LOSS OF CONTROL TESTING OF LIGHT AIRCRAFT AND A COST EFFECTIVE APPROACH TO FLIGHT TEST

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ABSTRACT

Loss of control in Visual Meteorological Conditions (VMC) is the most common cause of fatal accidents involving light aircraft in the UK and probably worldwide. Understanding why LoC events occur and why there are apparent differences between aircraft types is currently under investigation by Brunel Flight Safety Laboratory (BFSL).

Using a case study approach for selected light aircraft used in the training environment and based upon a 29 year study of UK fatal accidents, BFSL undertook a qualitative and quantitative review of fatal stall/spin accidents using a combination of statistical and qualitative analysis. Aircraft/model design differences and published material were reviewed with respect to performance and handling qualities for possible clues, and informal interviews were conducted with type-experienced students, pilots and flying instructors.

A flight test programme was executed using multiple examples (for fleet-wide attributes) of aircraft models to enable assessment and comparison of flying qualities (both qualitatively and quantitatively). Working within the continuous budget constraints of academia, a creative and cost effective flight test programme was developed without compromising safety. The two-man team (TP & FTE) used standard (unmodified) flying club and syndicate aircraft in conjunction with non-invasive low cost flight test instrumentation. Tests included apparent longitudinal (static and dynamic) stability and control characteristics, stall and low-speed handling characteristics and cockpit ergonomics / pilot workload. During this programme, adaptations were also made to the classic Cooper-Harper "point tracking" method towards a "boundary avoidance" method.

The paper describes tools and techniques used, research findings, the team's lessons learned and proposed future research. It also discusses the possible application of research results in aircraft, pilot and environmental causal factors, enabling a better understanding of LoC incidents and future avoidance within the light aircraft community.

NOMENCLATURE

Symbol	Meaning
BFSL	Brunel Flight Safety Laboratory
CAA	United Kingdom Civil Aviation Authority
CAS	Calibrated Airspeed
CG	Centre of Gravity
CHR	Cooper-Harper Handling Quality Ratings
CVR	Cockpit Voice Recorder
CFIT	Controlled Flight into Terrain
FCMC	Flight Control Mechanical Characteristics
FDR	Flight Data Recorder
FTE	Flight Test Engineer
GASCo	General Aviation Safety Council
IAS	Indicated Airspeed
IMC	Instrument Meteorological Conditions
KCAS	Knots Calibrated Air Speed
LoC	Loss of Control (in this paper, referring to in-flight, low speed, loss of control)
LSS	Longitudinal Static Stability
MAC	Mean Aerodynamic Chord
MTOW	Maximum Take-Off Weight
PFtS	Pull Force to Stall
PiC	Pilot in Command
PiL	Pilot in the Loop
TP	Test Pilot
VMC	Visual Meteorological Conditions
V_{stall}	Stall speed
V_{SO}	Stall speed in the landing configuration
W&CG	Weight and Balance

INTRODUCTION

A recent survey carried out by GASCo [1] for the period 1980 to 2008 (Figure 1), showed that for fixed wing aeroplanes with MTOW 994-12,569lb (450-5,700kg),Loss of Control (LoC) in Visual Meteorological Conditions (VMC) was a factor in 25% of all fatal accidents with a further 8% involved LoC in IMC conditions. Low flying, aerobatics and Controlled Flight Into Terrain (CFIT) the next two highest causal categories of 16% and 12% respectively, also involve low speed in-flight LoC to some degree. The net result is that low speed LoC probably accounts for around 50% of all light aviation fatal accidents in the United Kingdom, and most likely for the rest of the world also.

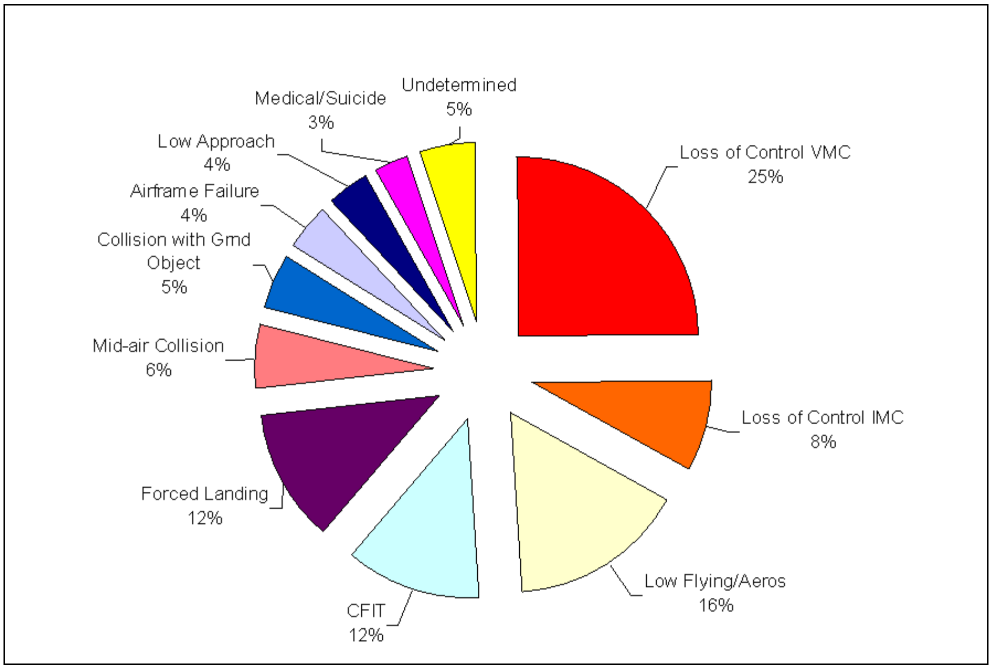

Figure 1, Causes in UK GA fatal accidents, 1980-2008

This understanding has led to a research project at Brunel University to understand some aspects of this, in particular the causes of low speed in-flight LoC (the classic stall, or stall/spin accident).

This research has created an understanding[2] that in considering departures from controlled flight, the classic flight test approach of measuring the pilot-aeroplane-combination's ability to maintain an optimal condition is much less interesting than the means of measuring the system's ability to avoid crossing whatever boundary marks the transition into loss of control. This is illustrated by

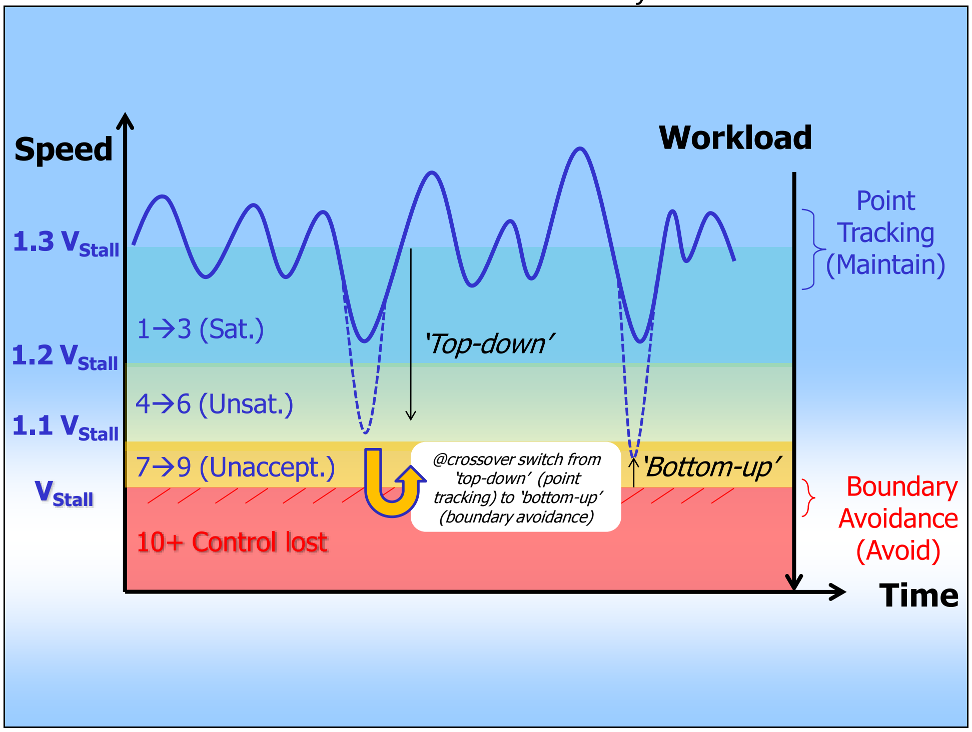

Figure 2 below which indicates the typical task of maintaining an initial speed of 1.3Vstall during an initial climb after a take-off or go-around. The task might classically be examined in flight test by constructing a Cooper-Harper task[3] such as maintain 1.3Vstall ±2 knots (desirable) / ±5 knots (adequate); however, as constructed this tells us little about stall avoidance. Another approach, and that is one adopted by this team, is to set the satisfactory (CHR 1→3) at the ability to keep the aeroplane above 1.2Vs, unsatisfactory (CHR 4→6) at the ability to keep the aeroplane above 1.1Vstall, unacceptable (CHR 7→9) at below 1.1Vstall but above the stall; the stall itself, clearly a loss of control, then being CHR10. This approach to handling qualities assessment has been termed Boundary Avoidance differentiating it from the more conventional Point Tracking handling qualities task. The concept originates at the USAF Test Pilot School[4, 5], but has been adapted by Brunel University [6].

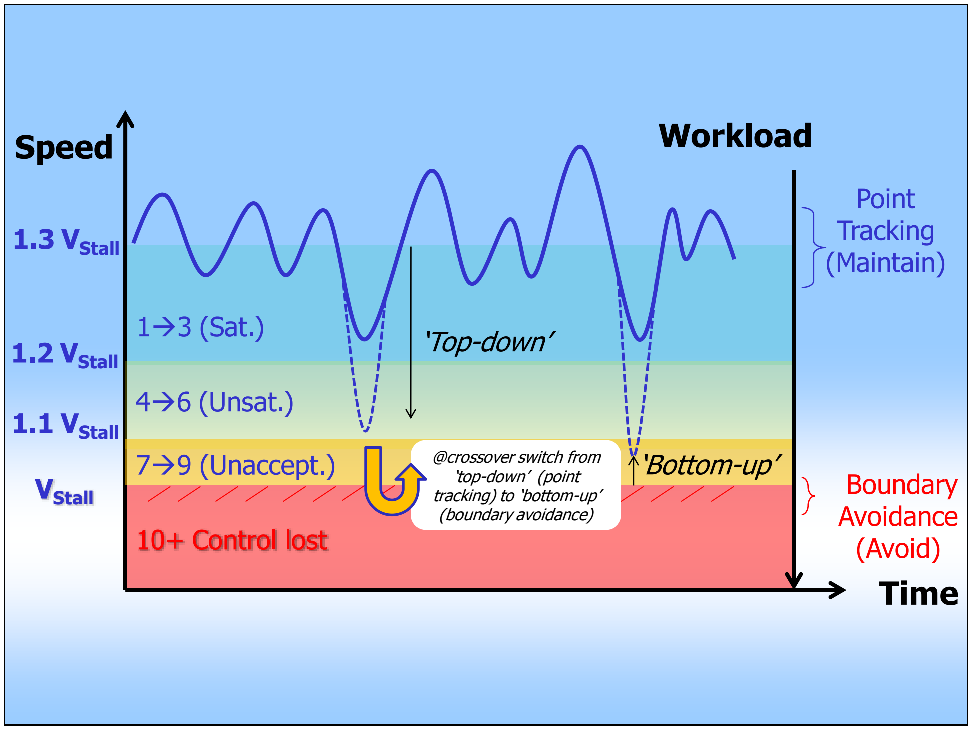

Figure 2, Illustration of speed control during an aeroplane's initial climb after take-off

CHARACTERISTICS OF THE CESSNA 150 AND CESSNA 152

Probably the most common training aeroplanes in the world, the Cessna 150 and 152 represent a family of 2-seat single engine high wing tractor monoplanes which feature somewhere in the logbooks of a large majority of the world's pilots. This study has concentrated upon three models: the C150L, C150M and C152 (including French Reims-Cessna built F150L, F150M and C152 models) which are summarised in Figure 3 below.

	C150L and C150M	**C152**
Powerplant	Continental, generating 100hp at 2750rpm	Lycoming, generating 110hp at 2550rpm
		
Propeller	McAuley Standard	McAuley Gull Wing
MTOW	1600 lbf	1670 lbf
CG Range	31.5-35" (19.9-30.1%MAC)	31-36.5" (19.1 – 28.4 %MAC)
Flap Range	0-40°	0-30°
Flap mechanisation	2 way switch, variable spring/latch characteristics. No détentes.	4 position gated switch. , Détentes at 0/10/20/30°. Indicator adjacent to switch

	C150L and C150M	**C152**
	Indicator in left hand door pillar. 	
V_{SO}, CAS	42 knots	41 knots
V_{SO}, IAS	31 knots (35 mph)	41 knots

Figure 3, Characteristics of C150L, C150M and C152

These relatively small differences between the aeroplanes models becomes particularly interesting when considering the safety records of the aeroplanes (grouping all C152s together, and all C150s together), which can be analysed readily because the UK practices both open accident reporting, and central collation of all civil aeroplanes' flying hours. For certified single engine aeroplanes with an MTOW above 600kgf (1323lbf), the GASCo study [1] shows a rate of 0.37 stall-related fatal accidents per 100,000 flying hours, (0.45 per 100,000 for all certified single engined aeroplanes), compared to 0.71 for all Cessna 150s, or 0.04 for all Cessna 152s. So, the C150 shows a stall related fatal accident rate about double the background population, whilst the C152 shows an order of magnitude better – and comparing the two, the C150 shows a stall related fatal accident rate around 17 times that for the C152. As a research problem, this is particularly interesting because the reasons for these differences must presumably lie somewhere in the relatively small number of design differences between the aeroplanes.

It was therefore decided to conduct a study – initially analytical but subsequently involving flight testing and simulator testing, comparing the characteristics of the two aeroplane families. On analysis the differences between non-aerobatic C152 models are small so these were treated as identical, but of the C150 models the F150L and F150M were of greatest interest since these were the aeroplanes in most of the UK's fatal accidents. This was only 10 fatal accidents – a small number but large enough to consider some analysis, a simple form of which is shown below in Figure 4, although the small number also necessitated considerable qualitative analysis also.

	Number of occurrences
Wind above 30 knots	4 / 10
2 persons on board	5 / 10
Instructor on board	3 / 10
Cessna 150 L or M	9 / 10
Cessna 150 A →K	0
Cessna 152	1/10
Go-around manoeuvre	4/10

Figure 4, Illustration of significant factors in UK C150/C152 fatal stall related accidents

It is not readily possible to compare these numbers to “normal” training aeroplane operations but intuitively it seems reasonable to assume that for an inexpensive 2-seat aeroplane approved for flying training, 2PoB on 50% of flights, and an instructor on board for 30% of flights is probably typical of flying club operations – therefore this seems to say nothing important. That the total wind was above 30 knots in 40% of cases, seems not unsurprising given that this is for fatal accidents and that the landing crosswind limit for the C150 is 15 knots (12 knots for the C152) and the stall speed about 42 knots ; this therefore was not explored further but it is noted that conventional advice [7] is that flying light aeroplanes is inadvisable if the total wind exceeds $^{2}/_{3}$ of stall speed – in this case that would be above 28 knots; the accident rate certainly does not lead one to suggest that this advice is wrong.

However, the large disparity of types (equating to a 17:1 difference when standardised by flying hours), and that 40% of these accidents are during a go-around (baulked landing) did seem to be significant. Thus the assumption became that there must be some differences which makes the C152 more safe in low speed handling than the C150, and that the go-around is representative of manoeuvres where a stall related fatal accident may occur.

EQUIPMENT USED

The aircraft have already been described, but the test equipment is clearly paramount to any understanding of a programme. In this case, all test equipment had to be portable and not affect the certification state of the aeroplanes – which were invariably hired by the hour from flying training schools in various parts of England.

Reliance upon traditional handheld equipment: the ruler, stopwatch, spring balance force gauge and kneeboard mounted test cards were considerable. Situational awareness was substantially aided: freeing pilot capacity to concentrate upon the testing task, by use of a portable GPS – in this case a Garmin GPSMAP 296, which was found to be an excellent tool.

Cockpit video was provided by a Go-Pro Hero wide-lens self contained video camera, with a mass of 150 grammes and the ability to record 2½ hours of video onto an SD card without needing an external power supply. This was useful for debriefs, but did not necessarily provide significant additional information for detailed flight test data analysis. As the authors had found on previous test programmes, the largest problem with such a camera was that the camera coped poorly with the high light level contrast between the cockpit interior (particularly instruments) and the outside view. This was mostly resolved by positioning it to avoid more than peripheral outside view, thus giving a reasonably useable view of cockpit instruments and the pilot and FTE's actions within the cockpit.

Of considerable benefit, and flown on most sorties was a self contained Appareo GAU1000A[**8**] flight data recorder, used with Appareo's proprietary *AS Flight* analysis software – often with subsequent analysis and/or presentation through either *Microsoft Excel* or *Google Earth*. This was a very useful and inexpensive facility which provided adequate quality inertial and positional data at about 4Hz – although it has its deficiencies: rapid motion tended to be amplified (e.g. 45° wing drop at the stall appeared to be around 65°) and experience on other programmes has shown that it is unreliable during aerobatic manoeuvring; additionally the barometric sensor within the system does not function and it was only possible to use GPS derived geopotential altitude. The system could be installed into any aeroplane in about 15 minutes, although it was helpful to have access to the aeroplane's electrical power supply, since the unit's own internal batteries did not have capacity for longer sorties flown. Cross-calibration of the recorder against the embedded flight test instrumentation on Cranfield University's National Flying Laboratory Centre (NFLC) Jetstream aircraft showed very good correlation.

A simple MP3 recorder, connected to a tie-clip microphone in one of the crew's headsets provided adequate cockpit voice recording capability, and with a little effort this could then be readily synchronised with both data from the flight data recorder, and from the cockpit camera. (In later simulator tests, it could also be synchronised with a heart rate monitor.)

CONSTRUCTING AND EXECUTING THE TEST PROGRAMME

Flight Testing

The main area of interest being low speed handling, and in particular stall avoidance, it was nonetheless clearly necessary to consider substantially the aeroplane performance and handling as it might affect low speed handling; but, it was anticipated that once initial testing had been carried out, the area of interest would probably narrow. So a carefully flexible test plan was prepared which covered apparent longitudinal static stability (LSS), all dynamic modes, climb and cruise performance, and stalling at the range of conditions permitted by the aeroplanes' operating manuals. All testing was to be carried out within those conditions, and without going outside the conditions of each aeroplane's Certificate of Airworthiness (CofA).

Planning was for use of equipment as shown above, and with early flying for a 2-man crew of Test Pilot plus Flight Test Engineer, with the latter then having primary responsible for data recording, which was often manual. It was originally anticipated that flying should be carried out approximately 50/50 solo and 2-up, but in practice it was found that the data acquisition and test flying efficiency benefits of flying 2-up were such that solo flight was kept to a minimum. From the start, the use of Cooper-Harper handling qualities ratings was planned for substantially since it was anticipated, correctly, that pilot's opinion of ease of airspeed maintenance and boundary avoidance would be of fundamental importance.

Despite all flight being within Certificate of Airworthiness (CofA) conditions, a conventional flight test safety assessment was carried out, which rated this flying as of medium risk, particularly because of the amount of stalling planned (with associated risk of inadvertent spin) but with this ameliorated by staying within certified flight limits, by Test Pilot workup including stall/spin refresher training, and by ensuring adequate height for all manoeuvres. This last was on occasion a cause for conflict with aircraft owners, who could for example not understand why with a 2,500ft cloudbase – which for most of their purposes would have been perfectly suitable for revenue earning flight, the test team declined to accept the aircraft, when their planning for aft CG stalling requiring a substantially greater cloudbase. One inadvertent spin (from a stall test in an F150L), from safe height and with a satisfactory recovery, justified this caution and it was found that so long as the test team was continuous and open in its explanation of test conduct and objectives, these problems were minimal.

With progress, the test programme came to concentrate upon apparent longitudinal static stability and cockpit workload during speed tasks. The eventual number of sorties is shown in Figure 5 below.

	Phase 1			Phase 2		Phase 2		Phase 3	
							A/c 2		A/c 2
Baseline (Aircraft 1)	CG1 Mid	CG2 Mid-Aft	CG3 Aft	Aircraft 2	CG2 Mid	Aircraft 3	CG2 Mid	Aircraft 4	CG2 Mid
C152	G-BOFL	G-BOFL	[illegible]	C152	G-BPEO	F152	G-BFLU		
TOW@% MAC:	1637 lbs@23.81%	1491 lbs@25.28%		TOW@% MAC:	1678 lbs@23.39%	TOW@% MAC:	1655 lbs@23.78%		
Flt Test/Sortie:	BTP-2008-06-04 (BTP-2008-06-01)	BTP-2008-06-05	BTP-2008-06-06	Flt Test/Sortie:	BTP-2008-06-09	Flt Test/Sortie:	BTP-2008-06-10		
F150L	G-GBLR								
TOW@% MAC:	1599 lbs@25.28%								
Flt Test/Sortie:	BTP-2008-06-02	n/a	n/a						
F150M	G-BCRT	G-BCRT	G-BCRT	C150M	G-NWFA	F150M	G-BCUH		
TOW@% MAC:	1600 lbs@25.68%	1425 lbs@27.22%	1598 lbs@27.99%	TOW@% MAC:	1580 lbs@27.00%	TOW@% MAC:	1599 LBS@25.07%		
Flt Test/Sortie:	BTP-2008-06-03	BTP-2008-06-08	BTP-2008-06-07	Flt Test/Sortie:	BTP-2008-06-11	Flt Test/Sortie:	BTP-2008-06-12		
F150G								F150G	G-AVGU
TOW@% MAC:								TOW@% MAC:	1591 LBS@26.57%
Flt Test/Sortie:								Flt Test/Sortie:	BTP-2008-06-14
Crew:	2	1	2	Crew:	2	Crew:	2	Crew:	2

Figure 5, Test Programme Flown (Totalling 17 test sorties and 3 checkouts, in 8 airframes: comprising 25:35 flying time)

The test organisation did not own any aircraft assets, but in any case it was decided after initially developing a good understanding of aircraft behaviour that it was important to obtain parallel results of the critical aspects for a range of airframes so that they could be compared. This required relationships to be developed with a number of different owning and renting organisations who were generally very helpful with regard to the test teams aims and objectives, and also prepared in most cases to avoid otherwise expensive and repetitive requirements for pre-rental checkouts of the Test Pilot, who had 57 hrs flying time on single engined Cessnas at the start of the programme. On one occasion, after quizzing the test team on their work and ongoing findings, a flying school even changed their own training practices on the types.

SIMULATOR TESTING

Flight test results indicated that differences in the performance and handling qualities of the two case study aircraft maybe due to different stick force gradients in the pitch axis. These differences potentially impact the low-speed handling qualities and may be related to the different fatal stall/spin accident rates during the take-off, climbout, approach & landing, go-around phases of flight and during forced landings. A simulation test programme was devised to gather additional research data in a controlled environment with volunteer pilots. The tests were design to assess point tracking & boundary avoidance during simulated potential, LoC scenarios using a selection of stick force gradients and also to assess pilot workload.

Flight Simulation Equipment

Early use of Brunel University's Merlin MP521 engineering flight simulator showed that there was a very strong need for fine resolution, small breakout, friction and freeplay values, and reconfigurable control force gradients in a simulator for it to have any value in handling qualities research.

A nationwide search of suitable low-cost simulation facilities within the academic environment identified a facility at Sheffield University for the simulation tests. The fixed-base engineering flight simulator offered precision control loading in a wide-screen, 150 degree HFOV by 40 degree VFOV suitable for circuit-based flying scenarios. The simulator uses a PC7 cockpit with basic instrument panel, control stick, pedals, brakes, flaps and elevator trim. This system allows stick force gradients to be software configured. A portable heart rate monitor was also used to gather additional data during the tests together with cockpit CVR, video and intercom for simulated radio communications.

Constructing and Executing the Simulation Test Programme

A flight simulation test programme was developed to determining reasons for different trends towards low level departures from controlled flight in various general aviation aeroplanes. The flight simulation test programme involved 26 (becoming 20 for later tests) volunteer general aviation pilots with a variety of experience from 35 to 12,000+ PiC hours (median 222 hours). Each pilot conducted 5 different flying scenarios using 3 programmed stick force gradients (high/medium/low). After completing a practice familiarisation circuit, pilots conducted a circuit, baulked landing/go-around, base to finals turn, take-off and climb-out and EFATO. The sequence of stick force gradients was cycled to minimise effects of task familiarisation as tests progressed. Simulated Air/Ground radio communications were used for all scenarios with all pilots required to make the radio calls as necessary for flight in the pattern/circuit. On completion of each scenario, NASA-TLX[9] workload assessment (un-weighted) was used to gauge pilot opinion based on a simple rating scale of 1~10. Pilots were asked to rate mental workload, physical workload, time pressures, their own performance, effort required and frustration with respect to each task. Each participant was required to wear a heart rate monitor from pre-flight briefing through to completion of all exercises and post-flight de-brief. A full simulator data-log was captured for each test scenario at a rate of 5 Hz. Control inputs and flight data parameters were recorded against a common synchronised timeline with CVR, camera & simulator. The use of simulator data together with NASA-TLX afforded both qualitative and qualitative research data for subsequent analysis.

RESULTS OF FLIGHT TESTING

Whilst a great deal of data was obtained, it became clear that this investigation needed t become essentially one into apparent Longitudinal Static Stability (LSS). Stick fixed apparent LSS (stick force per airspeed change) on all the aeroplanes tested, in all configurations, was low – consistently below for example the 6 knots per lb which is required by part 25.173 [10, 11], which is the only civil airworthiness standard to define stick force gradient requirements quantitatively.

However, there was also considerable variation between aeroplanes, and with configuration. Consider firstly Figure 6 ; this shows the stick force gradient per airspeed change in the cruise configuration – the C152 nearly meets the recommendation for 10lb /4.45daN) stick force to stall made by Ellis [12], whilst no other variant comes close – at 3daN for the F150L and 1.7daN for both the F150M and a C150G which was also tested – all of these at mid CG (in practice, anything aft of mid-range is almost unachievable in all of these aircraft due to design geometry and loading limits, so this represents a realistic worst case in real operations).

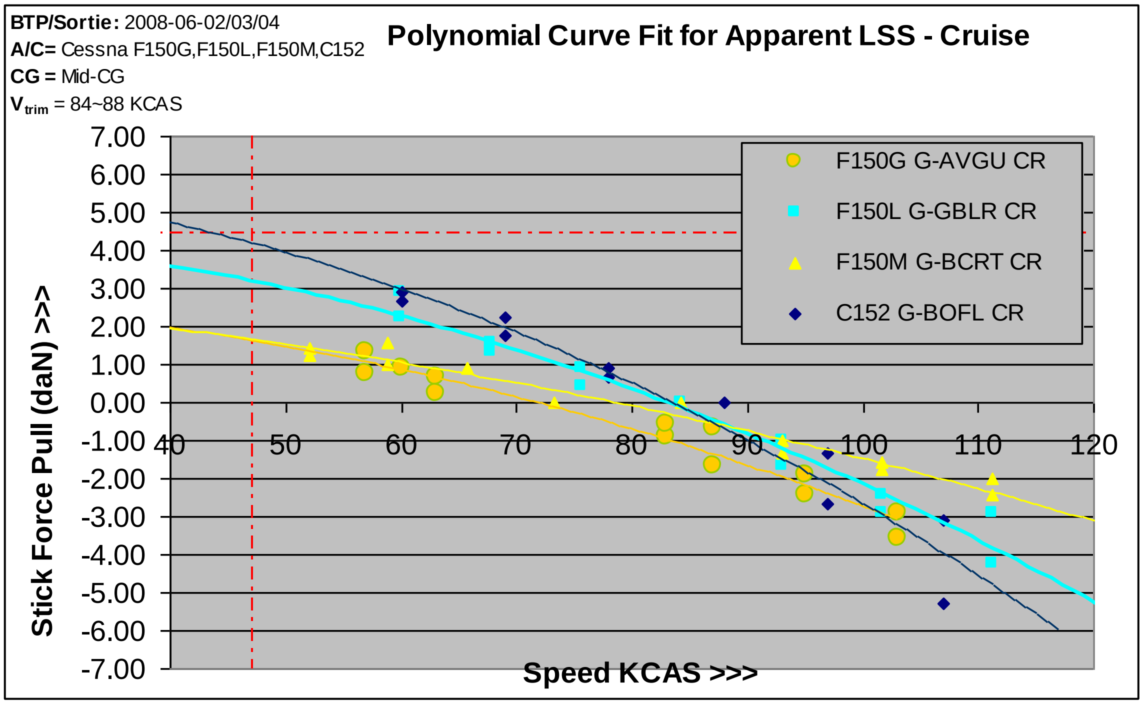

Figure 6, Stick Fixed Apparent LSS in cruise configuration: various Cessna models (Vertical line shows stall speed, horizontal line 10lbf, FCMC have been manually removed from data to give the apparence of no freeplay or friction)

However, as is commonly the case, the selection of flap was longitudinally destabilising, as illustrated in Figure 7 below; this shows apparent LSS with 30° of flap selected (the maximum for the C152 models, and 10° below the maximum for the C150 models). In this case the C152 remains the least-worst aeroplane, requiring about 1.4daN (one third of Ellis' proposed minimum) back stick to stall, which coincided with the F150L. The 40° flap case could not be evaluated quantitatively as C150 aircraft invariably had effectively neutral or slightly divergent apparent longitudinal stability characteristics with 40° of flap and any power setting representative of a normal or shallow approach.

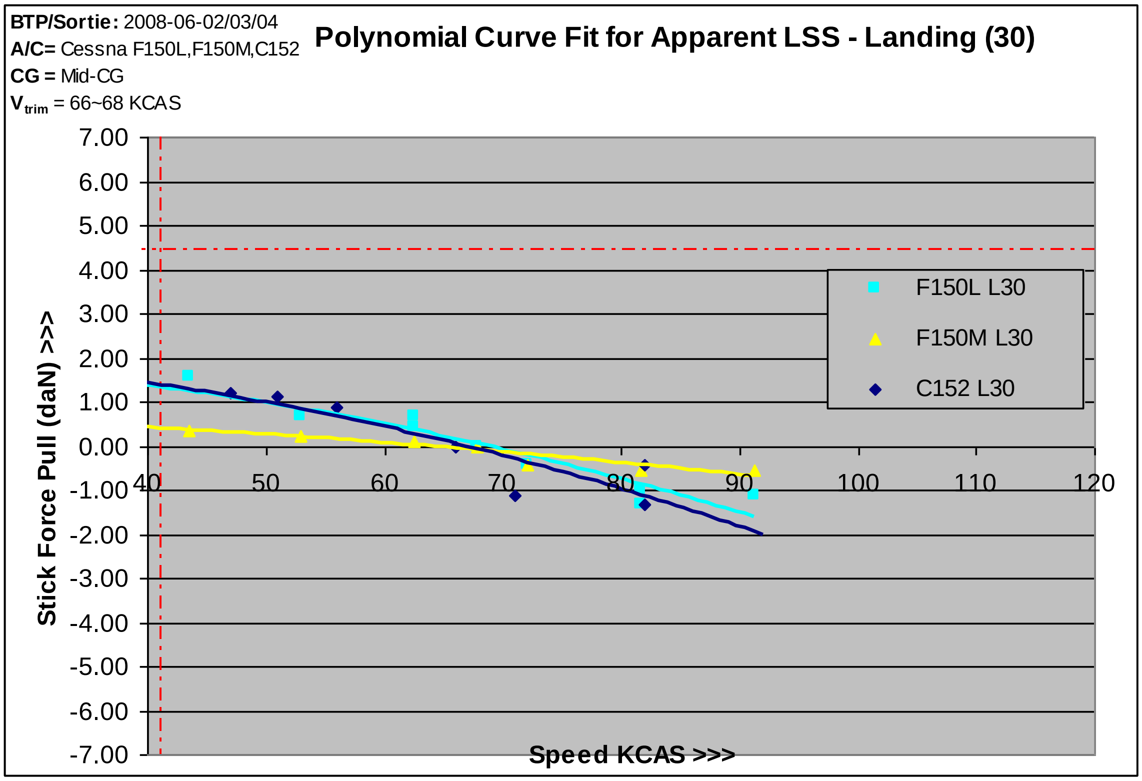

Figure 7, Stick Fixed Apparent LSS in land (30) configuration: various Cessna models (vertical line shows stall speed, horizontal line shows 10lbf, FCMC have been manually removed from data to give the apparence of no freeplay or friction)

The use of Cooper-Harper tasks was used relative to avoidance of the stall was primarily evaluated by use of Test Pilot opinion, for example the following is from the post flight report of a C152 mid-aft CG sortie:

> *Rotation was achieved at the targeted 50KIAS [52KCAS] (±2KIAS, HQR2) and then the aircraft naturally unstuck at about 57KIAS [58KCAS] without any particular difficulty maintaining the runway centreline through the ground roll. The targeted screen height of 67KIAS [66KCAS] was also achieved (not below 49KIAS[51KCAS]/1.2Vs, HQR2) without significant difficulty this being approximately the speed achieved with the take-off trim setting. Initial climb was similarly achieved at the same speed and with the same ease (not below 49KIAS/1.2Vs, HQR2), and the flaps were retracted at about 200ft with a single operation of the gated flap lever…* [G-BOFL, 11 March 2009]

The ability to track speeds was also evaluated, firstly by comparing the ability to accurately track an airspeed using the conventional Cooper-Harper method [3], using limits of ±2 knots for the satisfactory-without-improvement 1→3 band, and ±5 knots for the warrant-improvement band. This is shown below in Figure 8; this clearly illustrates that whilst G-BFLU, a C-152 showed good scores in the range 2-3, G-BCUH, an F150M showed poorer scores of about 5 – indicating that the aeroplane could be improved in this capacity.

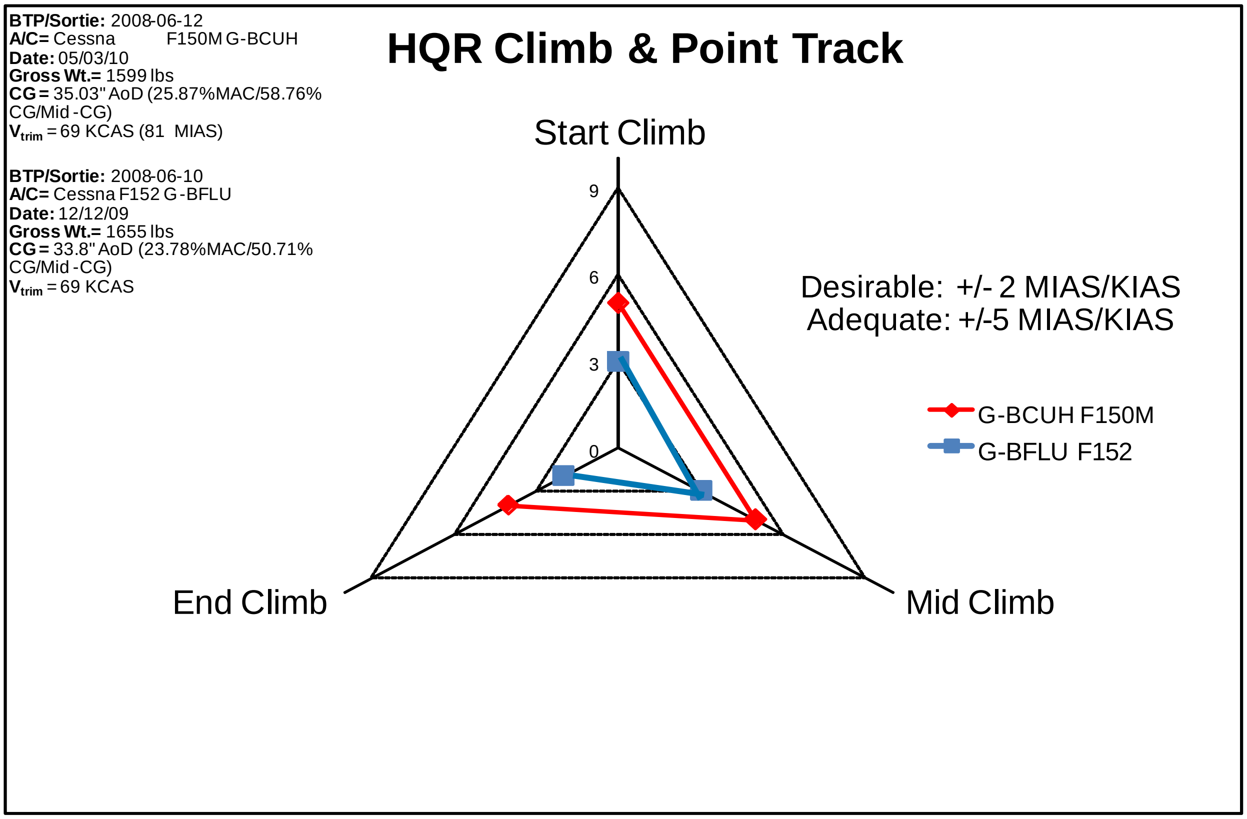

Figure 8, Classical Cooper Harper Scores for steady climb in C150 and C152 aircraft at best climb speed and full power, cruise configuration.

These data illustrate the general picture: clearly a great deal more data are available, but the story is consistent. Specifically:

- No variant of C152 or C150 tested exceeds Ellis' recommendations for 10lbf stick force to stall, although in cruise configuration, the C152 just meets the recommendation. C150 variants routinely demonstrate a force to stall of $^{2}/_{3}$ or less in the cruise configuration.
- No variant of C152 or C150 tested, with 30° of flaps (a typical landing configuration in either aeroplane) selected shows a large stick force to stall which might provide good warning. The best aircraft show a stick force of about 1 daN (2.2lbf) to stall, whilst the worst about 0.2daN (0.4lbf) to stall.
- No C150 variant flown, with 40° of flaps selected, showed a stick force to stall sufficiently large that it could be measured with the handheld instrumentation in use (the instrument in use could be resolved to 0.1daN / ¼lbf).
- Pilot opinion consistently showed large (4+) Cooper Harper ratings for speed holding, or stall avoidance, tasks where flaps were selected at climb power (an initial go-around case) in C150 variants.

RESULTS OF SIMULATOR TESTING

Analysis of the flight simulator data output for the climb-out by two volunteer pilots is presented in Figure 9 and Figure 10 below. The results for non-dimensionalised alpha versus non-dimensionalised elevator deflection consistently show that high stick force gradients have a smaller 'footprint' than both medium and low stick force gradients for a representative sample of GA pilots. Elevator deflection was initially in the 'pull' sense for high stick forces, moving to almost neutral and then to a 'push' sense for low stick force measurement. High stick forces exhibited less alpha and airspeed variation in all cases. All results highlight that increased elevator stick movement is required for the medium and low stick force gradients, with the medium stick force gradient apparently performing worst of all. The results also indicate differences between a typical medium hour private pilot (pilot 23) and a high hours professional pilot (pilot 24). For identical tasks the high hours professional pilot consistently applied much smaller control inputs and achieved a more precise result, however, even the high hours pilot experienced a degradation in precision as the stick forces were reduced. Pilots were observed to make less use of the elevator trim with low and medum stick force gradents. Variability in piloting technique was also observed during the tests.

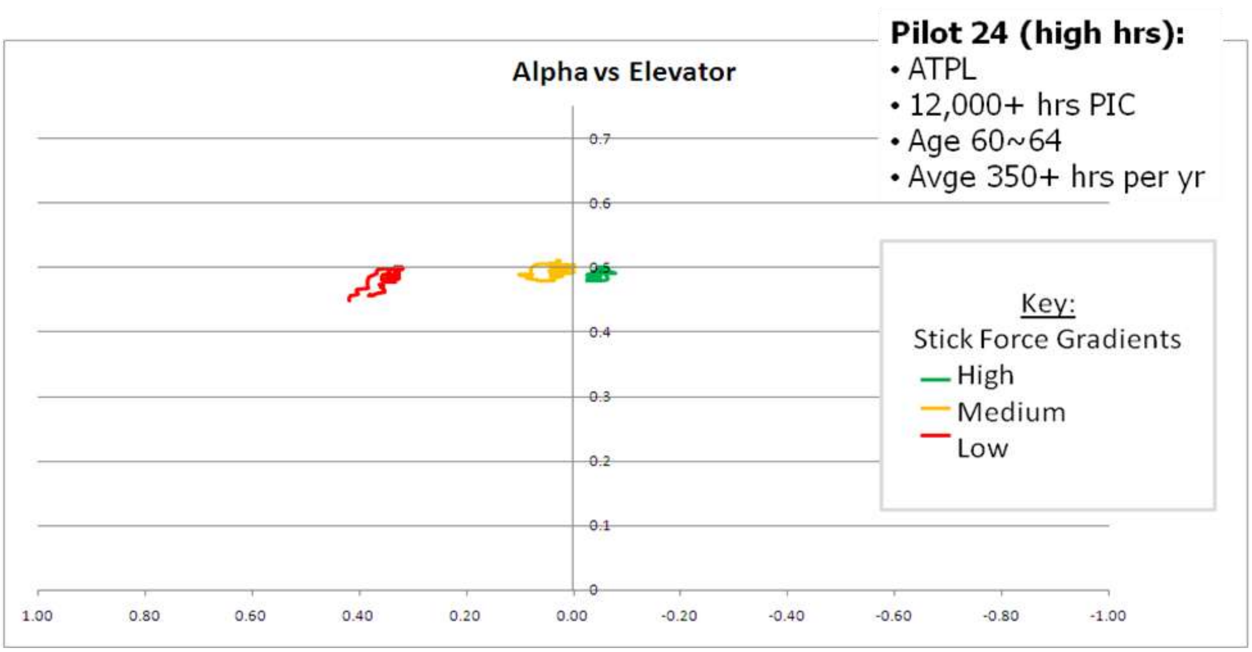

Figure 9, Non-dimensionalised AoA versus elevator position for high experience pilot executing climb-out

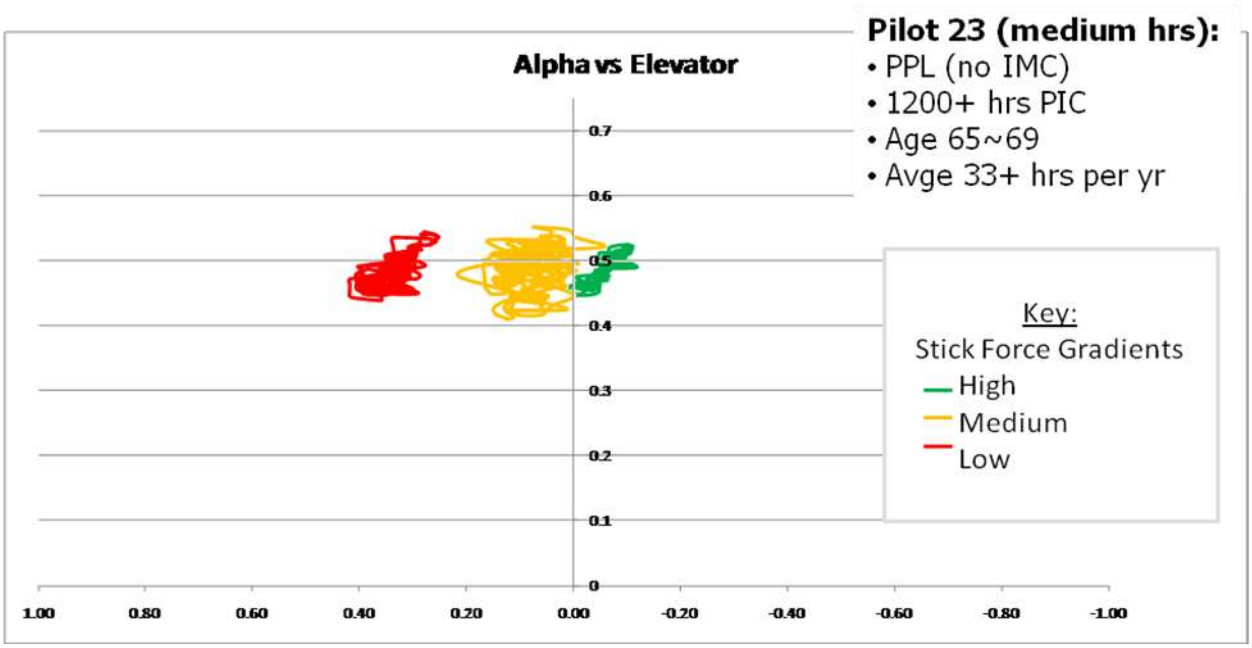

Figure 10, Non-dimensionalised AoA versus elevator position for medium experience pilot executing climb-out

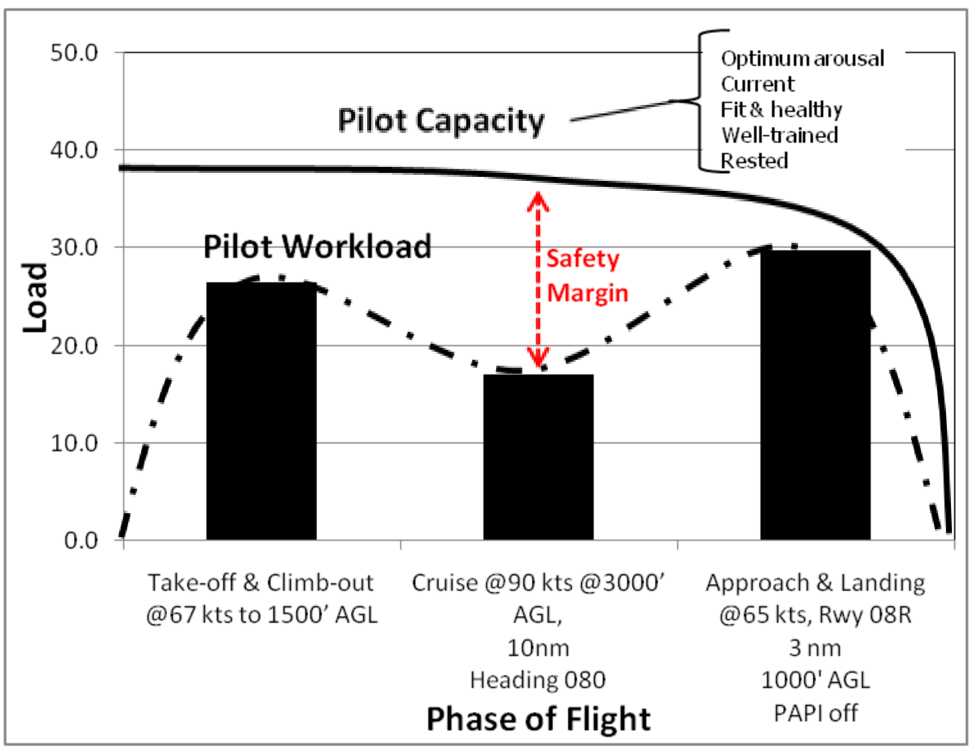

Figure 11, Illustration of pilot workload through prior flight from simulator results

Figure 11, shows the variation of pilot workload from an earlier group of experiments to examine the variation of workload with phase of flight. The results show that for an optimally aroused, current, fit & healthy, well-trained and rested pilot, pilot capacity gradually decreases over time. Pilot workload increases with task complexity (e.g. re-configuration resulting in power, flap and hence trim changes). The take-off & climb-out and approach & landing result in higher workload than cruising fight. 'Safety margin' is represented by the difference between pilot capacity and pilot workload. The 'safety margin' decreases in safety-critical high workload phases of flight such as the takeoff & climb-out and approach & landing.

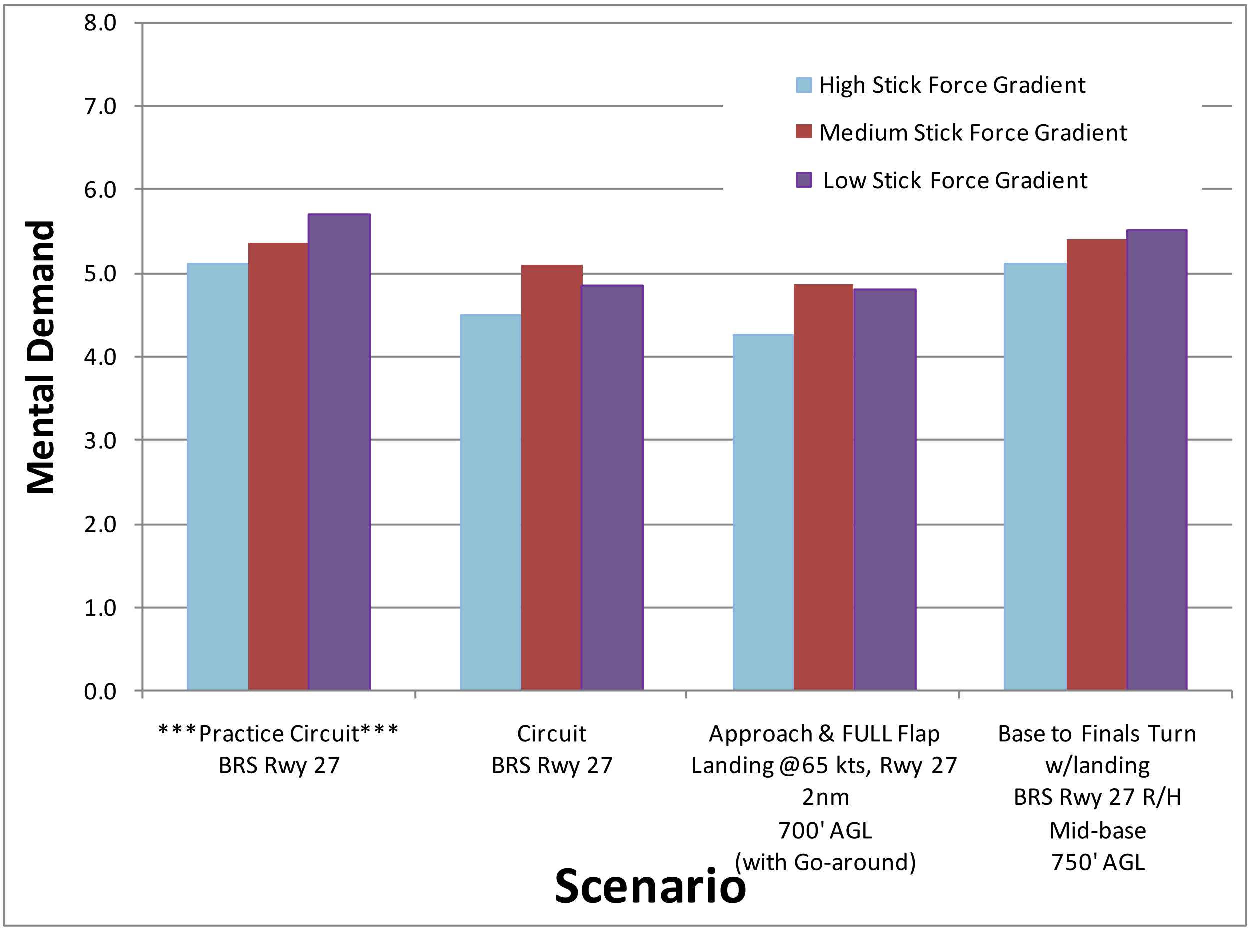

Figure 12, Illustration of pilot mental demand through flight from simulator results

Figure 12 shows the recorded mean pilot mental workload during a practice circuit, circuit, approach and landing with baulked landing and base to finals turn for all three stick force gradients (high ~0.0666 daN/kn, equating to about 4½lb to stall, medium ~0.03 daN/kn, low ~0.006 daN/kn). Although there are local discrepancies, in general, the results show increased mental workload for both medium and low stick force gradients compared to high.

CONCLUSIONS ABOUT LOSS OF CONTROL

It was concluded from this work that avoidance of low speed in-flight loss of control (LoC, or stall) is primarily about preventing the pilot-aeroplane combination from crossing the high AoA / low speed boundary which defines the stall. Providing the pilot with the ability to avoid this, requires good cues, and also a sufficiently low workload that they can perceive these cues. Whilst this itself should be fairly self evident, this study has also shown that all else remaining unchanged, in such low performance aeroplanes designed for student and private pilots, pitch control forces are very significant in helping a pilot avoid the stall, with higher control force gradients providing better avoidance.

With regard to the particular aeroplanes, it was also the view of the researchers that the Cessna 150 and Cessna 152 aeroplanes should be regarded as separate types with conversion training in either direction – but particularly when a pilot goes from the Cessna 152 to the Cessna 150, which has poorer flap mechanisation and lower control force gradients. This is a reflection of the fact that when Cessna developed the C150 into the C152, they clearly made significant safety improvements to the design with regard to cockpit ergonomics, performance and pitch control.

When comparing these aeroplanes to certification standards, it became the opinion of the researchers that most standards leave the issue of pitch control forces, particularly approaching the stall, are too poorly defined making it possible for aeroplanes with very little control force based low speed warning to become certified on the basis of subjective opinion. The Cessna 152, which has low control forces but a very good safety record has pull forces to stall of 4.2 daN (9lbf) in cruise configuration, or 1.4daN (3lbf) in landing configuration. These might therefore be a good starting point for any future requirement for a minimum pull force to stall (PFtS). The research team have also found the use of human factors tools – traditional cockpit assessment and the Cooper Harper Rating (CHR) scale very beneficial in this assessment, and they should almost certainly be useful to other assessment teams, as of-course they have been in the past.

Further work is required, and some of this will be done by the authors in their continued flight safety research. In particular further investigation of how pilots can be made aware of the implications of the stalling characteristics of their particular aeroplane, perhaps with reference to historical standards, and also with regard to how to incorporate the Flight Control Mechanical Characteristics (FCMC) in LSS models.

LESSONS LEARNED IN CONDUCTING THE TEST PROGRAMME

This was an unusual test programme – conducted using non-dedicated, non-owned flight test resources within flying schools. In particular, all management of non-standard equipment must remain fully with the test team, who must be sufficiently current in its use to be able to fit and remove it, as well as conduct flight test sorties, within the standard flying school 2-hour “slot”. Maintenance standards were variable, and the test team also had to be particularly diligent in their go/no-go serviceability decisions, as well as always checking (back to the calculations from empty aircraft wheel-weights) all weight and balance reports, which routinely contained errors.

Workup, with multiple test resources spread across different airfields and organisations, needed managing very carefully. Sharing information about the programme, Test Pilot recency, and workup flying with aircraft owners helped considerably, but it also rested with the flight test team to both ensure adequate recency and type knowledge, and to take advantage of increasing recency to obtain greater testing efficiency.

It was necessary to start with a relatively general test programme, covering much more information than would be eventually needed. In doing so, it was important to continuously review test results, so as to narrow into the tests that would become genuinely important to the research conclusions. It is, of-course, never good practice to launch on any test sortie without sufficient analysis of all previous sorties but this is for test efficiency reasons, as well as the more commonly discussed safety ones.

This test programme has re-learned the classic lesson that numerical test data, must always be supplemented and qualified by cockpit obtained data, and by the opinion of a competent and current Test Pilot.

FINANCIAL SUMMARY

This paper is about low cost flight testing, and so it is appropriate to indicate the cost of this programme. The two main researchers time isn't accounted here – Guy Gratton's time is released from a day job with the Natural Environment Research Council, whilst Mike Bromfield's is funded by the Thomas Gerald Gray Charitable Trust Research Scholarship Scheme. However, the remainder can be accounted and provides an illustration of the costs of a test programme in light aeroplanes.

No.	Item	Approx. Cost (US$ at 2010 rates)
1	25hrs 35 mins flying time in rented aeroplanes	4,500
2	Handheld cockpit test equipment	150
3	Cockpit mounted video recorder	450
4	Appareo GAU1000A Flight Data Recorder	2,000
5	Garmin 296 GPS	1,500
6	47 hrs in the Sheffield University research simulator	4,000
	Total:	12,600

There was additional use of simulators at Brunel University which were available to the research team free of charge, because this equipment was purchased for and primarily used for undergraduate teaching purposes.

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AUTHORS

Mike Bromfield is a postgraduate research student investigating the factors affecting loss of control of light aircraft. Mike started his career in Aviation in 1979 at Westland Aircraft, completing a 5-year Technologist Apprenticeship/Thin Sandwich Course in conjunction with the University of Bath. After his apprenticeship, Mike left Westlands to work for a product development company, gaining his MPhil in 1988 and becoming a Chartered Mechanical Engineer in 1990. Between 1991 and 2007, Mike alternated between the UK and Australia working on various Information Technology and flight simulation projects, also gaining his PPL and building up flying hours in 12 different aircraft types. In October 2007, Mike joined Brunel University and is funded by Brunel University and the Thomas Gerald Gray Charitable Trust, whilst working closely with the General Aviation Safety Council.

Dr Guy Gratton started his career at the Royal Aircraft Establishment at Farnborough in 1988, then Southampton University. After graduating from Southampton he worked as a fixed wing Flight Test Engineer, then Environmental Test manager at the Aeroplane and Armaments Experimental Establishment at Boscombe Down – also becoming a Chartered Aeronautical (and later Mechanical) Engineer in 1995. Leaving there in 1997 to become Chief Technical Officer to the British Microlight Aircraft Association where he became approved by the CAA as a Microlight Test Pilot in 1999 and gained a PhD from Southampton in aerospace engineering in 2004. Guy has been with Brunel University since 2005, although now primarily manages the UK's Facility for Airborne Atmospheric Measurements based at Cranfield University. Guy has written 1 book, over 130 magazine articles, and 9 first author academic journal papers on aviation topics, and has 1100 flying hours of which about 360 were in flight test – split between TP and FTE flying.

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