Continued VFR into IMC: An Empirical Investigation of the Possible Causes

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INTRODUCTION

For many years, crashes involving visual flight rules (VFR) flight into instrument meteorological conditions (IMC) have been one of the most serious problems in general aviation. A recent report by the U.S. National Transportation Safety Board (NTSB, 1989) shows that although 'VFR into IMC' crashes are a relatively small proportion of the total number of GA crashes (4%), they account for 19% of the GA fatalities. In fact, 72% of 'VFR into IMC' crashes are fatal, compared to an overall figure of 17%.

Whilst the overall GA crash rate has been trending downwards in the United States over the past decade (NTSB, 1989), this has not been the case in other countries such as the U.K. or New Zealand. Even in the U.S., the decline in 'VFR into IMC' crash rates has been much less than the decline in overall GA rates. There is little doubt that human judgment and decision making are critical elements of these crashes.

Jensen & Benel (1977) analysed the NTSB records of GA crashes in the period 1970-1974, and found that whereas the majority of non-fatal crashes were associated with perceptual-motor activities (eg judgment of speed, distance, altitude etc), the majority of fatal crashes were associated with decisional processes (e.g. self assessment of skill, setting priorities, planning etc). In a recent analysis of nearly ten years fixed-wing aircrash data from New Zealand (O'Hare, Batt, Wiggins, & Morrison, 1994), the same pattern was evident, with decisional activities accounting for over 60% of the fatal crashes.

Aviation writers have advanced many explanations for why VFR pilots would risk "pressing on" into deteriorating weather conditions. The most unhelpful 'explanation' has been to replace one unknown ("pressing on") with another, such as "get-home-itis". Other factors mentioned include over-confidence, carelessness, and lack of awareness (e.g. Bramson, 1988). Some support for the role of over-confidence comes from the NTSB review cited above. NTSB investigators cited over-confidence as a factor in approximately 19% of the 364 'VFR into IMC' crashes during the 1983-86 period. Indirect evidence for the other factors may be reflected in failures to obtain weather briefings, failing to file a flight plan, inadequate pre-flight planning and so forth. Following a particularly poor year for GA safety (1987), the U.K. Civil Aviation Authority set up a Study Group to review the accident record. Their report (CAA, 1988) contains much speculation on the factors contributing to the increase in errors related to weather conditions. The authors conclude that psychological factors such as 'excessive optimism', 'reluctance to admit limited capability' and 'lack of appreciation of real dangers' were behind the errors of judgment and decision making which led to the crashes.

In summary, the GA crash record in different countries shows that 'VFR into IMC' flight continues to represent a major hazard. Speculation as to the causes of this problem has focussed on a wide variety of psychological factors such as over-confidence, lack of awareness, and risk-perception. The precise role of such factors remains highly speculative in the absence of well-designed empirical research. The ultimate aim of the proposed research is to develop intervention strategies which can be used to promote safer and more effective decision making in VFR cross-country flight. Such tools can only be effective, however, if they are based on a sound understanding of the behavioral and psychological mechanisms which govern decision making in VFR cross-country flight.

Continued VFR flight into IMC: Situational Awareness or Risky Decision Making?

The most important requirement is to develop an appropriate experimental technique using PC-based flight simulation software which will allow VFR rated pilots to make realistic in-flight weather-related decisions. It will be necessary to develop suitable flight scenarios which present pilots with various weather-related and aircraft systems events which present the opportunity for in-flight decision making. It will also be necessary to develop appropriate protocols and questionnaires to measure as wide a variety of situational assessment and response option measures as possible. The remainder of this section outlines the direction of the subsequent research based on the development of these procedures.

Once we have developed an appropriate laboratory paradigm utilising PC-based flight simulation and associated protocols and questionnaire measures, then we will be able to look at a broad range of factors which might affect decision making in these VFR cross-country scenarios. In the later parts of the research we would need to extend the investigations to the performance of pilots in more realistic flight simulators involving a higher level of task management and workload requirements.

Situational Awareness

In recent years there has been a flurry of research on situational awareness in pilots and air traffic controllers. In aviation, as in other complex dynamic systems, the operator's awareness of the current state of the system, and their expectations about the future state of the system are likely to have a significant impact on their overall level of performance. The 'VFR into IMC' event may be precipitated by loss of situational awareness due to tiredness, fatigue, workload or social pressures. Orasanu (1993, p. 22) has hypothesized that these events are more likely to "occur following schedule delays or at the end of long trips when the crew is eager to get home". She specifically suggests an underlying mechanism whereby ambiguous or discrepant information is subjectively 'normalized' or disregarded. Previous research on information processing failures in aviation accidents (O'Hare et al, 1994) has shown that errors early in the process (at the stage of diagnosing the problem, for example) are apt to have more serious consequences than errors made later in the process (e.g. handling errors).

We can investigate the differences in situational awareness which characterize problem solving early in a VFR cross country flight compared to solving the same problem later in flight. We can also compare the situational awareness of pilots who continue a flight into IMC compared to those who discontinue the flight at the same point. It should also be possible to investigate a range of specific hypotheses such as that suggested by Orasanu (1993). It would be desirable to utilize a range of problem situations including system anomalies as well as weather-related events.

Response Selection and Risk Management

A more traditional approach to pilot decision making has been to look at the processes by which pilots choose between various options. This is a reflection of the field of decision making in general which has developed normative (e.g. subjective expected utility theory) and descriptive (e.g. prospect theory) approaches to the choice amongst alternatives under uncertainty. The key elements in the normative approach are the end states which the decision maker believes will result from each course of action and the subjective probabilities of those outcomes occurring. A substantial body of research has demonstrated that actual decision making does not follow the prescriptive rules very closely.

More recently, Kahneman and Tversky (1979) have proposed that people view decisions in terms of gains or losses from a reference point rather than in terms of end states. They have developed a theory of decision making under uncertainty called Prospect Theory. An important implication of the theory is that "variations of the reference point can therefore determine whether a given outcome is evaluated as a gain or as a loss" (Tversky & Kahneman, 1981, p. 211). The implications of this for aeronautical decision making were explored by O'Hare and Smitheram (1995) who showed that decisions to continue a flight into uncertain conditions were less likely when the prospects were framed in terms of possible gains rather than as possible losses. In this study participants responded to static information about a hypothetical cross-country VFR flight.

Although recent meta-analyses (e.g. Kuhberger, 1998) have confirmed that framing is a reliable phenomena, we need to replicate the O'Hare and Smitheram (1995) study using a more dynamic decision making task. A number of additional predictions can be derived from Prospect theory. For example, the effects of changes in outcome uncertainty may have predictable effects on choice. The perception of risks in choosing between various options on a cross-country flight might be affected by the initial framing of those risks (certain versus uncertain prospects) and any changes in those prospects encountered during the flight. Once a suitable decision making paradigm has been developed (see Preliminary Study below) then it will be possible to explore the effects of variations in response framing on decisions in simulated VFR cross country flights.

A related perspective which has been widely investigated in the context of business investment decisions is the sunk-cost approach (Arkes & Blumer, 1985). The sunk-cost effect describes the behavior of individuals who continue to invest in a losing course of action when it would be more advantageous to discontinue investment. It has been suggested that the psychological motive of not wishing to appear wasteful is one of the driving forces behind this tendency. The phenomenon also appears to be consistent with Prospect theory. The same paradigm can be used to explain the apparent tendency of pilots to continue with a potentially risky course of action later in a flight. To abandon the flight at a late stage involves 'wasting' the time and resources already invested in the flight. Factors which increase this investment (e.g. costly aircraft charges) or the psychological connection with the investment (e.g. personal responsibility for organizing the flight, presence of passengers etc) should strengthen the sunk-cost effect and increase the tendency for poor decision making later in flight. The most important factors can be identified from previous literature and their applicability to the aeronautical decision making context determined empirically.

The behavioral science literature contains suggestions for overcoming the sunk-cost effect on behavior. For example, Staw (1976) has suggested that entrapment is less likely where individuals have been required to make a series of on-going decisions rather than a single one-off decision. This suggestion could be empirically investigated in the cross-country VFR situation.

METHOD

We selected the PC-based X-Plane aeronautical design system (Laminar Research Inc, 1998) as a potential tool for investigating pilot decision making in the laboratory. The X-Plane flight simulator is a versatile simulation package which provides a wide variety of aircraft models. The pilot is presented with an easily configurable panel display complete with full nav/com and GPS requirements. The out-of-the-cockpit view (360^0 in 45^0 increments) can be selected fore and aft or to either side. Considerable control is available over weather and aircraft systems. Detailed output covering a wide variety of aircraft and control parameters is available. X-Plane requires a high-end PC with an open-GL graphics accelerator card and considerable RAM to operate smoothly.

We set-up the X-Plane simulation in our laboratory and created a number of potential decision making scenarios involving various weather effects. The scenarios were tested for basic coherence and plausibility with participants who were familiar with PC-based flight simulators. Based on this pre-testing, the most suitable scenario was used for an initial study of VFR pilot decision making in weather encounters early and late in a planned cross-country flight.

Participants

The participants were 20 qualified VFR pilots recruited locally through direct contact and via the local flight training organization. Ages ranged from 18 to 72 years and up to 18,000 Hours Total Flight Time.

Apparatus

A Pentium III 450MHz computer with Riva TNT2 Open-GL chipset and 256Mb RAM was used. The computer was used to run the X-Plane Version 5.01(Laminar Research Inc, 1998) flight simulation program. Participants interacted with the program via a CH Flight Sim Yoke and Simped Rudder Pedals. The simulation was presented on a 21" high-resolution Phillips 201B color monitor.

Questionnaires covering demographic and flight experience measures, situational awareness, and response option assessment were developed (see Appendix 1).

Design

The design of this study was a one-factor between-subjects experimental design. The manipulated variable was the temporal location of the critical event. This was presented either early (approximately 15 minutes after takeoff on a planned 1-hour flight) or late (approximately 15 minutes before reaching the destination on a planned 1-hour flight). The measured variables include various aspects of situational awareness, response option assessment as well as the decision to continue or discontinue the flight at the critical point. An additional set of measured variables derived from the X-Plane output of flight parameters (e.g. pitch and roll, altitude, heading, power setting, flap settings etc) were also collected and analyzed where appropriate. Basic descriptive analyses, including product-moment correlations between appropriately-measured variables were conducted. Differences between the two conditions (early/late) were tested for each variable individually using one-way ANOVA where appropriate and Mann-Whitney or Chi-Square analysis otherwise.

Procedure

Participants were tested individually. After reading a brief description of the study they were asked to sign a standard consent form. They were then introduced to the simulator setup and given written specifications of the plane they would be flying (a GPS equipped Cessna 172R). All this material was contained in a spiral-bound 'flipbook' (see Appendix 2). A familiarization 'flight' was conducted to become familiar with the controls and the set-up of the simulation and provided an introduction to the use of the GPS for navigation. The main task was introduced by means of a written set of instructions outlining a scenario for the flight. Participants were provided with a weather report, an en-route map showing locations of other airports, and a proposed route of flight. The planned flight was approximately 100nm.

After reading the provided materials, participants were asked to take off and follow the flight plan. Conditions were well above those required for VFR flight until a point either 15 minutes into flight (short condition) or 45 minutes into flight (long condition) where they deteriorated to around the minimum required for VFR flight. At this point pilots were faced with a combination of rising terrain, lowering overcast and reducing visibility. If the participant elected to discontinue the flight (either verbally or by taking actions to discontinue the flight) the simulation was paused, the screen turned off and the main experimental questionnaires produced. If the participant continued the flight after the point at which VFR flight was marginal the experimenter paused the simulation as above.

The questionnaire measures covered aspects of the participant's situational awareness (e.g. the weather conditions, the aircraft's altitude, heading etc) and response appraisal (e.g. options available, risks associated with each option etc). We also administered the SAGAT procedure following the blanking out of the screen. This involved the participant recalling as much of the current flight conditions as possible. Finally, they were asked to complete a questionnaire covering basic demographic and flight experience details

RESULTS

The data were analysed using two different group allocation methods. The first was using the Long/Short flight variable, and the second split the data on the basis of whether participants elected to continue the flight on towards the planned destination or not. Before analyses data were carefully examined to determine whether the distributional assumptions of parametric testing were met. Where appropriate, data were transformed before analysis. Data which were unable to be normalised were analysed using the Mann-Whitney or Chi-square analysis. The level of significance used for all tests was $p < .05$, however, due to the preliminary nature of the study scores results with $p < .08$ were considered useful for this summary.

Group Allocation 1: Flight Length - Short/Long

Table 1. Significant Comparisons Between the Long and Short Flight Groups

Measured Variable	Short Flight Mean	Long Flight Mean	Significance
Altitude AGL[1]	2265 ft	1380 ft	0.076
# Airports Recalled[2]	3.1	1.7	0.036*
Map Displaying Airport Information Y/N (2/1)[3]	1.6	1.2	0.068
Airport Name Score[2]	1.07	0.35	0.064
Code Name Score[2]	0.22	1.12	0.003*
# Intended Route Items for Course of Action	2.25	0.78	0.002*
# of Details for WX Expected for Course of Action[2]	2.7	1.5	0.065
# Benefits for Returning to Departure Airport[2]	1.9	.05	0.003*
Risk of Returning to Departure Airport[1]	0.45	0.71	0.027*
# Benefits for Diverting[2]	0.5	1.1	0.051
Risk of Returning to Trinity Centre[2]	3.1	5.1	0.023*

1 – ANOVA; 2 - Mann-Whitney; 3 - Chi-Square Analysis * = $p < .05$ or better

The measured variables providing significant results can be grouped into four categories:

1. Aircraft Status
2. Recall quantity and accuracy of airport information
3. Route planning detail
4. Cost, benefit and risk of the course of action options

Table 1 shows a total of 6 significant and 5 marginally significant comparisons out of the 83 measured variables tested. These findings and their implications are discussed below.

1. Aircraft Status

The Short flight group was found to have an average altitude nearly 1000 ft AGL higher than their Long flight counterparts. This result demonstrates that at the time the simulator was stopped the Short flight group was in a safer position than those in the long condition. Despite the terrain generally rising over the course of the flight this finding does not suggest that the Short flight acted earlier than the long flight when faced with deteriorating weather. As there was no difference found in the level of visibility when the simulator was stopped all pilots flew for a similar time before making a decision after the weather changed to overcast.

2. Recall Quantity and Accuracy of Airport Information

The Short flight group recalled double the number of airports the Long Group did. In parallel to this, the Short group also used maps more frequently than Long group to express information about airports they recalled. The Short group also recalled the names of airports with greater accuracy than the Long group, but the opposite is true for the recall accuracy of the codes associated with each airport. Overall these results show a higher rate of recall and better accuracy for the Short flight group over the Long flight group. The contradictory recall result for the accuracy of airport code recall is arguably of little importance. It is potentially more important that a pilot who is lost is able to ask ATC for assistance using an airport name rather than an airport code. Further, these results showed the short flight group having a more complete picture of their location in relation to possible landing sites. Being able to produce a map may indicate that this information was in a form readily able to be used for basic navigation to a destination.

It must be noted that even for the Short flight group the proportion of airports recalled out of all present on the sectional chart provided was paltry. Airports not on the flight plan were almost completely ignored. Even the airport attached to the weather forecast was recalled by only one subject despite the fact that the subjects were made aware of its location at the beginning of the flight. In addition, only one out of three closest airports to the aircraft when the simulator was stopped Trinity Centre was regularly recalled for both groups, but this airport was on the flight plan for both groups. A second airport, Dunsmuir Municipal, was recalled once in the Short condition and twice in the Long condition. The third airport was never recalled.

The pattern of airport recall was not random. There was a distinct tendency to recall airports on the flight plans for both groups, lending credence to a 'route myopia' explanation. However, the short group recalled many more airports even though the flights were of similar lengths and had comparable numbers of waypoints (airports). In the Long flight condition the subjects seemed to forget about airports they had passed over during their flight. This suggests route myopia affects recall of airports not extending from the last airport passed forward.

3. Route Planning Detail

Two measures showed significant differences between groups for the amount of detail provided for subject's planned course of action. Both the number of route details for the planned course of action and the number of weather details expected during the execution of this plan were greater for the Short flight group. When these findings are coupled with the recall of route details it is clear that the situational awareness of the Short flight group was better. This was reflected in their ability to recall more and plan more thoroughly than the Long flight group.

4. Cost, Benefit and Risk of the Course of Action Options

Short and Long flight groups showed a significant difference in the appraisal of factors associated with returning to the departure airport. Here the Short flight group stated more benefits and rated the risk of returning to the departure airport lower than those in the long group. However, this result is spurious due to the different departure airports for the two groups.

These data were reanalysed creating a 'Return to Trinity Centre' variable which was a consistent measure for both Long and Short flight groups. These data showed a significant difference in risk perception. The Long flight group perceived this option as being riskier than the Short flight group. This finding is relevant to the other decrements in planning performance discussed earlier for Long flight group. The lack of an immediately available detailed model of the environment may be reflected in the higher level of perceived risk found here. In an earlier simple correlation analysis using the first 15 subjects it was found that reduced awareness of environmental detail was correlated with increased rating of risk. There is therefore some evidence that situational awareness of route and geographical details and their spatial relationship reduces during the course of a flight.

The final significant result for this part of the analysis was a difference in the number of benefits stated for diverting to another airport other than the closest available or the departure airports. Here the Long flight group listed more benefits for this option than the short group. This result is difficult to interpret as it is confounded by the fact that the closest available airport that the subjects were largely aware of was also the departure airport to those in the Short flight group.

Overall these finding suggest that the members of the Short flight group were in a generally safer position (higher altitude) and had somewhat better environmental situational awareness. The results showed that the short flight group had a more complete picture of their location in relation to possible landing sites. Being able to produce a map may indicate that this information is in a form readily able to be used for basic navigation to a destination.

Group Allocation 2: Course of Action - Continue to Planned Destination / Return to Trinity Centre

Measured Variable	Continue Group Mean	Return Group Mean	Significance
Airspeed[1]	109 KIAS	89 KIAS	0.027*
Altitude AMSL[2]	6598 ft	7923 ft	0.016*
Error in Estimated Altitude AGL[1]	16.28	32.73	0.080
Airport Name Score[2]	0.53	0.93	0.056
Code Name Score[2]	0.27	0.72	0.034*
# of Expected VFR Violations if Continuing to Weed[2]	0.60	1.40	0.074
# Benefits of Continuing to Weed[2]	2.40	0.87	0.005*
# of Costs of Continuing to Weed[2]	2.40	1.27	0.034*
Risk of Returning to Departure Airport[1]	0.68	0.54	0.027*
# Benefits of Return to Trinity Centre[2]	1.95	2.45	0.072
Risk of Landing at Closest Available Airport[2]	3.40	6.13	0.010*

1 – ANOVA; 2 - Mann-Whitney * = $p < .05$ or better

As with the first analysis we can group the significant comparison variables into groups. Here there were no significant differences found in route planning, giving 4 groups:

1. Aircraft Status
2. Error in Estimated Altitude
3. Recall accuracy of airport information
4. Cost, benefit and risk of course of action options

1. Aircraft Status

Data relating to the Aircraft Status provided two significant differences. Firstly, the group continuing to Weed were flying nearly 20 KIAS faster than those who chose to return to Weed. While a higher airspeed is potentially safer because the speed can be turned into altitude this result is complicated by other factors present at the time the simulator was stopped. One factor is the other significant difference in Aircraft Status found here, altitude AMSL. As all subjects cruised at about the same altitude prior to the weather deteriorating the greater airspeed of the Weed group could be accounted for by their descent. Also, the subjects who chose to return to Trinity Centre showed their choice by turning back, most likely bleeding off airspeed in the process and increasing the difference between the groups.

The second significant result was that the continue to Weed group were flying nearly 1500 ft lower than those choosing to return to Trinity Centre. This can be explained to an extent by the fact that all pilots choosing to continue also chose to fly beneath the cloud layer. While most of those returning also chose to do this, some attempted to climb above the cloud. This meant an altitude of at least 8500 ft. For those continuing to Weed it was probably safer to remain under the cloud so as to sight their destination and not become disoriented in cloud. Their average airspeed was also higher so they could climb swiftly if the need arose. It must also be said that there was no difference found in altitude AGL. In summary, the differences in Aircraft Status found do not reflect a real difference in safety at the time the simulator was stopped.

2. Error in Estimated Altitude

Of greater issue is the difference found in estimated altitude AGL. Both groups underestimated their altitude AGL. This result shows the group returning to Trinity Centre had twice the level of error than those continuing. This may have been a result of performing a turn and momentarily losing an accurate mental representation of the aircraft's status. Whatever the reason, this shows that subjects pushing on had a slightly more accurate representation of this than those turning back.

3. Recall accuracy of airport information

This group of significant differences showed that recall accuracy of airport names and codes was higher for the group returning to Trinity Centre. This potentially left them in a position to receive assistance from ATC more quickly than those continuing.

4. Cost, benefit and risk of course of action options

The group continuing to Weed expected fewer VFR violations and more benefits for the option to continue to Weed than those not willing to press on. These results suggest that the pilots who continued to Weed perceived a lower level of risk associated with carrying on. However, there were no differences found between the two groups in risk appraisal for the time the simulator was stopped or for the risk associated with carrying on to Weed. This could be explained if those who chose to continue were more experienced pilots than those who chose to return. More experienced pilots may rate any given situation as less risky than less experienced pilots. However, there were no differences found in the flight experience measures (total hours, total hours as pilot in command, total hours flying cross-country, hours in the last 12 months, cross country hours in the last 12 months, time since certification, Instrument rating, instructor rating, or previous VFR into IMC experience), hence, there was no indication that the pilots carrying on had any reason to rate their choice less risky than those who chose to return. The fact that pilots continuing to Weed associated more costs with this course of action than those returning to Trinity Centre confuses this issue further.

Inspection of the costs and benefits given for either continuing on towards the original destination (Option A), or for returning to the last airport (Option B) provides a potentially valuable insight into the decision making process. The data for the four participants who elected to continue are shown below.

Subj No.	Condition	Option A Benefit Items	Option A Cost Items
6	Short	Getting aircraft onto ground safely and quickly	Prevent myself and passengers from reaching desired destination
		Not much passenger discomfort	Weather doesn't improve and terrain clearance is not possible
		Possibility weather would improve	
13	Short	Continuation of flight to destination/waypoint	Possible collision with mountain peaks if weather deteriorates to 0 visibility
		Turning back could take plane into more bad weather	Rough ride - turbulence
		Avoid possibility of becoming disoriented/lost if turned back	Possible fuel shortage
10	Long	Not hitting high ground	Possibility of high ground further on
		Not running out of fuel	Possibility of having to make a similar decision again
		Probably better weather ahead	Unknown territory
16	Long	Get back in time	Cloud may thicken why may mean a forced landing
		Avoid spending night at unplanned destination	Danger to aircraft and people

These participants seem to have engaged in a detailed weighing up of the pros and cons of continuing, with the number of reasons for and against roughly equal. The number of pros and cons for the chosen option was significantly greater than for the rejected option (z = -2.25, p < .025). There is a noticeable lack of direct reference to the potentially fatal consequences of "pressing on". In contrast, they have few pros and cons for the rejected option (return to the last airport) as shown below.

Subj No.	**Condition**	**Option B Benefit Items**	**Option B Cost Items**
6	Short	Safe trip	Passengers get frustrated
13	Short	Get home in one piece	Get lost
			Run into more bad weather
			Hit mountain
10	Long	Known terrain so most likely can cover again	Weather may have closed in
16	Long	Getting safely on ground	Be late to work the next day

This qualitative pattern is consistent with the central idea of recognition-primed decision making (Klein, 1989) where options are considered serially rather than concurrently. These participants appear to have engaged in extensive processing only of the chosen alternative. There is little evidence that the participants were considering the options in equal depth, nor is there any evidence for a concern with providing a good justification for rejecting the less-risky alternative of returning to the last airport.

The data for the participants who elected to discontinue the planned flight and return to the last airport are less clear cut. Once again, there is evidence of considerable weighing up of the pros and cons of the chosen alternative (Option B). The number of pros and cons for the chosen option was again significantly greater than for the rejected option (z = -2.28, p < .023).

Subj No.	**Condition**	**Option B Benefit Items**	**Option B Cost Items**
1	Short	Stay alive	nil
3	Short	Aware of terrain	Have to do trip again
		Know airport is 20 miles away	Not 100% sure of position so may be flying into danger
		Flying away from high ground	Passengers may be distressed
		Known airfield	
		Weather clear below 9000'	
4	Short	Safest	Won't get to destination on time
		Certain can find landing site	
		Known route	
		Weather clear for last few minutes	
9	Short	Avoid bad weather ahead by reducing altitude to keep out of cloud	Front may overtake
11	Short	Most safe option	Unlikely to make destination on same day
15	Short	Save lives and aircraft	Delay
			Miss work
			Cost of hire car
17	Short	Safety for all on board	Not get back on time
		Not becoming disorientated	
19	Short	Maintain control of situation	Not get to work

		Live to fly another day	
2	Long	Higher chance of safe landing in better visibility	Time to get to Weed by car
		Close to Weed	Inconvenience to person who booked plane
			Might not be suitable airfield
5	Long	Safety and survival of self and plane	Time
			Fuel
7	Long	Get out of cloud	Disorientation
		May not be fog there yet	Fuel status
			May be fog there
8	Long	Get out of air quickest	Unknown terrain
12	Long	Aircraft/pilot safe in event of bad weather setting in	Aircraft unavailable to Aero Club
14	Long	Keep me alive	Time
		Should weather clear the continuing possible	Unknown terrain
		Land quickly	
18	Long	Close to home	Rental accommodation/vehicle
			Phone calls
			Not getting to work

As in the previous case, there seems to have been less processing of the rejected alternative. In contrast to those participants who chose Option A (continue), the participants who rejected Option A frequently mentioned the potentially fatal consequences associated with this option.

Overall, there was a marginally significant difference ($z = -1.82$, $p < .068$) in the total numbers of pros and cons for both options listed by the group who elected to continue the flight compared to those who elected to divert to the last airport overflown. There was a highly significant difference between the total number of pros and cons for the accepted option and those for the rejected option ($z = -2.08$, $p < .003$).

Subj No.	**Condition**	**Option A Benefit Items**	**Option A Cost Items**
1	Short	nil	nil
3	Short	Get home	Dead
4	Short	Get to destination on time	Crash
9	Short	Weather may clear	Fly into cloud
11	Short	Likely to make destination if Weed can be reached	Large risk in continuing toward cloud area
15	Short	Get to work	IMC in non-de-iced aircraft
			High winds
			Sick passengers
			No options in case of forced landing
17	Short	Less drive to final destination	Aircraft stuck
19	Short	nil	Fly into terrain
2	Long	Less inconvenience	Possibility of crashing
5	Long	nil	Fatal
7	Long	nil	Probably would not have got there due to weather conditions

8	Long	Get to Weed	Risk lives
		Save time	Crash
			May not be better weather ahead
12	Long	No inconvenience to passengers	Loss of pilot/plane
			Rescue services deployed
14	Long	Get home	Death
			Damaged aircraft
18	Long	Get home on time as planned	nil

The question remains, why some did individuals make the choice to continue into deteriorating weather over unfamiliar terrain while others did not? It could be that the group who chose to continue to Weed simply perceived the weather situation differently to those who returned to Trinity Centre. This difference in perception could have resulted in the option to continue appearing less risky than the option to turn back to those who continued, and vice versa. This explanation is consistent with the significant difference found between the two groups in the number of VFR violations expected if the pilots continued to Weed.

Finally, the difference in perceived risk associated with diverting to another airport other than the departure airport or the closest available airport was significant. The group continuing to Weed rated this option considerably less risky than subjects turning back. This could be explained by the Weed group being more comfortable flying over unfamiliar terrain. This group were already prepared to fly on over unfamiliar terrain to Weed so there could be little difference seen in flying over other unfamiliar terrain in order to divert. The Weed group appraised their choice as having equal risk to the choice to return despite the fact that it was objectively the riskier decision. This suggests a perceptual difference in the appraisal of the weather resulting in it appearing less severe to the Weed group. The number of costs and benefits listed by both groups showed a strong bias for the choice each group made. This leaves a chicken and egg problem. Did the perceptual difference cause a more positive appraisal of the option taken because the option appeared better, or after the choice was made was the option appraised more positively than others available to make the choice appear more justifiable?

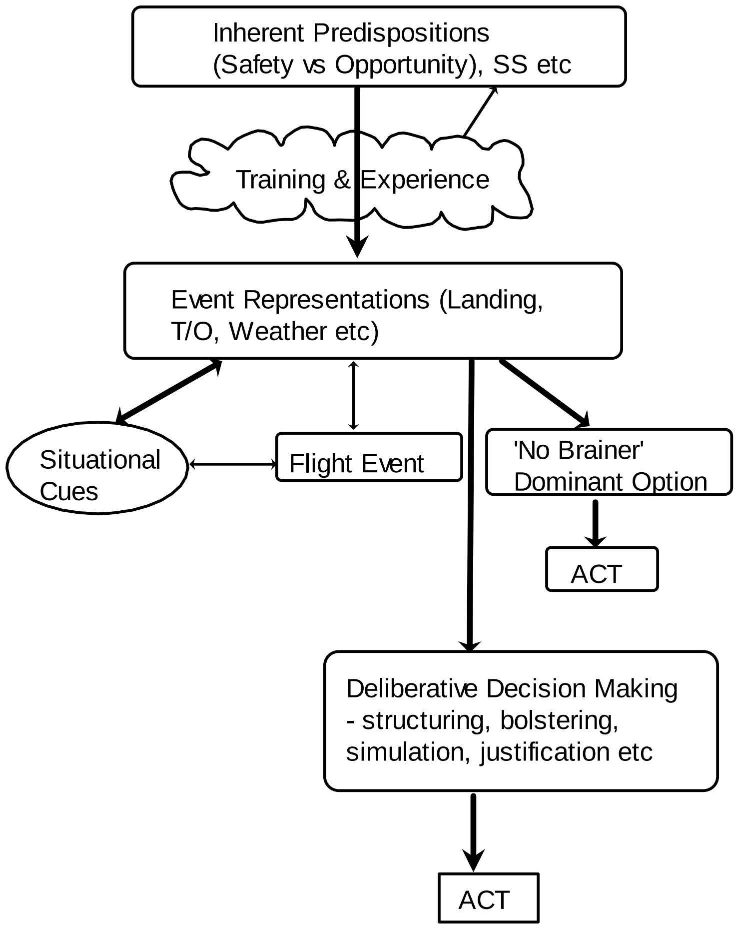
DISCUSSION

The primary aims of this preliminary study were to develop an involving simulated cross-country VFR flight using the latest in PC-based flight simulation software and to develop measures of flight performance, decision making and situational awareness which would enable us to identify the critical components of the decision to continue a VFR flight in deteriorating circumstances. The initial empirical study with 20 participants produced a "pressing on" rate of 20% which allowed us to investigate the characteristics associated with this decision.

The main experimental variable was duration of flight prior to encountering the deteriorating weather. Although this had no effect on the decision to continue the flight the data showed that participants who had flown further had poorer situational awareness and rated the risks of returning to the last airport overflown more highly than participants on the short flight. Both groups showed little awareness of details not directly ahead on the route of flight.

There were no obvious differences between those who continued the flight onwards and those who diverted the flight in terms of flight experience or demographic variables. The two groups differed in their assessment of the costs and benefits of the two options and in their perception of the weather conditions ahead. The decision making process appeared consistent with the serial evaluation strategy proposed in the recognition-primed decision model of Klein (1989). Pilots who continued on showed a strong tendency to avoid mentioning the potentially fatal consequences of their choice. These were commonly alluded to by pilots electing to divert the flight.

The fact that the pilots who continued showed very little evidence of considering the alternative option suggests that their decision was probably the most likely one for them even before the adverse circumstances were encountered. This is not to suggest that it is simply a matter of a risk-seeking personality or propensity dominating all circumstances, but that prior dispositions may affect the kind of domain relevant experiences and the cognitive representation of those experiences which a pilot comes to hold. We have developed a speculative model that addresses the various facets of decision making which may be relevant to understanding the complex question of how decisions are made in circumstances such as those investigated in this preliminary study.



The model assumes that pilots vary in terms of inherent predispositions particularly with respect to safety and security (risk aversion) or opportunity and potential (risk seeking). According to Lopes (1987) these tendencies are present in everyone to some extent, but the dominant tendency will affect the way people normally look at risk. These tendencies will be modified to some extent by training and experience in aviation and will affect the nature of the cognitive structures ('schemas') which will develop to represent these experiences. Schematic representations are fundamental to how we subsequently make assessments and judgements in a domain (Anderson, 1980).

Situational cues are interpreted with reference to the schema for that event (e.g. landing). Klein (1989) suggests that the schema includes information about plausible goals, critical cues, expectancies, and typical actions. In many cases decision making consists of simply recognising a critical cue and performing the associated action. There are numerous theoretical accounts of more complex decision making processes including Montgomery's (1983) Dominance Search model. This model proposes that the decision maker searches and structures the available information to determine if there is a dominant option. From the qualitative analysis of the perceived costs and benefits of diverting the flight, it would appear that for most participants the option of diverting was clearly dominant. Those who continued appear to have engaged in a more deliberative process resulting in the preference for continuing. Given that these analyses are based on stated costs and benefits of alternative courses of action obtained some time after the decision was made, they are clearly speculative in terms of possible ongoing processes. We propose to continue the development of this theoretical model and to empirically test predictions derived from it alongside the development of further experimental work on the nature of pilot decision making in dealing with deteriorating weather conditions and related events.

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Appendix 1: Decision Making Questionnaire used in Preliminary Study

Developed by Douglas Owen and David O'Hare

UNIVERSITY of OTAGO
TE WHARE WĀNANGA O OTĀGO

DECISION MAKING

QUESTIONNAIRE

SHORT / LONG No.

ANSWER THE FOLLOWING QUESTIONS FROM WHAT YOU CAN REMEMBER FROM THE MOMENT BEFORE THE SCREEN WAS TURNED OFF. PLEASE BE AS ACCURATE AS YOU CAN.

What was your airspeed (Kts)?

What was your heading (degrees)?

What was the heading to Weed (O46) from your position (degrees)?

What was your altitude AMSL (feet)?

What was your altitude AGL (feet)?

What was your rate of climb/descent (feet per minute)?

How much fuel is left (% of max)?

What was your engine rpm?

What was the outside air temperature?

What was your distance to Weed (O46)?

What was your flight time remaining to Weed (O46)?

How long has the flight taken up until the time the screen was turned off (minutes)?

What are distances and headings to other airports (excluding Weed) from your current position? If you prefer you may draw including the information under the headings below.

Airport Name	**Code**	Distance	**Estimated Flight Time**	**Heading**

Map (Optional):

What altitude is the cloud base at your current position (feet)?

AGL

AMSL

Approximately what was your visibility (km)?

What is your ideal course of action from your current point onward? (Tick One).

a) Continue to Weed (O46).

b) Land immediately at closest available airstrip.

c) Divert to another airport other than the closest available airstrip or your departure airport.

d) Return to Departure Airport.

Give specific details of your ideal course of action under the headings below.

Destination:

Estimated distance to destination:

Estimated flight time to destination:

Heading:

Altitude:

Airspeed:

Specify Intended Route (ie. What waypoints will you use?):

Other:

How confident are you that this course of action will have a successful outcome? (Circle)

1 – Not at all Confident   10 – Extremely Confident

1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10

What information did you consider in deciding upon your ideal course of action? (Give details about what you consider important about the information). Assign each item you list with an importance rating (see below) to specify its contribution to the development of your ideal course of action.

1 – Unimportant to 10 – Very Important

Information	**Rating**

What do you think are the potential benefits of your course of action?

What do you think are the potential costs of this course of action?

What do you think is the meteorological process causing current weather conditions?

If you were now to fly the route stated as your ideal course of action, what weather do you expect to encounter on your intended route?

How certain are you that this is the best course of action? (Circle)

1 – Not at all certain 10 – Absolutely certain

1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10

Describe important aspects of the terrain under the headings below. Please be a give as much information and be specific as possible.

Terrain immediately around the aircraft:

Terrain you have flown over:

Terrain you will fly over on your ideal course of action:

Terrain you will fly over if original course to Weed (O46) is continued:

How risky do you think the situation was when the simulation was stopped?

1 –No risk at all   10 – Extreme risk

1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10

Is there any other information that you think you should have considered in choosing your course of action? If so, what?

How important do you consider it is to get to Weed (your original destination)?

1 – Not important 10 – Absolutely vital

1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10

Describe how you put all the information together in your head to decide upon your ideal course of action.

Does your ideal course of action violate VFR flight rules? If yes, in what respect?

Would continuing to Weed (O46) violate VFR flight rules? If yes, in what respect?

Did you consider any other options before settling on the course of action you chose? If so, give specific details.

FLIGHT OPTIONS	**POTENTIAL BENEFITS**	**POTENTIAL COSTS**	**RISKINESS** (Circle) **1 –No risk at all 10 – Extreme risk**
Continue to Weed (O46).			1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10
Return to Departure Airport.			1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10
Land immediately at closest available airstrip.			1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10
Divert to another airport other than the closest available airstrip or your departure airport.			1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10

DEMOGRAPHIC INFORMATION

Name: ______________________ Age: ____________

The following questions relate to your flying experience. Please answer the questions as accurately as possible.

Total number of hours:

Number of hours as pilot-in-command:

Number of hours as pilot-in-command on cross country flights:

Number of hours accumulated as pilot-in-command over the last 12 months:

Number of hours cross-country flights in the last 12 months:

What is the highest level of certification you currently hold? (PPL / CPL / ATPL)

How long have you held this certification?

Do you hold, or have you ever held an instrument rating?

Do you hold, or have you ever held a flight instructors rating?

Have you ever been forced to land at an airport other than your destination due to a weather situation? If yes, please recount the most recent event giving as much detail as possible – include weather, terrain, and aircraft factors.

Appendix 2: 'Flipbook' Instructions for Participants in the Short Flight Condition

FILING A FLIGHT PLAN/COMMUNICATING WITH AIR TRAFFIC CONTROL

1. Press the left trigger button to contact ATC
2. Highlight "File Fight Plan" from the list using the red buttons on the left of the yoke or the mouse.
3. Press the left trigger button to select this option.
4. Complete the flight plan using the mouse.

Select from green areas:

VFR flight.
Cruising altitude - Set to 7500 ft.
Destination airport code (see Flight Plan).
Gender.

5. Close the window by clicking on the grey button on the top left or right of the panel.
6. Press the left trigger button to contact ATC
7. Highlight " DUK would like to pick up my flight plan" from the list using the red buttons or the mouse.
8. Press the left trigger button to select this option.
9. Enter the radio frequency and transponder code using the mouse. Press "ID" on the transponder.
10. Follow the ATC instructions and contact them when airborne select "Centre, DUK With You" option from the list.
11. ATC will tell you to contact them when required from now on. Follow their instructions. **Listen for your callsign.**

Note: If at any time you have not heard all of the instructions from ATC, contact them and select "Say again" from the list.

Cessna 172 Specifications

ENGINE		
Type	Textron Lycoming IO-360 L2A	
Horsepower	160	
Max RPM	2700	
SPEEDS		KIAS
Maximum Speed Permitted		158
Normal Operating Speed		127
Maximum Speed Flaps Extended		
10^o		-
20^o		110
30^o		85
Stall Speed		
Full flaps		33
No flaps		44
Maximum Maneuvering Speed		
At 1600 lbs		81
At 2400 lbs		99
Climb Speed		80
Lift Off Speed		55
Rate of climb (sea level)		720fpm
Ceiling (service)		13,500ft
Total Take-off Distance		945ft
Landing ground roll		550ft
FUEL US. GAL		
Capacity (useable)		43 US Gall.
High Speed Cruise		9.1/hour
Normal Cruise		8.1/hour
Economy Cruise		7.1/hour
Long Range Cruise		5.8/hour

Controls

Joystick Controls

Pitch, Roll Yaw: As in a normal plane

Rudder Trim: Right hand yoke rocker switch

Elevator Trim: Left hand yoke rocker switch

Throttle: Lever on base

Flaps: Far right rocker switch on base

Wheel Brake Release: Inside right rocker switch on base

Contact ATC/ Confirm Option: Left trigger button

Select ATC Option: Red buttons on yoke (up/down)

Controlling cockpit views: Right hat switch

Mouse Controls

The GPS settings are controlled with the mouse by clicking on the appropriate switch.

Scroll Switch

Scroll Digit/Name Forward: Click down arrow

Scroll Digit/Name Backward: Click up arrow

Digit Switch

Select Next Digit: Click down arrow

Select Previous Digit: Click up arrow

Keyboard Controls

Engine mixture:

F9 – Lean mixture **Backspace (←)** – Enrich mixture

Carb Heat: 4 On / **3** Off

Flight Information

Aircraft Weights

Aircraft Dry	1440 lb
Passengers and Crew	621 lb
Fuel	86 lb (2.0 hr)
Total	2147 lb (Max 2400)

Flight Plan

Departure Airport	O86	Trinity Centre
	O46	Weed
	CA10	Little Shasta
	CA03	Butte Valley (Dorris Butte)
Destination	2S7	Chiloquin State

Weather Report: Klamath Falls (KLMT)

0800 Hours

Scattered and Broken Cloud at 9000 ft AMSL

Visibility 15 NM (27 KM)

Atmospheric Pressure 142 Millibars

Temperature 70^{o} Fahrenheit

Dewpoint 65^{o}

Light north westerly 7 to 14 kt

Barometric Pressure 29.92

Appendix 3: Statistical Tests of Differences in Listed Reasons

1 *Overall Pros and Cons for Both Options*
Continue Group Mean = 7.75
Divert Group mean = 5
Mann-Whitney U = 12
Z = -1.82
P = .068

2 *Continue Group – Difference between Total # of Reasons for Continuing and # of Reasons for Diverting*
Continue Reasons Mean = 5.25
Divert Reasons Mean = 2.5
Mann-Whitney U = .5
Z = -2.247
P = .025

3 *Divert Group – Difference between # of Reasons for Continuing and # of Reasons for Diverting*
Continue Reasons Mean = 2.13
Divert Reasons Mean = 3.47
Mann-Whitney U = 59
Z = -2.281
P = .023

4 *Difference between # of Reasons for Accepted Option and # of Reasons for Rejected Option*
Accepted Mean = 3.84
Rejected Mean = 2.2
Mann-Whitney U = 81.5
Z = -2.967
P = .003

5 *Difference between # of Reasons for Accepted Option – Continue Group vs Divert Group*
Continue Group Mean = 5.25
Divert Group Mean = 3.47
Mann-Whitney U = 9.5
Z = -2.082
P = .037