



Australian Government
Australian Transport Safety Bureau



Safe Transport

AVIATION RESEARCH INVESTIGATION REPORT
B2005/0127

General Aviation Pilot Behaviours in the Face of Adverse Weather

June 2005





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June 2005

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Contents

EXECUTIVE SUMMARY	v
1 INTRODUCTION.....	1
1.1 The central nature of aeronautical decision making	2
1.2 Different pilot responses to adverse weather	2
2 METHOD	7
2.1 VFR into IMC occurrences	7
2.2 Precautionary landing occurrences	10
2.3 Weather avoidance occurrences	12
3 RESULTS	15
3.1 Occurrence outcome	15
3.2 Pilot demographics.....	20
3.3 Operational factors.....	25
3.4 Aircraft characteristics	26
3.5 Geographical and environmental factors	29
3.6 Absolute and relative flight distances	37
4 DISCUSSION	47
4.1 VFR into IMC – a deadly scenario	47
4.2 Comparison of results with previous ‘outcome’ based studies	49
4.3 Measures of absolute and relative flight distance	50
4.4 A safe pilot is a proactive pilot	52
5 CONCLUSIONS	55
6 REFERENCES.....	57

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EXECUTIVE SUMMARY

Weather-related general aviation accidents remain one of the most significant causes for concern in aviation safety. This is despite over half a century of work by aviation professionals and human factors researchers aimed at understanding the reasons behind accidents such as those involving Visual Flight Rules flight into Instrument Meteorological Conditions ('VFR into IMC').

Previous studies into the factors associated with weather-related general aviation occurrences have typically compared accident and non-accident cases. In contrast, this study does not concentrate on occurrence outcome. Instead, the emphasis is on the different behaviours that pilots exhibit in the face of adverse weather and, by inference, on the decision making processes that underlie those behaviours.

The work of this study is based on a set of 491 aviation accident and incident reports drawn from the Australian Transport Safety Bureau (ATSB) 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 flight 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.

In comparison with previous 'outcome' based studies of general aviation accidents, the current study found few significant differences among the three weather-related behavior groups in terms of pilot demographics, aircraft characteristics, geographic factors, or absolute flight distances. However, the pattern of relative flight distances (a psychological construct) was markedly different for the three groups, with pilots in the 'weather avoidance' group being distinguished by taking timely action. The results suggest that the mid-point of the flight can be a 'psychological turning point' for pilots, irrespective of the absolute flight distance involved.

The 'VFR into IMC' group had the greatest risk of a fatality or serious injury, while the 'precautionary landing' group had the greatest risk of some form of aircraft damage. Taken together, these results may help to explain the genesis of some VFR into IMC occurrences.

This research reinforces the significant dangers associated with VFR flight into IMC – 76% of VFR into IMC accidents involved a fatality. The chances of a VFR into IMC encounter increased as the flight progressed until they reached a maximum during the final 20% of the flight distance. This result highlights the danger of pilots 'pressing on' to reach their destination.

The results emphasise that a safe pilot is a proactive pilot and that dealing with adverse weather is not a one-off decision but a continually evolving process. This aspect is discussed in terms of the concept of 'mindfulness'.

1 INTRODUCTION

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Previous 'outcome' based studies of general aviation accidents have explored the influence of a range of pilot demographic and operational variables. The current 'behaviour' based study also analyses the effect of these variables, and compares and contrasts the results with those found in previous traditional studies.

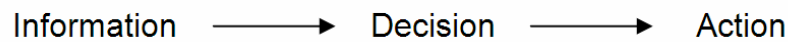
The risk factors for involvement in aviation accidents have been reviewed by Li (1994) and O'Hare (1999). Accident rates have generally been found to decrease for pilots with higher licence qualifications and for pilots with a greater number of total flying hours. Results relating to pilot age have been mixed, with various studies reporting that accident risk increases, decreases, or stays the same, with increasing age. A significant influence of geographical region has been reported in some studies (Baker and Lamb, 1989; NTSB, 1974; NTSB, 1976).

The results of this study emphasise the importance of psychological aspects in pilot weather-related behaviour. This is in contrast to previous outcome-based studies (e.g. accident versus non-accident) that have emphasised the role of pilot demographic, operational, and geographic factors.

¹ For example, see early work by Bryan, Stonecipher, and Aaron (1954).

1.1 The central nature of aeronautical 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 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);



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 an intangible aspect of airmanship. Experienced and successful pilots embodied 'the right stuff' compared with 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 and 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, and 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.

1.2 Different pilot responses to 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 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.

However, whatever the pilot's response to deteriorating weather, the final outcome of a safety-related occurrence will depend on a myriad of factors, and in the final analysis chance can play a significant part. The following two accident case histories illustrate this point.

Case 1.

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 en route 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 1. 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 2.

The planned flight was from Bendigo to Albury. The area forecast indicated that the weather en route would be suitable for VFR flight. A cold front was moving slowly through the region from the south-west, 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 three 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.

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 looping 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.

Figure 2. An aircraft substantially damaged as a result of a precautionary landing²



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

² Accident photographs are for general illustrative purposes only. They should not be taken as relating to any particular accident discussed in this study.

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 their resolve to conduct their 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, and Lee, 1995).

Following this line of argument, the work of this study 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 inherent nature of the pilot? Or could it have happened to anyone? What was going on in the pilot's mind? What was the pilot thinking as events progressed? Did the pilot misjudge the weather situation? Or did they realise that the weather was deteriorating significantly, and yet consciously decide to press on for reasons known only to themselves? These are questions about *process*, about how the situation had its genesis, and how it developed over time.

2 METHOD

This study is based on a set of aviation accident and incident occurrences that reflect different pilot behaviours in the face of adverse weather conditions, namely:

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

The database from which the weather-related occurrences were drawn was the record of Australian aviation accidents and incidents held by the ATSB. The initial dataset of potential occurrences for the study was formed by selecting all VFR fixed-wing general aviation flight occurrences, but excluding night VFR flights, sport aviation and all aerial work operations. Relevant weather-related occurrences were then identified by keyword screening of the narrative text and from information in certain key descriptive fields. The final dataset included a total of 491 occurrences as follows: VFR into IMC (280 cases), precautionary landing (60 cases), and weather avoidance (151 cases).

The aim of the study was to compare the three groups, based as they were on pilots' behaviour in the face of adverse weather, and not on the basis of the final outcome of the event. A range of pilot demographic, operational, geographical and environmental variables were compared, and the results contrasted with those from outcome-based studies. An alpha level of $p < .05$ was used for assessing the statistical significance of the comparisons (ANOVA or χ^2). For some variables with non-normal distributions, non-parametric tests produced the same results.

Details and examples of the three weather-related behaviour groups are given below.

2.1 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 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 3. Local weather conditions at the time of a fatal VFR into IMC accident



Figure 3 shows 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 included³;

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.

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.

³ Occurrence numbers refer to the dataset of cases in this study, not to ATSB database occurrences numbers. Some occurrence summaries have been edited for brevity.

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 the aircraft then 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 exited the cloud and was able to conduct the rest of the flight in VMC.

Figure 4. A VFR into IMC accident site



Figure 4 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 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.

2.2 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. The type of landing sites typically used for a precautionary landing include any sufficiently large open area such as 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 away from a recognised aerodrome is a prudent course of action in the face of significantly adverse weather and pilots are trained for such an eventuality. The alternative of 'pressing on' may well place the aircraft and its occupants in a potentially very risky situation. However, a precautionary landing is not a 'normal' operation and in most cases it will indicate that 'VMC assurance'⁴ has been lost. Perhaps the situation can best be

4 '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 and 'continuing airworthiness assurance' in aircraft certification and maintenance (ATSB, 2002).

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 the following:

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. The pilot made a diversion to remain in VMC and landed after deciding that it would not be possible 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

While en route, cloud base lowered and showers became more frequent. On receipt of advice on weather ahead from another aircraft, the 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 first to Orange and then 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 SARTIME⁵ 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.

2.3 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, it was possible that the situation could have escalated and that VMC assurance might have been lost.

Figure 5. Cloud formation near Canberra, ACT



⁵ 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.

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 the pilot failed to cancel a SARTIME. That in itself, however, does not detract from the appropriateness of the pilot's prudent weather-related action.

Examples of weather avoidance occurrences included the following:

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. The aircraft was eventually landed at Roma without incident.

Occurrence 65

The student on solo navex was authorised by an instructor in spite of the forecast indicating marginal VMC en route. The 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.

Occurrence 295

The aircraft was on a VFR operation when it encountered deteriorating weather conditions on route to Jandakot. The pilot advised Perth Control that due to reduced visibility and low cloud the aircraft was diverting to Wongan Hills. The phase was cancelled when the pilot advised Perth Control that he was in VMC conditions and that the aircraft was on track back to Wongan Hills.

Occurrence 303

The pilot failed to cancel SARTIME of 0840 with the Darwin Tower. The aircraft was subsequently located at Katherine Gorge. The pilot had apparently returned to the departure point due to poor weather, but had failed to advise ATC.

Occurrence 370

The pilot contacted air traffic services and requested assistance to track to Jandakot via Woodman Point. He advised that he was clear of cloud but would enter cloud on his present track and altitude. A combination of radar vectors and visual navigation by the pilot kept him clear of cloud and enabled him to identify Jandakot airfield. He landed successfully.

3 RESULTS

The current study compares the three weather-related behaviour groups on a range of variables and contrasts the results with those obtained in previous outcome-based studies. Quantitative analyses comparing the three groups were carried out in the following areas:

- occurrence outcome
- pilot demographics
- operational factors
- aircraft characteristics
- geographical and environmental factors
- absolute and relative flight distances.

The results of these analyses are detailed below.

3.1 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.

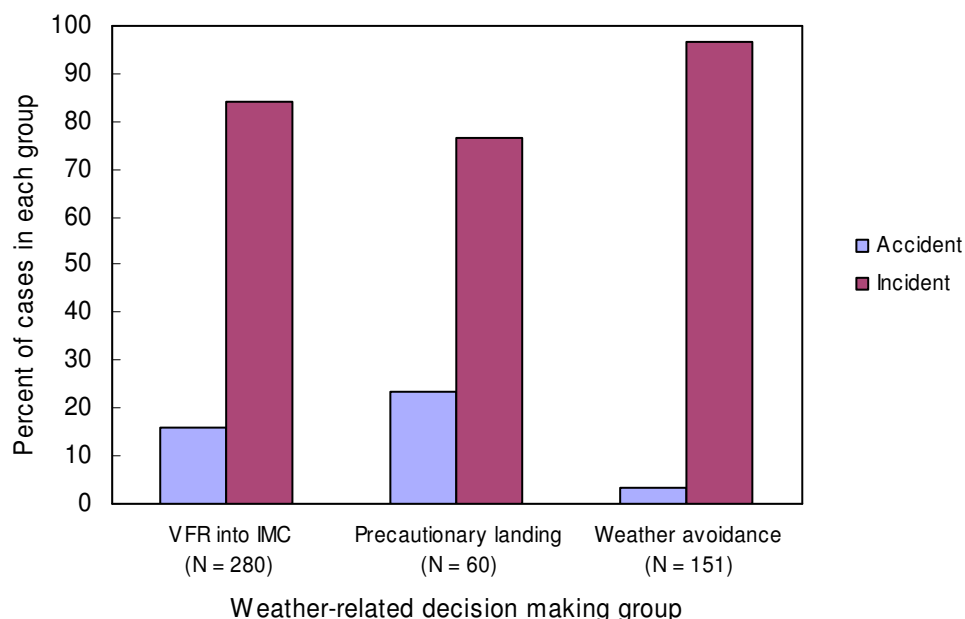
3.1.1 Accident or incident

Overall, 13% of the occurrences in the weather-related decision making dataset involved accidents, and 87% involved incidents (see Figure 6). 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 flight⁶.

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 ($\chi^2(2) = 20.49$, $p = 0.000$).

⁶ Definitions of the terms accident and incident are given in ICAO Annex 13, *Aircraft Accident and Incident Investigation*, Chapter 1, and in the Australian *Transport Safety Investigation Act 2003*, Section 3.

Figure 6. Percentage of accidents and incidents in each weather-related decision making group



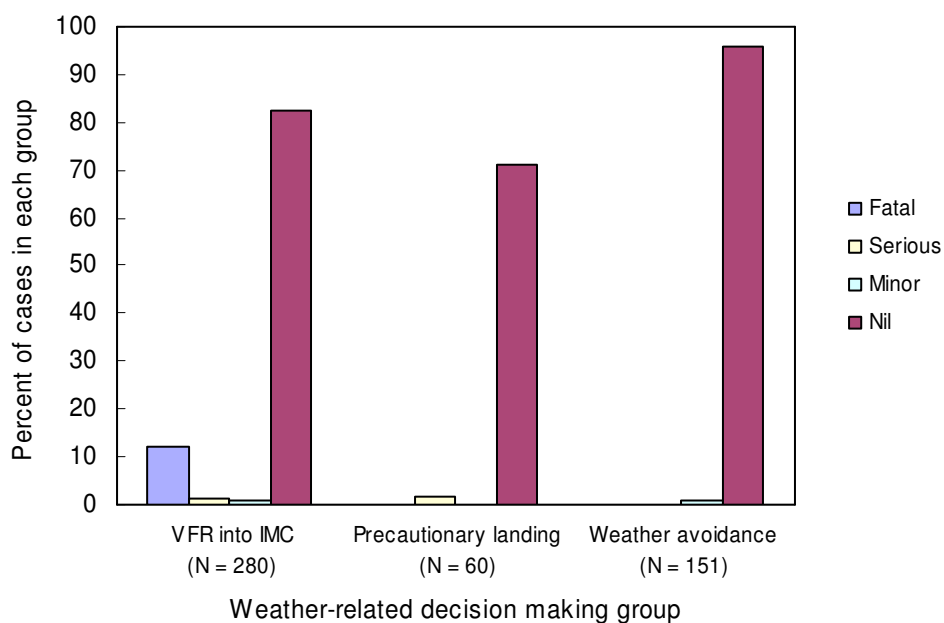
The highest proportion of accidents (23.3%) occurred within the precautionary landing group, followed by the VFR into IMC group (16.1% accidents), and the weather avoidance group (3.3% accidents).

One aspect to be considered is whether the greater proportion of accidents in the precautionary landing group simply reflects a reporting bias where non-accident precautionary landings are less likely to be reported to the ATSB. However, militating against this explanation is the fact that over three quarters (76.7%) of the precautionary landing occurrences in the dataset were incidents, and not accidents (see Figure 7). Hence, there is evidence that the reporting of precautionary landing occurrences does not overly depend on the nature of the outcome.

3.1.2 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 ($\chi^2(6) = 30.6$, $p = 0.000$), as shown in Figure 7.

Figure 7. Degree of severity of injury to pilot or passengers for each weather-related decision making group



Almost all injuries to pilots and 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.

Figure 8. Wreckage of a light aircraft VFR into IMC accident



The very serious nature of VFR into IMC accidents⁷ 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.

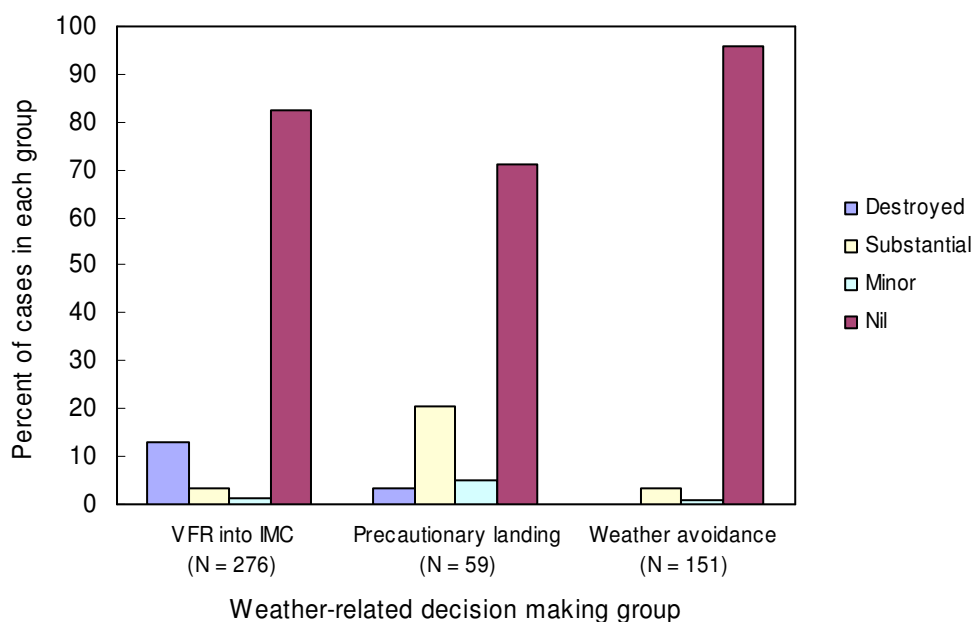
3.1.3 Aircraft damage

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 among the three weather-related decision making groups in terms of the degree of damage that the aircraft sustained as a result of the occurrence ($\chi^2(6) = 61.1$, $p = 0.000$), as shown in Figure 9.

⁷ These statistics relate to accidents only, while all other statistics are for accidents and incidents.

Figure 9. Degree of aircraft damage for each weather-related decision making group



Two main findings were apparent in relation to the aircraft damage data. Firstly, for the cases in the sample, 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%).

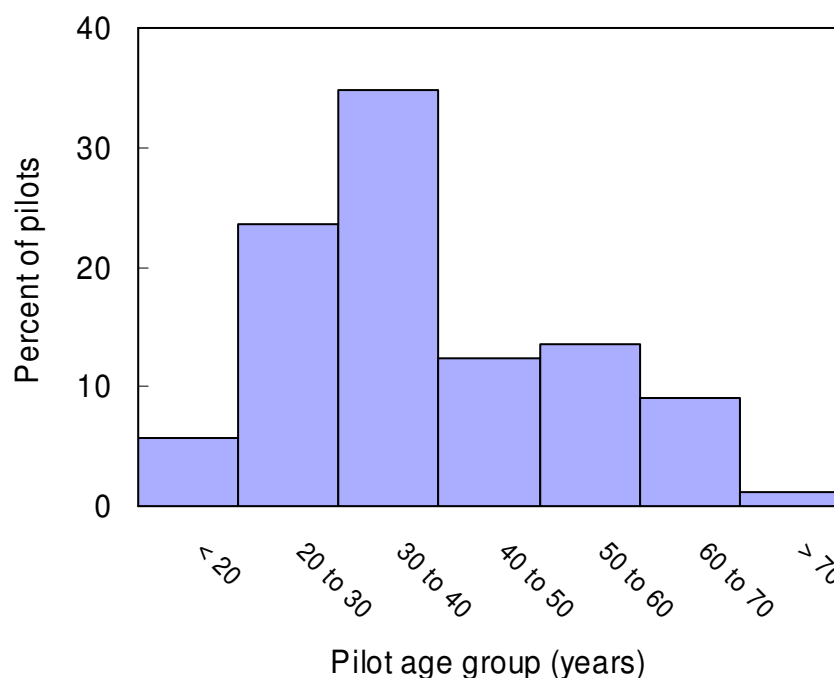
Secondly, where damage did occur, the likely severity of the damage was greatest in the VFR into IMC group (13.0% destroyed), followed by the precautionary landing group (20.3% substantial damage), and lastly the weather avoidance group (3.3% substantial damage).

3.2 Pilot demographics

3.2.1 Age

The age of the pilot was recorded in the ATSB occurrence 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 10.

Figure 10. Age distribution of pilots for all weather-related decision making groups



The age of pilots within the three weather-related decision making groups did not differ significantly ($F(2,86) = 1.04$, $p = 0.358$).

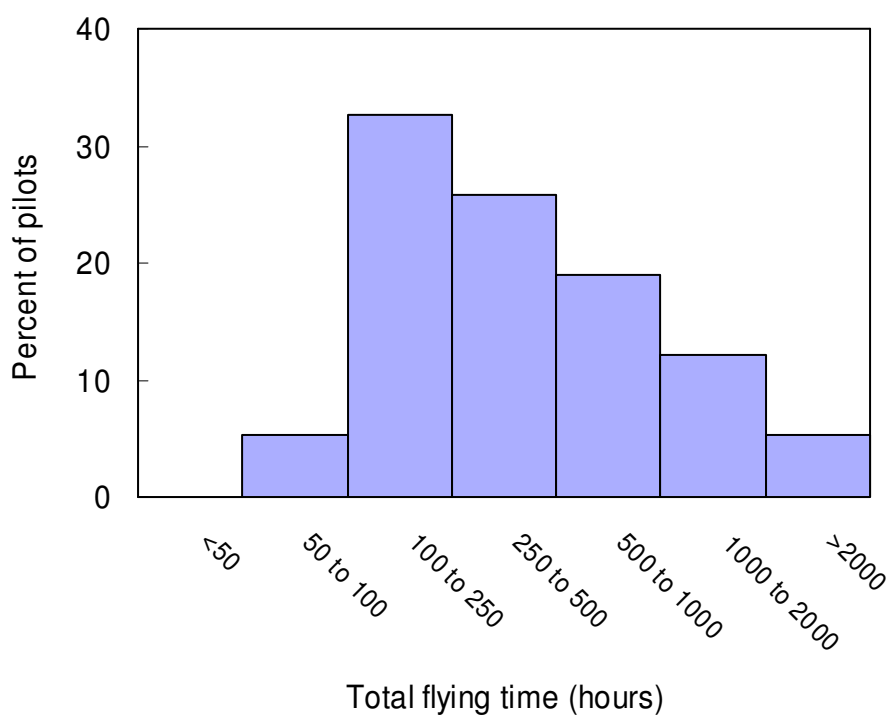
3.2.2 Flying experience

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).

3.2.3 Total flying time

The total number of hours flown by the pilot was recorded for a total of 132 cases in the dataset (see Figure 11). Total flying time ranged from 53 to 19,400 hours (mean $776 \pm 1,860$ SD⁸).

Figure 11. Total flying time for pilots in all weather-related decision making groups



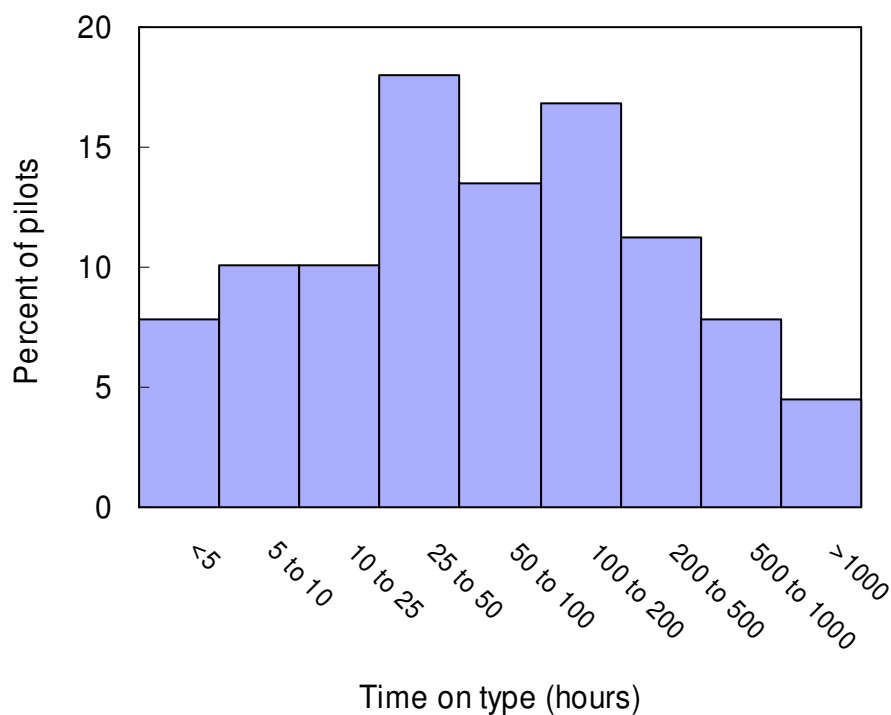
There were no significant differences among the three weather-related decision making groups in terms of the pilot's total flying hours ($F(2,129) = 0.182$, $p = 0.834$).

⁸ Standard Deviation, see Shavelson (1996).

3.2.4 Time on type

The total number of hours flown by the pilot on the make and model of aircraft involved in the occurrence was recorded for a total of 89 cases in the dataset (see Figure 12). Time on type ranged from 1 to 1,625 hours (Mean 198 ± 312 SD).

Figure 12. Time on type for pilots in all weather-related decision making groups

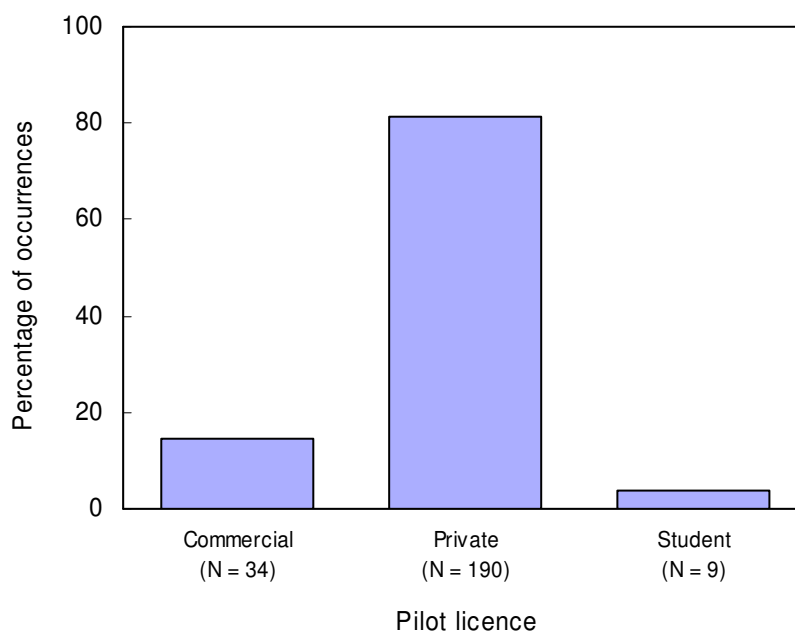


There were no significant differences among the three weather-related decision making groups in terms of the pilot's time on type ($F(2,86) = 0.068$, $p = 0.934$).

3.2.5 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 among the three weather-related decision making groups ($\chi^2(8) = 5.19$, $p = 0.737$). The overall proportion of licence holders in each category is shown in Figure 13.

Figure 13. Pilot licence type for all decision making groups

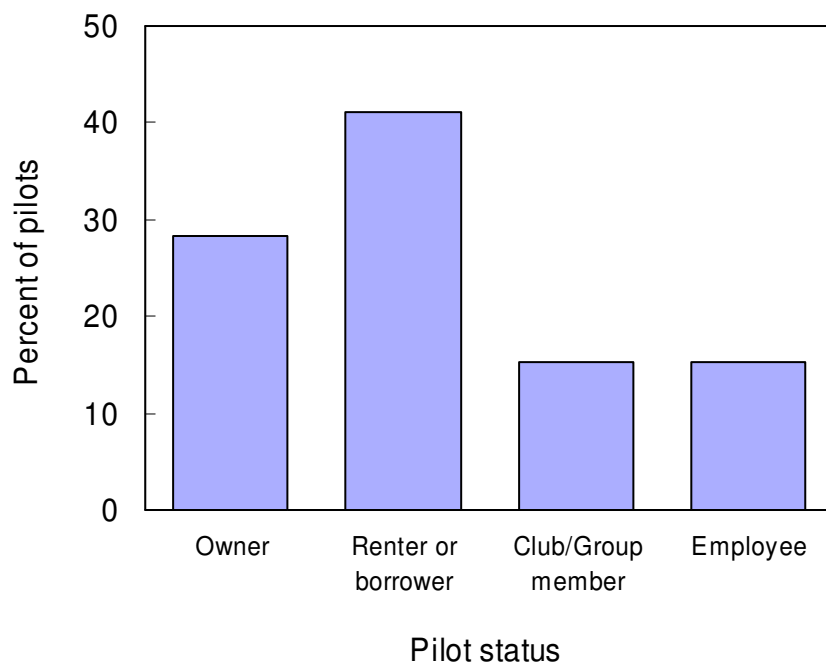


The majority of pilots held a private pilot's licence (81.5%). A commercial pilot's licence was held by 14.6% of pilots, and a student pilot's licence by 3.8%.

3.2.6 Pilot ownership status

Pilot ownership status was recorded in a total of 85 cases. The majority of pilots (72%) did not own the aircraft they were flying at the time of the occurrence (see Figure 14).

Figure 14. Pilot ownership status for all decision making groups



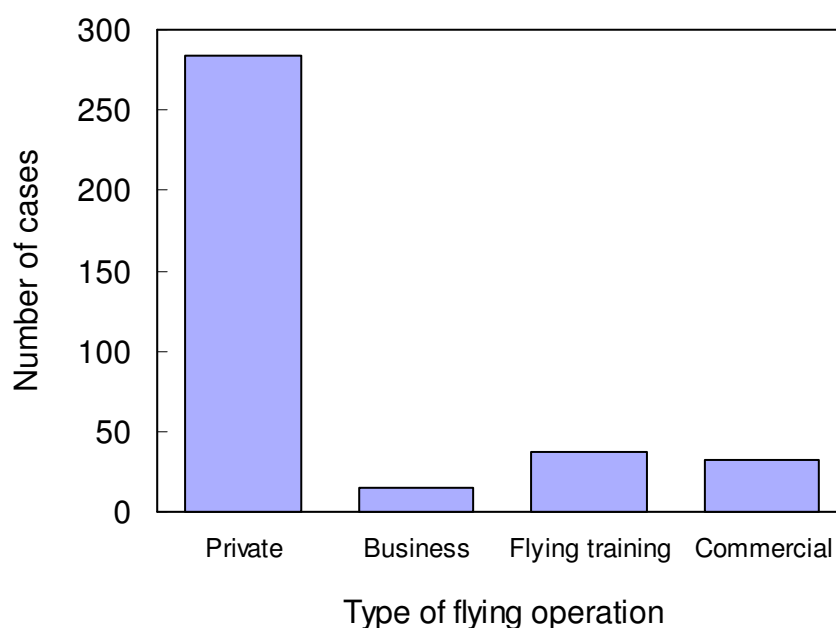
There was no significant difference among the three weather-related decision making groups in terms of pilot ownership status ($\chi^2(6) = 6.58$, $p = 0.362$).

3.3 Operational factors

3.3.1 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 small proportions of business flights (4.1%), flying training flights (10.1%), and commercial operations (8.7%). The commercial operations consisted primarily of charter flights.

Figure 15. Type of flying operation for all decision making groups

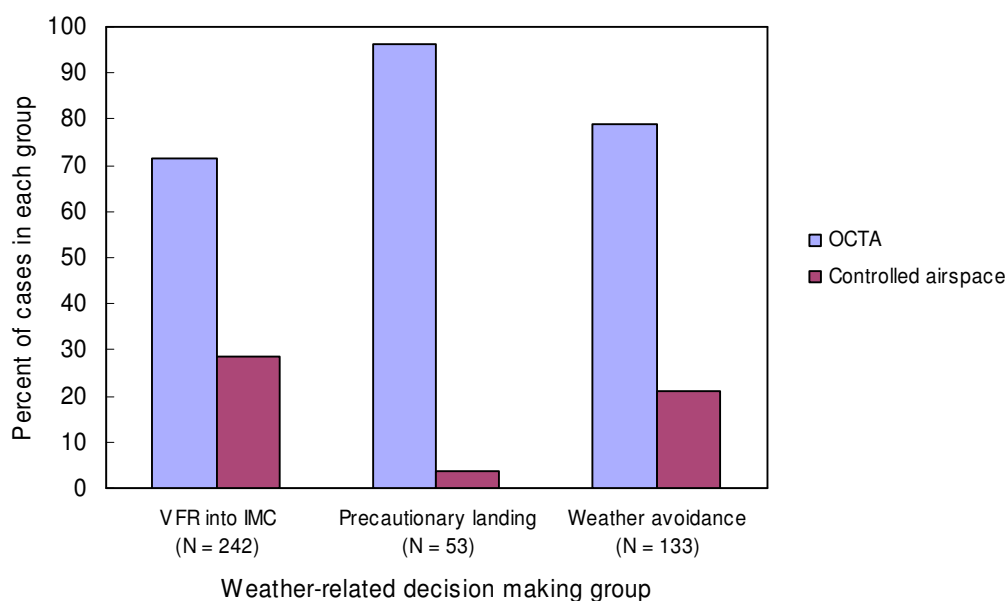


There were no significant differences among the three weather-related decision making groups in terms of flying operation type ($\chi^2(10) = 6.72$, $p = 0.752$). The overall distribution of operation types is shown in Figure 15.

3.3.2 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 16. 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 16. There was a significant difference among the three groups in this regard ($\chi^2(2) = 15.43$, $p = 0.000$). Almost all (96%) of precautionary landings took place outside controlled airspace. In comparison, 79% of weather avoidance occurrences, and 71% of VFR into IMC occurrences took place outside controlled airspace.

3.4 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 pilots to 'stay ahead of the aircraft'. That is, because pilots have 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 propeller⁹.

The following aircraft type characteristics were analysed to determine if there were any significant differences among the three weather-related decision making groups:

- maximum certificated takeoff weight (MTOW)
- number of engines
- type of landing gear
- type of propeller.

3.4.1 Maximum certificated takeoff weight

Aircraft maximum certificated takeoff weight data were available for 488 cases. Typical aircraft types within each maximum takeoff weight range are shown in Table 1¹⁰.

9 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)).

10 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 dataset.

Table 1. Typical aircraft types in maximum certificated takeoff weight ranges

MTOW range	N ^a	Examples of aircraft types in MTOW range	Typical aircraft characteristics ^b
500 to 1000 Kg	51	Cessna C150 Victa Airtourer	2 seat, 90-110 HP, 80-95 kts
1000 to 1250 Kg	202	Cessna 172 Skyhawk Piper PA-28 Cherokee	4 seat, 140-180 HP, 90-120 kts
1250 to 1500 Kg	85	Cessna 182 Skylane Piper PA-24 Comanche Mooney M20	4 seat, 230-280 HP, 125-160 kts
1500 to 1750 Kg	102	Cessna 210 Centurion Piper PA-44 Seminole Beech 36 Bonanza	4-6 seat, 260-300 HP (single) or 2 x 160-180 HP (twin), 150-180 kts
1750 to 2000 Kg	13	Beech 76 Duchess Piper PA-30 Twin Comanche	4-6 seat, 2 x 180-200 HP, 150-180 kts
2000 to 2500 Kg	23	Beech 58 Baron Piper PA-34 Seneca Cessna 310	6 seat, 2 x 220-300 HP, 170-190 kts
above 2500 Kg	10	Cessna 402 Piper PA-31 Navajo	6-8 seat, 2 x 300-350 HP, 170-210 kts.

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.

The type of weather-related decision making behaviours observed did not vary significantly for operations involving aircraft types of different maximum takeoff weights ($F(2,483) = 1.762, p = 0.173$).

3.4.2 Number of engines

The majority of the aircraft (89%) in the weather-related occurrence dataset were single-engine. The remaining aircraft were twin-engine. There was no significant difference among the three weather-related decision making groups in terms of whether the aircraft in question was single-engine or twin-engine ($\chi^2(2) = 4.43, p = 0.109$).

3.4.3 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 among the three weather-related decision making groups in terms of aircraft landing gear type ($\chi^2(2) = 3.28, p = 0.194$).

3.4.4 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 among the three weather-related decision making groups in terms of propeller type ($\chi^2(2) = 3.49$, $p = 0.175$).

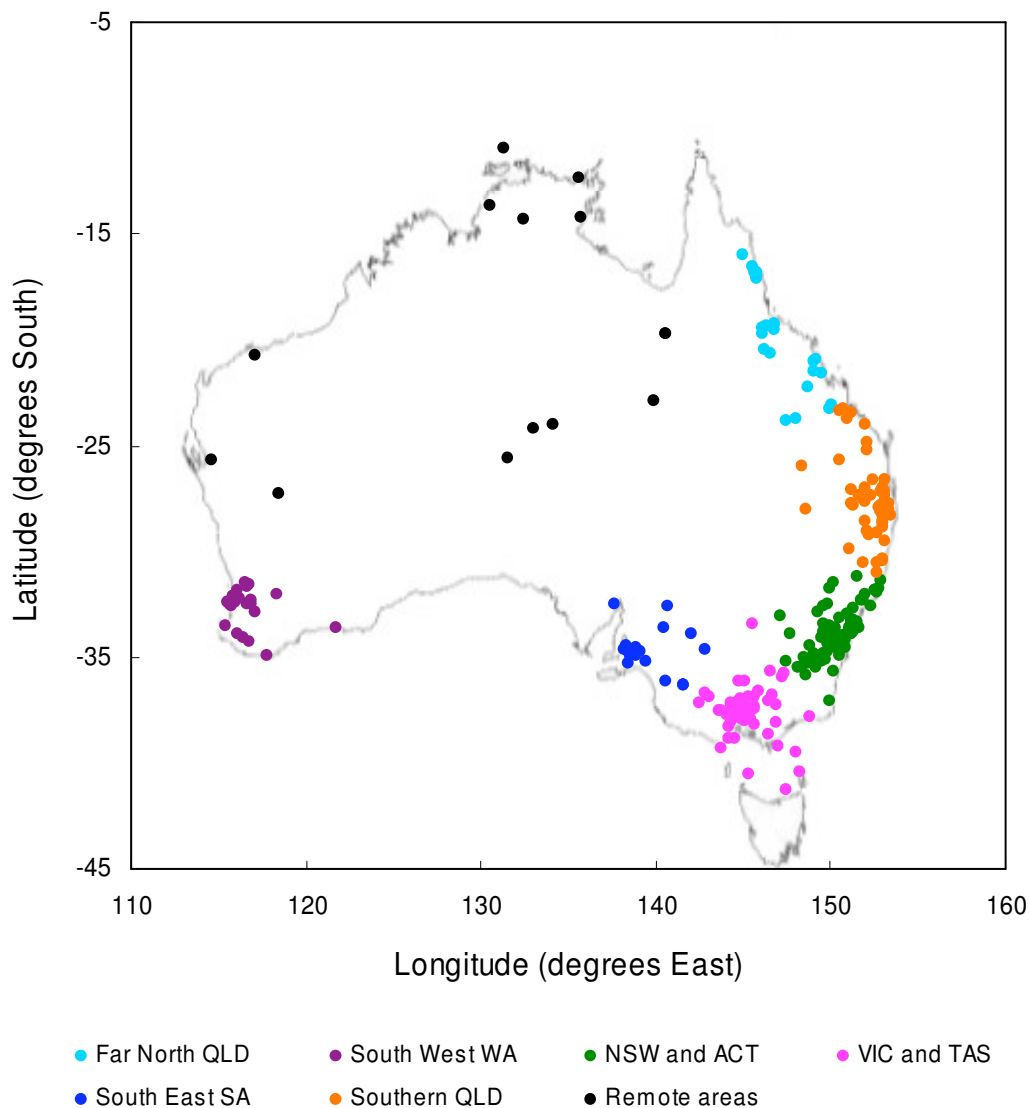
3.5 Geographical and environmental factors

3.5.1 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 on 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. Statistical clustering (SPSS 11.5 KMeans) was employed to classify the cases into seven groups. However, four of the geographical groups in remote areas of Australia included only a small number of cases (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 17.

Figure 17. Geographical location of weather-related decision making occurrences in all groups



The number of cases within each geographical area is shown in Table 2. 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 2. Approximate geographical areas for all weather-related decision making occurrences

Approximate geographical area^a	N^b	Percent^c
NSW and ACT, including Sydney, Canberra, Wagga Wagga, Goulburn	75	26.1
VIC and TAS, including Melbourne, Ballarat, Echuca, King Island, Wynyard	70	24.4
Southern QLD, including Brisbane, Coolangatta, Maroochydore	50	17.4
South West WA, including Perth, Albany, Bunbury	28	9.8
Far North QLD, including Townsville, Cairns, Mackay, Rockhampton	26	9.1
South East SA, including Adelaide, Port Augusta	24	8.4
Remote areas, including NT, remote WA, and inland Australia	14	4.9

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.
 (c) Percentages do not add to 100 due to rounding.

There was no significant difference in the types of weather-related decisions made in each of the geographical areas ($\chi^2(12) = 12.32$, $p = 0.420$).

3.5.2 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 a 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 grazer 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.

Figure 18. Fatal VFR into IMC accident site



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 a distinction that may be useful when comparing different aspects of pilots' flying behaviour, such as the weather-related decision making comparisons in this 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.

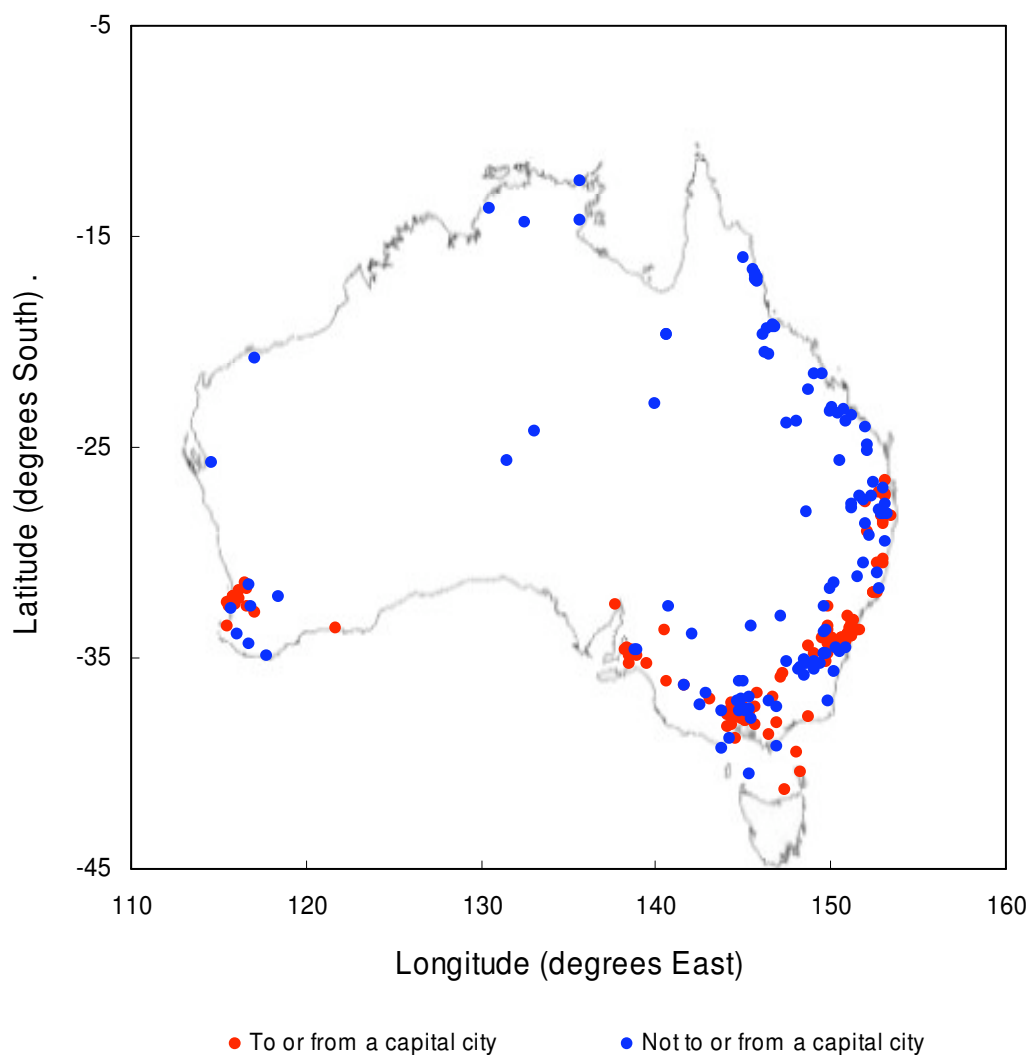
For the purposes of this study, an occurrence was coded as being either a 'city flight' or a 'country flight' depending on whether either one, or both, of the point of departure or intended destination was a State capital city¹¹. While this categorisation will not be appropriate in all cases – for example, 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 distribution¹².

Figure 19 shows the overall distribution of flights to or from a State capital city for occurrences in all three decision making groups.

11 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).

12 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.

Figure 19. Distribution of city flights and country flights for occurrences in all groups



Overall, occurrences in the weather-related decision making dataset were approximately equally divided between ‘city flying’ and country flying’ (see Table 3).

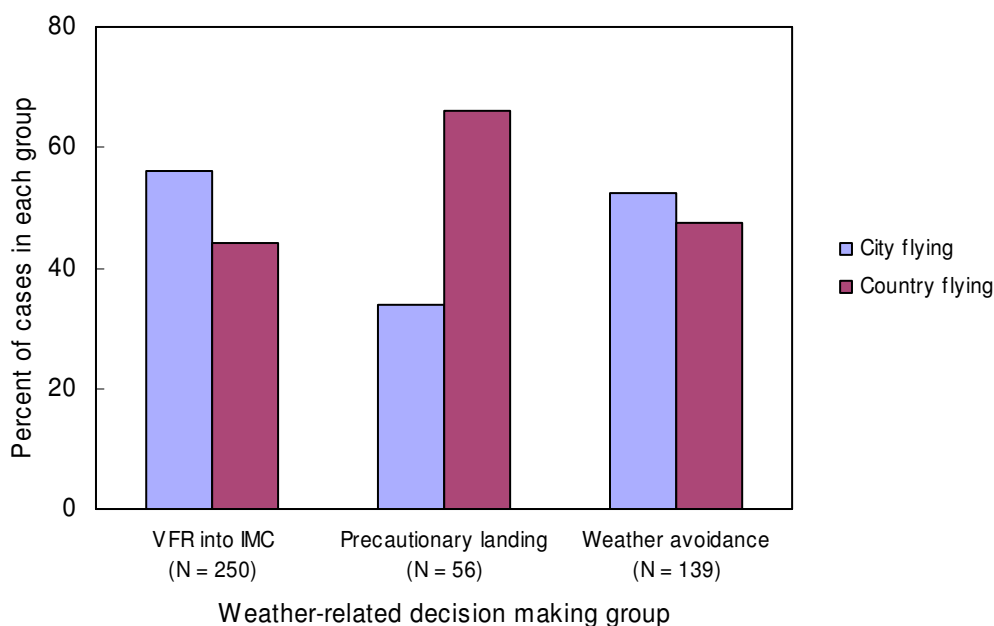
Table 3. Proportion of all occurrences that were city flights or country flights

Flying environment	N	Percent
City	232	52.1%
Country	213	47.9%
Total	445	100%

There were significant differences among the three weather-related decision making groups in relation to city flying or country flying ($\chi^2(2) = 8.943$, $p = 0.011$). 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 with the city flying group (34%) (see Figure 20).

Figure 20. Proportion of occurrences for city versus country flying by decision making group



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 ($\chi^2(1) = 2.13$, $p = 0.145$). 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 SEM¹³) 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.

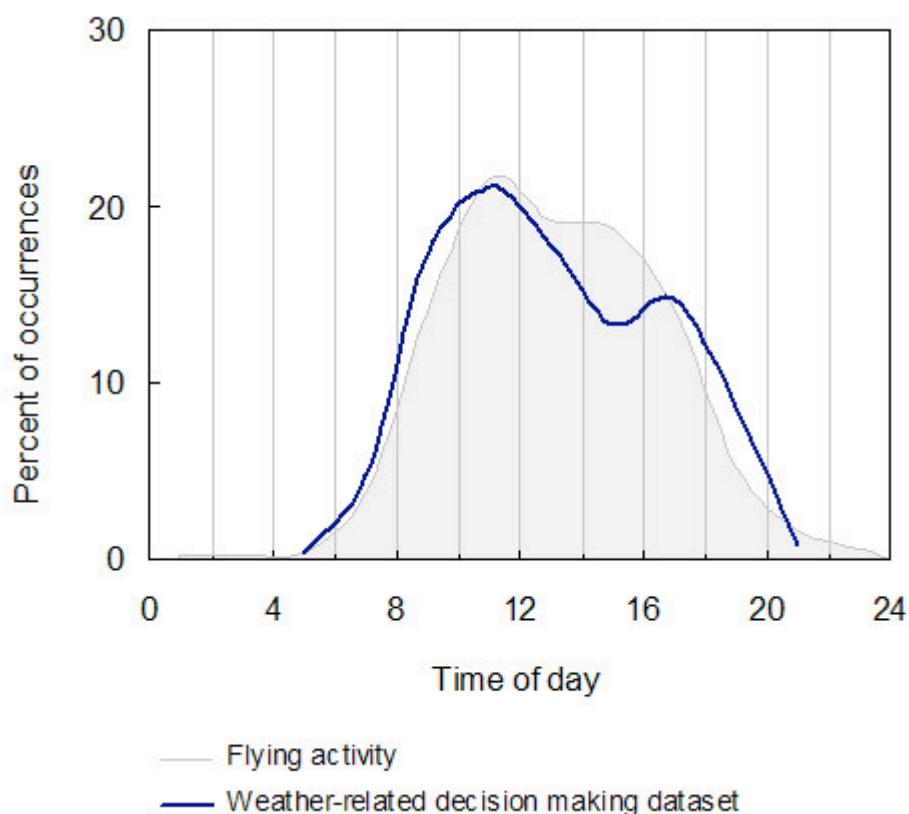
3.5.3 Time of day of occurrence

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 21, compared with the

¹³ Standard Error of the Mean, see Shavelson (1996).

distribution of all occurrence times for similar flying activity during the day¹⁴ (shaded area). The two distributions are similar, except that the weather-related decision making dataset shows a smaller proportion of occurrences during the period from approximately 2 pm to 4 pm.

Figure 21. Distribution of local time (24 hr) of occurrences in comparison to flying activity



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 HSD¹⁵) indicated that the only significant pairwise comparison was that between the VFR into IMC and weather avoidance groups ($p = 0.022$).

¹⁴ 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.

¹⁵ Honestly Significant Difference, see Shavelson (1996).

Table 4. Statistics for time of day (24 hr) of weather-related decision making occurrences¹⁶

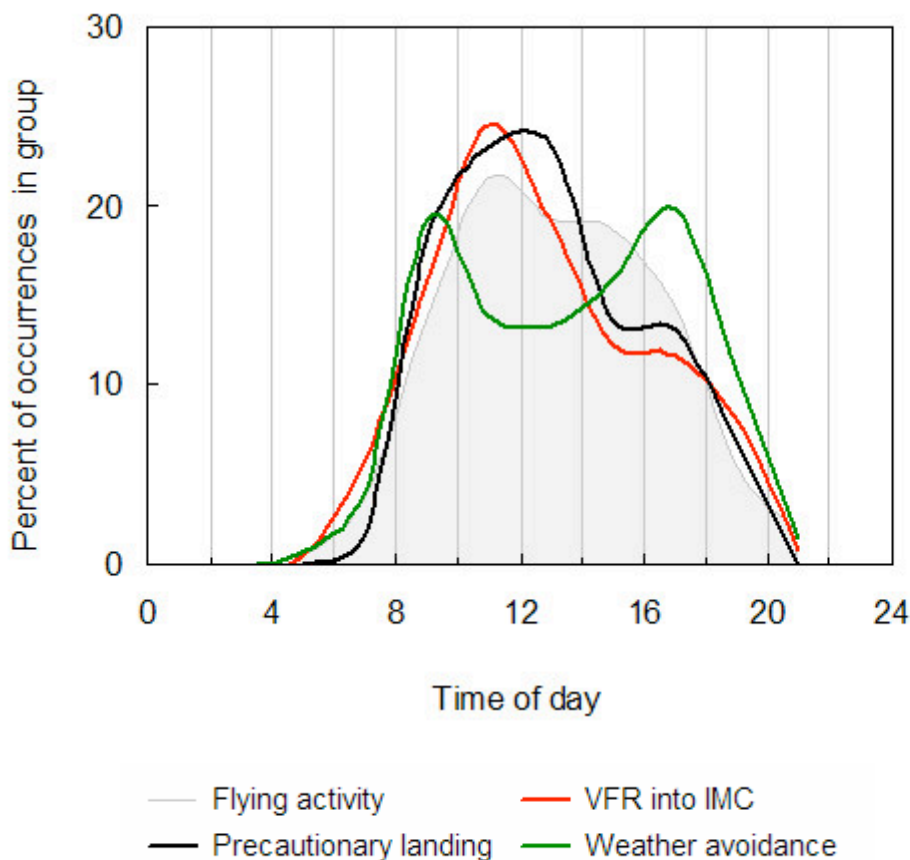
Group	N	Mean	SEM[†]	Median
VFR into IMC	277	12:43	00:13	12:13
Precautionary landing	60	12:44	00:23	12:25
Weather avoidance	151	13:40	00:19	13:52
All groups	488	13:01	00:10	12:30

[†] Standard Error of the Mean (see Shavelson, 1996).

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 22). 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.

¹⁶ All calculations were done using decimal hour values. Times are reported as 24 hour 'hrs:min' values for convenience.

Figure 22. Distribution of occurrences by local time of day for each decision making group



Hence, there was 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 peaked at approximately 11 am, and that for precautionary landings at about noon.

3.6 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'¹⁷ flight distances. For example, are certain pilot behaviours more evident on shorter flights compared with longer flights, or will there be an increasing propensity for pilots to 'press on' into deteriorating weather as they approach their destination?

The ATSB occurrence database 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

¹⁷ The term 'relative' flight distance refers to measures such as the proportion of the total planned flight distance completed at the point that the accident or incident occurred.

the Geoscience Australia *Gazetteer of Australia 2002* (<http://www.ga.gov.au>) compilation of Australian geographic names.

3.6.1 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 suggests that it is a reasonable assumption for many of the general aviation type flights typical of this study. Importantly, there is no prior 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, (lat1, long1) and (lat2, long2), is given by,

$$D \text{ (km)} = 1.852 * 60 * \text{Arcos}(\text{Sin}(\text{lat1}) * \text{Sin}(\text{lat2}) + \text{Cos}(\text{lat1}) * \text{Cos}(\text{lat2}) * \text{Cos}(\text{long2} - \text{long1}))$$

3.6.2 Absolute flight distances

The following absolute distances (in kilometres) were calculated for the purposes of this study:

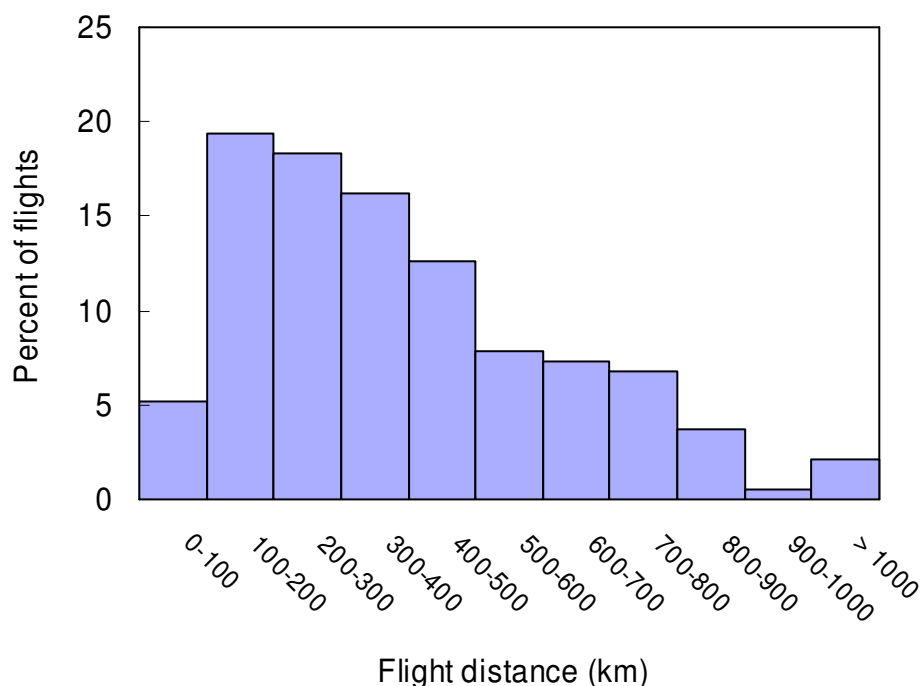
- total planned flight distance from point of departure to planned destination
- distance from point of departure to point of the occurrence
- distance from point of occurrence to planned destination.

3.6.3 Total planned flight distance

The total planned flight distance 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 for all occurrences in the dataset is shown in Figure 23. The mean flight distance was approximately 400 km, and the median flight distance was approximately 350 km¹⁸.

18 Approximate flight distance estimates for all private general aviation flights based on data from the Australian Government AVSTATS 2002 flying activity survey (Bureau of Transport and Regional Economics, 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 include circuit training and training area flights, as well as cross-country flights.

Figure 23. Frequency distribution of total flight planned distances for all flights



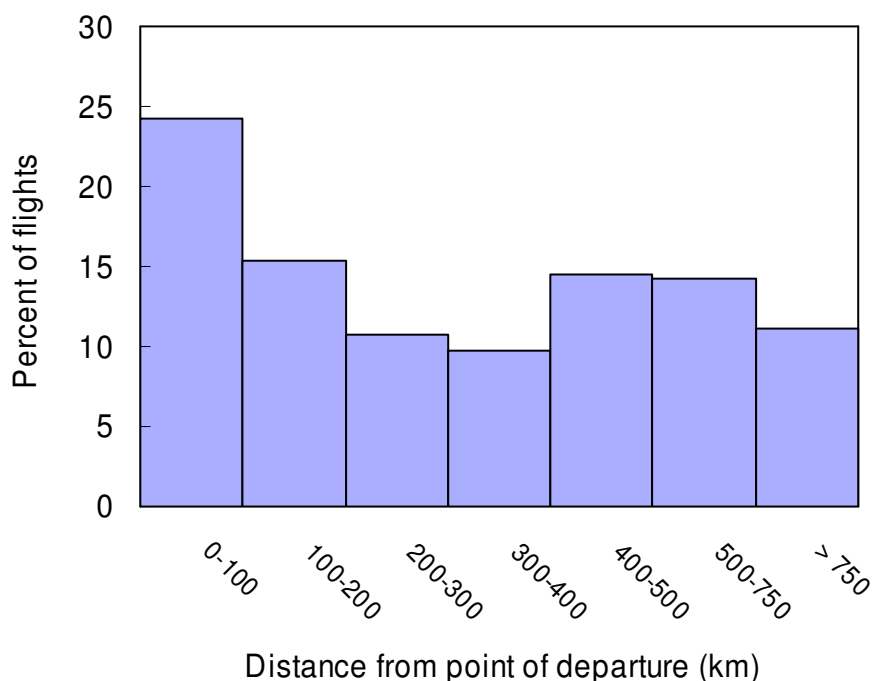
There was no significant difference among the three weather-related decision making groups with respect to flight distance ($F(2,188) = 1.512$, $p = 0.223$). Hence, there is no evidence that the length of the planned flight had any differential influence on pilots' weather-related decision making behaviour.

3.6.4 Distance from point of departure

The distance from the point of departure at which the occurrence took place ranged from 0 to over 1,000 kilometres (one case). The median distance was 138 km and the mean distance 205 km.

Figure 24 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 fewer flights of longer distances. That is, it would predominantly reflect the underlying frequency distribution of flight distances shown in Figure 23, rather than any relationship between weather occurrences and distance from point of departure.

Figure 24. Distance from point of departure to occurrence location for all occurrences



Although Figure 24 suggests a somewhat greater representation of occurrences in the 0-100 km distance group, the overall variation across distance groups was not significant ($\chi^2(6) = 10.02$, $p=0.124$).

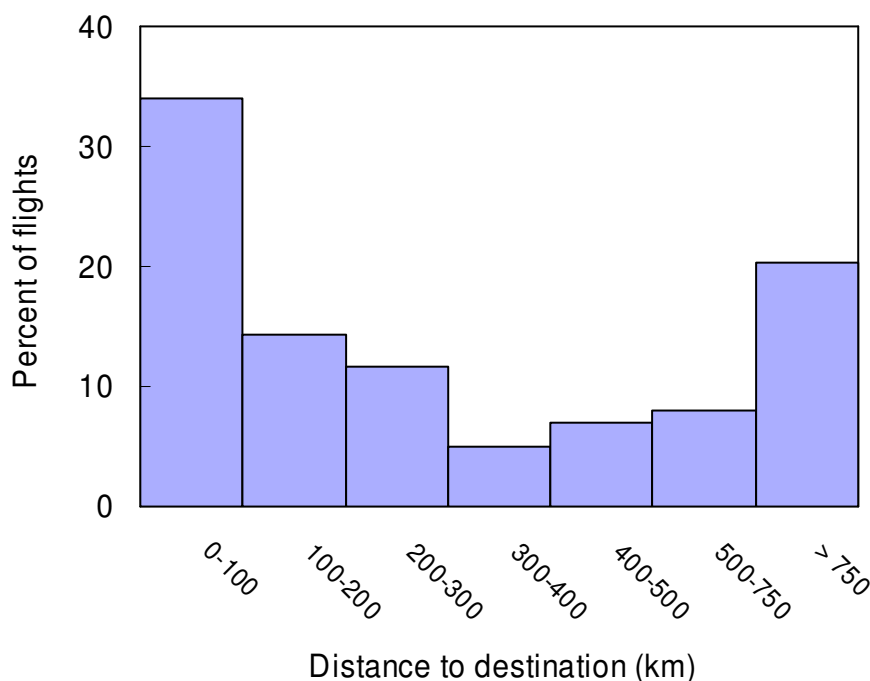
A comparison of the three weather-related decision making groups in relation to the distance from the point of departure to the occurrence location did not indicate any significant difference among the three groups ($F(2,201) = 1.415$, $p = 0.245$).

3.6.5 Distance to planned destination

The distance from the planned destination at which the accident or incident occurred ranged from 0 to over 1,000 kilometres (2 cases). The median distance was 96 km and the mean distance 168 km.

Figure 25 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 23).

Figure 25. Distance from occurrence location to planned destination for all occurrences



The overall variation across ‘distance to destination’ groups was significant ($\chi^2(6) = 42.65$, $p = 0.000$). As shown in Figure 25, 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.

A comparison of the three weather-related decision making groups (VFR into IMC, precautionary landing, and weather avoidance) in relation to the distance from the occurrence location to the planned destination showed a significant difference among 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. However, post hoc tests (Tukey’s HSD) did not produce significant pairwise comparisons at the 5% level, the highest level achieved being that between the weather avoidance and precautionary landing groups ($p = 0.061$).

The median distance values for the VFR into IMC and precautionary landing groups were similar, in contrast to the median for the weather avoidance 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.

3.6.6 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 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 thoughts 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 destination.

The following relative distance measures were considered in this study:

- whether the occurrence took place before or after the mid-point of the flight
- the proportion of the planned flight distance completed at the point of occurrence.

3.6.7 Point of occurrence before or after the mid-point of the flight

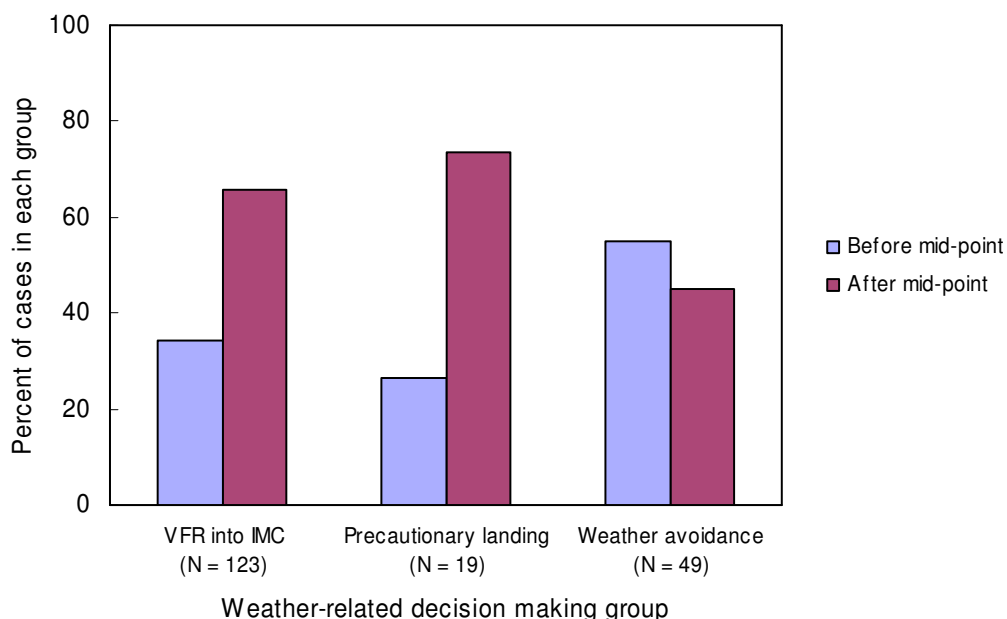
An analysis was carried out to investigate whether pilots' weather-related behaviour varied significantly before or after the psychological 'half-way' point of their planned flight.

Table 5. Proportion of all occurrences before and after mid-point of flight

Location of occurrence	N	Percent
Before mid-point of flight	74	38.7%
After mid-point of flight	117	61.3%
Total	191	100%

Overall, the majority of occurrences (approximately 61%) occurred during the second half of the flight (see Table 5). This result was statistically significant ($\chi^2(1) = 9.68$, $p = 0.002$).

Figure 26. Proportion of occurrences before and after mid-point of flight by decision making group



There were significant differences among the three weather-related decision making groups in terms of the occurrence location before or after the mid-point of the planned flight ($\chi^2(2) = 7.86$, $p = 0.020$). 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 26).

3.6.8 Proportion of planned flight completed at point of occurrence

The proportion of the flight distance that had been completed at the point of the occurrence ranged across the full spectrum, from 0% to 100% of the planned flight distance. There were less than expected occurrences across the range 20% to 40%, and a greater than expected proportion of occurrences during the second half of the flight (see Figure 27, top left panel), as indicated by the ‘before or after halfway’ results described above.

A comparison of the three weather-related decision making groups in relation to the percent of flight distance completed at point of occurrence indicated a significant difference among the three groups ($F(2,188) = 6.133$, $p = 0.003$). The same pattern of results was also shown for median values (see Table 6).

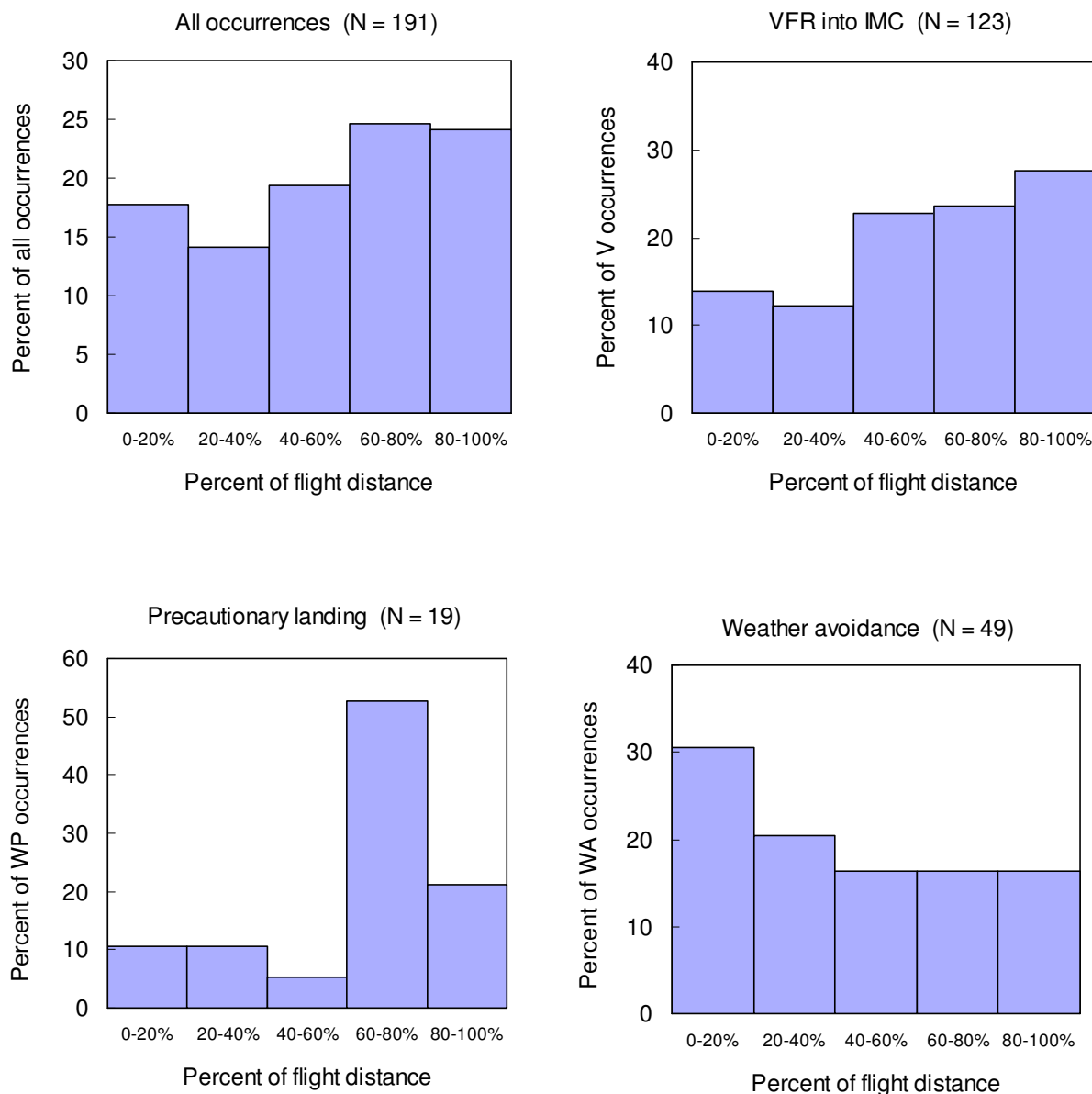
Table 6. Statistics for percent of flight distance completed at point of occurrence

Group	N	Mean	SEM	Median
VFR into IMC	123	57.6%	2.60%	60.8%
Precautionary landing	19	63.8%	6.62%	71.4%
Weather avoidance	49	42.2%	4.12%	39.9%
All groups	191	54.3%	2.74%	59.8%

Post hoc tests (Tukey's HSD) indicated a significant difference between the weather avoidance group and the other two groups. 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 27 shows in detail how pilot flying behaviour varied as a function of the proportion of planned flight distance completed. The pattern for each of the three weather-related decision making groups was very 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 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 27. Percent of flight distance completed at point of occurrence by decision making group



The distribution of precautionary landing occurrences across the flight profile was very distinct (Figure 27, 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 from 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.

4 DISCUSSION

4.1 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, 1989; 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, 1989).

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).

Figure 28. Fatal VFR into IMC accident site



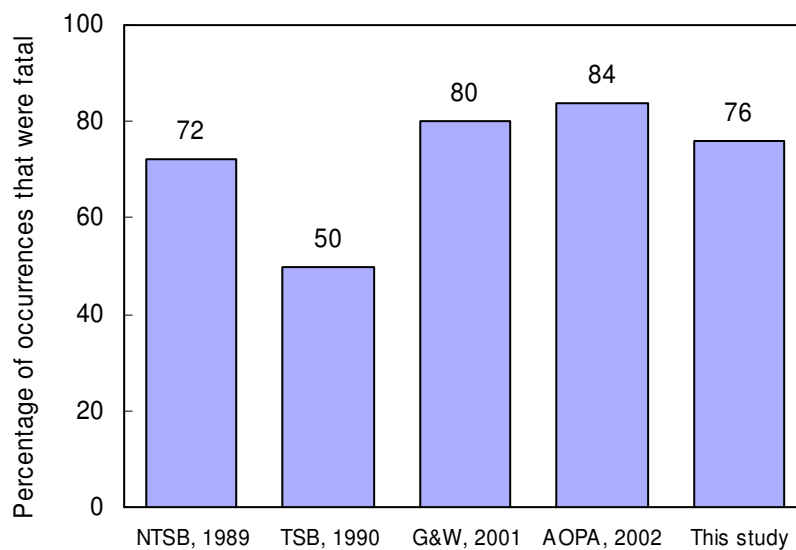
More recent US statistics include a study by Goh and Wiegmann (2001) that reports an average VFR into IMC fatality rate of approximately 80% for the period 1990 to 1997. The 2002 Nall Report¹⁹ (AOPA, 2002) indicates that VFR flight into IMC continues to be the

¹⁹ 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.

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, 75.6% 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 29 compares the fatal accident rate for VFR into IMC accidents found in previous studies with the results found in the current study.

Figure 29. 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 forms 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 (28.8%) is actually higher than that for VFR into IMC occurrences (17.4%). 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.

4.2 Comparison of results with previous 'outcome' based studies

In contrast to previous 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 groups in terms of the type of flying operation or aircraft characteristics. 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 knots²⁰. 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 pilots had an adequate opportunity to appraise the immediate weather situation and decide on an appropriate course of action.

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.

²⁰ Knots = nautical miles per hour.

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 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.

4.3 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.

4.3.1 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.

4.3.2 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.

Figure 30. Cloud formation near Albury, NSW



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.

4.4 A safe pilot is a proactive pilot

Comparison of the three weather-related behaviour groups highlights that in-flight decision making can best be characterised as a dynamic, ongoing process. One particular weather avoidance occurrence from the dataset 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.

5 CONCLUSIONS

Based on 491 ATSB occurrence reports, this study compared three groups of general aviation pilots who exhibited different weather-related decision making behaviours, namely:

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

The findings of this research can be summarised in the following points:

- The results confirm previous findings of the significant dangers associated with VFR flight into IMC.
- The VFR into IMC group had the greatest risk of a fatality or serious injury, while the precautionary landing group had the greatest risk of some form of aircraft damage. Taken together, these results may help to explain the genesis of some VFR into IMC occurrences.
- In contrast to previous studies based on flight outcome (e.g. accident or non-accident), no significant differences were found among the three weather-related behaviour groups on the basis of pilot demographics.
- There were no significant differences among the three groups in terms of the geographical location of the occurrence, despite the large variations in terrain and weather environment across the Australian continent.
- Pilots' thoughts and actions appear to have become more focussed on weather-related aspects of their flight once they had passed the mid-point of their journey. Hence, psychological aspects rather than specific operational considerations seem to be the primary influence on pilots' decision making in these situations.
- The weather avoidance group was distinguished from the other two groups in taking action in a more timely manner.
- The chances of a VFR into IMC encounter increased as the flight progressed until they reached a maximum during the final 20% of the flight distance. This result highlights the danger of pilots 'pressing on' to reach their destination.
- In-flight decision making can best be characterised as a dynamic, ongoing process, rather than a static one-off decision.
- A safe pilot is a proactive pilot.

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