

The benefits and limitations of ground-based upset-recovery training for general aviation pilots

R. O. Rogers

rogers@erau.edu

Department of Aeronautical Science
Embry-Riddle Aeronautical University
Daytona Beach, Florida
USA

A. Boquet

boque007@erau.edu

Department of Human Factors
Embry-Riddle Aeronautical University
Daytona Beach, Florida
USA

ABSTRACT

Research by Rogers *et al* (2009) and Leland *et al* established that flight simulator training can improve a pilot's ability to recover a general aviation aeroplane from an in-flight upset. To reach this conclusion, they administered simulator-based and classroom-based upset-recovery training to two groups of student pilots, then compared their performance in recovering an aerobatic Decathlon aeroplane from a series of four upsets with the performance of a third group of untrained control group pilots subjected to the same upsets. We extend this result by addressing the unanswered question of how much classroom-based training as opposed to simulator-based training contributes to improving a pilot's upset-recovery manoeuvring skills. After receiving classroom-based upset-recovery training but no simulator training, our participants were subjected to the same series of four upsets in the same Decathlon aeroplane. We then compared the performance of the classroom-trained pilots with the performances of control group pilots and the two groups of simulator-trained pilots. Statistical analysis suggests that classroom-based instruction alone improves a pilot's ability to recover an aeroplane from an upset. We summarise related research, describe the training experiment and the training program, analyse and interpret flight-test data, and explain what our research implies with respect to establishing career-long commercial pilot upset-recovery training requirements.

NOMENCLATURE

AHRS	attitude and heading reference system
Allowable G	maximum allowable G force beyond which wing spar damage is possible
AOA	angle-of-attack of an aeroplane's wing
APS	Aviation Performance Solutions, an upset-recovery training company
AURTA	Aeroplane Upset Recovery Training Aid
Available G	for a given airspeed, maximum G force possible before an aeroplane's wing stalls
ERAU	Embry-Riddle Aeronautical University
FAA	US Federal Aviation Administration
FFS	full flight simulator, i.e. Level D flight simulator
fpm	Frames per minute
FPM	feet per minute
GL2000	centrifugal flight simulator manufactured by Environmental Tectonics Corporation
ICATEE	International Committee for Aeronautical Training in Extended Envelops
LOC-I	loss of control in-flight
MANOVA	multivariate analysis of variance
MFS	Microsoft Flight Simulator
MPH	miles per hour
MSL	mean sea level
n	number of data sets processed in statistical analysis
NASTAR	National Aerospace Training and Research
RAeS	Royal Aeronautical Society, London, UK
RPM	propeller revolutions per minute
Ultimate G	G force at which failure of an aeroplane's wing spars is expected
$V-n$	V = airspeed and n = G force in an aeroplane's $V-n$ diagram
V_{NE}	an aeroplane's never exceed or redline speed
V_S	an aeroplane's 1G stall speed

1.0 INTRODUCTION

An upset occurs when an aeroplane enters an unexpected attitude that threatens loss of control in-flight (LOC-I) and subsequent ground impact. It is well known that from 1991 onward LOC-I has been a major cause of air transport accidents worldwide⁽¹⁾. The same holds true for general aviation aeroplane accidents in the US and Australia during approximately the same time period⁽²⁾. As a consequence, the importance of upset-recovery training has been widely publicised in the past two decades, and air transport pilots typically receive such training in flight-simulator sessions combined with classroom instruction. However, few experimental studies exist to verify the effectiveness of ground-based upset-recovery training in improving a pilot's upset-recovery manoeuvring skills. We report on a research experiment to evaluate transfer of upset-recovery training conducted using classroom instruction only. We assessed training effectiveness by means of in-flight upset-recovery testing in an aerobatic general aviation aeroplane. Our research also implies that there may be notable limits to the effectiveness of ground-based upset-recovery training, whether classroom-based or simulator-based or both. In what follows, we

- Briefly summarise relevant prior research
- Describe the experiment
- Explain how we instructed research participants
- Present and interpret the experimental results
- Explain what our research implies about the need for career-long pilot upset-recovery training

2.0 PRIOR RESEARCH

We are aware of only a few research articles related to the transfer of simulator-based upset-recovery training. In what follows we briefly summarise these articles in five subsections. The first subsection discusses research conducted at the Calspan In-Flight Upset Recovery Training Programme in Roswell, New Mexico. The second summarises articles which discuss human factors considerations in upset-recovery training. A third subsection discusses training transfer when all-attitude manoeuvring is taught using low-cost flight simulation software running on desktop computers. The fourth presents a single article on training transfer when upset-recovery training is conducted in a centrifugal flight simulator. The fifth subsection discusses articles emanating from the June 2009 RAeS Flight Simulation Group Conference and from ICATEE, an RAeS initiative.

2.1 Calspan related research

Calspan provides in-flight simulator-based upset-recovery training in a variable stability Learjet 25 with fly-by-wire right-seat controls computer designed to simulate the control characteristics of a medium-size air transport aeroplane, e.g. a B737. The Calspan Lear can simulate various accident scenarios that in the past have resulted in air transport upsets leading to uncontrolled crashes, including hardover rudder displacement unrequested by the pilot, stuck aileron, complete loss of flight controls, etc.

Gawron⁽³⁾ used Calspan's Learjet to test five groups of airline pilots with varying degrees of upset-recovery training and/or aerobatics experience on a series of eight upsets, hypothesising that pilots with more training and/or experience would outperform those with less. However, she found no significant difference among the performances of the five groups.

Kochan⁽⁴⁾ used the Calspan Lear to examine the roles of domain knowledge and judgment in upset-recovery proficiency. Domain knowledge is specific knowledge about upset-recovery procedures. Judgment is the ability to analyse and learn from an in-flight upset-recovery experience. She tested four groups of participants on a series of three in-flight upsets. Statistical analyses revealed that judgment was a significant factor in successful upset recovery, especially when a pilot has low domain knowledge, i.e., when a pilot is not trained to proficiency in upset recovery.

Kochan and Priest⁽⁵⁾ studied the effect of upset-recovery training in the Lear. They measured pre- and post-training pilot performance in recovering from a series of upsets. Statistical analysis indicated 'a strong positive influence of the (Calspan programme) on a pilot's ability to respond to an in-flight upset.'

Kochan *et al*(2005)⁽⁶⁾ surveyed retention of knowledge in Calspan-trained pilots. Although participants 'rated their ability to recover from loss-of-control situations as being greatly improved by the training,' in retrospect most were unable to recall various specific details about pilot upset-recovery manoeuvring techniques taught during their training.

2.2 Human factors considerations in upset-recovery training

A number of papers examine the 'surprise' or 'startle' factor in aviation, an effect that can hinder a pilot's ability to respond appropriately to an emergency situation such as an upset. Kochan *et al*(2004)⁽⁷⁾ found pilots often miss cues that might lead to avoiding an emergency that later arrives as a surprise. In a follow-on paper, the same researchers developed 'a conceptual framework for the study of unexpected events in aviation'⁽⁸⁾. Kochan, Priest, and Moskal^(9,10) used a model for the 'cognitive process of surprise'⁽¹¹⁾ to study 'how an unexpected event can escalate to a loss-of-control situation.' They concluded that in-flight (as opposed to ground-based) simulator training may be necessary to teach pilots to deal adequately with their perceptual biases (i.e. systematic individual biases that unconsciously influence perception) in processing information during a surprise upset. In a related paper, Kochan⁽¹²⁾ argued that a pilot's response to unexpected events can be improved through cognitive flexibility training (to discourage formulaic and encourage flexible responses to surprise events), adaptive expertise training (to reinforce modified or new responses to surprise based on responses learned in previous expert training), and metacognitive training (to teach pilots how to evaluate their mental processes in responding to surprise).

2.3 Low-cost flight simulation

Roessingh⁽¹³⁾ studied transfer of low-cost flight-simulator training to control of an actual aeroplane during aerobatic flight. Two experimental groups received ground-based instruction in aerobatic manoeuvring using desktop flight simulators. The simulator syllabus was the same for both groups, but one experimental group's simulator training was enhanced with a more 'realistic layout of stick, rudder pedals, and throttle' (i.e. more like the actual aeroplane). Then the two experimental groups and a control group received five hours of in-flight aerobatic training. Data collected during subsequent testing revealed no significant difference in the aerobatic manoeuvring of two groups of trained pilots and control group pilots.

Rogers *et al*(2007)⁽¹⁴⁾ trained pilots in upset recovery using classroom instruction and low-cost desktop flight simulation. They then subjected them to a series of upsets in an aerobatic Beech Bonanza aeroplane and compared their performance with the performance of untrained control group pilots subjected to the same upsets. Statistical analysis revealed that trained participants outperformed control group participants in a variety of dependent variable such as thrust manipulation, G force control, and roll responses; however, in the most important discriminator, altitude loss, there was no significant difference between the two groups. The authors argued that shortcomings in training and testing procedures negatively influenced the experimental results, conjecturing that increased training transfer would result if the experiment were repeated with improved approaches to training and testing.

This conjecture was confirmed in Rogers *et al*(2009)⁽¹⁵⁾. As in the earlier study, self-selected participants were student pilots at Embry-Riddle Aeronautical University (ERAU) with a current instrument rating, implying they also held a private pilot certificate. They had also completed an academic course in basic aerodynamics for pilots, and none had prior aerobatic experience or had received prior upset-recovery training beyond what is minimally required for FAA flight certificates and ratings. Half of the participants received upset-recovery instruction using Microsoft Flight Simulator (MFS) reinforced by classroom

instruction; half were assigned to an untrained control group. All participants were subjected to a series of four upsets in an aerobatic Decathlon aeroplane. A two group multivariate analysis with six dependant measures revealed that MFS-trained pilots outperformed untrained control groups pilots in most dependent measures, including altitude loss in two nose–low but not in two nose–high upsets.

2.4 Centrifuge-based flight simulation

Leland *et al*⁽¹⁶⁾ extended Rogers *et al*(2009) by introducing a third group of research participants who, as before, held an instrument rating, had completed a course in aerodynamics, and were inexperienced in aerobatics and upset-recovery manoeuvring. This third group of ERAU pilots received classroom training and simulator training in both MFS and in an Environmental Tectonics Corporation GL-2000 centrifugal flight simulator capable of generating sustained G forces. They were then subjected to the same four upsets in the same aeroplane used in Rogers *et al*(2009). A three group multivariate analyses revealed that the pilots trained on both MFS and the GL2000 outperformed control group pilots but only very slightly outperformed pilots trained solely on MFS, who also outperformed control group pilots.

2.5 Royal Aeronautical Society/ICATEE initiative on upset prevention and recovery

For the past two and a half years, The International Committee for Aeronautical Training in Extended Envelopes (ICATEE) has been researching information to produce documents on upset-recovery training and flight simulator fidelity. The committee's goal is the improvement worldwide of transport pilot upset manoeuvring skills. ICATEE will identify changes to air transport full flight simulators and to instructor operating stations that can improve stall training and upset recovery training. In addition, the committee will provide updates and additions to Version 2 of the Aeroplane Upset Recovery Training Aid (AURTA)⁽¹⁷⁾ and will promulgate a plan for career-long air transport pilot upset recovery training beginning with student pilot credentialing. Recommendations will be forthcoming in 2012, and it seems likely that they will have a profound long-term effect on upset recovery training.

An initiative of the Royal Aeronautical Society (RAeS), ICATEE was formed at the June 2009 RAeS Flight Simulation Group Conference on Flight Simulation: Towards the Edge of the Envelope. ICATEE is chaired by Sunjoo Advani, who also chaired the June 2009 RAeS Conference. A number of conference presentations focused on upset-recovery training. Captain Bryan Burks⁽¹⁸⁾ summarised shortcomings in current air transport upset-recovery training and suggested needed improvements. Captain David Carbaugh *et al*⁽¹⁹⁾ explained approaches to upset-recovery training at the Boeing Company and described an experiment (based on a paper by Boeing test pilot William Roberson⁽²⁰⁾) to determine the utility of various pilot techniques for recovering an air transport aeroplane from an upset attitude. Jim Priest⁽²¹⁾ described an upset-recovery training programme Calspan developed for FedEx that distinguishes between training that can be done satisfactorily in a full flight simulator (FFS) and training which must be accomplished in an in-flight simulator such as the Calspan LearJet mentioned in Section 2.1. Paul 'BJ' Ransbury⁽²²⁾ explained an

upset-recovery training programme conducted at APS Emergency Manoeuvre Training in Mesa, Arizona which employs both an FFS and an Extra-300 aerobatic aeroplane. Keith George⁽²³⁾ described upset-recovery training conducted in centrifuge-based flight simulators at the Environmental Tectonics Corporation's NASTAR Centre. Finally, a follow-on article by Advani *et al*⁽²⁴⁾ is an excellent summary of ICATEE's accomplishments to date.

3.0 THE RESEARCH EXPERIMENT

3.1 Experiment design

Rogers *et al*(2009) and Leland *et al* established that a combination of classroom-based and simulator-based upset-recovery training can improve a pilot's ability to recover a light general aviation aeroplane from an upset. However, both analyses left unanswered the question of how much classroom-based training, as opposed to simulator-based training, contributed to improving pilot upset-recovery manoeuvring skills. Our research introduces a fourth group of pilots to address this question. We hypothesised that classroom-based upset-recovery training alone is sufficient to develop aeronautical knowledge that improves a pilot's ability to recover from an upset in a real aeroplane. To test this hypothesis, we exposed a fourth group of self-selected ERAU student pilots to ten hours of classroom-based upset-recovery training only. We then subjected these classroom-trained pilots to the same in-flight upsets in the same Decathlon aeroplane used in Rogers *et al*(2009) and Leland *et al*. As previously explained, all research participants held an instrument rating, all had completed a course in aerodynamics for pilots, and none had prior aerobatic experience or had received prior upset-recovery training beyond what is required for FAA flight certificates and ratings.

As reflected in Table 1, our experiment is a 4×4 repeated measures factorial. The first independent variable is degree of training and has four levels: GL2000-trained, MFS-trained, classroom-trained, and untrained. GL2000-trained participants received ten hours of classroom training and ten hours of simulator training, five hours in MFS and five hours in the GL2000. MFS-trained participants received ten hours of classroom training and ten hours of MFS-based simulator training. Classroom-trained pilots received ten hours of classroom-based instruction but no simulator training. Control group pilots received no classroom or simulator training. The second independent variable is upset attitude. It has four levels corresponding to the four upsets each participant was subjected to during flight testing.

Table 1
4 × 4 Factorial design

4 x 4 Factorial		Upset Attitude (Repeated Measure)			
		Nose-High Upright	Nose-Low Upright	Nose-High Inverted	Nose-Low Inverted
Training	10 Hours Classroom / 5 Hours MFS +5 Hours GL2000	GL-2000/MFS-Trained Pilots	GL-2000/MFS-Trained Pilots	GL-2000/MFS-Trained Pilots	GL-2000/MFS-Trained Pilots
	10 Hours Classroom 10 Hours MFS Training	MFS-Trained Pilots	MFS-Trained Pilots	MFS-Trained Pilots	MFS-Trained Pilots
	10 Hours Classroom No Simulator Training	Classroom-Trained Pilots	Classroom-Trained Pilots	Classroom-Trained Pilots	Classroom-Trained Pilots
	None	Untrained Pilots	Untrained Pilots	Untrained Pilots	Untrained Pilots

3.2 Upset attitudes and aircraft energy levels

Upset attitudes are categorised as nose-high or nose-low and as upright or inverted. An inverted attitude is one where the bank angle exceeds 90° . Table 2 specifies the attitude, thrust setting, kinetic energy level, and initial rate of climb or descent for each of the four upsets. The vertical speeds are calculated from initial pitch attitudes and airspeeds, not set by the safety pilot, and are included solely for reader interest. Nose-high initial airspeeds were set 12mph above $V_S = 53\text{mph}$ for the Decathlon, while nose-lose airspeeds reflect a maximum safe value based on the Decathlon's red line speed $V_{NE} = 200\text{mph}$. The 180° roll attitude for inverted upsets was chosen because it simplified the demanding safety-pilot task of positioning the aircraft accurately from the Decathlon back seat, which has no instrumentation. Accurate positioning is critical to the success of the experiment because deviations from a prescribed upset attitude or airspeed affect the potential minimum altitude loss during an upset recovery.

Table 2
Levels of the upset attitude independent variable

Upset	Pitch	Bank	Airspeed	Vertical. Speed	Thrust
Nose-high Upright	60° Nose-High	45° Left Wing Down	65 MPH	4954 FPM \uparrow	Idle
Nose-low Upright	45° Nose-Low	70° Right Wing Down	130 MPH	8089 FPM \downarrow	Full
Nose-high Inverted	60° Nose-High	180° (Inverted, Wings Level)	65 MPH	4954 FPM \uparrow	Idle
Nose-low Inverted	20° Nose-Low	180° (Inverted, Wings Level)	110 MPH	3311 FPM \downarrow	Full

3.3 Dependent variables

Following Rogers *et al*(2009)⁽²⁾ and Leland *et al*⁽¹⁶⁾, we defined a good upset recovery as one where a pilot respects aircraft operating limitations while returning the aircraft to straight-and-level flight in the shortest possible time with the minimum possible loss of altitude. Minimum altitude loss and a short time to recover will result from:

- Prompt and correct control and throttle inputs in response to an upset situation
- A high roll rate toward an upright attitude to orient the lift vector toward the sky
- Appropriate G forces unloading during low-speed flight or inverted rolls
- Application of high Gs in upright dive pullouts while avoiding accelerated stalls

The dependent variables in our experiment, shown in Table 3, are designed to measure these factors.

Table 3
Dependent variables

Dependent Measure
Altitude Loss in Feet: Negative Value = Altitude Gain
Maximum G Force in Dive Pullout
Minimum G Force Unloading during Rolls
Time to First Correct Throttle Response in Seconds
Time to First Correct Roll Response in Seconds
Time to Recover in Seconds

3.4 Flight testing procedures and data collection methodology

To administer each upset, the safety pilot positioned the aircraft in straight-and-level flight at 5,000ft MSL. At the safety pilot's request, the participant pilot reset the G meter's maximum and minimum markers to zero. Then the safety pilot instructed the participant pilot to 'close your eyes,' and, after turning on the video recorder, manoeuvred the aeroplane into position for the next upset while the participant pilot's eyes remained closed. When the aeroplane was in position, the safety pilot's voice transmission to the participant pilot to assume control was 'recover, recover, recover.' Upon hearing this transmission, the participant pilot opened his or her eyes and attempted to return the aircraft to straight-and level flight. A recovery was successful if the participant pilot recovered the aircraft without assistance from the safety pilot. If the safety pilot felt compelled for safety considerations to take control of the aeroplane during recovery, he did so by announcing 'I have the aeroplane.' Whenever that happened, typically as a result of threatening V_{NE} during nose-low recoveries, the recovery was categorised as unsuccessful.

Data was collected using a battery-operated video camera focused on the Decathlon's instrument panel. A high-resolution palm-size video recorder (640 × 480 @ 30fps) captured the camera's output and cockpit voice communications. Two factors prevented using a more sophisticated data recording system: the very significant cost of a flight data recorder and a prohibition against invasive instrumentation in an ERAU training aircraft. Also installed in the Decathlon was an Appareo GAU-1000 AHRS data recorder, an inexpensive battery operated GPS-based system capable of capturing aircraft position, altitude, airspeed, attitude (pitch and bank), G forces (x , y , and z), yaw angles (β), and similar parameters. However, only the G force readings were reliable in aerobatic flight.

Figure 1 presents a frame capture of a video recorded during flight testing. Initial and final altitude readings were used to determine altitude loss. Throttle changes could be seen on the RPM gauge and roll responses on the attitude indicator. Elapsed times to throttle application, roll initiation, and upset recovery were determined using the time stamp on each video frame. The GAU-1000 G readings and the Decathlon G-meter readings supplied G force information. The two values typically were identical and never differed by more than $\pm 0.2Gs$; if the readings were not the same, we averaged the two to determine G force.

3.5 Group sizes and average flight time

Table 4 reports pilot demographics.

Table 4
Group sizes and average flight time for each of the four participant groups

Group	Pilots	Mean Flight Hours	Standard Deviation
GSL2000 Trained	25	249.9	134.9
MFS-Trained	25	201.2	85.9
Classroom-Trained	24	224.2	83.2
Control	26	160.5	54.0



Figure 1. Sample decathlon video recorder output.

4.0 THE TRAINING PROGRAMME

In this section, we provide a brief overview of how research participants were trained. It would require a separate paper to describe our upset-recovery training regimen fully and to explain everything we learned about effective upset-recovery instruction over four flight testing periods.

All trained research participants were ERAU students registered for a one credit-hour academic course—AS471 All Attitude Flight and Upset Recovery. The course was developed and has been refined by the first author of this paper over a period of nine years. The course requires ten hours of classroom and ten hours of simulator-based instruction, both delivered at the rate of one hour per week. As explained in Section 3, classroom-trained research participants received only the ten hours of classroom instruction. AS471 training materials including the current version of the course text and instructional videos may be viewed at the course web site: <http://faculty.erau.edu/rogersr/as471>.

4.1 Training instructors

The first author of this paper delivered classroom instruction for all three groups of trained pilots. He also wrote the AS471 textbook. All simulator-based training was delivered by ERAU student lab assistants trained by the first author, with the exception of the five hours of centrifuge-based training, which was conducted by instructors at the Environmental Tectonics Corporation in Pennsylvania over the course of five successive weekends, with 5 of 25 research participants trained during each weekend.

4.2 Classroom instruction in upset-recovery aerodynamics

The first four of the ten classroom hours were devoted to the study of aerodynamic principles and concepts relevant to upset-recovery manoeuvring. Concepts presented in class reading and lectures included but were not limited to:

- the necessity of creating unbalanced lift in order to manoeuvre.
- the effect of G force on stall speed.
- definitions of available, allowable, and ultimate G.
- the effect of high G on induced drag.
- the relationship between airspeed and available G.
- an aeroplane's V - n diagram.
- stall avoidance and recovery with particular emphasis on accelerated stalls.
- the fact that an aerodynamic stall cannot occur at 0G.
- rolling G limitations.
- the effect of airspeed on flight control effectiveness.
- the effect of AOA on aileron effectiveness in general aviation aeroplanes.
- the relationship between the lift vector and the weight vector during inverted manoeuvring.
- dihedral effect and yaw-induced roll and its application in low speed rolling manoeuvres in general aviation aeroplanes.

Knowledge of these and related aerodynamic concepts provided students a knowledge base to use in conceiving and executing a plan for recovering an aeroplane from an in-flight upset.

It is interesting to note that although research participants had previously completed a semester-long academic course in aerodynamics, they remembered little of what they had learned and were unaware of how to apply whatever knowledge they retained to the operation of an actual aeroplane during manoeuvring flight. Perhaps this is because their training almost exclusively involves flying straight and level or at shallow bank angles. They had never experienced very large bank or steep pitch angles, high-G forces, high-G accelerated stalls, inverted flight, or airspeeds below V_s or near V_{NE} . Thus they had little need and hence little motivation to remember what they had learned about aerodynamics.

4.3 Classroom instruction in upset-recovery manoeuvring

The remaining six hours of classroom instruction focused on upset-recovery manoeuvring. The upset-recovery process is a severely time-constrained problem-solving enterprise comprised of three stages. First, a pilot must categorise an upset with respect to pitch and roll attitudes and the aeroplane's potential and kinetic energy states. Next, he or she must devise a recovery strategy or plan based upon aeronautical principles applicable to the particular upset situation. Finally, the pilot must execute the recovery plan effectively, modifying it whenever the recovery does not proceed as anticipated.

Categorising an Upset. To teach upset categorisation to classroom-trained pilots, we used screen-capture videos of MFS upset-recovery manoeuvres to show classroom-trained participants what they would observe outside the Decathlon cockpit during nose-high and nose-low upright and inverted manoeuvring. MFS supports multiple windows which can be used to provide pilots with different outside-the-cockpit views on a single computer screen. Figure 2 depicts a screen-capture of an MFS video of a manoeuvring Decathlon. The small windows



Figure 2. A Frame from an MFS screen-capture video used to teach research participants how to use out-the-window views to determine an aeroplane's pitch and bank angles.

at mid-screen left, top, and mid-screen right look 90° left, straight ahead, and 90° right respectively. In early iterations of AS471, students were also instructed in using cockpit instruments to categorise an upset, but it became apparent from results of flight testing that it is extremely difficult to teach such information successfully to pilots who have never experienced all-attitude flight in an actual aeroplane. Subsequently we abandoned this effort and focused exclusively on upset-recovery manoeuvring during visual meteorological conditions.

Formulating a Recovery Plane. In this stage of classroom instruction, pilots learned how to make practical use of information they mastered in the four classroom hours devoted to upset-recovery aerodynamics. Well-trained pilots should be able to categorise an upset with respect to aircraft attitude and energy levels within a second or two. Once an upset is categorised, a pilot must rapidly construct a recovery plan (and commence executing it) using aerodynamic principles and concepts applicable to the current upset situation. Examples of applying such principles in planning include:

- G Control
 - Unloading to 0G to prevent a stall in a nose-high, low kinetic-energy upset. Zero G must be maintained until the nose falls through the horizon and the airspeed increases sufficiently to allow recovery from the ensuing dive.
 - Unloading to 0G in a nose-low inverted upset to avoid an increase in dive angle and a subsequent increased altitude loss. A pilot must not apply positive G on an aeroplane when the lift vector is pointed toward the ground. In the Decathlon, exerting a slight negative G force while inverted will save considerable altitude loss during recovery.
 - Pulling out of a dive at available/allowable G to minimise altitude loss.

- Avoiding an accelerated stall during manoeuvring by not attempting to apply more Gs than are available. This requires that a pilot memorise the minimum airspeeds at which 1, 2, 3, 4, 5, ... Gs are available in the aeroplane he or she is flying.
- Control Inputs
 - Using larger control inputs in upset-recovery manoeuvring situations than in typical general aviation flying at small pitch and bank angles.
 - Using larger control inputs at low airspeeds than at high airspeeds because control responsiveness is proportional to airspeed (dynamic or ram air pressure).
 - Using rudder to assist aileron in general aviation aeroplane rolls at low airspeeds; using rudder exclusively to roll at high AOA.
 - Immediately applying full thrust in a nose-high, low kinetic energy upset and reducing thrust to idle in a nose-low, high kinetic energy upset.

Executing the Recovery Plan – Conventional Upset Recoveries. We first taught research participants ‘canonical’ or conventional approaches to upset-recovery manoeuvring. For nose-high, low kinetic energy upsets, a conventional recovery requires applying full thrust, unloading to 0G, and rolling the aeroplane in the shorter direction to an upright steep bank (45–60° or more) to allow the nose to fall below the horizon and airspeed to increase above V_S . When flying airspeed is regained, the pilot rolls wings level and raises the nose to the horizon. Such a recovery is often referred to as a ‘knife-edge’ recovery because the nearly vertical wing is slicing through the air like a knife while the nose is falling toward the horizon.

For nose-low, high kinetic energy upsets, the conventional recovery involves rolling in the shorter direction towards a wings-level upright attitude. If the aeroplane is inverted during the first portion of the roll, the wing must be unloaded to 0G, because lift generated in an inverted attitude will steepen the dive angle and increase altitude loss significantly. Once the plane is no longer inverted and the lift vector is oriented toward the sky, it is possible to commence a rolling dive pullout immediately. Conventional wisdom, however, argues that the dive pullout should not commence until the wings are level or almost level: the closer to lift vector is to vertical, the more efficient the dive pullout. This approach to dive recovery minimises altitude loss only if the roll to an upright wings-level attitude is executed at a high roll rate and if a pilot promptly applies available/allowable G once a wings-level attitude is reached.

Minimum-Altitude-Loss Upset-Recovery Manoeuvring in the Decathlon Aeroplane. We understand that achieving minimum altitude loss is important in upset manoeuvring primarily when an aeroplane is close to the ground. However, in devising real-number dependent variables capable of being captured using a video camera focused on the instrument panel, altitude loss emerges as one of a relatively few quantifiable measures of pilot skills. In any event, our research experiment was constructed to address the question of whether upset manoeuvring techniques taught on the ground transfer to operation of a general aviation aeroplane during an in-flight upset situation, not to determine the best way to recover a light aeroplane from an upset. Moreover, the ability to recover from an upset with minimum altitude loss while respecting aeroplane limitations would seem to be a clear indication of superior piloting skills.

In early flight testing we observed that the knife-edge recovery for a nose-high upset in the Decathlon results in excessive altitude loss. Thereafter we taught AS471 students to use an ‘over-the-top’ nose-high recovery, so called because the recovery resembles the last portion of an Immelmann manoeuvre, during which an aeroplane rolls toward a wings level attitude while the nose is above the horizon and falling. In an over-the top recovery, the pilot unloads to 0G at full thrust and

rolls in the shorter direction towards a wings-level attitude. The high thrust-to-weight ratio of the Decathlon compared to conventional general aviation light aeroplanes facilitates an over-the-top recovery: the aeroplane ‘hangs’ on the propeller (a phenomenon sometimes called ‘helicopter effect’) as gravity pulls the nose of the aeroplane toward the horizon.

When an over-the-top manoeuvre is executed properly, the wings will be level or nearly level by the time the nose drops below the horizon, although airspeed will still be significantly below the 1G stall speed $V_s = 53\text{mph}$. At this point the pilot must continue to maintain 0G and allow the dive angle to increase until 65-70mph airspeed is reached, then gently raise the nose to the horizon to complete the manoeuvre. The pullout must be executed with patience. In the Decathlon, less than 2Gs are available at 65-70mph, and if a pilot pulls back too hard on the control stick, the wing will stall and the aircraft may depart from controlled flight, resulting in a very large altitude loss. In the nose-high upset attitudes described in Table 2, a properly executed over-the-top recovery will result in an altitude loss of no more than 200ft, and often significantly less. Occasionally an altitude gain occurs, since the climbing aeroplane continues to ascend until the nose falls below the horizon.

With respect to nose-low, high kinetic-energy upsets, in the conventional recovery the plane remains unloaded and continues to lose altitude rapidly until the wings are level and dive pullout commences. Flight testing revealed that participant pilots who used the conventional recovery lost excessive altitude. This happened because pilots inexperienced in all-attitude manoeuvring are slow to roll wings level, losing altitude the entire time they are rolling, and because they typically apply low G during the dive pullout. Average altitude losses decreased after we began teaching participant to use rolling pullouts.

4.4 Microsoft Flight Simulator advantages and limitations

During classroom training, research participants who received simulator-based training were introduced to the aerobatic manoeuvres they would perform on Microsoft Flight Simulator: Aileron Roll, Loop, Half- and Full-Cuban Eight, Split-S, Barrel Roll, and Immelmann. They were also briefed on the advantages and limitations of MFS as an upset-recovery training device. Advantages include excellent visuals; the ability to open multiple windows to show different outside-the-cockpit views on a single computer screen; the ability to attach peripheral devices such as joysticks and rudder pedals; realistic responses to control inputs when an aeroplane is flying near the middle of the flight envelop, as for example in aerobatic flight; and accurate instrument responses to changes in aircraft attitudes and speeds. Disadvantages include lack of control-force feedback, which makes it easy to over-control the simulated aeroplane (force-feedback joysticks were tried initially but quickly rejected as less desirable than conventional joysticks); the inability to provide motion cues and to simulate G forces encountered in all-attitude manoeuvring; and an imperfect aerodynamic model resulting in somewhat inaccurate responses to stall-recovery control inputs during low-speed dive pullouts. Of course, simulator limitations can lead to negative training, so participants were constantly apprised of situations where simulator responses to control input differed from responses they would encounter while flying the Decathlon flight-test aeroplane. We return to the subject of MFS limitations in Subsection 5.3 in the nose-high upright upset analysis.

4.5 Flight simulator instruction

Four of the ten hours of simulator-based instruction were devoted to aerobatics. Aerobatic manoeuvring allowed a student inexperienced in all-attitude flight to become used to flight at large pitch and bank angles including of course inverted flight. MFS responds to control input remarkably like a real aeroplane during aerobatic flight, which is conducted near the middle of the flight

envelop ($V-n$ diagram). The remaining six hours of instruction were spent practicing upset-recovery manoeuvring using the recovery strategies described above.

4.6 Evaluating student learning

Initially we used in-class examinations to test classroom learning. This conventional academic approach proved to be less than ideal because a student can pass a test without fully comprehending the concepts being tested, which could lead in turn to reduced pilot performance during flight testing. In aviation, to borrow a nice idea from an 18th century British poet, 'a little learning is a dangerous thing.' To improve student comprehension, ultimately we adopted a 'mastery learning' approach to assessing student learning. In mastery learning, whenever testing reveals a deficiency in comprehension, a student devotes additional study to any unmastered topics and repeats the test until a high level of comprehension is reflected. As implied by the results of our experiment as reported in the next section, the mastery learning approach was effective.

After adopting mastery learning, we tested classroom-learning using seven quizzes completed as homework assignments. The quizzes required a student to write paragraph answers to questions related to the assigned reading. Quiz contents evolved as the instructor learned more and more about what subjects students learn easily and what subjects they are challenged to comprehend. Quizzes were submitted on the day a course lecture presented the subjects covered on a quiz, ensuring that students arrived prepared to learn. A quiz was graded and returned at the following class period, during which the instructor engaged students in discussion about subjects they experienced difficulty in comprehending fully. Subsequently students revised and resubmitted quiz questions that reflected imperfect comprehension until mastery learning was achieved. Quizzes may be viewed at the AS471 course website.

Learning in simulator-based instruction was tested by means of an aerobatic flight check and an upset-recovery flight check. Both checks were conducted using MFS and also required closed-book quizzes touching on relevant flight concepts. Aerobatic manoeuvring was evaluated by measuring heading, altitude, and bank-angle control; proper application of G forces; and smoothness and appropriateness of control stick, rudder pedal, and throttle inputs. Upset-recovery manoeuvring was evaluated using the same parameters and, in addition, by measuring altitude loss during a recovery. If a flight check revealed performance deficiencies, a student reflow the check after additional study.

5.0 RESULTS

5.1 Flight-test data

Various factors including airsickness, equipment malfunction, and unsuccessful recoveries precluded obtaining a complete data set for every participant on every upset. Table 5 reports the total number of participants for whom we obtained usable data for each of the four upsets. Table 6 presents mean and standard deviation values for data collected during flight testing. Figure 3 depicts Table 6 mean values in graphical format.

5.2 Data analysis methodology

We conducted individual MANOVAs for each of the four upsets. Two factors motivated our decision to forego a more traditional 4×4 mixed-model analysis. First, because we eliminated data

Table 5
Group sizes for the four participant groups

Upset		Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
Pilot Group	Centrifuge-Trained Pilots	n=23	n=23	n=21	n=22
	MFS-Trained Pilots	n=25	n=25	n=19	n=24
	Classroom-Trained Pilots	n=24	n=24	n=19	n=23
	Control Group Pilots	n=26	n=26	n=17	n=26
	Combined Pilot Groups	n=98	n=98	n=76	n=95

Table 6
Mean and standard deviation dependent variable values for each upset

Upset	Nose-Low Upright				Nose-High Upright			
	GL2000	MFS	Class	Control	GL2000	MFS	Class	Control
Altitude Loss in Feet	600.00 <i>181.29</i>	565.20 <i>75.28</i>	573.75 <i>155.59</i>	728.46 <i>169.51</i>	213.04 <i>157.87</i>	331.20 <i>225.56</i>	107.50 <i>108.24</i>	340.38 <i>184.75</i>
Min Unload G in Rolls	Not Applicable: Pilots Were Trained to Use Rolling Dive Pullouts				0.10 <i>0.06</i>	0.00 <i>0.12</i>	0.08 <i>0.18</i>	-0.04 <i>0.15</i>
Max G in Dive Pullout	3.78 <i>0.57</i>	3.70 <i>0.64</i>	3.35 <i>0.79</i>	2.90 <i>0.49</i>	1.87 <i>0.42</i>	2.41 <i>0.90</i>	1.68 <i>0.41</i>	1.82 <i>0.30</i>
Seconds to First Throttle	2.45 <i>1.68</i>	3.00 <i>1.66</i>	3.04 <i>2.16</i>	5.19 <i>2.43</i>	1.83 <i>2.01</i>	2.12 <i>1.62</i>	1.54 <i>0.83</i>	3.27 <i>2.97</i>
Seconds to First Roll	1.32 <i>0.57</i>	1.28 <i>.46</i>	1.33 <i>0.48</i>	1.85 <i>0.68</i>	1.91 <i>0.90</i>	2.28 <i>-.89</i>	1.92 <i>0.58</i>	3.15 <i>1.38</i>
Seconds to Recover	5.27 <i>1.24</i>	5.40 <i>1.38</i>	5.46 <i>1.25</i>	7.04 <i>1.64</i>	10.26 <i>1.57</i>	11.16 <i>1.43</i>	9.21 <i>2.04</i>	12.88 <i>2.98</i>

Upset	Nose-Low Inverted				Nose-High Inverted			
	GL2000	MFS	Class	Control	GL2000	MFS	Class	Control
Altitude Loss in Feet	884.76 <i>179.41</i>	948.95 <i>167.03</i>	814.74 <i>233.01</i>	1069.41 <i>139.08</i>	368.18 <i>169.19</i>	382.08 <i>200.65</i>	418.70 <i>192.74</i>	464.62 <i>169.59</i>
Min Unload G in Rolls	0.57 <i>0.90</i>	0.99 <i>0.86</i>	-0.21 <i>0.87</i>	1.41 <i>0.63</i>	-0.39 <i>0.18</i>	-0.47 <i>0.28</i>	-0.45 <i>0.28</i>	-0.43 <i>0.26</i>
Max G in Dive Pullout	4.42 <i>0.57</i>	4.74 <i>0.62</i>	3.88 <i>1.00</i>	3.98 <i>0.50</i>	2.65 <i>0.49</i>	2.90 <i>0.84</i>	2.37 <i>0.65</i>	2.34 <i>0.45</i>
Seconds to First Throttle	2.90 <i>2.10</i>	2.79 <i>1.78</i>	5.21 <i>4.10</i>	4.41 <i>2.81</i>	2.14 <i>4.02</i>	1.48 <i>0.68</i>	2.43 <i>3.01</i>	3.31 <i>3.21</i>
Seconds to First Roll	2.48 <i>1.78</i>	1.68 <i>0.67</i>	1.95 <i>1.22</i>	4.88 <i>3.30</i>	4.41 <i>2.48</i>	3.04 <i>1.30</i>	3.39 <i>1.95</i>	6.15 <i>2.98</i>
Seconds to Recover	7.05 <i>0.97</i>	7.11 <i>1.29</i>	8.05 <i>2.04</i>	7.88 <i>0.99</i>	12.00 <i>2.91</i>	13.33 <i>1.74</i>	12.00 <i>2.00</i>	15.23 <i>2.27</i>

from unsuccessful recoveries in the nose-low inverted upset, a mixed-model analysis would have substantially reduced the sample size. Second, the nature of the upset data themselves argues against the direct comparisons that characterise a repeated-measures MANOVA. For example, a nose-high recovery may lead to an altitude gain whereas nose-low recoveries invariably result in significant altitude losses. Rather than compare disparate datum values, we utilised a more direct and operationally more relevant approach to data analysis.

Table 7 reports the Wilks Lambda, Alpha, and Partial Eta-squared values for each of the four MANOVAs. The results reflect a significant difference between the four groups at $p = 0.000$ for all four upsets. The consistent Eta-squared values indicate that about one-quarter (20%, 25%, 33%, 25%) of the variance detected by the MANOVAs is accounted for by the model; i.e., approximately one-quarter of the performance difference in each upset stems from differences in average performances

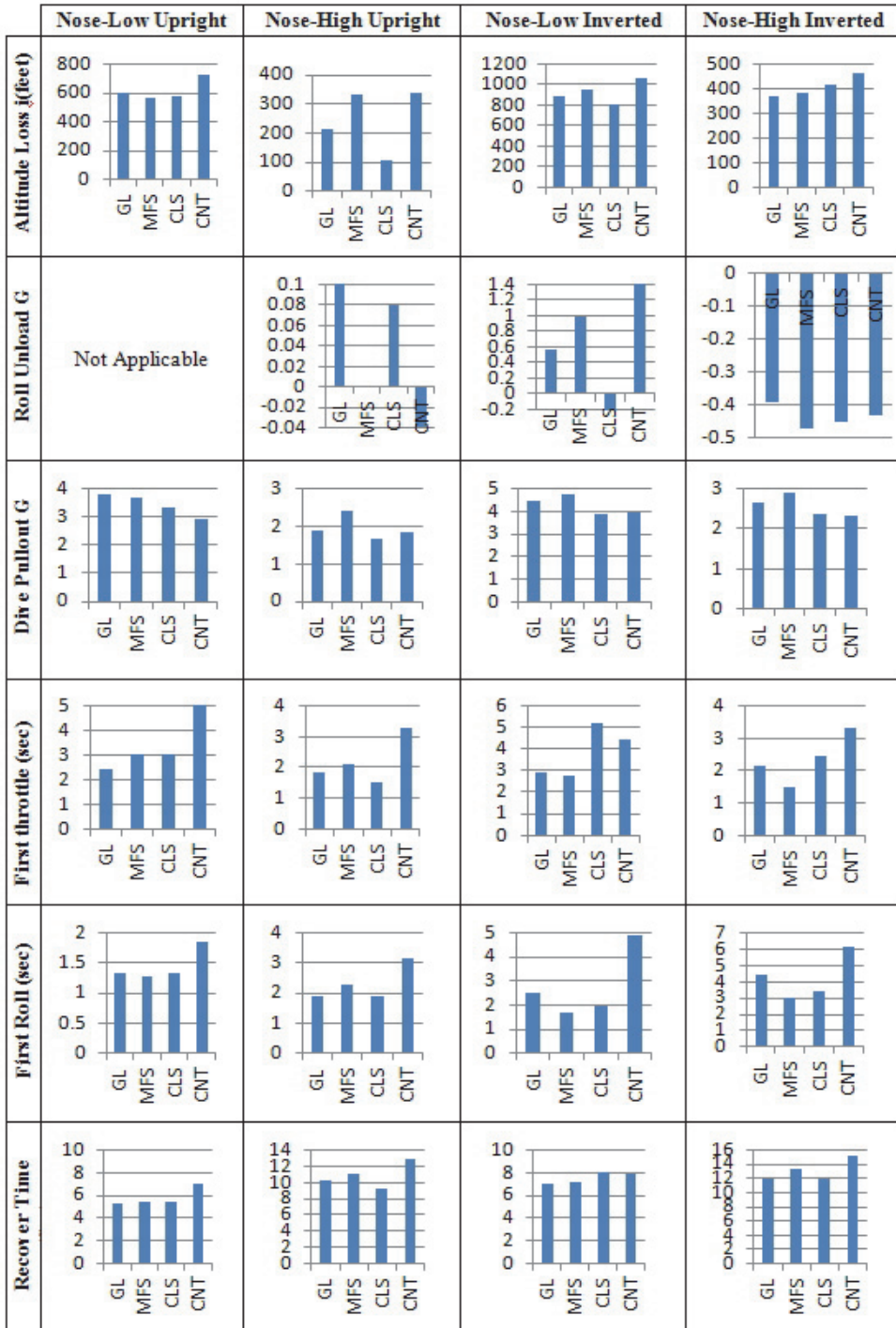


Figure 3. Graphical representations of mean datum values in Table 6.

among the four groups, while the remaining three-quarters results from differences in individual performances within each of the four groups. We understand that performing multiple one-way MANOVAs increases the family-wise error rate. However, the low computed alphas together with the magnitude of effect for each of the analyses provides confidence in our results while maintaining acceptable type 1 risks (below 0.05).

Table 7
Multivariate Wilks' lambda, alpha, and partial eta squared values for each upset

Upset	Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
Wilks' Lambda Value	F (15,246) = 4.49 p = 0.000 $\eta^2 = 0.199$	F (18,252) = 5.00 p = 0.000 $\eta^2 = 0.250$	F (18,190) = 5.70 p = 0.000 $\eta^2 = 0.334$	F (18,244) = 4.93 p = 0.000 $\eta^2 = 0.254$

Since the MANOVAs revealed a significant difference among groups for all four upsets, we conducted univariate analyses to assess the contribution of each dependent variable to statistical differences detected by the MANOVAs. The results of these ANOVAs are presented in Table 8.

Table 8
Univariate test F and alpha values for each of the four upsets
(**Bold** = Significant Difference; *Unbolded Italics* = No Significant Difference)

Dependent Measure	Upset			
	Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
Altitude Loss	F(3,93) = 6.51 p = 0.000	F(3,94) = 9.71 p = 0.000	F(3, 72) = 6.22 p = 0.001	<i>F(3,91) = 1.35</i> p = 0.263
Minimum Unload G in Rolls	Not Applicable	F(3,94) = 7.13 p = 0.000	F(3, 72) = 12.53 p = 0.000	<i>F(3,91) = 0.32</i> p = 0.812
Maximum G Load in Dive Pullout	F(3,93) = 9.84 p = 0.000	F(3,94) = 8.52 p = 0.000	F(3, 72) = 6.27 p = 0.001	F(3,91) = 4.51 p = 0.005
Seconds to First Throttle	F(3,93) = 8.94 p = 0.000	F(3,94) = 3.50 p = 0.018	F(3, 72) = 3.36 p = 0.023 †	<i>F(3,91) = 1.63</i> p = 0.189
Seconds to First Roll	F(3,93) = 5.99 p = 0.001	F(3,94) = 8.78 p = 0.000	F(3, 72) = 9.91 p = 0.000	F(3,91) = 9.40 p = 0.000
Seconds to Recover	F(3,93) = 9.02 p = 0.000	F(3,94) = 13.51 p = 0.000	<i>F(3, 72) = 2.68</i> p = 0.054	F(3,91) = 11.27 p = 0.000

†The corresponding cell is empty in Table 9, which reports significant pairwise comparisons. This ANOVA significance at $p = 0.023$ appears to be driven by marginally insignificant pairwise differences, four of which out of six would be significant at $p \leq 0.08$, with none of the four significant at $p \leq 0.05$.

Whenever an ANOVA value in Table 8 indicated that a dependent variable contributed to a statistically significant difference between the groups, we conducted protected pairwise comparisons among the four groups using the Bonferroni adjustment to determine the nature of the difference. Table 9 presents the results of these pairwise tests.

5.3 Upset-by-upset analysis of statistical results

Simulator-trained pilots are pilots who, in addition to classroom training, received training in a flight simulator, i.e. in the GL2000 and/or in MFS. Trained pilots are pilots who received training in a flight simulator and/or in the classroom, as opposed to control group pilots who received no training.

Table 9
Statistically significant differences between
paired groups for all dependent variables

Dependent Measure	Upset			
	Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
Altitude Loss	GL2000 < Control MFS < Control Class < Control	Class < MFS Class < Control	GL2000 < Control Class < Control	ANOVA Not Significant
Minimum Unload G in Rolls	Not Applicable	MFS < GL2000 Control < Class Control < GL2000	Class < GL2000 < Control Class < MFS	ANOVA Not Significant
Maximum G Load in Dive Pullout	GL2000 > Control MFS > Control	MFS > GL2000† MFS > Class MFS > Control	MFS > Class MFS > Control	MFS > Class† MFS > Control
Seconds to First Throttle	GL2000 < Control MFS < Control Class < Control	Class < Control		ANOVA Not Significant
Seconds to First Roll	GL2000 < Control MFS < Control Class < Control	GL2000 < Control MFS < Control Class < Control	GL2000 < Control MFS < Control Class < Control	MFS < Control Class < Control
Seconds to Recover	GL2000 < Control MFS < Control Class < Control	Class < MFS < Control GL2000 < Control	ANOVA Not Significant	GL2000 < Control MFS < Control Class < Control

†As explained in Section 5.3, the finding that a pilot group applied significantly higher Gs during dive pullout while recovering from a nose-high upset does not necessarily imply superior overall upset manoeuvring performance.

Nose-Low Upright Upset. Trained pilots performed significantly better than control group pilots in four of the five dependent measures – altitude loss, time to first throttle, time to first roll, and time to recover. In addition, simulator-trained pilots outperformed control group pilots in maximum G in dive pullout, whereas classroom-trained pilots did not. There were no significant differences between simulator-trained pilots and classroom-trained pilots. To summarise, except for dive pullout G forces, classroom-trained pilots performed at the same proficiency level as simulator-trained pilots, and all three groups of trained pilots outperformed untrained control group pilots.

Nose-High Upright Upset. As in the nose low upright upset, trained pilots outperformed control group pilots in the nose-high upright upset. All three trained groups outperformed the control group in seconds to first roll and in seconds to recover. In addition, MFS-trained pilots applied significantly more Gs in dive pullout and classroom-trained pilots lost less altitude and were quicker to apply thrust than control group pilots. An exception to trained-pilot superiority over control group pilots is reflected in the result that control group pilots unloaded to a lower G force than classroom-trained and GL2000-trained pilots during rolls. However, since all four pilot groups unloaded to within 0.1G of 0.0 – the ideal unload G – this statistically significant difference is of small consequence. The same observation diminishes the importance of MFS-trained pilots unloading more than GL2000-trained pilots.

In contrast to the nose-low upright upset, in the nose-high upright upset there were also important performance differences among trained-pilot groups. Unexpectedly, classroom-trained pilots lost significantly less altitude than MFS-trained pilots. One possible interpretation of this result is that limitations of MFS resulted in negative training. A nose-high low-air-speed upset in the Decathlon invariably evolves into a low-speed dive situation, requiring a pilot seeking a minimum altitude loss to pull out from the dive near the critical angle-of-attack, risking an accelerated stall. As previously explained, MFS's simulated Decathlon responds somewhat differently than the actual aeroplane to low-speed accelerated stall recovery control inputs, a fact which supports the negative training explanation.

We discount the negative-training explanation, however, because we are convinced that the small altitude loss achieved by classroom-trained pilots results instead from improved classroom training about how to avoid accelerated stalls/loss-of-control during low speed dive pullouts. When the Decathlon first reaches a nose-low attitude during a nose-high low-speed upset recovery, airspeed is typically 20-25mph below the 1G stall speed $V_S = 53$ mph. Several seconds elapse before gravity accelerates the aeroplane to 'flying' airspeed. Inexperienced pilots confronted with this situation too often attempt to pull out of the dive prematurely. Since more than 1G is required to raise the nose, and since available G at 37mph is 0.5 and 1.0 at 53mph, the attempt invariably fails. The result is an accelerated stall often followed by a departure from controlled flight, resulting in a steeper dive angle, increased airspeed before dive recovery is completed, and a much increased altitude loss. We frequently observed such accelerated-stall departures in both trained and untrained pilots during our first two flight testing periods conducted in the Decathlon.

To help classroom-trained pilots avoid this error, we repeatedly stressed that 0G must be maintained during nose-high recoveries until the nose falls low enough that airspeed increases to a minimum of 65mph. The oft-repeated mantra was: 'Stay at 0G when the nose falls below the horizon; get on the airspeed indicator, and don't try to stop the fall of the nose or recover from the dive until you see 65-70mph. Then without delay start a gentle dive pullout near available G, increasing G as airspeed increases. Do not stall the aeroplane.' At 65mph in the Decathlon about 1.5Gs are available, with 2Gs available at 75mph and 3Gs at 92mph.

Apparently classroom-trained pilots absorbed this concept and applied it successfully while flying the Decathlon. Only a very few classroom-trained pilots experienced an accelerated stall during low-speed dive recoveries, and without exception those few who did recovered quickly from the stall without departing from controlled flight. As a result, most of them recovered from the dive without exceeding 90mph, reducing altitude loss that increases as airspeed increases. The fact that classroom-trained pilots applied the lowest G forces of the four groups in the pullouts reflects the lower G available at their lower dive-recovery airspeeds. In contrast, MFS-trained pilots applied higher Gs than other groups in the nose-high upright upset dive recovery, yet still recorded a significantly larger altitude loss than classroom-trained pilots. This happened because a number of them experienced departures from controlled flight that caused nose-down pitches, resulting in an increase in airspeed and available G, but also in a significantly larger altitude loss. Thus the fact that MFS-trained pilots on average applied higher Gs than GL2000-trained, classroom-trained, or control group pilots reflects not overall superior upset-recovery performance. Instead it reflects failure in a number of cases to keep the aeroplane under control during low-speed dive pullout. This interpretation is strongly reinforced by the very high standard deviation (0.9Gs) of the mean dive pullout G (2.4Gs) for MFS-trained pilots.

Nose-Low Inverted Upset. Both GL2000-trained and classroom-trained pilots lost significantly less altitude than control-group pilots, and all three groups of trained pilots initiated rolls toward an upright attitude faster than control group pilots. In addition, GL2000-trained and classroom-trained pilots unloaded to a significantly lower G force than control group pilots while executing the roll to upright.

Differences between trained pilot groups occurred in unloading during inverted rolls, where classroom-trained pilots unloaded more efficiently than both GL2000-trained and MFS-trained pilots. We believe this result reflects constant reinforcement during classroom training to unload to between 0.0 and minus 0.5Gs while inverted. We did this to counter a very common general-aviation pilot response to a nose-low inverted upset – applying positive Gs while still inverted, i.e. 'pulling through' in a descending barrel roll or split-S recovery. The result is always an unnecessarily large altitude loss. This was a commonly observed response in the first two Decathlon flight-testing periods.

In addition, MFS-trained pilots pulled significantly more Gs in the upright pullout portion of the recovery yet lost more altitude than classroom-trained pilots. This result at first seems anomalous, since high G in a dive pullout reduces altitude loss and yet classroom-trained pilot lost less altitude in the recovery than MFS-trained pilots even though they pulled lower Gs in dive recovery. However, proper G unloading during the inverted portion of the recovery also substantially decreases altitude loss, since low G while inverted prevents the nose of the aeroplane from falling rapidly while rolling upright, resulting in a shallower dive angle when pullout commences after an upright attitude is achieved. Classroom-trained pilots lost significantly less altitude than MFS-trained pilots because the shallower dive angle resulting from their more efficient G unloading while inverted more than compensated for the fact that they applied significantly lower G forces than MFS-trained pilots during the upright dive-pullout portion of the recovery.

Note the interesting correlation in Table 5 between unloading G force and altitude loss: without exception a higher unload G corresponds to a larger altitude loss. However, a higher G force in dive pullout does not necessarily result in a smaller altitude loss. For example, MFS-trained pilots pulled the highest G force among the three trained groups and still lost the most altitude, whereas classroom-trained pilots pulled the lowest G force among the three and still lost the least altitude due to efficient unloading while inverted.

Nose-High Inverted Upset. MFS-trained and classroom-trained pilots commenced rolls toward an upright attitude and recovered significantly faster than control group pilots. In addition, MFS-trained pilots applied significantly higher G forces during dive pullout than control group pilots. In general, however, trained pilots outperformed control pilot groups to a lesser extent in this upset than in the other three. In particular, there was no significant difference in altitude losses among the four pilot groups.

The only significant difference among trained pilot groups was that MFS-trained pilots pulled more Gs in dive pullout than classroom-trained pilots without, however, losing significantly less altitude. This result again reflects the difficulty some MFS-trained pilots experienced maintaining control in low-speed dive pullouts due to accelerated stalls. As in the nose-high upright upset, this phenomenon is seen in the high standard deviation (0.84Gs) of the mean dive-pullout G force (2.9Gs) MFS-trained pilots applied.

5.4 Effectiveness of classroom-based training

Our research establishes that ground-based upset-recovery training – whether delivered in a flight simulator or solely in a classroom – improves a pilot's ability to recover a general aviation aeroplane from an in-flight upset. In general, classroom-trained pilots exhibited upset manoeuvring skills equal to simulator-trained pilots; i.e. some aspects of upset-recovery manoeuvring can be taught as well in the classroom as in a flight simulator. For example, the effectiveness of using MFS video captures to train pilots how to categorise upset attitudes is implied by the fact that classroom-trained pilots were quicker to initiate correct roll responses than control group pilots in all four upsets, and quicker to apply correct throttle inputs in upright upsets. Neither of these responses can occur until aircraft attitude is first determined correctly. Classroom-trained pilots also recovered to straight-and-level flight more quickly than control group pilots, handled G forces better, and lost significantly less altitude than control group pilots in three of the four upsets.

Unexpectedly, classroom-trained pilots occasionally outperformed simulator-trained pilots. We interpret this result as reflecting improved classroom training techniques resulting from experience gained during three previous upset-recovery flight testing periods. As previously explained, our training techniques continually improved as the research progressed over the course

of four years. We regularly revised the course textbook to reflect new insights gained from the most recent flight testing period; created online videos and learning modules on upset-recovery aerodynamics for pilot self-study; adopted a mastery-learning approach to testing; and improved testing instruments. Because they were trained last, classroom-trained pilots received better classroom training than MFS-trained and GL2000-trained pilots, hence were well prepared to recover the Decathlon from the upsets encountered during flight testing despite the fact that they had not received simulator-based training. We believe that if we repeated the experiments described in Rogers *et al*(2009) and Leland *et al*, the flight-test performances of MFS-trained and GL2000-trained pilots would improve because participants would be exposed to improved classroom training.

6.0 THE NEED FOR CAREER-LONG PILOT UPSET-RECOVERY TRAINING

The ideas expressed in this section are opinions of the authors. These ideas are not directly supported by our research results, but we believe our results imply that they are valid. We also believe that properly designed and conducted research experiments would confirm most if not all of the assertions that follow.

Our research establishes that knowledge and skills required to recover a light aeroplane from an upset can be taught successfully in ground-based training. However, it also suggests that ground-based training has distinct limits in improving pilot upset-recovery skills. Trained pilots outperformed control group pilots on the inverted upset recoveries to a lesser extent than on the upright recoveries, probably because inverted upsets are more difficult to deal with than upright upsets. More important, whenever it was manifested in upright recoveries, the statistically significantly ‘better’ performance of trained pilots was typically far from superior. For example, although GL2000-trained and MFS-trained pilots pulled significantly more Gs than control group pilots in dive pullout from the nose-low upright recovery, the average G forces they applied were 3.78 and 3.70 respectively (as opposed to 2.90 by control group pilots), whereas ground-based training set a target of 5.5Gs, a safe rolling G limit at half-aileron deflection given the Decathlon’s 6.0 allowable G limit with symmetric wing loading. A similar result is seen in the altitude loss data, arguably the most important of our experiment’s dependent measures. As reiterated in Table 10, trained pilots lost significantly less altitude than control group pilots in three of the four upsets. However, a comparison of trained-pilot altitude losses with altitude losses achieved by a pilot

Table 10
Altitude losses to nearest foot for the four upsets

Bold = significantly better than untrained pilots

* = Also significantly better than MFS-trained pilots

Data Source	Altitude Loss in Feet			
	Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
GL2000-Trained Pilot Average	600	213	885	368
MFS-Trained Pilot Average	565	331	949	382
Classroom-Trained Pilot Average	574	108*	815	418
Control Group Pilot Average	728	340	1069	465
Observed Minimums with an Experienced Pilot †	220	-50	365	-30

† The values in the last row of Table 10 are not average losses expected after on-aircraft training, a subject we have not studied systematically. They merely reflect the minimum observed altitude losses with an experienced pilot manoeuvring the Decathlon during safety pilot standardisation.

experienced in all-attitude manoeuvring, shown in the last row of the table, reveals that the ‘better’ trained-pilot performance is a modest achievement indeed.

An important implication follows: if our research argues for ground-based upset-recovery training as a means of improving a pilot’s ability to recover a general aviation aeroplane from an upset, it also implies the need to follow up ground-based instruction with upset-recovery training in a general aviation aerobatic aeroplane. Few if any pilots trained in aerobatic and upset-recovery manoeuvring doubt that such confidence-building experience, whether in a light aeroplane or in a military high-performance jet aeroplane, dramatically improves a pilot’s ability to deal with an in-flight upset. Even the best and most expensive flight simulators available today cannot approach the training experience of a real aeroplane, where pilots can endure sustained high G forces; receive realistic motion cuing; learn how an aeroplane flies near the available G line of the $V-n$ diagram (where the aerodynamic model for even the most expensive flight simulators available today is inaccurate); experience 1G and accelerated stalls and departures from controlled flight; and with repeated exposure gradually overcome the trepidation that most pilots initially feel when confronted with all-attitude manoeuvring situations.

Given the fact that LOC-I is the major cause of air transport accidents and fatalities, we find it perplexing that regulatory authorities do not require specialised upset-recovery training for the commercial pilot certificate. Absent such training, pilots receive the commercial rating knowing almost nothing about upset-recovery manoeuvring. Moreover, very little upset-recovery training is conducted at the air transport pilot level – approximately four hours of classroom-based and an hour of simulator-based instruction during initial training at US major airlines – despite the fact that almost all pilots arrive inexperienced in all-attitude manoeuvring and have never been upside down in any aeroplane. In addition, very little funding is available to support upset-recovery research.

Why is this the case? First, the air transport accident rate in developed countries is at an all-time low, so LOC-I accidents, frequent in a statistical sense, occur only rarely in a temporal sense. This enables air transport regulators and managers alike to devote limited financial resources to issues they deem more pressing than improving upset-recovery pilot skills. Second, there seems to exist a growing belief that automation, not the pilot, should fly an air transport aeroplane to the maximum extent possible. This belief is reflected in the well-worn joke that an ideal cockpit crew consists of a pilot and a dog, the pilot charged with feeding the dog, while the dog must bite any pilot who tries to touch the flight controls. A corollary to this droll idea is that automation will prevent most upsets from occurring in the first place, and that automation is superior to pilots in recovering if and when an upset does in fact occur – in short, that loss-of-control accidents due to automation mistakes are preferable to loss-of-control accidents due to pilot mistakes.

Such an argument reflects flawed circular reasoning:

- Pilots are inexperienced in upset-recovery manoeuvring; therefore automation should be used to recover an aeroplane from an upset because it can do a better job than a pilot.
- Automation is superior to inexperienced pilots in upset-recovery manoeuvring; therefore it is unnecessary to spend additional money training pilots to do what automation presently can do better.

In our opinion, this approach to LOC-I accident prevention is opportunistic and wilfully obtuse. Reducing the LOC-I accident rate requires improving the upset-recovery manoeuvring skills of air transport pilots, not depending on automation to prevent upsets from occurring. We believe that more extensive upset-recovery pilot training, career-long training, is desirable, as opposed to the minimal training air transport pilots now receive.

Specifically, we believe that regulatory authorities should mandate both ground-based and on-aircraft

upset-recovery training for pilots pursuing the commercial pilot certificate. Training at this point in a pilot's career is both safe and relatively inexpensive compared to training at the air transport level. Based on our research results, ten hours of classroom-based and ten hours of simulator-based training might constitute a reasonable requirement; additional research could of course determine more precisely the optimal amount of training. Ground-based instruction would then be followed by perhaps ten hours of on-aircraft experience. Again, research would be required to determine how much in-flight training would suffice. Pilots thus trained would arrive for initial employment at air transport companies much better prepared to profit from the limited initial and recurrent FSS-based upset-recovery training affordable at that level. One should add that this argument that has gained credence among members of ICATEE's Training Subcommittee.

We also believe that regulators must mandate ground-based and on-aircraft recurrent training in a light aerobatic aeroplane for air transport pilots to maintain proficiency and confidence in upset-recovery manoeuvring skills developed during commercial pilot licensing and subsequent air transport company training. In addition, it will likely be necessary to implement a new flight instructor qualification – upset recovery manoeuvring instructor – to insure high quality training. Finally, very little research exists to assess the effectiveness of upset-recovery training in full flight simulators or to address related research subjects. Governmental authorities and companies who profit from safety in air transport operations should make funding available to support continuing research into best practises in delivering career-long pilot training in upset-recovery manoeuvring.

7.0 SUMMARY OF CONCLUSIONS

Our research supports three important observations about ground-based upset-recovery training:

1. Ground-based upset-recovery training conducted using desktop flight simulation and/or classroom instruction can improve a pilot's ability to recover a general aviation aeroplane from an in-flight upset.
2. The quality of upset-recovery training – both the content and the delivery method – affects the degree to which the training transfers to operation of an actual aeroplane.
3. It appears that on-aircraft training is required to hone the limited manoeuvring skills developed during ground-based upset-recovery training.

Statistical analysis of the flight-test data we collected confirms the first point. With respect to the second, Section 4 and portions of Section 5 above explain how we gradually improved our ground training programme based on lessons learned over the course of four flight-testing sessions. Improved training is the most logical explanation of why classroom-trained participants, who were trained last, performed as well as they did without the benefit of simulator-based training. The third point, though as yet unsupported by experimental research, would seem to be a straightforward implication of the observed limited training transfer resulting from our ground-based upset-recovery programme.

ACKNOWLEDGEMENT

The FAA's Civil Aerospace Medical Institute provided funding for the research reported in this paper. Embry-Riddle Aeronautical University underwrote the last flight-testing session. The authors sincerely thank the referees and the Associate Editor for their many insightful suggestions for improving our paper.

REFERENCES

1. Statistical summary of commercial jet airplane accidents, World wide operations, Boeing Aircraft Company, 1955–2009, <http://www.boeing.com/news/techissues/pdf/statsum.pdf>, accessed 27 August 2011.
2. ROGERS, R.O., BOQUET, A., HOWELL, C. and DEJOHN, C. An experiment to evaluate transfer of low-cost simulator-based upset-recovery training, FAA Technical Report DOT/FAA/AM09/05, Office of Aerospace Medicine, Washington, DC, USA, 2009.
3. GAWRON, V. Aircraft upset training evaluation report (revision 20), National Aeronautics and Space Administration (NASA): NAS2-99070, 2004.
4. KOCHAN, J.A. The Role of Domain Expertise and Judgment in Dealing with Unexpected Events, Ph.D. Dissertation, Department of Psychology, University of Central Florida, Orlando, Florida, USA, Summer Term 2005.
5. KOCHAN, J.A. and PRIEST, J.E. Program update and prospects for in-flight upset recovery training, Proceedings of the 13th International Symposium on Aviation Psychology, 2005, Oklahoma City, Oklahoma, USA: Wright State University, 2005.
6. KOCHAN, J.A., BREITER, E., HILSCHER, M. and PRIEST, J.E. Pilots' perception and retention of in-flight upset recovery training: Evidence for review and practice, Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting, Orlando, Florida, USA: 26-30 September, 2005.
7. KOCHAN, J.A., BREITER, E.G. and JENTSCH, F. Surprise and unexpectedness in flying: Database reviews and analysis, Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Louisiana, USA: Human Factors and Ergonomic Society, 2004.
8. KOCHAN, J.A., BREITER, E.G. and JENTSCH, F. Surprise and unexpectedness in flying: Database factors and features, Proceedings of the 13th International Symposium on Aviation Psychology, Oklahoma City, Oklahoma, USA: Wright State University, 2005.
9. KOCHAN, J.A., PRIEST, J.E. and MOSKAL, M. The application of human factors principles to upset recovery training, 50th Annual Corporate Aviation Safety Seminar, Orlando, Florida, USA: Flight Safety Foundation and National Business Association, 26-28 April 2005.
10. KOCHAN, J.A. PRIEST, J.E. and MOSKAL, M. Human factors aspect of upset recovery training, 17th Annual European Aviation Safety Seminar, Warsaw, Poland: Flight Safety Foundation and European Regions Airline Association, 14-16 March 2005.
11. Based on Kochan, 2005.
12. KOCHAN, J.A. Human factors aspects of unexpected events as precursors to unwanted outcomes, 18th Annual European Aviation Safety Seminar, Flight Safety Foundation and European Regions Airline Association: Athens, Greece, 13-15 March 2006.
13. ROESSINGH, JAN J.M. Transfer of manual flying skills from PC-based simulation to actual flight—comparison of in-flight data and instructor ratings, *Int J Aviation Psychology*, 2005, **15**, (1), pp 67-90.
14. ROGERS, R.O., BOQUET, A., HOWELL, C. and DEJOHN, C. Preliminary results of an experiment to evaluate transfer of low-cost, simulator-based Airplane upset-recovery training, FAA Technical Report DOT/FAA/AM07/28, Office of Aerospace Medicine, Washington, DC, USA, 2007.
15. ROGERS, R.O., BOQUET, A., HOWELL, C. and CHARLES DEJOHN, C. An experiment to evaluate transfer of low-cost simulator-based airplane upset-recovery training, FAA Technical Report DOT/FAA/AM-09/5, Office of Aerospace Medicine, Washington, DC, USA, 2009. See also ROGERS, R.O. AND BOQUET, A., HOWELL, C., and DEJOHN, C. A two-group experiment to measure simulator-based upset recovery training transfer, *Int J Applied Aviation Science*, Summer 2010, **10**, (1), pp 153-168.
16. LELAND, R., ROGERS, R.O., BOQUET, A. and GLASER, S. An experiment to evaluate transfer of upset-recovery training using two different flight simulator devices, FAA Technical Report DOT/FAA/AM-09/17, Office of Aerospace Medicine, Washington, DC, USA, 2009.
17. CARBAUGH, D., ROCKLIFF, L. and VANDEL, B. Airplane Upset Recovery Training Aid, Version 2, November 2008, http://flightsafety.org/files/AP_UpsetRecovery_Book.pdf.
18. BURKS, B. Upset recovery training: a call for a higher standard, Proceedings of the Royal Aeronautical Society Flight Simulation Group Conference, 3-4 June 2009, London, UK.
19. CARBAUGH, D.C., CORNUTT, R.A. AND ROBERSON, W.C. Simulator upset recovery training, Proceedings of the Royal Aeronautical Society Flight Simulation Group Conference, 3-4 June 2009, London, UK.
20. ROBERSON, W.C. *An evaluation of the effectiveness of airplane upset recovery training*, unpublished paper submitted in partial fulfillment of the requirements for the Embry-Riddle MS Degree in Technical Management, 2008, available from Captain Roberson at William.c.roberson@boeing.com.

21. PRIEST, J. Upset recovery and pilot training—the quest for safety, Proceedings of the Royal Aeronautical Society Flight Simulation Group Conference, 3-4 June 2009, London, UK.
22. RANSBURY, P. Unusual attitude training, Proceedings of the Royal Aeronautical Society Flight Simulation Group Conference, 3-4 June 2009, London, UK.
23. GEORGE, K.A. Upset recovery and disorientation training at NASTAR center, Proceedings of the Royal Aeronautical Society Flight Simulation Group Conference, 3-4 June 2009, London, UK.
24. ADVANI, S.K., SCHROEDER, J.A. and BURKS, B. What really can be done in simulation to improve upset training?, Proceedings of the AIAA Guidance, Navigation, and Control Conference, 2-5 August 2010, Montreal, Ontario, Canada.