........77
Figure 12. Flow chart of the ARTFUL decision-making model........82
Figure 13. Conceptual framework of pilots’ weather-related decision making......................................................92
Figure 14. Accident site of Boeing 737-400 G-OBME near Kegworth on 8 January 1989.................................................95
Figure 15. Accident site of McDonnell Douglas MD-81 OY-KHO at Gottrora on 27 December 27 1991.................................97
Figure 16. The burnt out hull of Saudi Arabian Airlines Flight 163 in Riyadh, 19 August 1980................................................104
Figure 17. Stricken Pacific Southwest Airlines Boeing 727 after midair collision 25 September 1978....................................117
Figure 18. Age distribution for all pilots........................................130
Figure 19. Proportion of pilots in each licence category..................131
Figure 20. Total hours flying time frequency distribution for all pilots...............................................................132
Figure 21. Average number of hours flown per year for all pilots.....132
Figure 22. Types of aircraft flown by all pilots.................................133
Figure 23. Flying activities engaged in by all pilots........................134
Figure 24. Experience levels of all pilots.........................................135
Figure 50. The effect decision response time on final cloud score (mean ± SE) .......................................................... 187
Figure 51. A screen shot from one of the How Low To Go scenarios... 190
Figure 52. A screen shot from the How Low To Go rule-based training material .......................................................... 192
Figure 53. High (a), middle (b), and low (c) altitude views in the How Low To Go scenario .................................................. 194
Figure 54. Example flight profiles from the How Low To Go scenario. .......................................................... 197
Figure 55. Proportion of participants in each of the three decision groups .......................................................... 201
Figure 56. Distribution of final altitude scores for all participants. .... 202
Figure 57. The effect of training group on final altitude score (mean ± SE). .......................................................... 203
Figure 58. The effect of training for quick decision making How Low To Go participants (mean ± SE) ......................... 204
Figure 59. Quick decision making group participants final altitude scores by training group .......................................................... 204
Figure 60. Scatter plot of final altitude by case-based training time. ... 205
Figure 61. The effect of gender on final altitude score (mean ± SE). .. 206
Figure 62. An aircraft in marginal VFR weather conditions .......... 207
Figure 63. An aircraft substantially damaged as a result of a precautionary landing .......................................................... 208
Figure 64. Local weather conditions at the time of a fatal VFR into IMC accident .......................................................... 217
Figure 65. VFR into IMC accident site .......................................................... 218
Figure 66. Percentage of accidents and incidents in each weather-related decision making group .......................................................... 223
Figure 67. Degree of severity of injury to pilot or passengers for each weather-related decision making group ........... 224
Figure 68. Wreckage of an unsurvivable VFR into IMC accident ..... 225
Figure 69. Degree of aircraft damage for each weather-related decision making group .......................................................... 226
Figure 70. Wreckage of a light aircraft VFR into IMC accident .......... 227
Figure 71. Age distribution of pilots for all weather-related decision making groups .......................................................... 228
Figure 72. Total flying time for pilots in all weather-related decision making groups .......................................................... 229
Figure 73. Time on type for pilots in all weather-related decision making groups. 230
Figure 74. Pilot licence type for all decision making groups. 231
Figure 75. Pilot ownership status for all decision making groups. 232
Figure 76. Type of flying operation for all decision making groups. 233
Figure 77. Type of airspace in which occurrence took place by decision making group. 234
Figure 78. Geographical location of weather-related decision making occurrences in all groups. 237
Figure 79. Distribution of city flights and country flight for occurrences in all groups. 239
Figure 80. Proportion of occurrences for city versus country flying by group (V, WP, WA). 241
Figure 81. Distribution of local time (24 hr) of occurrences in comparison to flying activity. 242
Figure 82. Distribution of occurrences by local time of day for each group (V, WP, WA). 243
Figure 83. Frequency distribution of flight distances for all flights. 246
Figure 84. Distance from point of departure to occurrence location for all occurrences. 247
Figure 85. Distance from occurrence location to planned destination for all occurrences. 248
Figure 86. Proportion of occurrences before and after mid-point of flight by group (V, WP, WA). 251
Figure 87. Percent of flight distance completed at point of occurrence for all groups. 252
Figure 88. Percent of flight distance completed at point of occurrence by group (All, V, WP, WA). 253
Figure 89. Fatality rate for VFR into IMC accidents. 291
Figure 90. VFR into IMC accident site. 292
Figure 91. Cloud formation near Albury, NSW. 297
Figure 92. VFR into IMC accident site. 304
Figure 93. The interplay of case-based and rule-based reasoning in aeronautical decision making. 305
Figure 94. Cloud formation near Canberra, ACT. 308
List of Appendices

Appendix 1........Aviation safety survey form 340
Appendix 2........Aviation safety questionnaire form 341
Appendix 3........Training Presentation And Analysis program code 346
Appendix 4........Bad weather flying case-based training module 353
Appendix 5........Bad weather flying rule-based training module 364
Appendix 6........Bad weather flying case-based questionnaire 376
Appendix 7........Bad weather flying rule-based questionnaire 378
Appendix 8........Icarus flight simulator program code 380
Appendix 9........Example Icarus flight simulator subject data file 402
Appendix 10.......Icarus task file for *When To Turn Back* scenario 411
Appendix 11.......Low flying case-based training module 416
Appendix 12.......Low flying rule-based training module 427
Appendix 13.......Low flying case-based questionnaire 439
Appendix 14.......Low flying rule-based questionnaire 441
Appendix 15.......Example transcript of responses to decision probes 443
Appendix 16.......Risk factors for involvement in aircraft accidents 445
Appendix 1. Aviation safety survey form

Do we remember all those stories when it counts?

Most of us have read countless stories about particular flying accidents in aviation magazines or flight safety bulletins. Examples of what 'not to do' often feature prominently in articles written to improve flight safety. Many pilots will have read numerous accident reports and the official verdict as to what went wrong. Sometimes we will have heard first hand from other pilots about mistakes they've made that we should avoid. But how well do we learn from other peoples' experience? Do we recall these examples when it matters most, when we are in a similar situation and the safety of our flight may be at risk?

As part of research for a Master's thesis in aviation psychology at the University of Otago, New Zealand, I am very interested in hearing from pilots about whether they have recalled previous cases at a critical time. That is, when faced with a similar situation has the recollection of an earlier case influenced you in deciding what to do?

I'm interested in hearing from all pilots, private or commercial, civilian or military, low time or experienced, fixed wing or rotor.

As an example, a private pilot on a cross country flight might, when faced with a similar situation, recall reading about a specific example that highlighted the dangers of continuing on into deteriorating weather. Or perhaps a pilot tempted to buzz a friend's farm might remember the case of a pilot that came to grief by engaging in unnecessary low flying.

In one reported case the crew of a McDonnell Douglas MD-81 that crashed near Gottrora, Sweden, in December 1991 after losing engine power described afterwards that at the time of the incident they recalled the 'Kegworth accident' and did their utmost to avoid making the same mistake. In August 1990 a Boeing 737-400 crashed near Kegworth, England, when the crew inadvertently shut down the wrong engine after an engine failure.

If you have ever been in a situation where you recalled a previous specific example at a critical time I would be most interested to hear the details from you. All individual information will be treated in strictest confidence and will not used by any other person or reported in any way that could identify the source.

As well as hearing from pilots that have been helped by recalling case studies they've read or heard about I would be equally interested in hearing from pilots who feel that in spite of being exposed to case studies from various sources they have not consciously brought them to mind when it mattered most.

The goal of this work is to better understand how we learn from experience, both our own experience and that of others. Hopefully, this will ultimately lead to improved training methods in pilot decision making.

I will provide a full summary of my results and conclusions to all that help and if there is a general interest in the newsgroup I will post a summary there.

Thanks very much in advance to anyone that can help with anecdotes of their own. Please pass on this request to any pilot groups or associations that might have members that could help. Again thanks.

Cheers, Richard

Richard Batt
Appendix 2. Aviation safety questionnaire form

Dear ....,

My name is Richard Batt. I am a private recreational pilot from Adelaide, Australia.

I am sending this email to ask if you would consider taking part in a study concerning flight safety. Your participation would involve completing the short questionnaire below. Any information you send will be kept strictly confidential and I will provide a summary of the results to all participants. Your help would be very much appreciated.

This work is one aspect of a study I am doing into ways that aviation safety training can be improved, as part of a Masters degree in Aviation Psychology at the University of Otago, New Zealand. I am sending this request to people that listed as pilots in the Four 11 online directory service and to UK pilots listed on the Charlie Alpha web site. If you do not wish to take part in this study then simply ignore this request. I will not contact you again.

The questionnaire was developed after receiving input via aviation newsgroups and web sites from 140 pilots from all over the world. The Aviation Safety Connection web site has kindly agreed to make this original material available on-line so that it will be accessible to as many pilots as possible. The reports make fascinating reading I think; a real wealth of stories, information and insights.

The Aviation Safety Connection is on-line at http://www.aviation.org

I have no association with the Aviation Safety Connection, except that I very much appreciate them making this material available on their web site. It is an excellent site and well worth a visit I think. To read the reports that formed the basis of the questionnaire go to “Ready Room/Discussions”, then “Learning From Experiences”, then “Learning Stories Forum”. As well as reading the contributions by other pilots you can leave comments or start a new topic yourself with your own anecdote or observation.

Your help in completing the questionnaire would be most appreciated. I will send a summary of the results to all participants. If you would like any further information please let me know.

Thank you and safe flying.

Cheers, Richard

Richard Batt

Do we remember all those stories when it counts?

Most of us have read countless stories about particular flying accidents in aviation magazines or flight safety bulletins. Examples of what 'not to do' often feature prominently in articles written to improve flight safety. Many pilots will have read numerous accident reports and the official verdict as to what went wrong. Sometimes we will have heard first hand from other pilots about mistakes they've made that we should avoid. But how well do we learn from other peoples' experience? Do we recall these examples when it matters most, when we are in a similar situation and the safety of our flight may be at risk?

As an example, a private pilot on a cross country flight might, when faced with a similar situation, recall reading about a specific example that highlighted the dangers of continuing on into deteriorating weather. Or perhaps a pilot tempted to buzz a friend's farm might remember the case of a pilot that came to grief by engaging in unnecessary low flying.
In one reported case the crew of a McDonnell Douglas MD-81 that crashed near Gottrora, Sweden, in December 1991 after losing engine power described afterwards that at the time of incident they recalled the 'Kegworth accident' and did their utmost to avoid making the same mistake. In August 1990 a Being 737-400 crashed near Kegworth, England, when the crew inadvertently shut down the wrong engine after an engine failure.

The goal of this work is to better understand how we learn from experience, both our own experience and that of others. Hopefully, this will ultimately lead to improved training methods in pilot decision making.

Your information will be kept strictly confidential. I will not divulge individual data to anyone else at all - I will note your answers and then delete your email. The database will not include your name or any information that would identify you. Again thank you very much for your help, I really appreciate it!

I've tried to keep the format simple so that you can use any mail program or editor. If you just hit reply and then type in your answers that should work just fine! If a question doesn't apply to you just leave it blank.

Firstly some basic details please,

1) Your age...

2) Your sex...

3) Your nationality...

4) Your general education.

Please put an X next to the alternative that best describes your highest qualification.

[ ] Primary
[ ] Secondary, eg high school
[ ] Tertiary, eg college or university

Now some info about your flying please,

5) How many years flying experience do you have?...

6) How many flying hours in total do you have?...

7) What licences/certificates have you held?

Please put an X next to each one.

[ ] Student
[ ] Private
[ ] Commercial
[ ] Airline Transport
[ ] Other, please give details...

8) What ratings have you held?

Please put an X next to each one.

[ ] Instrument
[ ] Multi-engine
[ ] Helicopter
[ ] Flight Instructor
[ ] Other, please give details...

9) Please very briefly describe your history of flying training over the years.

For example, "WW2 air force, various airlines" say, or "Local flying club".

Your details...
10) What types of aircraft have you flown?

Please put an X next to each type of aircraft that you have flown. Use as few or as many X's as you like.

[ ] Light single-engine piston
[ ] Light twin-engine piston
[ ] Medium multi-engine piston
[ ] Heavy multi-engine piston
[ ] Light jet/turboprop
[ ] Medium jet/turboprop
[ ] Heavy jet/turboprop
[ ] Jet fighter
[ ] Helicopter
[ ] Ultralight
[ ] Glider/sailplane
[ ] Other, please give details...

11) What types of flying activities have you been involved with?

Please put an X next to each type of flying activity that you have been involved with. Use as few or as many X's as you like.

[ ] Recreational
[ ] Light Commuter/Charter
[ ] Corporate
[ ] Airline
[ ] Military
[ ] Flight Instruction
[ ] Aerial Work/Agricultural
[ ] Emergency Services
[ ] Test Flying
[ ] Other, please give details...

12) Personally, how passionately do you feel about flying!?

Please put an X next to the alternative that best describes your feelings.

[ ] What else is there? It's my life!
[ ] It's always been one of my prime interests, I'm very involved.
[ ] It's important to me.
[ ] Just a job really (or) A pleasant hobby.
[ ] It's a minor interest.

Now a few questions about accident and incident reports,

13) What, if any, aviation safety reports or periodicals do you read?

Please put an X next to each one that you read.

[ ] Individual accident/incident full reports (eg NTSB, BASI, CAA, TSB)
[ ] Approach (US Navy)
[ ] Asia Pacific Air Safety (BASI Australia)
[ ] Aviation Safety (Belvoir)
[ ] Aviation Safety Letter (Transport Canada)
[ ] Aviation Safety Reflections (Transport Canada)
[ ] Callback (NASA ASRS)
[ ] Crosstoll (US Air Force)
[ ] GASIL (CAA UK)
[ ] New Zealand Flight Safety (CAA NZ)
[ ] Other, please give details...
14) What, if any, aviation safety magazine columns do you read?

Please put an X next to each one that you read.
[ ] "Aftermath" - Flying (US)
[ ] "Incident Reports" - Flyer (UK)
[ ] "I learned about flying from that" - Flying (US)
[ ] "NTSB Debriefer" - Plane and Pilot (US)
[ ] Other, please give details...

15) How recently did you read any of the air safety reports, periodicals or magazine columns that you listed in questions 14) and 15) above?

Please put an X next to one alternative.
[ ] In the last two days
[ ] In the last week
[ ] In the last month
[ ] In the last three months
[ ] In the last year
[ ] More than a year ago

Finally some questions asking whether you agree or disagree with some of the points made by other respondents to question "Do we remember those stories when it counts?" Please read each statement carefully and then indicate whether you agree or disagree with it.

16) "Yes we do recall those stories when it counts. The specifics of accident and incident reports do come to mind at critical flight times, often in surprisingly vivid detail."

Please place an X next to the alternative that best describes how you feel about this statement.
[ ] Strongly disagree
[ ] Disagree
[ ] Neither agree nor disagree
[ ] Agree
[ ] Strongly agree

17) "I would say that similar sorts of accident case histories tend to merge into one, and it is this composite picture that we recall at a critical moment, rather than remembering any individual story."

Please place an X next to the alternative that best describes how you feel about this statement.
[ ] Strongly disagree
[ ] Disagree
[ ] Neither agree nor disagree
[ ] Agree
[ ] Strongly agree

18) "Depends on how much time you have. If time is short, say an engine failure on takeoff, then your response is based on standard drills and procedures rather than on the recollection of prior cases. With longer time though, say a flight into deteriorating weather, it's more likely that you'll remember specific accident reports that you have read."

Please place an X next to the alternative that best describes how you feel about this statement.
[ ] Strongly disagree
[ ] Disagree
[ ] Neither agree nor disagree
[ ] Agree
[ ] Strongly agree
19) "At the time you don't remember particular case histories but on later reflection, after the danger has passed, you tend to recall details of the specific cases that may have influenced you."

Please place an X next to the alternative that best describes how you feel about this statement.

[ ] Strongly disagree
[ ] Disagree
[ ] Neither agree nor disagree
[ ] Agree
[ ] Strongly agree

20) "Reading the case histories adds to our store of aviation knowledge in general. The important information is remembered in an abstract and integrated form, but the details of particular cases are not recalled."

Please place an X next to the alternative that best describes how you feel about this statement.

[ ] Strongly disagree
[ ] Disagree
[ ] Neither agree nor disagree
[ ] Agree
[ ] Strongly agree

21) "Exposure to aircraft accident and incident reports has influenced the way I plan and carry out my flying activities. Recalling specific case histories has enabled me to avoid critical situations in the first place."

Please place an X next to the alternative that best describes how you feel about this statement.

[ ] Strongly disagree
[ ] Disagree
[ ] Neither agree nor disagree
[ ] Agree
[ ] Strongly agree

22) "A good scare is worth more than good advice."

Please place an X next to the alternative that best describes how you feel about this statement.

[ ] Strongly disagree
[ ] Disagree
[ ] Neither agree nor disagree
[ ] Agree
[ ] Strongly agree

That's it! Thank you very much! Your help is greatly appreciated. I will send you a summary of the final results.

Cheers, Richard

Richard Batt
Appendix 3. Training Presentation And Analysis program code

Declarations

Declare Sub set_cursor_pos Lib "User" (ByVal x As Integer, ByVal y As Integer)

Global display_screen(50) As Form 'array of forms to display info
Global screen_name(50)
Global screen_time(50) 'cumulative time spent on display_screen()
Global total_time 'sum of screen_times
Global start_time 'at start of each screen
Global csn 'current screen number
Global total_screen 'total number of screens in presentation
Global subject_run 'subject (not preview)
Global subject_time 'time presentation to subject
Global subject_backtrack 'allow subject to backtrack
Global s_id, s_name, s_dob, s_sex 'subject information
Global path_name, file_name, outfile 'filename for save data
Global condition 'expt condition (module) number
Global description 'module description
Global cx, cy 'cursor position

Sub adjust_screen (sform As Form)
' could hardwire some of this
sform.Top = 0
sform.Left = 0
sform.Height = screen.Height
sform.Width = screen.Width
sform.Enabled = False 'for safety
End Sub

Sub centre_dialog_box (dbox As Form)
dbox.Left = (screen.Width - dbox.Width) / 2
dbox.Top = (screen.Height - dbox.Height) / 2
End Sub

Sub delay (delay_time)
time_now = Timer
Do Loop Until Timer > time_now + delay_time

End Sub

Sub end_prog ()
ReDim dummy(50) As Form
For x = 0 To forms.Count - 1
Set dummy(x) = forms(x)
Next x
For x = 0 To forms.Count - 1
Unload dummy(x)
Next x
End
End Sub

Sub examples_badwx ()
total_screen = 23
Set display_screen(1) = intro
Set display_screen(2) = badwx
Set display_screen(3) = exh1
Set display_screen(4) = exbw1a
Set display_screen(5) = exbw1b
Set display_screen(6) = exbw1c
Set display_screen(7) = exbw1d
Set display_screen(8) = exh2
Set display_screen(9) = exbw2a
Set display_screen(10) = exbw2b
Set display_screen(11) = exbw2c
Set display_screen(12) = exbw2d
Set display_screen(13) = exh3
Set display_screen(14) = exbw3a
Set display_screen(15) = exbw3b
Set display_screen(16) = exbw3c
Set display_screen(17) = exbw3d
Set display_screen(18) = exh4
Set display_screen(19) = exbw4a
Set display_screen(20) = exbw4b
Set display_screen(21) = exbw4c
Set display_screen(22) = exbw4d
Set display_screen(23) = final
screen_name(1) = "intro"
screen_name(2) = "badwx"
screen_name(3) = "exh1"
screen_name(4) = "exbw1a"
screen_name(5) = "exbw1b"
screen_name(6) = "exbw1c"
screen_name(7) = "exbw1d"
Sub examples_lowfly()

total_screen = 23

Set display_screen(1) = intro
Set display_screen(2) = lowfly
Set display_screen(3) = exh1
Set display_screen(4) = exlf1a
Set display_screen(5) = exlf1b
Set display_screen(6) = exlf1c
Set display_screen(7) = exlf1d
Set display_screen(8) = exh2
Set display_screen(9) = exlf2a
Set display_screen(10) = exlf2b
Set display_screen(11) = exlf2c
Set display_screen(12) = exlf2d
Set display_screen(13) = exh3
Set display_screen(14) = exlf3a
Set display_screen(15) = exlf3b
Set display_screen(16) = exlf3c
Set display_screen(17) = exlf3d
Set display_screen(18) = exh4
Set display_screen(19) = exlf4a
Set display_screen(20) = exlf4b
Set display_screen(21) = exlf4c
Set display_screen(22) = exlf4d
Set display_screen(23) = final

End Sub
delay 2 'pad out to show start screen

subject_run = False
subject_backtrack = False
subject_time = True
path_name = CurDir & tf(Right(CurDir, 1) = "\", """")
file_name = "TPAA_000.DAT"
outfile = path_name & file_name
setup.Label3.Caption = outfile

setup.Show 0
screen.MousePointer = 0
Unload start

End Sub

Sub next_screen()

screen.MousePointer = 11

If csn > 0 Then
off_timer csn
End If

csn = csn + 1

If csn < total_screen Then
show_display_screen csn
on_timer
Else
show_display_screen csn 'final
save_data
End If

If csn > 2 Then
Unload display_screen(csn - 2)
End If

If csn < total_screen - 1 Then
Load display_screen(csn + 1)
End If

screen.MousePointer = 0

End Sub

Sub off_timer (k)

screen_time(k) = screen_time(k) + Timer - start_time

End Sub

Sub on_timer ()

start_time = Timer

End Sub

Sub prev_screen ()

screen.MousePointer = 11

If csn > 1 Then
off_timer csn
csn = csn - 1
show_display_screen csn
on_timer
Unload display_screen(csn + 1)
End If

screen.MousePointer = 0

End Sub

Sub rules_badwx()

total_screen = 25

Set display_screen(1) = intro
Set display_screen(2) = badwx
Set display_screen(3) = ruh1
Set display_screen(4) = ru1
Set display_screen(5) = ru2
Set display_screen(6) = ru3
Set display_screen(7) = ru4
Set display_screen(8) = rubwh1
Set display_screen(9) = rubw1
Set display_screen(10) = rubw2
Set display_screen(11) = rubw3
Set display_screen(12) = rubw4
Set display_screen(13) = rubwh2
Set display_screen(14) = rubw5
Set display_screen(15) = rubw6
Set display_screen(16) = rubw7
Set display_screen(17) = rubwh3
Set display_screen(18) = rubw8
Set display_screen(19) = rubw9
Set display_screen(20) = rubw10
Set display_screen(21) = rubwh4
Set display_screen(22) = rubw11
Set display_screen(23) = rubh2
Set display_screen(24) = rubw12
Set display_screen(25) = final

screen_name(1) = "intro"
screen_name(2) = "badwx"
screen_name(3) = "ruh1"
screen_name(4) = "ru1"
screen_name(5) = "ru2"
screen_name(6) = "ru3"
screen_name(7) = "ru4"
screen_name(8) = "rubwh1"
screen_name(9) = "rubw1"
screen_name(10) = "rubw2"
screen_name(11) = "rubw3"
screen_name(12) = "rubw4"
screen_name(13) = "rubw2"
screen_name(14) = "rubw5"
screen_name(15) = "rubw6"
screen_name(16) = "rubw7"
screen_name(17) = "rubw3"
screen_name(18) = "rubw8"
screen_name(19) = "rubw9"
screen_name(20) = "rubw10"
screen_name(21) = "rubw4"
screen_name(22) = "rubw11"
screen_name(23) = "rubw2"
screen_name(24) = "rubw12"
screen_name(25) = "final"

End Sub

Sub rules_decide()

End Sub

Sub rules_examples_badwx()

End Sub

Sub rules_examples_badwx()

End Sub
Set display_screen(45) = final

screen_name(1) = "intro"
screen_name(2) = "badwx"
screen_name(3) = "ruh1"
screen_name(4) = "ru1"
screen_name(5) = "ru2"
screen_name(6) = "ru3"
screen_name(7) = "ru4"
screen_name(8) = "rubwh1"
screen_name(9) = "rubw1"
screen_name(10) = "rubw2"
screen_name(11) = "rubw3"
screen_name(12) = "rubw4"
screen_name(13) = "rubw5"
screen_name(14) = "rubw6"
screen_name(15) = "rubw7"
screen_name(16) = "rubwh3"
screen_name(17) = "rubw8"
screen_name(18) = "rubw9"
screen_name(19) = "rubw10"
screen_name(20) = "rubw11"
screen_name(21) = "rubw12"
screen_name(22) = "ruh2"
screen_name(23) = "rubw13"
screen_name(24) = "rubw14"
screen_name(25) = "rubw15"
screen_name(26) = "rubw16"
screen_name(27) = "rubw17"
screen_name(28) = "rubw18"
screen_name(29) = "rubw19"
screen_name(30) = "rubw20"

End Sub

Sub rules_examples_lowfly()

Set display_screen(7) = ru4
Set display_screen(8) = rulfh1
Set display_screen(9) = rulf1
Set display_screen(10) = rulf2
Set display_screen(11) = rulfh2
Set display_screen(12) = rulf3
Set display_screen(13) = rulf4
Set display_screen(14) = rulf5
Set display_screen(15) = rulfh3
Set display_screen(16) = rulf6
Set display_screen(17) = rulfh4
Set display_screen(18) = rulf7
Set display_screen(19) = rulfh5
Set display_screen(20) = rulf8
Set display_screen(21) = rulf9
Set display_screen(22) = rulf10
Set display_screen(23) = rulf11
Set display_screen(24) = rulf2
Set display_screen(25) = rulf12
Set display_screen(26) = exh1
Set display_screen(27) = exlf1a
Set display_screen(28) = exlf1b
Set display_screen(29) = exlf1c
Set display_screen(30) = exlf1d
Set display_screen(31) = exh2
Set display_screen(32) = exlf2a
Set display_screen(33) = exlf2b
Set display_screen(34) = exlf2c
Set display_screen(35) = exlf2d
Set display_screen(36) = exh3
Set display_screen(37) = exlf3a
Set display_screen(38) = exlf3b
Set display_screen(39) = exlf3c
Set display_screen(40) = exlf3d
Set display_screen(41) = exh4
Set display_screen(42) = exlf4a
Set display_screen(43) = exlf4b
Set display_screen(44) = exlf4c
Set display_screen(45) = exlf4d
Set display_screen(46) = final

screen_name(1) = "intro"
screen_name(2) = "lowfly"
screen_name(3) = "ruh1"
screen_name(4) = "ru1"
screen_name(5) = "ru2"
screen_name(6) = "ru3"
screen_name(7) = "ru4"
screen_name(8) = "rulfh1"
screen_name(9) = "rulf1"
screen_name(10) = "rulf2"
screen_name(11) = "rulfh2"
screen_name(12) = "rulf3"
screen_name(13) = "rulf4"
screen_name(14) = "rulf5"
screen_name(15) = "rulfh3"
screen_name(16) = "rulf6"
screen_name(17) = "rulfh4"
screen_name(18) = "rulf7"
screen_name(19) = "rulfh5"
screen_name(20) = "rulf8"

Sub rules_examples_lowfly()

total_screen = 46

Set display_screen(1) = intro
Set display_screen(2) = lowfly
Set display_screen(3) = ruh1
Set display_screen(4) = ru1
Set display_screen(5) = ru2
Set display_screen(6) = ru3
Sub rules_lowfly ()

  total_screen = 26
  Set display_screen(1) = intro
  Set display_screen(2) = lowfly
  Set display_screen(3) = ruh1
  Set display_screen(4) = ru1
  Set display_screen(5) = ru2
  Set display_screen(6) = ru3
  Set display_screen(7) = ru4
  Set display_screen(8) = rulf11
  Set display_screen(9) = rulf1
  Set display_screen(10) = rulf2
  Set display_screen(11) = rulfh2
  Set display_screen(12) = rulf3
  Set display_screen(13) = rulf4
  Set display_screen(14) = rulf5
  Set display_screen(15) = rulfh3
  Set display_screen(16) = rulf6
  Set display_screen(17) = rulfh4
  Set display_screen(18) = rulf7
  Set display_screen(19) = rulfh5
  Set display_screen(20) = rulf8
  Set display_screen(21) = rulf9
  Set display_screen(22) = rulf10
  Set display_screen(23) = rulf11
  Set display_screen(24) = rulf12
  Set display_screen(25) = rulf13
  Set display_screen(26) = final

End Sub

Sub save_data ()

  total_time = 0
  For n = 2 To total_screen - 1
    total_time = total_time + screen_time(n)
  Next n

  Open outfile For Output As #1
  Print #1, "ID = ", s_id, " Condition = ";
  Print #1, "description"; Format(Now, "dddd, d mmmm yyyy"); Format(Now, "h:mm:ss")
  Print #1, "n", "screen", "time (secs)"
  For n = 2 To total_screen - 1
    Print #1, n, screen_name(n), Format(screen_time(n), "0.00")
  Next n
  Print #1, "total time = "; Format(total_time, "0.0")
  Close #1

End Sub

Sub setup_module ()

  setcursorpos cx, cy
If setup!Option1(0) Then  
  condition = 1  
  description = "Rules - Bad Weather"  
  rules_badwx  
Elseif setup!Option1(1) Then  
  condition = 2  
  description = "Examples - Bad Weather"  
  examples_badwx  
Elseif setup!Option1(2) Then  
  condition = 3  
  description = "Rules & Examples - Bad Weather"  
  rules_examples_badwx  
Elseif setup!Option1(3) Then  
  condition = 4  
  description = "Rules - Low Flying"  
  rules_lowfly  
Elseif setup!Option1(4) Then  
  condition = 5  
  description = "Examples - Low Flying"  
  examples_lowfly  
Elseif setup!Option1(5) Then  
  condition = 6  
  description = "Rules & Examples - Low Flying"  
  rules_examples_lowfly  
Elseif setup!Option1(6) Then  
  condition = 7  
  description = "DECIDE"  
  rules_decide  
End if  

End Sub

Sub show_display_screen (k)  
  display_screen(k).Show 0  
  display_screen(k).Refresh

Sub show_setup ()  
  Unload display_screen(csn)  
  csn = 1  
  setup.Show 0

End Sub

Sub show_start ()  
  centre_dialog_box start  
  start!Image1.Left = .5 * (start.Width - start!Image1.Width) 'centre image on form  
  start.Show 0 'processing stops if modal  
  start.Refresh

End Sub

Function tf (test_variable, result_if_true, result_if_false)  
  ' returns result_if_true if test_variable is true, else returns result_if_false  
  If test_variable Then  
    tf = result_if_true  
  Else  
    tf = result_if_false  
  End If

End Function
Appendix 4.  Bad weather flying case-based training module

Disclaimer

The training material reproduced in the following Appendices was used for private experimental work only. The pictures came from a range of aviation magazines and books and were for illustration only. They do not show the actual aircraft, people, or locations involved in the accidents and incidents described in the accompanying text. There is absolutely no suggestion that the aircraft or people depicted in the training material were involved in any unsafe flying activity, or were involved in any accident or incident, however arising.

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Richard Batt
Example 1

"I planned my flight from Hamilton to Wanganui and then on to Wellington via the Kapiti coast. The weather from Hamilton was excellent except for a band of very heavy showers moving east from about 20 kilometres north of Wanganui towards Taihape. The weather was fine at Wanganui towards Taihape and cloudless further along the coast towards Paraparaumu."
“About 8 miles south of Raetihi I contacted Ohakea Control for clearance through their zone at 4,000 feet. At that stage I could see right through to Wanganui without difficulty. I had however misjudged how rapidly the heavy showers were moving. It became obvious that I would have to alter heading to avoid rapidly reducing visibility. I advised Ohakea and began a lefthand turn to avoid cloud - and quickly found myself in cloud.”

“Being suddenly enveloped in cloud produced an incredible feeling of isolation and inadequacy. Fortunately though expert help was only a radio call away. When I contacted the Ohakea controller and requested help it was immediately forthcoming. His instructions to me were to concentrate on keeping my wings level, assuring me that I had ample ground clearance, and that my groundspeed was good.”
"The feeling of being alone had gone, and concentrating on the job in hand became a priority. It was like having an instructor sitting with you while flying. The controller told me that my heading was good and that I would soon see Wanganui, which was 15 miles away. As quickly as I had entered cloud I burst out of it, with a great debt of gratitude to the Ohakea controller."
The planned flight was from Dunedin to Christchurch via the coast. At approximately 3.15pm the pilot arrived at the Taieri aerodrome and assessed the current weather conditions to be "slightly better than had been forecast". No flight plan was filed. Departing Taieri at 3.50pm the aircraft proceeded to fly north-east towards Oamaru.

On passing Moeraki the weather began deteriorating "with light drizzle and a reducing cloud base". At this point the pilot considered whether to turn back. His attention was diverted by a problem directional gyro and the aircraft began to diverge from its intended flight path.

The pilot recalls losing visual contact with the coast in the region of Oamaru and deciding "to forget about the directional gyro and track back to Dunedin using the magnetic compass". He opted to maintain 1,500 feet "for safety, not realizing how far off-track I had flown".

What follows is his actual account of the crash:
"During a turn to the left to return to Dunedin, I vaguely remember the first impact of one wheel and part of the elevator striking a tree. However, I do not recall anything after that until I was on the ground. No mayday or distress calls were made as the aircraft impact was very sudden and I wasn't expecting it.

When I came to after the crash I was able to walk to a nearby farmhouse to sound the alarm that an accident had occurred."

The aircraft crashed near Oamaru at approximately 4.40pm. The aircraft was totally destroyed on impact. The pilot was very fortunate that he survived the crash and that the aircraft did not catch fire.
Example 3

The aircraft was carrying out a private VFR flight from Wellington to Christchurch. Weather conditions were poor with cloud cover across most of Nelson-Marlborough and Canterbury. A squall-line passing across the coast near Kaikoura resulted in areas of driving rain, cloud in excess of 5/8's cover down to 500 feet, with lower patches, and visibility down to 500 metres.
At 10.07 am the pilot reported to Christchurch Flight Service that he was coastal in the Woodend area, requesting radar vectoring to Christchurch. He subsequently advised that he was "trying to find" his way and again requested radar vectoring. He did not declare an emergency.

Christchurch Radar observed the aircraft to be east of Amberley, outside the radar area of responsibility. The pilot was unaware of the discrepancy between his reported position and his position observed on radar. Christchurch Flight Service attempted to advise the pilot but received only a broken transmission from an unidentified station.

Christchurch Radar observed a brief radar return of the aircraft carrying out left orbits at about 800 feet over Pegasus Bay. Shortly after this observation, the aircraft flew into the sea. The wreckage and the bodies of the pilot and his three passengers were recovered the following day.
Damage to the aircraft indicated that it impacted with the sea in a wings-level, slightly nose-down attitude with the engine operating at a low power setting.

The subsequent accident investigation report concluded that the following factors were responsible for the crash,

- The weather was unsuitable for visual flight.
- The pilot did not declare an in-flight emergency.

Example 4
Weather conditions on Stewart Island had deteriorated during the day of the accident. The pilot of an aircraft which had operated an earlier flight reported that the weather was changing rapidly, with clear patches interspersed with areas of low cloud in the region of Horseshoe Bay and Halfmoon Bay. Estimates of the cloud base at the time varied between 150 to 250 feet above sea level with associated areas of misty rain.

At about 5.25pm the pilot of the accident aircraft, accompanied by a passenger, took off from the beach at Horseshoe Bay, with the intention of completing one circuit and landing before tying down the aircraft for the night.

During the circuit a patch of fog was encountered in the vicinity of Bragg Point. Under the impression that it was an isolated patch the pilot continued the circuit and flew into the fog, expecting very shortly to regain clear conditions. However the fog and low cloud proved more extensive than the pilot had imagined.
Conditions worsened and only brief glimpses of the ground or water could be seen. The pilot decided to divert to Invercargill. He recalled reaching down with his right hand in order to contact Invercargill Air Traffic Control. Shortly afterwards the aircraft became completely enveloped in cloud and the pilot lost all sight of the ground or water.

He was unable to recall any further events leading up to the accident.

When the aircraft did not return an aerial search was commenced but it failed to find any trace of the missing aircraft before nightfall. The search was resumed at first light the next morning and at 7.10 am the wreckage of the aircraft was sighted in bush covered country near Halfmoon Bay.

The pilot, who had sustained serious injury to his legs, was trapped in the wreckage. The seriously injured passenger was nearby. Both occupants were lifted from the site by helicopter and taken to Invercargill Hospital.
Appendix 5. Bad weather flying rule-based training module

Don’t fly into BAD WEATHER

Flying training and Aeronautical Decision Making
Safe flying depends on both mechanical and human factors. Modern design and construction techniques mean that today's light aircraft are very unlikely to suffer major mechanical problems. However equally important as the integrity of the aircraft is the ability of the pilot in command.

Pilots undergo rigorous and comprehensive training to ensure that their skills match the requirements of the demanding environment in which they operate.

There are two distinct but complementary aspects to pilot training. As well as "hands on" instruction in the air, students also complete a course of ground based theory instruction. This includes aspects of aerodynamic theory as well as an understanding of the nature and operation of the airframe, engine, and instruments. Other topics include radio work, meteorology and navigation.

A proficient pilot, however, needs more than just basic knowledge and flying skills. Another very important ability is that of good decision making.
Good decision making will not happen automatically. It can be learnt by experience but the cost may be very high. In the extreme, bad aeronautical decision making can result in death or serious injury, no less so than might be caused by major mechanical problems.

Flying training emphasizes the importance of good decision making and attempts to improve pilots’ skills in that area.

Decision making is a process which involves recognizing and analyzing all the information relevant to the situation, followed by the evaluation of alternative courses of action, and finally the execution of the chosen course in a timely manner.
One important decision making skill that pilots must develop is that of weather awareness. The weather plays a major role in many aspects of flying and accident research shows that weather factors contribute to many aviation crashes. This is particularly true in the case of light aircraft being flown by private pilots. Many accidents involving this group are the result of the pilot failing to recognize the significance of deteriorating weather conditions and continuing the flight into a potentially dangerous situation.
Most private flying for business or pleasure is done under Visual Meteorological Conditions (VMC). In simple terms VMC means staying out of clouds. More specifically in New Zealand a pilot must keep a distance of at least one nautical mile horizontally and one thousand feet vertically from cloud. In VMC flying visual reference to the outside world is essential for both controlling the aircraft and for cross country navigation. In contrast, flying in cloud requires special training to rely entirely on the aircraft's instruments.

If a pilot without instrument training suddenly finds him or herself in cloud then typically disorientation and loss of control will occur within a matter of minutes. Once visual reference is lost sensory illusions occur that make it very difficult to determine the aircraft's attitude. Instrument pilots are trained to ignore these false sensations and rely entirely on the aircraft's instruments. However this is very hard to do without proper training.
Research has shown that untrained pilots will lose control within an average of 178 seconds once they no longer have visual reference to orientate them. For this reason it is vital that VMC rated pilots avoid entering cloud.

How to stay out of trouble
One crucial way in which a VMC pilot can lessen the risk that they will encounter conditions that they are not equipped to handle is by getting a thorough preflight weather briefing. Even in fine conditions the pilot should always obtain a forecast. If the forecast indicates bad weather along the planned route that may jeopardize the safety of the flight then the pilot should choose an alternative route if possible or else delay or postpone the flight.

At times the forecast weather may be acceptable but in practice the enroute weather may deteriorate significantly. If the pilot is faced with this situation then early recognition of the problem will allow a safe diversion to an alternative aerodrome or backtrack to the point of departure. It is important not to wait until conditions deteriorate to a dangerous level before taking appropriate action. Pressing on into deteriorating weather is a major cause of VMC light aircraft accidents.
It is of critical importance that the pilot continually monitor and assess any varying weather conditions that could affect the flight. Rarely does the weather change from VMC to non-VMC instantaneously. Usually there are numerous indications that the situation is changing for the worse. If the pilot is alert to these signs and heeds their warning then possible disaster can be averted.

The dead-end trap
The combination of a lowering cloud base and rising ground is particularly deadly. Many accidents of this type result from flight into a valley with rising ground and lowering cloud. Often visibility will be poor, perhaps rain is falling and the light is beginning to fade. In these conditions the scope that the pilot has for maneuvering will decrease rapidly. If a decision to turn back is not made quickly then the aircraft may soon become trapped as the valley walls close in.

A timely retreat however may well rescue the situation. A 180 degree turn is likely to take the aircraft back to better conditions and allow the pilot to plan a safe completion to the flight. Time is of the essence though. If the decision to turn back is left too late then the weather behind may have closed in. As a last resort a precautionary landing while the aircraft is still under control is preferable to flight into cloud.
In a precautionary landing the pilot selects an area such as a field or clearing that appears to be adequate to safely land the aircraft. A low pass is then made over the area at slow speed, noting any obstructions such as power lines or tall trees. Finally the approach and landing is made at slow speed.

A controlled arrival in this way is very much more likely to be successful than uncontrolled flight into terrain.

Pressure to press-on
Often the pilot will face strong pressures to continue the flight as planned. There might a work obligation or perhaps the flight involves a social occasion and the pilot feels that by canceling or delaying they will let down family or friends. Whatever the case though the pilot must learn to make flying decisions purely from a flying point of view. Other considerations must be put to one side. In practice this can sometimes be very hard to do.
• Weather awareness is one important aspect of good aeronautical decision making.
• Pilots flying under VMC are particularly at risk from continued flight into deteriorating weather.
• While the pressure to press on with a flight can be very great it must be resisted.
• A decision to divert or turn back should be made as soon as it appears that the safety of the flight may be jeopardized.
• As a last resort a precautionary landing may avert a tragedy.
Appendix 6.  Bad weather flying case-based questionnaire

Please provide the missing information or circle the correct alternative from (a) (b) (c)

The following four questions relate to Example 1

1) The planned flight was from Hamilton to

2) About 8 miles south of Raetihi the pilot contacted Ohakea Control for clearance through their zone at,
   (a) 4,000 feet
   (b) 6,000 feet
   (c) 8,000 feet

3) The pilot had misjudged,
   (a) the direction in which the showers were moving
   (b) the height of the approaching cloud base
   (c) how rapidly the heavy showers were moving

4) The Ohakea controller's instructions to the pilot were to concentrate on,
   (a) assuring that he had ample ground clearance
   (b) keeping the wings level
   (c) making sure that the groundspeed was good

The following four questions relate to Example 2

5) The planned flight was from  to Christchurch.

6) The pilot arrived at the aerodrome and assessed the current weather to be,
   (a) slightly worse than forecast
   (b) as forecast
   (c) slightly better than had been forecast

7) During the flight a problem developed with the,
   (a) magnetic compass
   (b) directional gyro
   (c) radio

8) After the crash the pilot,
   (a) was trapped in the aircraft until rescued
   (b) attended to the injured passenger
   (c) walked to a nearby farmhouse
The following four questions relate to Example 3

9) The planned flight was from Wellington to 

10) After encountering poor weather the pilot, 
   (b) declined radar vectoring 
   (a) requested confirmation of his estimated position 
   (c) did not declare an in-flight emergency 

11) Damage to the aircraft indicated that it impacted with the sea, 
   (a) in a wings-level, slightly nose-down attitude 
   (b) in a spiral dive at high airspeed 
   (c) with the engine operating at a cruise power setting 

12) As a result of the crash, 
   (a) the pilot died while the two passengers survived 
   (b) the pilot and one passenger died 
   (c) the pilot and three passengers died 

The following four questions relate to Example 4

13) The aircraft departed from 

14) The pilot took off with the intention of, 
   (a) flying directly to Invercargill 
   (b) completing one circuit and landing 
   (c) completing one circuit before flying to Invercargill 

15) The pilot flew into the fog expecting, 
   (a) very shortly to regain clear conditions 
   (b) radar vectoring from Invercargill Air Traffic Control 
   (c) to maintain control by reference to instruments 

16) The wreckage of the aircraft was located, 
   (a) just before nightfall 
   (b) in bush covered country 
   (c) in the sea the following day
Appendix 7. Bad weather flying rule-based questionnaire

Please provide the missing information or circle the correct alternative from (a) (b) (c)

1) Safe flying depends on both ___________ and ___________ factors.

2) A proficient pilot needs more than just basic knowledge and flying skills. Another very important ability is that of ________________________________

3) VMC stands for ________________________________

4) A pilot flying under VMC must keep a horizontal distance from cloud of at least,
   (a) half a nautical mile
   (b) one nautical mile
   (c) two nautical miles

5) A pilot flying under VMC must keep a vertical distance from cloud of at least,
   (a) 500 feet
   (b) 750 feet
   (c) 1,000 feet

6) Research has shown that once untrained pilots enter cloud they will lose control within an average of,
   (a) 78 seconds
   (b) 178 seconds
   (c) 187 seconds

7) In VMC flying visual reference to the outside world is essential for both
   ________________________________ and ________________________________

8) Flying in cloud requires special training for the pilot to,
   (a) sense the attitude of the aircraft
   (b) rely entirely on the aircraft's instruments
   (c) avoid being mislead by instrument indications
9) If the weather before the flight is fine the pilot should,
   (a) obtain a forecast if the planned route is new to them
   (b) obtain a forecast if they are inexperienced
   (c) always obtain a forecast

10) If the forecast indicates bad weather along the planned route the pilot should either
    __________________________ or __________________________

11) If the enroute weather deteriorates significantly then early recognition of the problem will
    allow the pilot to __________________________ or __________________________

12) For pilots flying into deteriorating weather the combination of
    __________________________ and __________________________
    is particularly deadly.

13) In a precautionary landing the pilot,
    (a) returns to land at the point of departure
    (b) diverts to an alternate aerodrome
    (c) lands in any field or clearing that appears to be adequate

14) The pilot must learn to make flying decisions,
    (a) as quickly as possible
    (b) purely from a flying point of view
    (c) taking into account all flying and non-flying factors

15) A pilot without instrument training should,
    (a) avoid entering cloud at all costs
    (b) only enter cloud for the minimum time possible
    (c) only enter cloud if an enroute weather forecast has been obtained

16) The change from VMC to non-VMC conditions usually occurs,
    (a) instantaneously
    (b) with very little warning unless accurately forecast
    (c) with numerous indications that the situation is changing for the worse
Appendix 8. Icarus flight simulator program code

Icarus parameter values

Unless otherwise stated default values are set in initial_values

Task

```
task_file = "C:\\BW_TASK.TXT" or
task_file = "C:\\LF_TASK.TXT"
test1_file = "C:\\TASK.TXT"
test2_file = "C:\\JUNK.TXT"
demo_file = "C:\\DEMO.TXT"
```

IEI - inter-event interval (msec)

```
task_timer - timer20.interval = 1,000 * (iei_base + RND * iei_var + iei) + 1
```

Minimum time between task events. IEI is minimum time after all, if any, text has been displayed on flight director screen before next input from task file. Actual IEI may be longer due to time needed for subject input, repeating text after an incorrect response, etc.

add 1 to avoid disabling timer with interval = 0

timer20.interval initially set at 5,000 msec in initial_values (must be non-zero to get task started)

```
iei_base = 1 (seconds)
iei_var = 2
iei read from task file
```

time before retransmission if no response received

```
repeat_timer - timer23.interval = 60,000 (60 seconds)
```

(need to be able to relay longer messages)

```
fd_timer - timer18.interval = 60 msec
```

(jerky if slower than this)

rate of teletype to flight director display

Approx max speed possible as minimum timer interval is 58 msecs.

Disturbance

```
disturb_timer - timer21.interval = 700 msec
```

altitude disturbance

```
alt_dismag = 10
start alcount = 1
altstep = 0.1
alcount = alcount + altstep, max = 100 => 833 steps * 0.7 sec = approx 9.7 min per cycle
```

Air3.Value = Air3.Value + alt_dismag * woffset(alcount)

heading disturbance

```
dg_dismag = 1
start dgcount = 30
dgstep = 0.15
dgcount = dgcount + dgstep, max = 100 => 1,000 steps * 0.7 sec = approx 11.7 min per cycle
```

Air6.Value = Air6.Value + dg_dismag * woffset(dgcount)

Air4.Value = Air4.Value + dg_dismag * woffset(dgcount)
Different count start values and step sizes ensure that altitude and heading disturbances are out of phase.

\[
\text{For } X = 1 \text{ To } 50 \\
Y = 0.186 \times X \times \sin(0.186 \times X) / 16 \\
\text{woffset}(X) = Y \\
\text{woffset}(101 - X) = -Y \\
\text{Next } X
\]

\[\text{woffset } \pm 0.5\]

**Check set values**

\[
\text{checkval}_{\text{timer}} - \text{timer22}.\text{interval} = 5,000 \text{ msec} \\
\text{altval}_{\text{margin}} = \pm 150 \text{ feet} \\
\text{dgval}_{\text{margin}} = \pm 7 \text{ degrees}
\]

Warning if
\[
\text{Abs(altval} - \text{altval}_{\text{set}}) > \text{altval}_{\text{margin}} \\
or \\
\text{Abs(dgval} - \text{dgval}_{\text{set}}) > \text{dgval}_{\text{margin}}
\]

\[\text{Absolute value } \Rightarrow \pm \text{ margin}\]

**Save to logfile**

\[
\text{log}_{\text{timer}} - \text{timer19}.\text{interval} = 5,000 \text{ msec}
\]

**Cloud movement**

\[
\text{cloud}_{\text{timer}} - \text{timer16}.\text{interval} = 200 \text{ msec} \\
\text{left} = -1600 \\
\text{itop} = 200 \\
\text{cloudmove}_{\text{offset}} = 1
\]

values in pixels relative to picture1 picture box, not scene form

\[
\text{scene!Picture1}.\text{Top} = -3000 \text{ twips } \Rightarrow \text{screen iTop} = 200 \text{ pixels} (3,000/15)
\]

1,600 pixels at 1 pixel/1.5 sec \(\Rightarrow\) 40 mins total

**Scene movement**

position of scene set in size_screens
\[
\text{top} = -3000 \\
\text{left} = 0
\]

change rate values hardwired in timers
\[
\text{pitch change} - 20 \times \text{ahad in timer9} \\
\text{pitch rtz} - (-20 \times \text{ahad in timer13} \\
\text{altitude change} - 5 \times \text{altad in timer8} \\
\text{heading change} - (-5 \times \text{ctd in timer3}
\]

**Fluctuation (jitter and wander)**

\[
\text{frequency} = 200 \\
in \text{set int (both timer intervals also set directly in initial values)} \\
\text{jitter}_{\text{timer}} - \text{timer1}.\text{interval} = 100,000/\text{frequency} \Rightarrow 500 \text{ msec} \\
\text{wander}_{\text{timer}} - \text{timer2}.\text{interval} = 500,000/\text{frequency} \Rightarrow 2,500 \text{ msec}
\]

\[
\text{magnitude} = 200 \\
in \text{set mag (also set directly in initial values)}
\]
jitmag = magnitude/10,000 => jitmag = .02
wanmag = magnitude/10,000 => wanmag = .02

frequency and magnitude can be varied by scroll bars.

jitter indiv factors
asval jitset = 100
ahp jitset = 75
ahb jitset = 100
tct jitset = 1000
tci jitset = 30
dgval jitset = 100
vsival jitset = 4000
fuelpval jitset = 20
ampspval jitset = 50
oilpval jitset = 20

wander indiv factors
wcount = 25
altval wannet = 1500
obic wannet = 150
obicd wannet = 5
obigsd wannet = 5
hsival wannet = 360
hsicd wannet = 15
hsigsd wannet = 15
ampspval wannet = 100

Initial instrument readings

initial values
115 knots, straight and level at 7,500 feet, heading NE (45 deg)

change rate values hardwired in timers
approx 22 feet/sec - 7 * altad in timer8
approx 2.5 deg/sec - 0.6 * ctd in timer3

airspeed
asval set = 115

artificial horizon
ahp set = 0
ahb set = 0

altimeter
altval set = 7,500

OBI - Omno Bearing Indicator
obic set = 45
obicd set = 0
obigsd set = 0

turn coordinator
tct set = 0
tci set = 0

DG - Directional Gyro, Heading Indicator
dgval set = 45

VSI - Vertical Speed Indicator
vsival set = 0
HSI - Horizontal Situation Indicator
hsival_set = 45
hsicd_set = 0
hsigsd_set = 0

fuel gauge
fuelpval_set = 35

ampmeter
ampspval_set = 25

oil pressure gauge
oilpval_set = 25

Declarations
Option Compare Text "=> not case sensitive

Declare Function LockWindowUpdate Lib "User" (ByVal hWnd As Integer) As Integer
Declare Sub CreateCaret Lib "user" (ByVal w%, ByVal x%, ByVal y%, ByVal z%)
Declare Function ShowCaret% Lib "user" (ByVal x%)
Declare Sub SetCursorPosition Lib "User" (ByVal x As Integer, ByVal y As Integer)

Global wttb, hltg
Global s_id, s_name, s_dob, s_sex,
  sinfo_exists, subject_running,
  subject_done, start_time

Global scenemove_on, cloudmove_on,
  cloud_pos(20), cloud_time(20),
  pos_num
Global hmove_allowed, vmove_allowed
Global cloud_left As Integer, cloud_top As Integer, cloud_offset
Global scene_xpos, scene_ypos,
  scene_xstop, scene_ystop
Global working_dir, data_dir, log_exists,
  log_on, logall_on
Global ack, ack_def, ack_1, ack_2,
  input_ack, retrans, input_retrans,
  retrans_on
Global task_name, task_on, preview_on,
  taskfile_open, testf1_file, testf2_file
Global task_file, bw_task, if_task,
  demo_file, dump_exists, dump_no
Global ie1_base, ie1_var, sender, end_now,
  last_sender, code
Global rescheck, response, button_set,
  button_caption(3, 3)
Global disturb_on, alt_dismag, dg_dismag,
  altcount, altstep, dgcount, dgstep

Global checkval_on, check_alt,
  check_head, altval_margin,
  dgval_margin

Global fd_screen As control
Global fdintext, fdscreen_col,
  fdscreen_count
Global pad, ni, sp, task_text, subject_text,
  inches
Global fdalt_text, fdhead_text, alt_prefix,
  head_prefix, alt_suffix, head_suffix
Global alt_warn, head_warn, input_warn,
  noresponse_warn, goodbye, fd_prefix
Global gear_up, gear_moving

Global adjtemp_on, r, g, b

Global altitude, heading, Pitch
Global default_alt, default_head
Global asval_set, ahp_set, ahb_set,
  altval_set, obic_set, obicd_set,
  obigsd_set
Global tct_set, tci_set, dgval_set,
  vsival_set, hsival_set, hsicd_set,
  hsigsd_set
Global fuelpval_set, ampspval_set,
  oilpval_set

Global fluc_on, frequency, magnitude,
  jitmag, wanmag, wcount, jcount
Global joffset(100), wosset(100)
Global asval_jitset, altval_jitset, ahp_jitset,
  ahb_jitset, tct_jitset
Global tci_jitset, dgval_jitset, vsival_jitset
Global fuelpv_jitset, ampaspv_jitset,
  oilp_jitset
Global asval JIT, altval JIT, ahp JIT, ahb JIT,
  tc jit, tci_jit, dgval JIT, vsival JIT
Global fuelpv jit, ampaspv jit, oilp_jit

Global altval_wanset, obic_wanset,
  obicd_wanset, obigsd_wanset
Global hsival_wanset, hsicd_wanset,
  hsigsd_wanset
Global altval_wan, obic_wan, obicd_wan, obigsd_wan, hsival_wan, hsicd_wan
Global hsigsd_wan
Global head_change, alt_change, ctd, ahtd, tctd, altad, ahad, vsiad, asad
Global accel
Global airspeed As control, ah As control, altimeter As control
Global omni As control, tb As control, dg As control, vsl As control
Global hsi As control, fuel As control, oil As control, amps As control
Global instrument(12) As control
Global msgfilter(12) As control
Global jitter_timer As timer, wander_timer As timer
Global head_change_timer As timer, abh_change_timer As timer
Global tcb_change_timer As timer, abh_rtz_timer As timer
Global tcb_rtz_timer As timer, alt_change_timer As timer
Global ahp_change_timer As timer, vsl_change_timer As timer
Global airspeed_dec_timer As timer, airspeed_inc_timer As timer
Global ahp_rtz_timer As timer, vsi_rtz_timer As timer
Global airspeed_rtz15_timer As timer
Global cloud_timer As timer, crash_timer As timer
Global fd_timer As timer, log_timer As timer
Global task_timer As timer, disturb_timer As timer
Global checkval_timer As timer, repeat_timer As timer

Global Const black = &H000000&
Global Const red = &HFF0000&
Global Const green = &HFF0000&
Global Const yellow = &HFFFF00&
Global Const BLUE = &HFF0000&
Global Const MAGENTA = &HFF0000&
Global Const CYAN = &HFFFF00&
Global Const WHITE = &HFFFFFF&
Global Const orange = &H80FF00&
Global Const light_grey = &HE9E9E9E9
Global Const mid_grey = &HC0C0C0C0
Global Const dark_grey = &H80000000&
Global Const vdark_grey = &H40404040&

Sub adjust_temp ()
If panel!VScroll1.Value <= 255 Then
r = 255 - panel!VScroll1.Value
b = 0
Else
r = 0
g = 511 - panel!VScroll1.Value
b = panel!VScroll1.Value - 255
End If
panel!Shape7.FillColor = RGB(r, g, b)
End Sub

Sub centre_dialog_box (dbox As Form)
dbox.Left = (screen.Width - dbox.Width) / 2
End Sub

Sub check_setval ()
' check for set altitude and heading
altval = altimeter.Value
dgval = dg.Value
alt_ok = True
head_ok = True
If (Abs(altval - altval_set) > altval_margin)
And check_alt Then alt_ok = False
End If
If Not alt_ok Then
Beep
If log_on And logall_on On Then log_print
"[Altitude warning]"
panel!Label8.Caption = alt_warn
panel!Label8.ForeColor = red
panel!Label8.BackColor = yellow
delay .5
End If
If Not head_ok Then
Beep
If log_on And logall_on On Then log_print
"[Heading warning]"
panel!Label9.Caption = head_warn
panel!Label9.ForeColor = red
panel!Label9.BackColor = yellow
End If
End If
If Not alt_ok Or Not head_ok Then
delay 2
panel!Label8.ForeColor = yellow
panel!Label8.BackColor = dark_grey
End If
Sub climb()

panel!Image10.Visible = True
panel!Image5.Enabled = True
ahp_rtz_timer.Enabled = False
vsi_rtz_timer.Enabled = False
airspeed_r115_timer.Enabled = False

alt_change = True
altad = 1
ahad = 1
vsiad = 1
asad = 1

' artificial horizon pitch, VSI and airspeed
ahp_jit = 0
vsi_jit = 0
asval_jit = 0
ahp_change_timer.Enabled = True
vsi_change_timer.Enabled = True
airspeed_dec_timer.Enabled = True
airspeed_inc_timer.Enabled = False

' altitude
altval_wan = 0
alt_change_timer.Enabled = True

End Sub

Sub close_files()

stop_task
stop_logdata

If dump_exists Then
Close #3
dump_exists = False
End If

End Sub

Sub crash()

' initiate spiral dive crash
' activate with crash_timer.Enabled = True

If accel < 20 Then
accel = accel + .07
End If

asval_jit = 0
ahp_jit = 0
ahb_jit = 0
tct_jit = 0
tci_jit = 0
dgval_jit = 0
vsi_jit = 0
panel!Shape2.FillColor = red
jitter_timer.Interval = 200
wander_timer.Enabled = False
head_change_timer.Enabled = False
ahb_change_timer.Enabled = False
tcb_change_timer.Enabled = False
ahb_rtz_timer.Enabled = False
tcb_rtz_timer.Enabled = False
alt_change_timer.Enabled = False
ahp_change_timer.Enabled = False
vsi_change_timer.Enabled = False
airspeed_dec_timer.Enabled = False
airspeed_r115_timer.Enabled = False
cloud_timer.Enabled = False
disturb_timer.Enabled = False

' VSI
If vsi.Value > -1400 Then
vsi.Value = vsi.Value - 5 * accel
Else
vsival_jit = vsival_jitset
End If

' airspeed
If airspeed.Value < 165 Then
airspeed.Value = airspeed.Value + .18 * accel
Else
asval_jit = asval_jitset
End If

' turn coordinator
If tb.Turn > -360 Then
tb.Turn = tb.Turn - 1.2 * accel
Else
tct_jit = tct_jitset
End If

If tb.Inclinometer > -12 Then
tb.Inclinometer = tb.Inclinometer - .05 * accel
Else
tci_jit = tci_jitset
End If
' artificial horizon
ah.Pitch = ah.Pitch - .31 * accel
If ah.Pitch < -300 Then
ah.Pitch = ah.Pitch + 360
End If
ah.Bank = ah.Bank + .3 * accel

' OBI, DG and HSI
'omni.OMICourse = omni.OMICourse - .3 * accel
dg.Value = dg.Value - .3 * accel
'hsi.Value = hsi.Value - .3 * accel

' altitude
If altimeter.Value > 100 Then
altimeter.Value = altimeter.Value - 3 * accel
Else
altimeter.Value = 0
delay .5
End If

Sub default_althead()
' reset altitude and heading to default values
alt_val_set = default_alt
altimeter.Value = default_alt
dg.Val_set = default_head
dg.Value = default_head
End Sub

Sub delay(Seconds As Double)
' delay, sleep, wait
' does fractions of seconds and handles midnight correctly
Dim TempTime As Double
TempTime = Timer
While Timer - TempTime < Seconds
DoEvents
If Timer < TempTime Then
TempTime = TempTime - 24# * 3600#
End If
Wend
End Sub

Sub descend()
panelmage1.Visible = True
panelmage1.Enabled = True
panelmage5.Enabled = True
panelmage10.Visible = False
ahp_rtz_timer.Enabled = False
vsirtz_timer. Enabled = False
airspeed_rti15_timer. Enabled = False

alt_change = True
altad = -1
ahad = -1
vsiad = -1
asad = -1

' artificial horizon pitch, VSI and airspeed
ahp_jit = 0
vsival_jit = 0
asval_jit = 0
ahp_change_timer.Enabled = True
vsival_change_timer.Enabled = True
airspeed_dec_timer.Enabled = False
airspeed_inc_timer.Enabled = True

' altitude
altval_wan = 0
Sub disturbance()

' altitude and heading disturbance

' different initial values and step values
altcount = altcount + altstep
dgcount = dgcount + dgstep

If altcount > 100 Then
    altcount = 1
End If

If dgcount > 100 Then
dgcount = 1
End If

' altimeter
If Not alt_change Then
    altimeter.Value = altimeter.Value + alt_dismag * woffset(altcount)
End If

' Directional Gyro
If Not head_change Then
    dg.Value = dg.Value + dg_dismag * woffset(dgcount)
End If

' OBI course
omni.Value = omni.Value + dg_dismag * woffset(dgcount)

End Sub

Sub dump_values()

If Not dump_exists Then
    create_dumpfile
    dump_no = dump_no + 1
End If

Print #3, Format(Now, "dddd, d mmmm yyyy"); Format(Now, ", h:mm:ss")
Print #3, "dump_no = "; dump_no
Print #3, "subject = "; s_id
Print #3, "task_file = "; task_file
Print #3, "demo_file = "; demo_file
Print #3, "test1_file = "; test1_file
Print #3, "test2_file = "; test2_file
Print #3, "jitter_timer = "; jitter_timer
Print #3, "wander_timer = "; wander_timer
Print #3, "cloud_timer = "; cloud_timer
Print #3, "crash_timer = "; crash_timer
Print #3, "fd_timer = "; fd_timer
Print #3, "log_timer = "; log_timer
Print #3, "task_timer = "; task_timer
Print #3, "disturb_timer = "; disturb_timer
Print #3, "checkval_timer = "; checkval_timer
Print #3, "repeat_timer = "; repeat_timer
Print #3, "input_ack = "; input_ack

End Sub

Sub end_program()

close_files

ReDim dummy(50) As Form

For x = 0 To forms.Count - 1
    Set dummy(x) = forms(x)
Next x

For x = 0 To forms.Count - 1
    Unload dummy(x)
Next x

End

End Sub

Sub end_run()

If subject_running Then
    subject_done = True
End If

subject_running = False

stop_cloudmove
stop_task
stop_disturbance
stop_checkval
stop_logdata

'MoveTransBit scene1!Picture1.hDC, scene1!Picture1.Picture, 0, 0,
Sub enter_sinfo ()
' input subject information
s_info.Show 1 'must be modal to halt program execution
sinfo_exists = True
End Sub

Sub fd_display (fdscreen_string)
cloud_timer.Enabled = False
fd_screen.Enabled = False 'disable subject input
fdscreen_count = 0
fd_intext = pad & fdscreen_string
fd_screen.SetStart = Len(fd_screen)
pad = ""
fd_timer.Enabled = True 'calls teletype
End Sub

Sub fluctuate_off ()
jitter_timer.Enabled = False
wander_timer.Enabled = False
End Sub

Sub fluctuate_on ()
jitter_timer.Enabled = True
wander_timer.Enabled = True
End Sub

Sub initial_values ()
'task
taskfile_open = False
task_on = False
ack_def = "Roger"
ack_1 = "WHISKEY GOLF LIMA Information received."
ack_2 = "This is CHARLIE FOXTROT MIKE Information received."
ack = ack_def
input_ack = False
retrans = ""
retrans_on = True
input_retrans = False
dump_exists = False
dump_no = 0
preview_on = False
iei_base = 1 'seconds
iei_var = 2
sender = ""
last_sender = ""
task_text = ""
fd_prefix = ""
subject_text = ""
input_retrans = False
input_warn = "NEGATIVE."
noresponse_warn = "ATTENTION ATTENTION ATTENTION."
goodbye = "Bye. Thanks for all your help. Have a nice day!! :-)"
'disturbance and check set values
disturb_on = False
alt_dismag = 15
dg_dismag = 1
altval_margin = 150
dgval_margin = 7
altcount = 1
dgcount = 1
altstep = .1
dgstep = .15
alt_warn = "MAINTAIN SET ALTITUDE"
head_warn = "MAINTAIN SET HEADING"
checkval_on = False
check_alt = True
check_head = True
'cloud movement
'values in pixels relative to picture1 picture box, not scene form
'scene!Picture2.Picture, 249, cloud_left, cloud_top
popup!menu_item_demo.Enabled = True
popup!menu_item_runsubject.Enabled = True
fd_screen.Enabled = True
If fd_screen.Enabled Then
  fd_screen.SetFocus
End Sub
scene_ypos = -3000
scene_xstop = scene.Width - scenePicture1.Width
scene_ystop = scene.Height - scenePicture1.Height
scenePicture1.Top = scene_xpos
scenePicture1.Left = scene_ypos

' log file
log_exists = False
log_on = False
logall_on = True

'subject info
subject_running = False
subject_done = False
sinfo_exists = False
s_id = ""
s_name = ""
s_dob = ""
s_sex = ""

' left turn, right turn, climb, descend
hmove_allowed = tft(wttb, True, False)
vmove_allowed = True
head_change = False
cld = 0
ahld = 0
tnd = 0
alt_change = False
altad = 0
ahad = 0
vsad = 0
asad = 0

' crash
accel = 0

' fluctuation
fluc_on = True
frequency = 200
magnitude = 200
jitmag = .02
wanmag = .02

' adjust temp
r = 0
g = 255
b = 0
adjtemp_on = False
panel!Shape7.FillColor = green
'temperature indicator
panel!VScroll1.Enabled = False

' landing gear
gear_up = True
gear_moving = False
panel!Shape6.FillColor = red
panel!Shape9.FillColor = red
panel!Shape10.FillColor = red

' jitter indiv factors
asval_jitset = 100
altval_jitset = 700
ahp_jitset = 75
ahb_jitset = 100
tct_jitset = 1000
tcl_jitset = 30
dgval_jitset = 100
vsival_jitset = 4000
fuelpval_jitset = 20
ampspval_jitset = 50
oilpval_jitset = 20
asval_jit = asval_jitset
altval_jit = altval_jitset
ahp_jit = ahp_jitset
ahb_jit = ahb_jitset
tct_jit = tct_jitset
tcl_jit = tcl_jitset
dgval_jit = dgval_jitset
vsival_jit = vsival_jitset
fuelpval_jit = fuelpval_jitset
ampspval_jit = ampspval_jitset
oilpval_jit = oilpval_jitset

' wander indiv factors
wcount = 25
altval_wanset = 1500
obic_wanset = 150
obicd_wanset = 5
obigsd_wanset = 5
hsival_wanset = 360
hsicd_wanset = 15
hsigsd_wanset = 15
altval_wan = altval_wanset
obic_wan = obic_wanset
obicd_wan = obicd_wanset
obigsd_wan = obigsd_wanset
hsival_wan = hsival_wanset
hsicd_wan = hsicd_wanset
hsigsd_wan = hsigsd_wanset

' ensure jitter centered around 'true' value
For x = 1 To 50
Y = Rnd -.5
joffset(x) = y
joffset(50 + x) = -y
Next x

' see wander.xls for graph (x in radians)
For x = 1 To 50
y = .188 * x * Sin(.188 * x) / 16
woffset(x) = y
woffset(101 - x) = -y
Next x

' printout to check graph
'Open "C:\richard\icarus\wander.dat" For Output As #1
'For x = 1 To 100
'Print #1, x, woffset(x)
'Next x
'Close #1
instrument readings - set values
115 knots, straight and level at 7,500 feet, heading NE (45 deg)

airval_set = 115 '0 to 175 with default dial, 0 to 360 max
ahp_set = 0 '180 to 180
ahb_set = 0 '0 to 360
default_alt = 7500 '0 to 32,000
altval_set = default_alt
obic_set = 45 '0 to 360
obicd_set = 0 '1 to 1
obigsd_set = 0 '1 to 1
tct_set = 0 '360 to 360
tci_set = 0 '15 to 15
default_head = 45 '0 to 360
dgval_set = default_head
vsival_set = 0 '2000 to 2000
hsival_set = 45 '0 to 360
hsicd_set = 0 '3 to 3
hsigsd_set = 0 '3 to 3
fuelpval_set = 35 '0 to 40
ampspval_set = 25 '0 to 40
oilpval_set = 25 '0 to 40

instrument readings - current values
airspeed.Value = airval_set
ah.Pitch = ahp_set
ah.Bank = ahb_set
altimeter.Value = altval_set
ombi.OBIcourse = obic_set
ombi.OBIcourseDeviation = obicd_set
ombi.OBIGlideSlope = obigsd_set
tb.Turn = tct_set
tb.Inclinometer = tci_set
dg.Value = dgval_set
vsl.Value = vsival_set
hsi.Value = hsival_set
hsi.HSICourseDeviation = hsicd_set
hsi.HSICourseDeviation = hsigsd_set
fuel.PointerValue = fuelpval_set
oil.PointerValue = oilpval_set
amps.PointerValue = ampsovval_set

flight director
pad = 
fd_intext = 
alt_prefix = " Set Altitude = "
head_prefix = " Set Heading = "
alt_suffix = " feet"
head_suffix = " degrees"
falt_text = alt_prefix & altval_set &
             alt_suffix 'must be after instrument value section"
fhead_text = head_prefix & dgval_set &
             head_suffix

fd_screen.Text = 
panel!Label8.Caption = falt_text
panel!Label9.Caption = fhead_text
panel!Label7.Caption = "00.0"
fd_screen.ForeColor = green
panel!Label8.ForeColor = yellow
panel!Label9.ForeColor = yellow
panel!Label7.ForeColor = black
fd_screen.BackColor = black
panel!Label8.BackColor = dark_grey
panel!Label9.BackColor = dark_grey
panel!Label7.BackColor = dark_grey
button_caption(0, 0) = ""
button_caption(0, 1) = ""
button_caption(0, 2) = ""
button_caption(1, 0) = "Yes"
button_caption(1, 1) = "No"
button_caption(1, 2) = ""
button_caption(2, 0) = "Continue"
button_caption(2, 1) = "Divert"
button_caption(2, 2) = "Return"

' yellow ON indicators for control input pad
panel!Image8.Visible = False
panel!Image9.Visible = False
panel!Image10.Visible = False
panel!Image11.Visible = False

' indicator panel
panel!Shape1.FillColor = red 'L - log data
panel!Shape2.FillColor = red 'C - cloud movement
panel!Shape3.FillColor = tf(wttb, red, green) 'S - scene movement
panel!Shape4.FillColor = red 'T - task
panel!Shape5.FillColor = red 'D - disturbance
panel!Shape6.FillColor = red 'V - check set values
x = 70
panel!Shape1.Height = x
panel!Shape1.Width = x
panel!Shape2.Height = x
panel!Shape2.Width = x
panel!Shape3.Height = x
panel!Shape3.Width = x
panel!Shape4.Height = x
panel!Shape4.Width = x
panel!Shape5.Height = x
panel!Shape5.Width = x
panel!Shape6.Height = x
panel!Shape6.Width = x

' timer interval in msec
jitter_timer.Interval = 500 'jitter
jitter_timer.Enabled = True
wander_timer.Interval = 2500 'wander
wander_timer.Enabled = True
head_change_timer.Interval = 200 'heading change
head_change_timer.Enabled = False
ahb_change_timer.Interval = 200 'AH bank change
ahb_change_timer.Enabled = False
tcb_change_timer.Interval = 200 'TC bank change
tcb_change_timer.Enabled = False
ahb_rtz_timer.Interval = 200 'AH bank return to zero
ahb_rtz_timer.Enabled = False
tcb_rtz_timer.Interval = 200 'TC bank return to zero
tcb_rtz_timer.Enabled = False
ahp_change_timer.Interval = 200 'altitude change
ahp_change_timer.Enabled = False
vsi_change_timer.Interval = 200 'VSI change
vsi_change_timer.Enabled = False
airspeed_dec_timer.Interval = 200 'airspeed decrease
airspeed_dec_timer.Enabled = False
airspeed_inc_timer.Interval = 200 'airspeed increase
airspeed_inc_timer.Enabled = False
ahp_rtz_timer.Interval = 200 'AH pitch change
ahp_rtz_timer.Enabled = False
vsi_rtz_timer.Interval = 200 'VSI change
vsi_rtz_timer.Enabled = False
airspeed_r115_timer.Interval = 200 'airspeed return to 115
airspeed_r115_timer.Enabled = False
cloud_timer.Interval = 200 'cloud move
cloud_timer.Enabled = False
crash_timer.Interval = 200 'crash
crash_timer.Enabled = False
fd_timer.Interval = 60 *flight director display
fd_timer.Enabled = False
log_timer.Interval = 5000 'save to logfile
log_timer.Enabled = False
task_timer.Interval = 1000 * (lei_base + .5 *
lei_var) 'task timer
task_timer.Enabled = False
disturb_timer.Interval = 700 'disturbance
disturb_timer.Enabled = False
checkval_timer.Interval = 5000 'check set altitude and heading
checkval_timer.Enabled = False
repeat_timer.Interval = 60000 'repeat transmission
repeat_timer.Enabled = False

Sub Jitter()

' instrument jitter
jcount = jcount + 1
If jcount > 100 Then
jcount = 1
End If

If Not alt_change Then altimeter.Value = altimeter.Value + altval_jit * jitmag *
joffset(jcount)
If Not head_change Then dg.Value =
dg.Value + dgval_jit * jitmag *
joffset(jcount)
ah.Pitch = ah.Pitch + ahp_jit * jitmag *
joffset(jcount)
ah.Bank = ah.Bank + ahp_jit * jitmag *
joffset(jcount)
tb.Turn = tb.Turn + tct_jit * jitmag *
joffset(jcount)
tb.Inclinometer = tb.Inclinometer + tci_jit *
jitmag * joffset(jcount)
vsL.Value = vsL.Value + vsival_jit * jitmag *
joffset(jcount)
fuel.PointerValue = fuel.PointerValue +
fuelval_jit * jitmag * joffset(jcount)
oil.PointerValue = oil.PointerValue +
oilval_jit * jitmag * joffset(jcount)
amps.PointerValue = amps.PointerValue +
ampsval_jit * jitmag * joffset(jcount)

End Sub

Sub key_catch(keycode As Integer, shift As Integer)

If (shift And 4) > 0 Then 'Alt key pressed
Select Case Chr(keycode)
Case "C": toggle_cloudmove
Case "P": preview_on = Not preview_on
	'toggle preview mode
Case "L": toggle_logdata
Case "O": start_demo
Case "R": run_subject
Case "T": toggle_task
Case "F": toggle_fluctuate 'jitter and wander
Case "D": toggle_disturbance
Case "V": toggle_checkval 'check set values
Case "I": enter_sinfo 'enter subject information
Case "E": end_run
Case "G": toggle_gear 'landing gear
Case "S": toggle_scenemove
Case "U": dump_values

End Sub

End Sub
Case "A"
If log_on Then toggle_jogal
End If

Case "---" 'toggle adjust temp
adjtemp_on = Not adjtemp_on
End If

Case "M" 'faster cloud movement
cloud_offset = cloud_offset + 100 'twips
If cloud_offset > 501 Then cloud_offset = 1
End Select

Sub log_print (log_text)
Print #1, Format(Now, "h:mm:ss"); Tab(55); log_text
End Sub

Sub main ()
set_names
set_version 'uses names

screen.MousePointer = 11 'hourglass
setcursorpos 570, 465 'left, top
size_screens
show_splash
delay 2 'includes DoEvents that removes win95 taskbar
initial_values
blank.Show 0 'leave in place to inhibit win95 taskbar
show_scene
show_panel
Unload splash
If fd_screen.Enabled Then
    fd_screen.SetFocus
screen.MousePointer = 0 'default
End Sub

Sub move_cloud ()
' move transparent bitmap cloud

If cloud_left < 0 Then
    MoveTransBit scene1Picture1.hDC, scene1Picture1.Picture, 0, 0, scene1Picture2.Picture, 249, cloud_left + cloud_offset, cloud_top, cloud_left, cloud_top
    cloud_left = cloud_left + cloud_offset
Else
    cloud_timer.Enabled = False
End If

End Sub

Sub move_scene()
    scene_xpos = -2640 + 8 * dg.Value
    scene_ypos = -12000 + 1.2 * altimeter.Value + 20 * ah.Pitch

    If scene_xpos > 0 Then scene_xpos = 0
    If scene_xpos < scene_xstop Then
        scene_xpos = scene_xstop
    End If

    If scene_ypos > 0 Then scene_ypos = 0
    If scene_ypos < scene_ystop Then
        scene_ypos = scene_ystop
    End If

    scene1Picture1.Move scene_xpos, scene_ypos
End Sub

Sub open_taskfile()
    ' open task file
    Open task_file For Input As #2
    taskfile_open = True
End Sub

Sub position_check()
    cloud_pos(pos_num) = cloud_left
    cloud_time(pos_num) = Format(Now, "h:mm:ss")
    pos_num = pos_num + 1
End Sub

Sub process_code()
    If log_on And logall_on Then log_print "[" & code & "]"
End Sub
Sub repeat_trans()
If retrans = "" Then
If log_on And logall_on Then Print #1, Format(Now, "h:mm:ss"); Tab(55); sender; "; noresponse_warn; task_text; "
fd_display noresponse_warn & task_text
Else
If log_on And logall_on Then Print #1, Format(Now, "h:mm:ss"); Tab(55); sender; "; retrans; 
fd_display retrans
End If
End Sub

Sub run_subject()
If subject_running Then Exit Sub
If subject_done Then
s_done.Show 1 'modal to halt code
Exit Sub
End If
If Not sinfo_exists Then enter_sinfo
If wttb Then
task_file = bw_task
ElseIf hitg Then
task_file = ff_task
Else
fd_screen.Text = "Task not defined"
End If
End Sub

subject_running = True
start_time = Timer
default_althead
stop_logdata
stop_task
start_logdata
If wttb Then
start_cloudmove
start_task
End If
'adjtemp_on = True
'panel!Shape6.FillColor = green
End Sub

Sub s_input(keyascii As Integer)
Select Case keyascii
Case 8 '<backspace>
If inchars < 0 Then inchars = inchars - 1
End If
Case 32 To 126 'valid input
inchars = inchars + 1
End If
Case 13 '<return>
pad = nl
start_pos = Len(fd_screen) - inchars + 1
If start_pos < 1 Then start_pos = 1
str_length = inchars
If str_length < 0 Then str_length = 0
subject_text = Mid(fd_screen, start_pos, str_length)
If log_on And logall_on Then Print #1, Format(Now, "h:mm:ss"); Tab(55); "SUBJ "; subject_text; "" 
ElseIf (bcheck = "BYE") Or (bcheck = "BY") Or (bcheck = "BUY") Then
end_run
fd_display goodbye
Exit Sub
End If
If rescheck = "Y" Then
repeat_timer.Enabled = False
If subject_text Like ("** & response & **") Then 'ie if s_input includes response
If log_on And logall_on Then Print #1, Format(Now, "h:mm:ss"); Tab(55); sender; "; ack; 
rescheck = "N"
fd_display ack
ack = ack_def 'revert to default
Else
fd_display input_warn & task_text
If log_on And logall_on Then Print #1, Format(Now, "h:mm:ss"); Tab(55); sender; "; ack; 
End If
Else
If log_on And logall_on Then Print #1, Format(Now, "h:mm:ss"); Tab(55); sender; "; ack; 
fd_display ack
ack = ack_def
End If
End If
End Sub
inchars = 0
End Select
End Sub

Sub set_names()

nl = Chr(13) & Chr(10)
sp = " 
working_dir = CurDir & tf(Right(CurDir, 1) = ",", ""

data_dir = CurDir & tf(Right(CurDir, 1) = ",", ""

bw_task = working_dir & "BW_TASK.TXT"
if_task = working_dir & "LF_TASK.TXT"
demo_file = working_dir & "DEMO.TXT"
test1_file = working_dir & "TASK.TXT"
test2_file = working_dir & "JUNK.TXT"

Set fd_screen = panel!Text1
Set airspeed = panel!Air1
Set ah = panel!Air2
Set omni = panel!Air4
Set tb = panel!Air5
Set vsi = panel!Air7
Set hsi = panel!Air8
Set fuel = panel!LGauge1
Set oil = panel!LGauge2
Set amps = panel!LGauge3

Set instrument(1) = panel!Air1
Set instrument(2) = panel!Air2
Set instrument(3) = panel!Air3
Set instrument(4) = panel!Air4
Set instrument(5) = panel!Air5
Set instrument(6) = panel!Air6
Set instrument(7) = panel!Air7
Set instrument(8) = panel!Air8
Set instrument(9) = panel!LGauge1
Set instrument(10) = panel!LGauge2
Set instrument(11) = panel!LGauge3
Set instrument(12) = panel!toggle1

Set jitter_timer = panel!Timer1
Set wander_timer = panel!Timer2
Set tcb_change_timer = panel!Timer3
Set ahp_change_timer = panel!Timer4
Set tcb_rtz_timer = panel!Timer5
Set ahb_change_timer = panel!Timer6
Set tcb_rtz_timer = panel!Timer7
Set alt_change_timer = panel!Timer8
Set ahp_change_timer = panel!Timer9
Set vsl_change_timer = panel!Timer10
Set airspeed_dec_timer = panel!Timer11
Set airspeed_inc_timer = panel!Timer12
Set ahp_rtz_timer = panel!Timer13
Set vsl_rtz_timer = panel!Timer14
Set airspeed_rtz_timer = panel!Timer15
Set cloud_timer = panel!Timer16
Set crash_rtz_timer = panel!Timer17
Set fd_timer = panel!Timer18
Set log_timer = panel!Timer19
Set task_timer = panel!Timer20
Set disturb_timer = panel!Timer21
Set checkval_timer = panel!Timer22
Set repeat_timer = panel!Timer23

Set msgfilter(1) = panel!MsgFilter1
Set msgfilter(2) = panel!MsgFilter2
Set msgfilter(3) = panel!MsgFilter3
Set msgfilter(4) = panel!MsgFilter4
Set msgfilter(5) = panel!MsgFilter5
Set msgfilter(6) = panel!MsgFilter6
Set msgfilter(7) = panel!MsgFilter7
Set msgfilter(8) = panel!MsgFilter8
Set msgfilter(9) = panel!MsgFilter9
Set msgfilter(10) = panel!MsgFilter10
Set msgfilter(11) = panel!MsgFilter11
Set msgfilter(12) = panel!MsgFilter12

End Sub

Sub set_version()

' program can run either as WTTB or HLTG
' version is set by TRUE or FALSE in next line
wttb = True
hltg = Not wttb
If wttb Then
task_name = "WTTB"
task_file = bw_task
scenemove_on = False
ElseIf hltg Then
task_name = "HLTG"
task_file = if_task
cloudmove_on = False
scenemove_on = True
End If

End Sub

Sub show_panel()

For n = 1 To 8
instrument(n).BackColor = 0
instrument(n).BorderWidth = 0
instrument(n).BevelWidth = 0
instrument(n).BevelInner = 0
instrument(n).BevelOuter = 0
Next n
' trapping WM_ERASEBKGND messages
  avoids white background flash
  ' msgfilter_message sub's contain no code
For n = 1 To 12
  msgfilter(n).hWndTarget = instrument(n).hWnd
  msgfilter(n).MsgList(0) = &H14
  'WM_ERASEBKGND
  msgfilter(n).MsgPassage(0) = 0
  'EATMESSAGE
Next n

' using LockWindowUpdate speeds up
instrument loading
res% = LockWindowUpdate(panel.hWnd)
panel.Show
DoEvents
res% = LockWindowUpdate(0)
End Sub

Sub show_scene()
  ' LockWindowUpdate avoids white flash
res% = LockWindowUpdate(scene.hWnd)
If wttb Then scene!Picture1.AutoRedraw = True 'trans bitmap initially persistent
scene.Show 0
If wttb Then LoadTransBit
  scene!Picture1.hDC, scene!Picture2.Picture, 249, cloud_left, cloud_top
scene!Picture1.AutoRedraw = False 'allows
  trans bitmap image to move
res% = LockWindowUpdate(0)
End Sub

Sub show_splash()
res% = LockWindowUpdate(splash.hWnd)
splash.Show 0
res% = LockWindowUpdate(0)
End Sub

Sub size_screens()
  ' size screens etc
  ' splash and blank screens are maximized
  (windowstate = 2)
panel.Width = screen.Width
panel.Height = .59 * screen.Height
End Sub

Sub start_checkval()
  checkval_on = True
  check_alt = True
  check_head = True
  checkval_timer.Enabled = True
  panel!Shape6.FillColor = green
End Sub

Sub start_cloudmove()
  cloud_move_on = True
  panel!Shape2.FillColor = green
End Sub

Sub start_demo()
If taskfile_open Then Exit Sub
task_file = demo_file
start_task
End Sub

Sub start_disturbance()
disturb_on = True
  disturb_timer.Enabled = True
  panel!Shape5.FillColor = green
End Sub

Sub start_logdata()
If Not log_exists Then create_logfile
log_on = True
log_timer.Enabled = True
panel!Shape1.FillColor = green
Print #1, Format(Now, "h:mm:ss"); Tab(11); "log on"
End Sub

Sub start_task ()
If Not taskfile_open Then open_taskfile
task_on = True
task_timer.Interval = 1000 * (iei_base + .5 * iei_var)
panel!Shape4.FillColor = green
fd_screen.Text = ""
lst_send = ""
popup!menu_item_demo.Enabled = False
popup!menu_item_runsubject.Enabled = False
End Sub

Sub stop_checkval ()
checkval_on = False
check_alt = False
check_head = False
checkval_timer.Enabled = False
panel!Shape6.FillColor = red
End Sub

Sub stop_cloudmove ()
cloud_timer.Enabled = False
panel!Shape2.FillColor = red
cloudmove_on = False
End Sub

Sub stop_disturbance ()
disturb_on = False
disturb_timer.Enabled = False
panel!Shape5.FillColor = red
End Sub

Sub stop_logdata ()
log_on = False
log_timer.Enabled = False
End Sub

End Sub

Sub start_task ()
If Not log_exists Then create_logfile
log_on = True
log_timer.Enabled = True
panel!Shape1.FillColor = green
Print #1, Format(Now, "h:mm:ss"); Tab(11); "log on"
End Sub

Sub stop_task ()

task_on = False
task_timer.Enabled = False
End Sub

Sub stop_turn ()

End Sub
head_change = False
cld = 0

If ah.Bank <= 0 Then
   ahtd = -1
Else
   ahtd = 1
End If

If tb.Turn <= 0 Then
tctd = -1
Else
tctd = 1
End If

, bank
ahb jit = 0
tct jit = 0
ahb_rtz_timer.Enabled = True
tcb_rtz_timer.Enabled = True
,
heading
head_change_timer.Enabled = False
dgval_jit = dgval_jiset
obic_wan = obic_wanset
hsival_wan = hsival_wanset

End Sub

Sub task()

' read task file and display on flight director
task_timer.Enabled = False
cloud_timer.Enabled = False
retrans_on = True
retrans = ""

Input #2, sender
sender = UCase(sender)
process_sender
If end_now Then Exit Sub

last_sender = sender

Input #2, altval_set
Input #2, dgval_set
fdalt_text = alt_prefix & altval_set & alt_suffix
panel1!Label8.ForeColor = yellow
panel1!Label8.BackColor = dark_grey
panel1!Label8.Caption = fdalt_text
fdhead_text = head_prefix & dgval_set & head_suffix
panel1!Label9.ForeColor = yellow
panel1!Label9.BackColor = dark_grey
panel1!Label9.Caption = fdhead_text

Input #2, code
code = UCase(code)
If code <> "NOP" Then process_code 'NOP
   = no operation
If end_now Then Exit Sub

Input #2, iei
' convert to mesec, takes effect from next
   cycle
iel_tot = 1000 * (iei_base + Rnd * iei_var + iei)
If iel_tot < 1 Then
   iel_tot = 1 'avoid disabling timer with interval
   = 0
ElseIf iel_tot > 65535 Then
   iel_tot = 65535 'max allowed interval
End If
If preview_on Then iel_tot = 1
   task_timer.Interval = iel_tot

Input #2, rescheck
rescheck = UCase(rescheck)
If rescheck = "Y" Then Input #2, response
   Line Input #2, task_text
   Input #2, sender
   sender = UCase(sender)
   process_sender
   If end_now Then Exit Sub

last_sender = sender

End Sub

Sub teletype()

' printing to flight director screen, teletype
effect
' called by fd_timer
fdscreen_count = fdscreen_count + 1

If fdscreen_count <= Len(fdjntext) Then ' avoids final <cr><lf>
   fd_screen.SetText = Mid(fdjntext,
                       fdscreen_count, 1)
Else ' all text displayed
If fd_screen.Enabled Then
    fd_screen.SetFocus
    fd_timer.Enabled = False
If rescheck = "Y" Then
    task_timer.Enabled = True
Else
    task_timer.Enabled = True
End If
If (cloudmove_on And task_timer) Then
    cloud_timer.Enabled = True
End If
End Sub

Function tf(test_variable, result_if_true, result_if_false)
    ' returns result_if_true if test_variable is true, else returns result_if_false
    If test_variable Then
        tf = result_if_true
    Else
        tf = result_if_false
    End If
End Function

Sub toggle_checkval()
    checkval_on = Not checkval_on
    If checkval_on Then
        start_checkval
    Else
        stop_checkval
    End If
End Sub

Sub toggle_cloudmove()
    cloudmove_on = Not cloudmove_on
    If cloudmove_on Then
        start_cloudmove
    Else
        stop_cloudmove
    End If
End Sub

Sub toggle_disturbance()
    disturb_on = Not disturb_on
    If disturb_on Then
        start_disturbance
    Else
        stop_disturbance
    End If
End Sub

Sub toggle_fluctuate()
    fluc_on = Not fluc_on
    If fluc_on Then
        jitter_timer.Enabled = True
        wander_timer.Enabled = True
        panel1Command1.Caption = "Fluctuate OFF"
    Else
        jitter_timer.Enabled = False
        wander_timer.Enabled = False
        panel1Command1.Caption = "Fluctuate ON"
    End If
End Sub

Sub toggle_gear()
    ' raise or lower landing gear
    If gear_moving Then Exit Sub
    gear_moving = True
    gear_up = Not gear_up
    If gear_up Then
        panel1Toggle1.Value = True
        panel1Shape8.FillColor = yellow
        panel1Shape9.FillColor = yellow
        panel1Shape10.FillColor = yellow
delay 2
        panel1Shape8.FillColor = red
delay 2
        panel1Shape9.FillColor = red
delay .1
        panel1Shape10.FillColor = red
    Else
        panel1Toggle1.Value = False
        panel1Shape8.FillColor = yellow
        panel1Shape9.FillColor = yellow
        panel1Shape10.FillColor = yellow
delay 2
        panel1Shape8.FillColor = green
delay 2
        panel1Shape9.FillColor = green
delay .1
        panel1Shape10.FillColor = green
    End If
gear_moving = False
panel!toggle1.Enabled = True
End Sub

Sub toggle_logall ()
' only called if log_on = true
logall_on = Not logall_on
If logall_on Then
panel!Shape1.FillColor = green
Print #1, Format(Now, "h:mm:ss"); Tab(11); "log all"
Else
panel!Shape1.FillColor = yellow
Print #1, Format(Now, "h:mm:ss"); Tab(11); "log data"
End If
End Sub

Sub toggle_logdata ()
If Not log_exists Then create_logfile
log_on = Not log_on
If log_on Then
log_timer.Enabled = True
If logall_on Then
panel!Shape1.FillColor = green
Else
panel!Shape1.FillColor = yellow
End If
Print #1, Format(Now, "h:mm:ss"); Tab(11); "log on"
Else
log_timer.Enabled = False
panel!Shape1.FillColor = red
Print #1, Format(Now, "h:mm:ss"); Tab(11); "log pause"
End If
End Sub

Sub toggle_scenemove ()
scenemove_on = Not scenemove_on
If scenemove_on Then
panel!Shape3.FillColor = green
Else
panel!Shape3.FillColor = red
End If
End Sub

Sub toggle_task ()
If Not taskfile_open Then open_taskfile
task_on = Not task_on
If task_on Then
task_timer.Enabled = True
If cloudmove_on Then cloud_timer.Enabled = True
panel!Shape4.FillColor = green
popup!menu_item_demo.Enabled = False
popup!menu_item_runsubject.Enabled = False
Else
task_timer.Enabled = False
cloud_timer.Enabled = False
panel!Shape4.FillColor = red
End If
End Sub

Sub turn_left ()
' standard rate 1 turn, 3 deg/sec (2 min for 360 deg)
' bank required depends on airspeed only, not weight etc
' rule of thumb - bank = airspeed/10 * 1.5
' eg for 115 knots = approx 17 deg
' turn off fluctuation for indiv instruments with constant movement

panel!Image9.Visible = True
panel!Image9.Enabled = True
panel!Image5.Enabled = True
panel!Image8.Visible = False

ahb_rtz_timer.Enabled = False
tcb_rtz_timer.Enabled = False
head_change = True
dgval jit = 0
tct_jit = 0
ahb_change_timer.Enabled = True
tcb_change_timer.Enabled = True

' heading
dgval_wan = 0
obic_wan = 0
hsival_wan = 0
head_change_timer.Enabled = True
End Sub

Sub turn_right ()

panelImage8.Visible = True
panelImage8.Enabled = True
panelImage5.Enabled = True
panelImage9.Visible = False

ahb_rtz_timer.Enabled = False
tcb_rtz_timer.Enabled = False

ahb_rtz_timer.Enabled = False
tcb_rtz_timer.Enabled = False

head_change = True
ctd = 1
ahtd = 1	
tcld = 1

' bank
ahb_jlt = 0
tct_jlt = 0
ahb_change_timer.Enabled = True
tcb_change_timer.Enabled = True

' heading
dgval_jlt = 0
obic_wan = 0
hsival_wan = 0

head_change_timer.Enabled = True

End Sub

Sub wander ()

' instrument wander

'wcount = wcount + 1
'If wcount > 100 Then
'wcount = 1
'End If

' altimeter
'If Not alt_change Then altimeter.Value =
altimeter.Value + alval_wan * wanmag * woffset(wcount)

'OBI - Omno Bearing Indicator
'omni.OBICourse = omni.OBICourse +
obic_wan * wanmag * woffset(wcount)

'omni.OBICourseDeviation =
omni.OBICourseDeviation + obicd_wan * wanmag * woffset(wcount)

'omni.OBIGlideSlope = omni.OBIGlideSlope +
hsigsd_wan * wanmag * woffset(wcount)

'HSI - Horizontal Situation Indicator
'hsi.Value = hsi.Value + hsival_wan * wanmag * woffset(wcount)

End Sub
**Appendix 9. Example Icarus flight simulator subject data file**

<table>
<thead>
<tr>
<th>time</th>
<th>status</th>
<th>alt</th>
<th>aset</th>
<th>head</th>
<th>hset</th>
<th>cloud</th>
<th>control and communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:29:13</td>
<td>log on</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This is Christchurch Air Traffic Control. Do you receive?</td>
<td>ATC &quot;WHISKEY GOLF LIMA&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:18</td>
<td>7504</td>
<td>7500</td>
<td>43.8</td>
<td>45</td>
<td>-1898</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:23</td>
<td>7504</td>
<td>7500</td>
<td>46.7</td>
<td>45</td>
<td>-1898</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:28</td>
<td>7500</td>
<td>7500</td>
<td>46.7</td>
<td>45</td>
<td>-1898</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your set altitude is 7500 feet. Please confirm 7500.&quot;</td>
<td>SUBJ &quot;yes&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:33</td>
<td>7497</td>
<td>7500</td>
<td>45.5</td>
<td>45</td>
<td>-1896</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:38</td>
<td>7490</td>
<td>7500</td>
<td>45.8</td>
<td>45</td>
<td>-1896</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:43</td>
<td>7484</td>
<td>7500</td>
<td>46.4</td>
<td>45</td>
<td>-1896</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:43</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your set heading is 45 degrees. Please confirm 45.</td>
<td>SUBJ &quot;45&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:48</td>
<td>7478</td>
<td>7500</td>
<td>47.5</td>
<td>45</td>
<td>-1894</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:53</td>
<td>7475</td>
<td>7500</td>
<td>44.7</td>
<td>45</td>
<td>-1894</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:29:56</td>
<td></td>
<td></td>
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<td>Maintain set altitude and heading.&quot;</td>
<td>SUBJ &quot;yes&quot;</td>
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<td>8:30:03</td>
<td>7473</td>
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<tr>
<td>This is Christchurch Air Traffic Control. To avoid conflicting traffic climb</td>
<td>ATC &quot;WHISKEY GOLF LIMA&quot;</td>
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<td>8:31:13</td>
<td>7520</td>
<td>8000</td>
<td>51.1</td>
<td>45</td>
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<td>8:31:18</td>
<td>7514</td>
<td>8000</td>
<td>50.2</td>
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<td>8:31:23</td>
<td>7506</td>
<td>8000</td>
<td>48.3</td>
<td>45</td>
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</table>
We have received information that a helicopter has crashed in your vicinity. Please monitor for radio transmissions from the crash site and report any information you receive.

Are you able to safely continue your flight and relay information received from the crash site?
Aeronautical decision making

8:34:37
8:34:40
ATTENTION ATTENTION. WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?
8:34:41
7986 8000 63.0 45 -1748
8:34:41
8:34:46
7972 8000 50.4 45 -1748
8:34:46
8:34:49
7964 8000 42.2 45 -1748
8:34:49
8:34:51
7961 8000 47.7 45 -1748
8:34:51
8:34:53
7966 8000 46.9 45 -1748
8:34:53
8:34:55
7978 8000 48.0 45 -1748
8:34:55
8:35:10
8:35:10
7996 8000 46.6 45 -1748
8:35:10
8:35:17
8014 8000 46.0 45 -1743
8:35:17
8:35:22
8036 8000 43.5 45 -1738
8:35:22
8:35:27
8063 8000 40.6 45 -1733
8:35:27
8:35:28
8:35:30
8:35:33
8087 8000 35.9 45 -1728
8:35:33
8:35:35
8117 8000 38.3 45 -1723
8:35:35
8:35:39
8:35:42
8:35:42
Climb to 8,500 feet. Please confirm 8500."
8:35:43
8:35:44
8143 8500 42.5 45 -1720
8:35:44
8:35:49
8181 8500 36.8 45 -1720
8:35:49
8:35:50
8:35:53
8:35:54
8:35:55
8057 8500 33.7 45 -1720
8:35:55
8:35:56
8014 8500 31.0 45 -1720
8:35:56
8:36:00
8:36:02
8:36:04
8:36:05
8:36:07
8:36:09
8:36:10
8:36:11
8:36:14
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8:36:36
8:36:36
8:36:40
8:36:42
8:36:45
8:36:45
8:36:49
8:36:49
ATTENTION ATTENTION. WHISKEY GOLF LIMA Climb to 8,500 feet. Please confirm 8500."
8:36:50 8496 8500 46.9 45 -1720 <Descend>
8:36:54 8498 8500 49.1 45 -1720 <Descend again>
8:37:00 8337 8500 51.6 45 -1720 [Heading warning]
8:37:05 8176 8500 50.6 45 -1720 [Heading warning]
8:37:09 8015 8500 53.4 45 -1720 [Heading warning]
8:37:11 7990 8500 57.2 45 -1720 [Heading warning]
8:37:13 8:37:15 [Heading warning]
8:37:17 8:37:18 [Heading warning]
8:37:20 7961 8500 58.0 45 -1719 [Heading warning]
8:37:26 7925 8500 59.1 45 -1714 [Heading warning]
8:37:27 7965 8500 59.1 45 -1709 [Heading warning]
8:37:29 8035 8500 54.3 45 -1704 [Heading warning]
8:37:32 8091 8500 49.5 45 -1700 [Heading warning]
8:37:34 8124 8500 45.6 45 -1695 [Heading warning]
8:37:36 <Climb>
8:37:38 <Climb again>
8:37:39 <Climb>
8:37:41 [ALTCHECK_ON]
8:37:43 <Climb again>
8:37:45 <Climb again>
8:37:47 <Climb again>
8:37:49 <Climb again>
8:37:50 <Climb again>
8:37:51 <Climb again>
8:37:52 <Climb again>
8:37:53 <Climb again>
8:37:54 8139 8500 45.8 45 -1691 [Altitude warning]
8:38:00 8209 8500 45.9 45 -1686 [Altitude warning]
8:38:05 8265 8500 45.1 45 -1681 [Altitude warning]
8:38:10 8335 8500 45.3 45 -1676 [Altitude warning]
8:38:12 8405 8500 46.1 45 -1671 [Altitude warning]
8:38:17 8475 8500 46.3 45 -1666 [Altitude warning]
8:38:23 8106 8500 45.3 45 -1665 [Altitude warning]
8:38:25 SUBJ "no"
8:38:26 ATC "Roger"
8:38:28 8468 8500 46.9 45 -1665 [Turn left]
8:38:33 8430 8500 43.6 45 -1665 [Turn right]
8:38:37 8388 8500 38.5 45 -1665 [Turn left]
8:38:39 8341 8500 46.3 45 -1665 [Turn left]
8:38:43 8341 8500 46.3 45 -1665 [Turn left]
8:38:46 8291 8500 50.9 45 -1665 [Turn left]
8:38:48 8241 8500 44.2 45 -1665 [Turn left]
8:38:50 8241 8500 44.2 45 -1665 [Turn left]
8:38:52 8106 8500 45.1 45 -1665 [Turn left]
8:38:54 8106 8500 45.1 45 -1665 [Turn left]
8:38:55 8106 8500 45.1 45 -1665 [Turn left]
8:38:58 8106 8500 45.1 45 -1665 [Turn left]
8:39:00 8106 8500 45.1 45 -1665 [Turn left]
8:39:02 8232 8500 47.1 45 -1665 [Heading warning]
8:39:03 8232 8500 47.1 45 -1665 [Heading warning]
8:39:06 8393 8500 43.2 45 -1665 [Heading warning]
8:39:08 8393 8500 43.2 45 -1665 [Heading warning]
8:39:10 8393 8500 43.2 45 -1665 [Heading warning]
8:39:12 8393 8500 43.2 45 -1665 [Heading warning]
8:39:13 8393 8500 43.2 45 -1665 [Heading warning]
8:39:15 8393 8500 43.2 45 -1665 [Heading warning]
8:39:17 8393 8500 43.2 45 -1665 [Heading warning]
8:39:19 8393 8500 43.2 45 -1665 [Heading warning]
8:39:21 8393 8500 43.2 45 -1665 [Heading warning]
8:39:23 8393 8500 43.2 45 -1665 [Heading warning]
8:39:25 8393 8500 43.2 45 -1665 [Heading warning]
8:39:27 8393 8500 43.2 45 -1665 [Heading warning]
8:39:29 8393 8500 43.2 45 -1665 [Heading warning]
8:39:31 ATC "WHISKEY GOLF LIMA"
8:39:34 Have you received any information from the reported crash site?" <Straight and level>
8:39:42 <Straight and level>
8:39:44 <Straight and level>
8:39:46 <Straight and level>
8:39:48 <Straight and level>
8:39:50 <Straight and level>
8:39:52 <Straight and level>
8:39:54 <Straight and level>
8:39:56 <Straight and level>
8:39:58 <Straight and level>
8:40:00 <Straight and level>
8:40:02 <Straight and level>
8:40:04 <Straight and level>
8:40:06 <Straight and level>
8:40:08 <Straight and level>
8:40:10 <Turn left>
8:40:12 <Straight and level>
8:40:14 <Straight and level>
8:40:16 <Straight and level>
8:40:18 <Straight and level>
8:40:20 <Straight and level>
8:40:22 <Straight and level>
8:40:24 <Straight and level>
406 Aeronautical decision making

8:39:29  8431  8500  45.0  45  -1662  <Climb>
8:39:31  8459  8500  44.5  45  -1657
8:39:35  8485  8500  43.4  45  -1652
8:39:40  8487  8500  42.3  45  -1647
8:39:40  8494  8500  46.5  45  -1642
8:39:46  8501  8500  47.2  45  -1637
8:39:52  8501  8500  47.2  45  -1637
8:39:53  8501  8500  47.2  45  -1637
8:39:55  8501  8500  47.2  45  -1637
8:39:55  8501  8500  47.2  45  -1637
8:39:59  8501  8500  47.2  45  -1637
Are you able to safely continue your flight and relay
from the crash site?"  
8:40:00  SUBJ "no"
8:40:01  ATC "Roger"
8:40:03  <Turn left>
8:40:06  <Straight and level>
8:40:07  <Turn left>
8:40:09  <Straight and level>
8:40:09  <Turn right>
8:40:13  [Heading warning]
8:40:16  <Straight and level>
8:40:18  <Turn left>
8:40:19  <Straight and level>
8:40:22  <Descend>
8:40:23  <Straight and level>
8:40:27  SUBJ "no"
8:40:33  ATC "Roger"
8:40:33  <Descend>
8:40:38  <Straight and level>
8:40:44  <Descend>
8:40:49  <Straight and level>
8:40:54  <Descend>
8:40:55  <Straight and level>
8:40:59  <Descend>
8:41:00  <Straight and level>
8:41:06  <Straight and level>
8:41:06  [ALTCHECK_OFF]
8:41:06  ATC "WHISKEY GOLF LIMA
8:41:06  Maintain 8,500 feet. Please confirm 8500."
8:41:08  <Descend>
8:41:11  <Straight and level>
8:41:11  <Turn left>
8:41:12  <Straight and level>
8:41:15  <Turn left>
8:41:16  <Straight and level>
8:41:17  <Turn right>
8:41:19  <Straight and level>
8:41:20  <Descend>
8:41:21  <Straight and level>
8:41:24  <Descend>
8:41:26  <Straight and level>
8:41:29  <Turn left>
8:41:31  <Straight and level>
8:41:31  <Turn left>
8:41:33  <Straight and level>
8:41:33  <Turn right>
8:41:36  <Straight and level>
8:41:38  <Descend>
8:41:41  <Straight and level>
8:41:41  <Turn left>
8:41:42  <Straight and level>
8:41:45  <Turn right>
8:41:46  [Heading warning]
8:41:47  8464  8500  34.2  45  -1607
8:41:51  8473  8500  46.8  45  -1607
8:41:52  8468  8500  42.8  45  -1607
8:41:58 SUBJ "8500"
8:41:58 ATC "Roger"
8:42:02  8450  8500  42.1  45  -1604
8:42:02 Descend
8:42:06 Climb
8:42:08  8463  8500  40.3  45  -1594
8:42:11 Sub and level
8:42:13 Turn left
8:42:14  8447  8500  43.4  45  -1589
8:42:20 Sub and level
8:42:21 Turn right
8:42:22  8386  8500  44.5  45  -1584
8:42:26 Sub and level
8:42:27 Turn left
8:42:28  8434  8500  42.9  45  -1579
8:42:35 Sub and level
8:42:38  8454  8500  42.0  45  -1574
8:42:41 Sub and level
8:42:42  8486  8500  42.4  45  -1569
8:42:46 Sub and level
8:42:49  8482  8500  44.8  45  -1564
8:42:50 Sub and level
8:42:55  8486  8500  44.9  45  -1559
8:43:00 Sub and level
8:43:03 [ACK_1]
8:43:03 HELI "MAYDAY MAYDAY
MAYDAY This is helicopter CHARLIE FOXTROT MIKE We have crashed west of Queenstown. Our emergency radio cannot reach Christchurch Air Traffic Control. Please relay our MAYDAY call immediately."
8:43:05  8503  8500  43.0  45  -1551
8:43:10  8508  8500  45.5  45  -1551
8:43:15  8510  8500  48.1  45  -1551
8:43:20  8508  8500  48.2  45  -1551
8:43:22 Sub and level
8:43:25  8501  8500  43.3  45  -1551
8:43:29  8491  8500  48.4  45  -1551
8:43:30 Sub and level
8:43:32 Sub and level
8:43:35  8477  8500  44.9  45  -1551
8:43:41  8463  8500  45.9  45  -1551
8:43:46  8448  8500  50.0  45  -1551
8:43:48 [Heading warning]
8:43:51  8436  8500  55.8  45  -1551
8:43:56  8427  8500  58.5  45  -1551
8:43:56 [Heading warning]
8:44:01 Sub and level
8:44:01 Sub and level
8:44:01 [Heading warning]
8:44:05 Sub and level
8:44:06 Sub and level
8:44:06 Sub and level
8:44:11 Sub and level
8:44:15 Sub and level
8:44:16 Sub and level
8:44:21 Sub and level
8:44:22 Sub and level
8:44:26 Sub and level
8:44:26 Sub and level
8:44:27
ATTENTION ATTENTION. MAYDAY MAYDAY MAYDAY This is helicopter CHARLIE
FOXTROT MIKE We have crashed west of Queenstown. Our emergency radio cannot
reach Christchurch Air Traffic Control. Please relay our MAYDAY call immediately.

8:44:29
8:44:31
8:44:36
8:44:38
8:44:39
8:44:40
8:44:41
8:44:45
8:44:46
8:44:51
again>
8:44:51
8:44:54
8:44:57
8:44:58
8:44:59
8:45:02
8:45:04
8:45:07
8:45:08

yes"
8:45:08
Information received."
8:45:12
8:45:14
8:45:17
8:45:21
8:45:23
8:45:26
8:45:31
8:45:33
8:45:34
8:45:39
8:45:45
8:45:45
Are you able to safely continue your flight and relay from the crash site?"
8:45:45
8:45:50
8:45:51
8:45:53
8:45:55
8:45:56
8:45:58
8:46:00
8:46:04
8:46:05
8:46:06
8:46:10
8:46:10
8:46:13
8:46:15
8:46:15
8:46:19
8:46:20
8:46:21
8:46:24
8:46:25
8:46:27
8:46:29
8:46:30
8:46:33
again>

HELIC "ATTENTION
HELIC "WHISKEY GOLF LIMA
HELIC "WHISKEY GOLF LIMA

<Descend>

<Straight and level>

<Turn left>

[Heading warning]

<Straight and level>

<Turn right>

<Straight and level>

<Straight and level>

<Turn left>

<Straight and level>

[Heading warning]

<Turn right>

<Straight and level>

SUBJ "1 immediately.

.HELI "WHISKEY GOLF LIMA

<Turn right>

<Straight and level>

<Turn right>

<Straight and level>

<Turn right>

<Altitude warning>

<Descend>

<Turn left>

<Straight and level>

<Turn right>

<Straight and level>

<Turn left>

<Straight and level>

<Straight and level>
8:46:35  8475  8500  46.7  45  -1523  <Turn left>
8:46:38  8441  8500  40.1  45  -1523  <Straight and level>  <Turn right>
8:46:40  8402  8500  45.2  45  -1523  <Straight and level>  <Descend>
8:46:47  8341  8500  50.9  45  -1523  <Climb>  [Heading warning]
8:46:50  8404  8500  54.5  45  -1523  <Straight and level>
8:46:51  ATC "ATTENTION WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?"
8:46:59  8444  8500  49.4  45  -1523  <Straight and level>  <Turn left>
8:47:01  8416  8500  45.5  45  -1523  <Straight and level>  <Turn right>
8:47:03  8449  8500  49.4  45  -1523  <Straight and level>
8:47:06  8476  8500  49.4  45  -1523  <Turn left>  <Straight and level>
8:47:16  8458  8500  41.0  45  -1523  <Turn left>  <Straight and level>  <Turn right>
8:47:19  8446  8500  45.2  45  -1523  <Straight and level>
8:47:26  8432  8500  47.2  45  -1523  <Climb>
8:47:31  8414  8500  46.7  45  -1523  <Climb>
8:47:36  8449  8500  49.4  45  -1523  <Turn left>  <Straight and level>
8:47:39  8476  8500  49.4  45  -1523  <Turn left>
8:47:39  ATC "WHISKEY GOLF LIMA Descend to 8,000 feet. Please confirm 8000."  <Straight and level>  <Climb>  <Turn right>
8:47:40  8392  8500  44.1  45  -1521  <Climb>  <Turn right>  <Descend>
8:47:45  8392  8500  43.5  45  -1516  <Climb>  <Turn right>  <Descend>
8:47:46  8426  8500  44.7  45  -1511  <Climb>  <Turn right>  <Descend>
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8:47:54  8432  8500  44.7  45  -1496  <Climb>  <Turn left>  <Climb>
8:47:55  [ALTCHECK_OFF]  ATC "WHISKEY GOLF LIMA ATC "Roger"  <Climb>  <Turn right>
8:47:56  8405  8000  38.4  45  -1495  <Straight and level>  <Climb>  <Turn right>  <Descend>
8:47:57  8504  8000  37.8  45  -1495  <Straight and level>  <Climb>  <Straight and level>  <Climb>
8:47:58  8376  8000  48.6  45  -1495  <Climb>  <Climb>  <Climb>
8:48:05  8492  8000  46.4  45  -1495  <Climb>  <Climb>  <Climb>
8:48:10  8486  8000  44.3  45  -1494  <Climb>  <Climb>  <Climb>
8:48:12  8492  8000  46.0  45  -1489  <Climb>  <Climb>  <Climb>
8:48:12  ATC "WHISKEY GOLF LIMA SUBJ "8000"  <Climb>  <Climb>  <Climb>
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8:48:17  8492  8000  46.0  45  -1489  <Climb>  <Climb>  <Climb>
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8:48:39  8492  8000  46.4  45  -1495  <Climb>  <Climb>  <Climb>
8:48:41  8492  8000  46.4  45  -1495  <Climb>  <Climb>  <Climb>
8:48:42  8492  8000  46.4  45  -1495  <Climb>  <Climb>  <Climb>
8:48:47  8457  8000  44.6  45  -1484  <Turn left>
8:48:48  8416  8000  44.6  45  -1479  <Straight and level>
8:48:54  8416  8000  44.6  45  -1479  <Descend>
8:48:55  8360  8000  43.3  45  -1475  <Turn left>
8:48:59  8318  8000  46.9  45  -1470  <Turn right>
8:49:04  8276  8000  43.3  45  -1465  [ALTCHK_ON]
8:49:07  8276  8000  43.3  45  -1465  [Altitude warning]
8:49:10  8264  8000  41.2  45  -1460  <Straight and level>
8:49:11  8253  8000  44.4  45  -1455  [Altitude warning]
8:49:13  8253  8000  42.5  45  -1455  <Turn left>
8:49:22  8183  8000  44.4  45  -1450  <Climb>
8:49:30  8113  8000  46.7  45  -1445  [Altitude warning]
8:49:33  8113  8000  46.7  45  -1445  <Turn left>
8:49:36  8069  8000  42.7  45  -1440  <Straight and level>
8:49:39  8069  8000  42.7  45  -1440  [ACK_1]
8:49:39  8069  8000  42.7  45  -1440  HELI "This is CHARLIE
8:49:39  8069  8000  42.7  45  -1440  FOXTROT MIKE We have two injured crew members and require medical assistance
8:49:39  8069  8000  42.7  45  -1440  as soon as possible. Please relay this information to Christchurch Air
8:49:39  8069  8000  42.7  45  -1440  Traffic Control." 8:49:39  8019  8000  45.1  45  -1440  <Straight and level>
8:49:41  8008  8000  41.4  45  -1440  <Turn left>
8:49:43  8036  8000  48.5  45  -1440  <Straight and level>
8:49:49  8069  8000  52.7  45  -1440  [Heading warning]
8:49:50  8069  8000  42.7  45  -1440  <Descend>
8:49:54  8019  8000  51.5  45  -1440  <Straight and level>
8:49:57  8019  8000  45.7  45  -1440  <Turn left>
8:49:59  8019  8000  44.7  45  -1440  <Straight and level>
8:50:00  8019  8000  44.7  45  -1440  [Altitude warning]
8:50:04  8062  8000  46.9  45  -1440  <Turn left>
8:50:09  8103  8000  49.1  45  -1440  <Straight and level>
8:50:15  8149  8000  46.9  45  -1440  [Altitude warning]
8:50:20  8201  8000  47.0  45  -1440  <Straight and level>
8:50:25  8201  8000  47.0  45  -1440  [Altitude warning]
8:50:30  8261  8000  49.2  45  -1440  log off
8:50:31

Position check data

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Appendix 10. Icarus task file for *When To Turn Back* scenario

**Format of task file**

Task input is in pairs of lines:
- first line lists data values for variables as described below,
- second line gives text to display on flight director screen.
- optional third line if input of custom acknowledgement or retransmission message

**Variables**

sender, altval_set, dgval_set, code, iei, rescheck, response

sender = ATC, HELI etc

altval_set - maintain set altitude value
dgval_set - maintain set heading value
code - code value, eg turn setval checking on/off, change button set, change temp indicator etc
iei - inter event interval, time after subject response before next task element presented
rescheck - should subject's response be checked
y = yes, response check required
n = no check
response - required response element, in double quotes " "

**Note**

if rescheck = no then leave rest of first line blank
If rescheck = yes then add required response in double quotes

'end' as first line stops task, any lines after that are ignored.

---

```
atc, 7500, 45, nop, 0, y, "yes"
WHISKEY GOLF LIMA This is Christchurch Air Traffic Control. Do you receive?
atc, 7500, 45, nop, 0, y, "7500"
WHISKEY GOLF LIMA Your set altitude is 7,500 feet. Please confirm 7500.
atc, 7500, 45, nop, 0, y, "45"
WHISKEY GOLF LIMA Your set heading is 45 degrees. Please confirm 45.
atc, 7500, 45, checkval_on, 0, n
WHISKEY GOLF LIMA Maintain set altitude and heading.
atc, 7500, 45, disturb_on, 60, n
/
atc, 8000, 45, altcheck_off, 30, y, "8000"
WHISKEY GOLF LIMA This is Christchurch Air Traffic Control. To avoid conflicting traffic climb to 8,000 feet. Please confirm 8000.
atc, 8000, 45, altcheck_on, 30, n
/
atc, 8000, 45, nop, 30, n
WHISKEY GOLF LIMA We have received information that a helicopter has crashed in your vicinity. Please monitor for radio transmissions from the crash site and report any information you receive.
```
ATC, 8000, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

ATC, 8500, 45, altcheck_off, 30, y, "8500"
WHISKEY GOLF LIMA Climb to 8,500 feet. Please confirm 8500.

ATC, 8500, 45, altcheck_on, 30, n

ATC, 8500, 45, nop, 30, y, ""
WHISKEY GOLF LIMA Have you received any information from the reported crash site?

ATC, 8500, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

ATC, 8500, 45, altcheck_off, 30, y, "8500"
WHISKEY GOLF LIMA Maintain 8,500 feet. Please confirm 8500.

ATC, 8500, 45, altcheck_on, 30, n

HEL, 8500, 45, ack_1, 30, y, ""
MAYDAY MAYDAY MAYDAY This is helicopter CHARLIE FOXTROT MIKE. We have crashed west of Queenstown. Our emergency radio cannot reach Christchurch Air Traffic Control. Please relay our MAYDAY call immediately.

ATC, 8500, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

ATC, 8000, 45, altcheck_off, 30, y, "8000"
WHISKEY GOLF LIMA Descend to 8,000 feet. Please confirm 8000.

ATC, 8000, 45, altcheck_on, 30, n

HEL, 8000, 45, ack_1, 30, y, ""
This is CHARLIE FOXTROT MIKE. We have two injured crew members and require medical assistance as soon as possible. Please relay this information to Christchurch Air Traffic Control.

ATC, 8000, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

ATC, 7500, 45, altcheck_off, 30, y, "7500"
WHISKEY GOLF LIMA Descend to 7,500 feet. Please confirm 7500.

ATC, 7500, 45, altcheck_on, 30, n

ATC, 7500, 45, ack_2, 30, y, ""
WHISKEY GOLF LIMA An air ambulance will be dispatched to the crash site. Please relay this information to CHARLIE FOXTROT MIKE.

ATC, 7500, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

ATC, 7000, 45, altcheck_off, 30, y, "7000"
WHISKEY GOLF LIMA Descend to 7,000 feet. Please confirm 7000.

atc, 7000, 45, altcheck_on, 30, n
/

heli, 7000, 45, ack_1, 30, y, ""
This is CHARLIE FOXTROT MIKE Pilot has suspected broken leg and copilot has burns to hands and arms. Please relay this information to Christchurch Air Traffic Control.

atc, 7000, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

atc, 7000, 45, altcheck_off, 30, y, "7000"
WHISKEY GOLF LIMA Maintain 7,000 feet. Please confirm 7000.

atc, 7000, 45, altcheck_on, 30, n
/

atc, 7000, 45, ack_2, 30, y, ""
WHISKEY GOLF LIMA Injured crew members should be treated for shock as per instructions in aircraft First Aid manual. Please relay this information to CHARLIE FOXTROT MIKE.

atc, 7000, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

atc, 7500, 45, altcheck_off, 30, y, "7500"
WHISKEY GOLF LIMA Climb to 7,500 feet. Please confirm 7500.

atc, 7500, 45, altcheck_on, 30, n
/

heli, 7500, 45, ack_1, 30, y, ""
This is CHARLIE FOXTROT MIKE The crash site is on the east side of a large lake. Please relay this information to Christchurch Air Traffic Control.

atc, 7500, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

atc, 8000, 45, altcheck_off, 30, y, "8000"
WHISKEY GOLF LIMA Climb to 8,000 feet. Please confirm 8000.

atc, 8000, 45, altcheck_on, 30, n
/

atc, 8000, 45, ack_2, 30, y, ""
WHISKEY GOLF LIMA If possible the crew at the crash site should prepare a smoke beacon to show their position. Please relay this information to CHARLIE FOXTROT MIKE.

atc, 8000, 45, pos_check, 30, y, ""
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

atc, 8500, 45, altcheck_off, 30, y, "8500"
WHISKEY GOLF LIMA Climb to 8,500 feet. Please confirm 8500.

atc, 8500, 45, altcheck_on, 30, n
This is CHARLIE FOXTROT MIKE. We have lit a smoke beacon near the crash site. Please relay this information to Christchurch Air Traffic Control.

WHISKEY GOLF LIMA: Are you able to safely continue your flight and relay information received from the crash site?

WHISKEY GOLF LIMA: Climb to 9,000 feet. Please confirm 9000.

This is CHARLIE FOXTROT MIKE. There is an open area suitable for a helicopter to land on a ridge about half a kilometre from the crash site. Please relay this information to Christchurch Air Traffic Control.

WHISKEY GOLF LIMA: Are you able to safely continue your flight and relay information received from the crash site?

WHISKEY GOLF LIMA: Maintain 9,000 feet. Please confirm 9000.

WHISKEY GOLF LIMA: The crew should stay at the crash site until help arrives. Please relay this information to CHARLIE FOXTROT MIKE.

WHISKEY GOLF LIMA: Are you able to safely continue your flight and relay information received from the crash site?

WHISKEY GOLF LIMA: Descend to 8,500 feet. Please confirm 8500.

WHISKEY GOLF LIMA: The air ambulance should arrive at the crash site in approximately 10 minutes. Please relay this information to CHARLIE FOXTROT MIKE.
WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?

WHISKEY GOLF LIMA Climb 9,000 feet. Please confirm 9000.

This is CHARLIE FOXTROT MIKE The battery power of our emergency radio is fading. Please relay this information to Christchurch Air Traffic Control.

WHISKEY GOLF LIMA Are you able to safely continue your flight and relay information received from the crash site?
Appendix 11.  Low flying case-based training module

Disclaimer

The training material reproduced in the following Appendices was used for private experimental work only. The pictures came from a range of aviation magazines and books and were for illustration only. They do not show the actual aircraft, people, or locations involved in the accidents and incidents described in the accompanying text. There is absolutely no suggestion that the aircraft or people depicted in the training material were involved in any unsafe flying activity, or were involved in any accident or incident, however arising.

The training material is shown here for information only. It is not in the public domain and must not be reproduced or further distributed in any form or manner whatsoever without written permission of the author.

Richard Batt

The DANGERS of Low Flying
Example 1

The aircraft was owned by a farmer and was operated from a grass strip. It had been flown twice that day prior to the accident flight and no unserviceabilities or problems had been reported.
During the earlier flights the pilot was reported to have performed aerobatic manoeuvres. The aircraft was not certified for aerobatic flight and no record was found of the pilot holding an endorsement to perform aerobatic manoeuvres.

After takeoff, the aircraft was seen by several witnesses to fly low over the strip and adjoining areas.

Witnesses reported that the pilot then attempted a manoeuvre at low level which resulted in the aircraft apparently stalling. The aircraft was then seen to rotate several times before crashing in a near vertical attitude through several branches of a large tree.

The observers ran to the aircraft and found the pilot dead but were able to free the passenger from the rear seat.
It would appear that at the time of the accident the pilot was carrying out some form of impromptu display at low level when he lost control. Such a manoeuvre was apparently induced by the pilot rather than being the result of him experiencing a problem with the aircraft.

The subsequent inquiry found the following factors were relevant to accident,

• The pilot was engaged in an impromptu display at low level and attempted manoeuvres beyond his level of experience.
• The aircraft stalled at a height insufficient for recovery.

---

Example 2
At the end of an aero club fly-in, the accident aircraft was fifth in line to depart. From a video recording available it appears that an impromptu air display had developed at the fly-in. This had commenced earlier in the afternoon with a short aerobatics sequence flown by an arriving aircraft and had been continued by another participant later in the day.

As the flying come to a close, four consecutive aircraft took off and departed to their various destinations and of these two carried out minor displays prior to their final departure. Immediately after this the accident aircraft took off and after a short ground roll accelerated slowly to a height of less than 50 feet. When the aircraft reached a point abeam the aircraft parking area it commenced a steep climb, combined almost immediately with a steeply banked right turn.
By the time the aircraft had turned through 180 degrees and reached a height of about 200 feet it appeared to have stalled. From the point of stall the aircraft pitched downwards just past the vertical and descended steeply into a spiral, beginning a recovery from the vertical attitude less than 100 feet above ground.

The aircraft hit the ground at an angle of more than 45 degrees, impacting with the left wingtip and nose first. Both occupants were killed on impact.

A Board of Inquiry found that the cause of the accident was that the pilot initiated an impromptu aerobatic display at an unsafe height. It was considered probable that the pilot was influenced by illusory effects due to the low height at which the manoeuvre was attempted.
Example 3

The pilot arranged to hire the aircraft from a flying school with which he had done much of his training. He was accompanied by a colleague from work and their intention was to fly around an area nearby where the passenger lived.
The aircraft departed normally and was seen by a number of witnesses over a period of some minutes. It was generally described as flying at a moderately low height and circling around. It particularly attracted the attention of some witnesses when they heard its engine sound change. This was described as the engine being throttled back, or stopping briefly, then the sound increasing again.

The aircraft was then seen to turn left and suddenly enter a very steep dive. It appeared to make two or three turns and then recover to level flight at a low height. Almost immediately after levelling it collided with a tree, then cartwheeled to the ground. Rescuers arrived at the scene within minutes.

The occupants were extricated from the wreckage, and the seriously injured passenger was evacuated by rescue helicopter. The pilot was killed on impact.
It is likely that the aircraft was being flown at a reduced speed in order to facilitate survey of the area. This would, however, have required vigilance and careful handling by the pilot because of the reduced margin above stall speed.

The subsequent accident investigation concluded that,

- The aircraft was being flown in normal turning manoeuvres at a moderately low height and a slow cruising speed when control was lost and it entered a spin.
- Wind perceptual effects may have promoted the onset of the spin.

Example 4
The pilot landed the aircraft on a strip near the lake and visited a group of friends on the shore with his passenger. It was arranged that the pilot would return in the aircraft and fly past for some photographs to be taken.

![Airplane](image)

After a first run past the group on the shore the aircraft was seen to turn and position for a second flypast. The aircraft passed over the observers at less than 50 feet above the ground and began to turn and start a steep climb. Witnesses reported that the speed of the aircraft reduced rapidly and, at about 150 feet, the engine noise apparently reduced or stopped. The aircraft then dropped the right wing and dived into the water.
The aircraft was seen to sink rapidly and only the passenger managed to extricate himself from the wreckage. He clung to the tail and was recovered quickly by rescuers in a power boat.

Despite repeated dives, the pilot could not be reached and his body was removed after the wreckage was towed to shore.

Detailed investigation did no reveal any faults or anomalies in the aircraft which could have contributed to the accident. It was considered that the reduced power at the top of the steep climb was pilot-induced during the attempted execution of a stall type manoeuvre.

Discussions with witnesses revealed that the pilot was overconfident in his attitude to flying and would not readily accept advice or counseling on his handling of the aircraft.
Appendix 12. Low flying rule-based training module

The DANGERS of Low Flying

Flying training and Aeronautical Decision Making
Safe flying depends on both mechanical and human factors. Modern design and construction techniques mean that today's light aircraft are very unlikely to suffer major mechanical problems. However equally important as the integrity of the aircraft is the ability of the pilot in command.

Pilots undergo rigorous and comprehensive training to ensure that their skills match the requirements of the demanding environment in which they operate.

There are two distinct but complementary aspects to pilot training. As well as "hands on" instruction in the air, students also complete a course of ground based theory instruction. This includes aspects of aerodynamic theory as well as an understanding of the nature and operation of the airframe, engine, and instruments. Other topics include radio work, meteorology and navigation.

A proficient pilot, however, needs more than just basic knowledge and flying skills. Another very important ability is that of good decision making.
Good decision making will not happen automatically. It can be learnt by experience but the cost may be very high. In the extreme, bad aeronautical decision making can result in death or serious injury, no less so than might be caused by major mechanical problems.

Flying training emphasizes the importance of good decision making and attempts to improve pilots' skills in that area.

Decision making is a process which involves recognizing and analyzing all the information relevant to the situation, followed by the evaluation of alternative courses of action, and finally the execution of the chosen course in a timely manner.
Low flying

Good aeronautical decision making skills will help to ensure that the pilot only undertakes operations that they have the qualifications and experience to conduct safely, and for which they have thoroughly planned and prepared. Embarking on inappropriate or unplanned exercises will almost certainly result in safety being jeopardised. One such type of activity that results in many serious light aircraft accidents is that of unwarranted low flying.
Except when taking-off or landing the minimum height at which a private light aircraft may fly during normal circumstances is 500 feet above ground level. Flight below 500 feet is potentially very dangerous and requires special training in both theory and practice.

The problems associated with flight at low level include,

- The effect of wind and turbulence.
- Unseen obstructions.
- The lack of room for error.

Wind and turbulence
Wind speed and direction have a major influence on aircraft operations. This is particularly true of light aircraft whose relatively small size and low airspeed make them more susceptible to the effects of wind.

Misleading visual effects can be caused by the wind when flying at low levels. For example the pilot may gain a false impression of the aircraft’s airspeed or turning performance.

A tailwind will increase the aircraft’s speed over the ground, hence creating a false impression of higher than normal airspeed. This is a potentially dangerous illusion as it may lead to the pilot mistakenly reducing the aircraft’s airspeed. In the extreme this could result in the speed dropping to near or below the aircraft’s stalling speed. If a stall occurs at low level then the aircraft will almost certainly crash.
Increased turbulence and wind gusts can be expected at low levels due to surface friction slowing down strong winds and uneven heating of the earth’s surface creating convection currents. Turbulence and wind gusts can reduce essential lift. This can result in the aircraft becoming temporarily unbalanced.

No room for error
The effect of wind or turbulence can be to momentarily unbalance the aircraft, either directly or through mishandling by the pilot. A minor disturbance such as this is likely to be of little consequence when the aircraft is at a safe height but can be fatal at low level. The pilot will have little safety margin in which to recover. For example, once the aircraft has entered a spin at low level there will be little chance of recovering control before the aircraft strikes the ground.

Unseen obstructions
There are many potential collision hazards in low flying. Obstructions such as trees, buildings and the terrain are ever present. Power lines are a particular danger and other wires, such as the guy lines holding masts, also pose a risk. Many obstructions can be hard to see while flying. For example they may be camouflaged and hidden by the background, or obscured by sun glare.

Why do pilots risk low flying?
Low flying can be exhilarating. However, while it may be tempting to engage in this activity many pilots have found to their cost that there can be deadly surprises for those that bend the rules.

Three activities cause the majority of low flying accidents,

- Beat-ups.
- Impromptu aerobatics.
- Circling to observe something on the ground.

A beat-up, flying low over a building or a person, is likely to be done on the spur of the moment without any planning or proper lookout for hazards. In many cases the result is a collision with an obstruction such as a tree or power line.

Impromptu aerobatics also bring the risk of collision as well as the added danger of loss of control. In many cases the pilot over-estimates their ability and mishandles the aircraft at a height from which it is impossible to recover.
Circling at low level to observe something on the ground is likely to lead to the pilot becoming distracted and failing to give full attention to flying the aircraft. This is particularly true when the pilot is not specifically trained in this type of manoeuvre and can result in the aircraft becoming destabilized, perhaps stalling or entering a spin. Again, loss of control at low level is likely to be disastrous.

A common element in many low level crashes is a desire to perform to the gallery. Particularly in the case of beat-ups and impromptu aerobatics the pilot’s actions are often carried out to impress someone known to them. Enthusiasm, however, needs to be tempered with self-discipline. If sound aeronautical decision making is abandoned then the result is likely to be serious injury or death.
Summary

Low flying awareness is one important aspect of good aeronautical decision making.

Low flying is potentially very dangerous because,

- Wind and turbulence can lead to loss of control.
- Unseen obstructions are a constant hazard.
- At low level there is no room for error.

Pilots must resist the temptation to play to the gallery with beat-ups or low level aerobatics.
Appendix 13. Low flying case-based questionnaire

Please provide the missing information or circle the correct alternative from (a) (b) (c)

The following four questions relate to Example 1

1) The aircraft was owned by __________________________ and operated from __________________________

2) During earlier flights that day the pilot was reported to have,
   (a) resisted advice on his handling of the aircraft
   (b) performed aerobatic manoeuvres
   (c) flown low over adjoining areas

3) The aircraft crashed,
   (a) with the engine operating at reduced power
   (b) at an angle of approximately 45 degrees
   (c) through the branches of a large tree

4) As a result of the crash,
   (a) the pilot and his passenger were seriously injured
   (b) the pilot was killed but his passenger survived
   (c) the pilot and his passenger were killed

The following four questions relate to Example 2

5) At the end of an aero club fly-in the accident aircraft was,
   (a) third in line to depart
   (b) fourth in line to depart
   (c) fifth in line to depart

6) After take off the aircraft accelerated slowly to a height of less than,
   (a) 50 feet
   (b) 100 feet
   (c) 150 feet

7) The aircraft impacted,
   (a) with the left wingtip and nose first
   (b) in a near vertical attitude
   (c) with a tree and then cartwheeled to the ground

8) As a result of the crash,
   (a) the pilot and his passenger were seriously injured
   (b) the pilot was killed and his passenger was seriously injured
   (c) the pilot and his passenger were killed
The following four questions relate to Example 3

9) The accident aircraft was,
   (a) owned by the pilot
   (b) hired from a work colleague
   (c) hired from a flying school

10) Witnesses described the aircraft as flying,
    (a) at a very low height
    (b) at a moderately low height
    (c) erratically

11) It is likely that the aircraft was being flown at a reduced speed in order to,
    (a) perform an aerobatic manoeuvre
    (b) allow photographs of the aircraft to be taken
    (c) facilitate survey of the area

12) The subsequent accident investigation concluded that,
    (a) the pilot attempted manoeuvres beyond his level of experience
    (b) wind perceptual effects may have promoted the onset of the spin
    (c) the pilot was engaged in an impromptu display at low level

The following four questions relate to Example 4

13) The accident aircraft passed over the observers at a height of less than,
    (a) 50 feet
    (b) 100 feet
    (c) 150 feet

14) The reduced power at the top of the steep climb was considered to be,
    (a) pilot induced
    (b) due to the aircraft's attitude
    (c) caused by an unknown factor

15) After the aircraft dived into the water the pilot,
    (a) clung to the tail until rescued
    (b) swam to shore
    (c) could not be reached

16) Discussions with witnesses revealed that the pilot was __________ in his attitude.
Appendix 14. Low flying rule-based questionnaire

Please provide the missing information or circle the correct alternative from (a) (b) (c)

1) Safe flying depends on both _______ and _______ factors.

2) A proficient pilot needs more than just basic knowledge and flying skills. Another very important ability is that of _______

3) Except when taking-off or landing the minimum height at which a private light aircraft may fly during normal circumstances is,
   (a) 500 feet above ground level
   (b) 1,000 feet above ground level
   (c) 1,500 feet above ground level

4) Flying below the minimum height requires special training,
   (a) in theory only
   (b) in practice only
   (c) in both theory and practice

5) Light aircraft are particularly susceptible to the effects of wind because of their relatively _______ and _______

6) When flying at low levels a tailwind can give a false impression of,
   (a) lower than normal airspeed
   (b) higher than normal airspeed
   (c) higher than normal height above the ground

7) At low levels essential lift can be reduced by _______
   and _______

8) A beat-up is,
   (a) performing unauthorized aerobatics
   (b) flying low over a building or person
   (c) circling to observe something on the ground

9) A minor disturbance to the aircraft may be fatal at low level because the pilot will have _______
10) Circling at low level to observe something on the ground is likely to lead to the pilot,
(a) misjudging the aircraft’s speed over the ground
(b) failing to give full attention to flying the aircraft
(c) performing impromptu aerobatics

11) Many pilots carrying out impromptu aerobatics,
(a) fail to reduce power as required
(b) underestimate their ability
(c) mishandle the aircraft

12) There are many potential collision hazards in low flying such as,
____________________  ____________________  ____________________
and ____________________

13) Beat-ups and impromptu aerobatics are often carried out to,
(a) observe something on the ground
(b) provide special training
(c) to impress someone known to the pilot

14) Many obstructions can be hard to see while flying. For example they may be,
____________________  ____________________

15) To safely circle at a low level a pilot should,
(a) reduce power when there is a tail wind
(b) increase power when there is a tail wind
(c) be specifically trained in this type of manoeuvre

16) Three activities cause the majority of low flying accidents,
____________________
____________________  ____________________  ____________________
and
Appendix 15. Example transcript of responses to decision probes

Subject 42

1) Um, two things at once. Um, yeah, trying to maintain my speed and also answer the questions that come up. Doesn’t seem to be quite as turbulent.

2) Um, it’s not quite as bad as it could be. Although it’s getting more and more difficult to [?] plane on the set headings, but, um, it’s still manageable within the parameters.

3) Um, similar to last time, that it’s not too bad yet, it’s not getting too much harder, sort of about the same. Um, well it’s certainly not perfect conditions but it’s, um, it’s at the moment manageable.

4) Um, that although there was a wee bit of turbulence before it’s settled down now and, um, yeah the fact that I think I can probably keep the plane still within the parameters for a little longer anyway.

5) Um, that it doesn’t seem to have got too much worse, it’s um, it’s very very similar to what it was before, um, certainly the cloud cover’s coming in but um, it’s, it’s not too bad, it only seems to get really bad when I have to relay a message, so it’s um.

6) Um, that the cloud cover is coming in but, um, the plane still seems to be maintaining it’s track not too well, not too badly. [?] although, it [?] wee bit interesting, I think it’s getting easier also to maintain it.

7) Um, that it’s getting, that I’ll, I think it’s getting near a point where it’s becoming you’re able to continue the flight safely but the relay of information part is becoming more difficult part, um, but still, still think I can maintain the aircraft within the set parameters, um, without too much risk to myself. However yeah, the risk is increasing.

8) Um, that although I’ve almost done most of what I’m meant to do I still think I can keep the flight going and there may be some other information, although the, the ground control know the extent of the injuries and the um, location, um, it’s I think I can probably stay just a bit longer just to make sure that there is, there isn’t a problem.

9)
Um, that although the cloud cover’s now becoming much more intense, um, that um, it’s not, doesn’t seem to be too bad at the moment, although hard to be, the cloud cover on the feeling of the controls I suspect it will be not long before it will be too difficult.

10) Um, that there’s not very much longer before I won’t be able to say that answer. Um, it’s kind of, it is getting much harder to maintain course and it’s um, it’s getting difficult, it’s not too bad yet, however the information that I’m relaying doesn’t become of any more importance than lighting fires and, or the fire is lit then I will probably [?], um. Then the other question is whether there’s the um, the altitude and things that they want us to, to go higher.

11) That I’ve still got a fair bit of visibility, um the difficulty in actually flying the mission, keeping it within it’s parameters is not increasing, um, however, yeah, should visibility get any less then I [?].

12) Um, at the present altitude I’d no longer be able to see, in a few more minutes.
Appendix 16. Risk factors for involvement in aircraft accidents

Results of previous studies into pilot-related factors in aircraft crashes.

Age - Various studies have reported that accident risk increases with age (Booze, 1977), decreases with age (Lubner, Markowitz, & Isherwood, 1991), or does not vary significantly with age (Mohler, Bedell, Ross, & Veregge, 1969).

Total flying time - Accidents rates have generally been found to decrease with total hours flown (Booze, 1977; Golaszewski, 1983; Li, Baker, Grabowski, Qiang, McCarthy, & Rebok, 2003). Decreasing accident rates with increasing total time have also been shown for air transport pilots’ involvement in general aviation accidents (Salvatore et al, 1986) and for aerial agriculture pilots (Hall, 1991). The finding that there is a special period of vulnerability between approximately 100 and 300 total time, reported by the NTSB (1974), was not supported by the work of O’Hare and Chalmers (1999).

Time on type - In a study of crashes in the mountains of Colorado, Baker and Lamb (1989) found that 44% of pilots had less than 100 hours on type. However, no comparative data was provided for non-accidents pilots. A study by the NTSB (1989b) reported that 46.3% of pilots involved in VFR into IMC accidents had less than 100 hours on type, but again provided no reference data.

Licence category - Lubner, Markowitz, & Isherwood (1991) reported that commercial pilot licence holders were twice as likely to be involved in an accident as other types of licence holders.

Pilot ownership status - The NTSB (1989b) reported pilot ownership status for VFR into IMC accidents, but as no reference data was provided no conclusions can be drawn.