Aspects of General Aviation flight safety research

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ABSTRACT

The largest cause of General Aviation Accidents is shown through an analysis of the 283 UK fatal accidents between 1980 and 2006 to be loss of control, most usually at low level. Evaluating the reasons behind this, it is shown to be due to a combination of aircraft characteristics and pilot situational awareness and response. The statistical analysis also shows that there are marked differences in the incidence of these accidents between some aircraft types, and this along with systems analysis and simulator experimental work has been used as a mechanism for researching how and why these accidents occur. A proposed mechanism is described, along with an ongoing programme of research, centred on certain single engined aeroplanes, aiming to investigate this and produce recommendations both for aircraft design and pilot training.

NOMENCLATURE

CFIT	Controlled Flight Into Terrain
GA	General (light) Aviation
GASCo	General Aviation Safety Council
IMC	Instrument Meteorological Conditions
KIAS	Knots Indicated Airspeed
LoC	Loss of Control
LPO	Long Period Oscillation
LSS	Longitudinal Static Stability
MAC	Mean Aerodynamic Centre
POH	Pilots Operating Handbook
SPO	Short Period Oscillation
VFR	Visual Flight Rules

1. INTRODUCTION

A subject which cannot avoid attention in General Aviation is that of safety, and in particular the avoidance of fatal accidents. Whilst it is potentially appealing to attribute one, or a small number of, cause(s) to any accident, in practice the number of events which can lead to any accident is large, and can stretch back many decades before the accident occurrence.

Consider, for example, the following hypothetical timeline for an accident, which occurs at T=0:

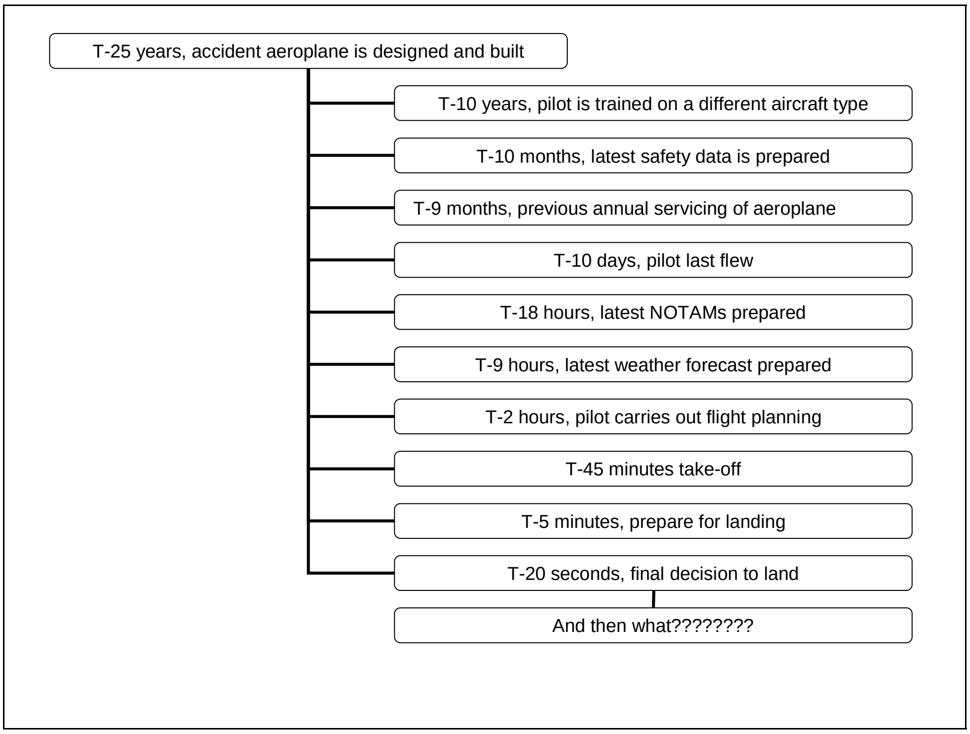


Figure 1, Hypothetical accident timeline

This complex timeline is intended to illustrate that there are numerous points at which factors can be introduced which might have led to this accident. This of-course is to be determined by a subsequent investigation, but highlights the validity of Reason's classic "Swiss Cheese" model of accident causality[1]. However, the Swiss Cheese model (conventionally applied to human factors failures, but equally applicable to all accident causal factors), which would describe each event as a layer of cheese containing holes – under normal circumstances when these events are laid upon each other, there is no co-incidence of holes right through the pile of cheese but, occasionally, all of these holes will line up allowing sight through the pile – where each hole is an error, then it is only when all of the holes line up that an accident can occur.

However, holes in the layers of hypothetical Swiss cheese are inevitable, and the only way to genuinely ensure perfect aviation safety is to ensure that the aircraft cannot possibly be flown, such as the aircraft shown in Figure 2 below.

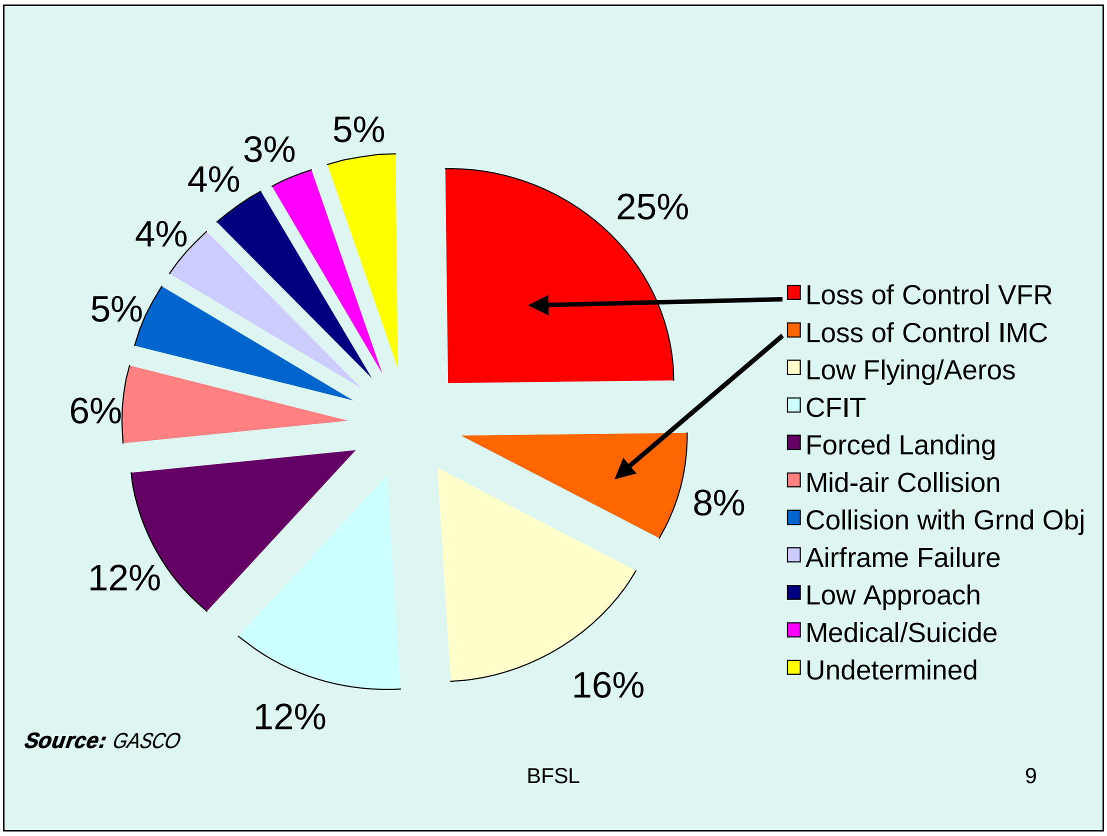
Figure 2, Brick-built biplane at Old Warden Airfield

The improvement of aviation safety therefore, is about identifying the holes in each cheese slice, and then a combination of eliminating them, or ensuring that these holes do not line up.

2. FINDING THE HOLES IN THE CHEESE

GASCo, the UK General Aviation Safety Council, have recently conducted a study into the history and causal factors behind UK General Aviation fatal accidents between 1980 and 2006 – a 27 year study. One of the objectives of this has been to identify the major causes behind these accidents; whilst this study has not to date been published in whole, a summary of the provisional conclusions is shown in Figure 3 below.

The study reviewed all 283 fatal accidents for UK-registered aeroplanes under 5,700 kgs. It highlighted that stall/spin was a factor in nearly all fatal accidents and also the marked variation in stall/spin susceptibility of different aircraft types.



Source: *GASCO*

Figure 3, primary attributed causal factors, UK GA fatal accidents 1980-2006 inclusive

Considering this information, it can be seen that the largest proportion of fatal accidents involve loss of control – either in visual or instrument conditions: totalling 33% of accidents. It is likely that the proportion of LoC related accidents is greater than that, since this is likely to also include a proportion of low flying/aerobatic fatalities also.

However, having established that LoC – which for present purposes will be equated with the stall/spin event, is the most common factor identified in fatal accidents, this only progresses the question forwards one step. The important question then becomes one of why these LoC events are occurring?.

In order to explore this, a useful starting point has been to separate out the two certain LoC categories (LoC in VFR and LoC IMC), and then further break down these accidents by other factors. One which has been particularly useful has been to break down these LoC accidents by aircraft type, and then to determine the number of LoC related fatal accidents per 100,000 flying hours per type. Whilst it is difficult to be definitive in drawing conclusions due to the (thankfully) small statistical sample, there are strong indications of differences between types. One which has been particularly striking has been the difference between the Cessna 150 and Cessna 152 aircraft

The C150 (0.68 fatals per 100,00 hours flown) falls approximately on the average for stall/spin related fatal accidents in the UK GA fleet (0.65 fatals per 100,00 hours). Alternately however, the C152 (0.05 fatals per 100,00 hours flown), which has despite being an extremely common type only suffered one stall spin related fatal accident during the period of the study, shows an extremely low accident rate. It was the researchers' opinion that this apparent difference – between the Cessna 150, and the Cessna 152 presented an extremely appealing research opportunity.

3. POTENTIAL CAUSES OF LOSS OF CONTROL

Consideration of the various aspects of a light aircraft flight, there are two ways in which one can classically consider the risk of an accident. The first is a commonly published model suggesting workload and pilot capacity through the various phases of the flight; an example is shown at Figure 4 below.

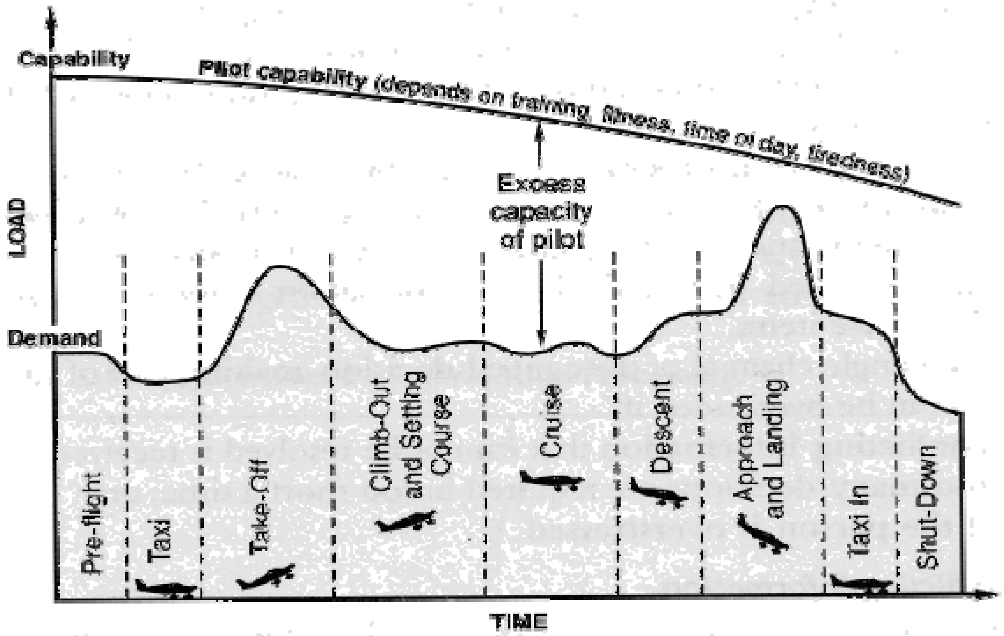


Figure 4, Classical pilot workload demand and capacity model[2]

This model, which is somewhat empirical but nonetheless widely used and respected, indicates that during two phases of flight in particular: the take-off, and the approach and landing, there is a relatively small available excess pilot capacity.

Another approach is to consider the basic flight mechanics of each mode of flight, and in particular the margin from the stall – that being the classic LoC event. By simple inspection, unless the aircraft is deliberately subjected to an unusual manoeuvre such as low level aerobatics, the margin from the stall is least during the take-off, and the approach and landing, phases of flight.

Unsurprisingly, accident statistics show that these two phases of flight are indeed those where over 50% of LoC accidents occur[3].

4. A PROPOSED MODEL FOR LOSS OF CONTROL OCCURRENCE

Inappropriate pilot actions (wrong actions) or inactions (failure to perform any action) can result in an LoC. Pilot Induced Oscillations (PIOs) are an extreme case of inappropriate pilot actions, whereby pilot control inputs and aircraft response outputs are dangerously out of phase with one another causing pronounced oscillations.

Gray[4] and later Warren[5], introduced a useful concept whilst intended for application to PIOs, may also help in our understanding of LoC in a wider context.

Offering a simplistic explanation of this model – consider task of riding a bicycle along, for example, a white line along the road within a tolerance of 150mm either side. This is not particularly difficult and most people would be prepared to try this, and would probably succeed. However, consider alternately the task of riding the same bicycle along the top of a 300mm wide wall. This changes the task in two important ways; firstly failure to succeed in this task now carries a substantial personal risk to the rider, and secondly that instead of the rider trying to follow a median condition (the white line) he or she is now instead trying to avoid two boundaries (the edges of the wall). This principle introduces two new concepts:

(i) Tracking point – the optimal condition which the pilot is trying to maintain.
(ii) Boundary – the condition which must not be crossed.

In piloting terms, a comparable situation would be the initial climb out after take-off: in this case the tracking point would be the aircraft's initial climb speed as given in the POH, whilst in the nose-up sense one boundary would be the stall condition. To understand the dynamics of this, consider the model shown in Figure 5 below.

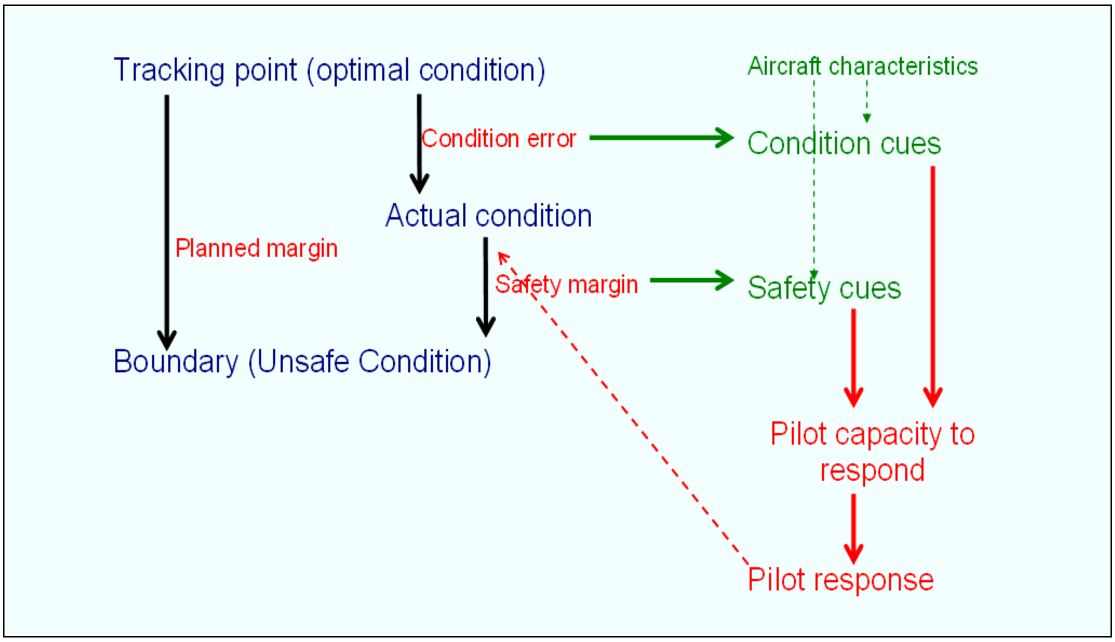


Figure 5, Proposed model for boundary tracking

This model essentially shows two different control loops which *may* potentially exist within the aircraft control task. The loop which compares the tracking point to the actual condition is a classical negative feedback loop which is attempting to drive the pilot/aeroplane combination back to the optimal condition (convergent). The second loop however compares the actual to boundary condition and is a positive feedback loop driving the pilot/aeroplane combination away from the boundary (divergent). In practice neither will be a simple relationship, but the combination of negative and positive feedback loops within the same system presents a duality of the pilot trying to maintain an optimal condition, and avoid a dangerous condition, offers a useful way of considering how a LoC may occur.

As an aside, it should be borne in mind that either a tracking point, or a boundary, may not exist; this is illustrated in Table 1 below.

Type of task	**Example**	**Tracking point**	**Boundary**
Tracking point only	Following a navigational route	Route heading	-
Boundary only	Taking off from a runway with no centreline marking	-	Runway edges
Tracking point + boundary	Taking off from a conventionally marked runway	Runway centreline markings	Runway edges

Table 1, comparison of tracking point and boundary tasks

For the present safety investigative purposes, the first case, of tracking point only, is of limited interest since no obvious safety boundary exists. So, the second and third cases are those of interest – the difference between them being the existence, or not, of the tracking point.

Analytically, it is relatively straightforward to identify the tracking point, actual condition and boundary condition, using some convenient variable such as airspeed, angle of attack, or lateral runway position. From these the condition error and safety margin can be determined. The important issue then is to develop an adequate understanding firstly of the aircraft's characteristics and how they translate these quantities into perceivable cues, and secondly how the pilot under the extant circumstances (which will certainly include workload/stress factors such as noise, procedural requirements, communications requirements, monitoring of other aircraft conditions, and so-on) will perceive and respond to those cues. So, this problem becomes a combined one of engineering (the mapping of condition error and safety margin to cues) and human factors (the alteration of these cues to pilot response). This paper is concerned with the likelihood of a departure from controlled flight, so the safety margin/cues and associated response become the subject of primary interest, and the condition error/cues and associated response a modifier.

5. APPLICATION OF THE LOSS OF CONTROL MODEL TO THE CESSNA PARADOX

The marked difference in safety records of the C150 and C152 which, as can be seen in Figure 6 below are extremely similar aeroplanes, offers the researcher an opportunity to develop and evaluate the LoC occurrence model described above. Starting from the assumption that the accident statistics accurately show the C152 as an aircraft which is very resistant to the risk of departure from controlled flight, and the C150 as one which displays an average risk – it is then useful to compare the characteristics of these aeroplanes.

Cessna A150M

Cessna 152

Figure 6, visual comparison of C150 and C152 aeroplanes

	Cessna 150	Cessna 152
Gross Weight (lbs)	1600	1670
CG Range (inches)	31.5~37.5	31~36.5
Elevator Range (deg)	+25/-15	+25/-18
Aileron Range (deg)	+20/-14	+20/-15
Flap Range (deg)	0~40	0~30
Stall Speed with Full Flaps & Rear CG (KIAS)	46	36

Table 2, Main differences between C150 and C152 aircraft

The key design differences of note between the Cessna 150 and 152 are Gross Weight, CG range and Location mainly due to the larger and heavier 108 and 110 hp Lycoming engines fitted to the Cessna 152. The Cessna 152 also has more downward elevator and aileron authority in addition to a limited flap range of 30 degrees.

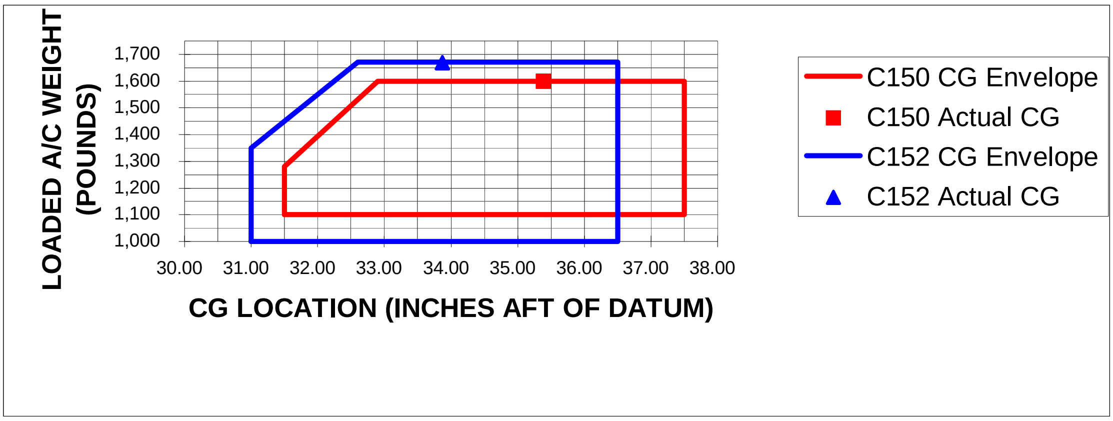


Figure 7, Comparison of CG Envelopes for Cessna 150 and Cessna 152 (MTOW)

Under a typical loading condition (MTOW), there is 1.5” difference between CG locations - Figure 7, Comparison of CG Envelopes for Cessna 150 and Cessna 152 (MTOW). Future flight tests and modelling are necessary to obtain further research data for comparison and validation.

6. RESULTS SO FAR

Flight tests were conducted in the Cessna 152 earlier in the year. The relevant flight tests with regard to key design differences were:-

- Apparent Longitudinal Static Stability (LSS) Stick-fixed & stick-free in the Cruise at different CG settings;
- Longitudinal Aircraft Dynamics including Short Period Oscillation (SPO), Phugoid (LPO), Dutch Roll, Spiral Mode & Roll Mode;
- Stall in different Configurations of CG, Flap & Power Settings

The Apparent LSS provides important information with regard to the apparent static stability of the aircraft. Theory suggests that the Cessna 152 is marginally more stable in pitch than the Cessna 150. The tests allow determination of the stick-fixed and stick-free neutral points, a measure of stability.

Aircraft dynamics testing provide an indication of the dynamic stability of the aircraft types. Manufacturer's information suggests that the Cessna 152 requires more entry with full rudder and elevator to enter a spin and then more likely to spiral than spin with forward CG loadings. Stall tests provide insight into the slow-speed handling qualities of the aircraft.

Qualitative characteristics leading up and at the stall are observed for different CG positions, configurations and power settings. Warning cues, speeds and stall speeds are determined.

All tests were repeated in the flight simulator to enable the aircraft simulation model to be refined for appropriate flying qualities and handling characteristics. The development of the simulation model is an iterative process and requires particular attention to detail. For example, stick forces in pitch need to accurately reflect the real aircraft. The simulator uses an artificial feel-system 'q-Feel' to replicate control forces and provide tactile cues to the pilot.

7. DEVELOPMENT OF THE RESEARCH AND OUTPUT OBJECTIVES

The next step in the research is to complete the flight test programme for the Cessna Case Study. The flight test programme will enable additional research data to be gathered to meet two key objectives:-

- Assessment and comparison of the apparent performance and handling qualities of both aircraft types (flight dynamics);
- Assessment of the utilisation of boundary/point tracking cues in a selection of typical loss of control scenarios.

For the aircraft performance and handling, additional tests for the Cessna 152 in different CG positions will be performed and then replicated for the Cessna 150L & M models for comparison and subsequent simulator model development. Apparent LSS, Longitudinal Dynamics and Stall tests as indicated in Section 6, will be executed.

For boundary/point tracking, simulation tests using the refined aircraft model will be conducted to gather additional research data using volunteer GA pilots. Before any tests are conducted a detailed questionnaire will be prepared and necessary ethical reviews conducted to ensure subject health & safety as well as data protection and confidentiality.

The simulation tests will be based on typical loss of control scenarios as identified by earlier research and confirmed by the questionnaire. The proposed situations to be considered are shown in Table 3 below:-

Phase of Flight	LoC Scenarios
Take-off	• Shortfield Takeoff, with risk of either terrain impact or stall. • Engine Failure After Takeoff (EFATO), with risk of stall.
Circuit	• Base to Finals turn, with risk of stall.
Approach and Landing	• Approach, with risk of either undershoot or stall.
Go-around	• Go-around with full flap & full power, with either failure to climb above terrain, or stall.

Table 3, Proposed Loss of Control Scenarios

In the future, it is proposed to extend the research into other aircraft types where marked differences in safety statistics are also apparent (e.g. slab wing vs straight wing PA-28).

The end result will be a broader understanding of the characteristics surrounding a loss of control and the essential factors to consider to avoid safety-critical boundaries. It is planned to publish this within the aircraft operating, training and design communities, specifically the Aeronautical Journal of the Royal Aeronautical Society (RAeS) and the Journal of Aircraft of American Institute of Aeronautics & Astronautics (AIAA). This it is hoped, will help primarily to improve safety with existing aircraft aswell as make future aircraft more resistant to these life-threatening situations.

8. CONCLUSIONS

In any flying situation, a pilot is continually multi-tasking, balancing tasks, priorities, time and safe limits of operation. The pilot is using a combination of point tracking. boundary tracking and piloting skills to position the aircraft correctly for safe flight. At critical points, such as the takeoff, approach & landing, safety-critical boundary limits for the specific aircraft type and peak pilot workload come together forming a potentially dangerous situation. Sensory cues act as the critical link between the aircraft response and the pilot inputs. Using a combination of theory, simulation and actual flight testing, safety critical Loss of Control (LoC) scenarios are being critically analysed to better understand these situations.

The end result will be a broader understanding of the characteristics surrounding LoC and the essential factors to consider to stay within the safe range of operation. It is planned to publish this within the aircraft operating, training and design communities. This, it is hoped, will help primarily to improve safety with existing aircraft as well as make future aircraft more resistant to these life-threatening situations.

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