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Preliminary Results of an Experiment to Evaluate Transfer of Low-Cost, Simulator-Based Airplane Upset-Recovery Training

Rodney O. Rogers
Albert Boquet
Cass Howell
Embry-Riddle Aeronautical University
Daytona Beach, FL 32114

Charles DeJohn
Federal Aviation Administration
Civil Aerospace Medical Institute
Oklahoma City, OK 73125

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16. Abstract

Many air transport training programs provide simulator-based upset-recovery instruction for company pilots. However, no research exists to demonstrate that such training transfers to an airplane in flight. We report on an in-progress FAA-funded research experiment to evaluate upset-recovery training transfer. Participant pilots are trained using low-cost desktop flight simulation, then subjected to serious in-flight upsets in an aerobatic airplane. Preliminary results comparing the performance of trained and control group pilots suggest that simulator-based training may improve a pilot's ability to recover an airplane from an upset. We summarize prior research, describe the experiment, and present results of Phase-One testing. We also detail planned refinements in Phase-Two flight training and testing that we hope will strengthen the results of our research. Although we are conducting flight testing in a general aviation airplane, our research has important implications for heavy aircraft upset recovery trainers.

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INTRODUCTION

We will describe ongoing FAA-funded research to study training transfer in low-cost, simulator-based upset-recovery training. While many air transport training programs contain a module instructing pilots how to recover an airplane from an upset, there appears to be little research establishing the effectiveness of such training. Our study evaluates the transfer of upset-recovery training conducted using classroom instruction and low-cost flight simulation. To assess the validity of the training, we conducted flight tests to compare the performance of trained and untrained pilots in recovering an airplane from serious in-flight upsets.

Our research is divided into two phases, the first of which is now complete. In what follows, we:
- Offer motivation for our work.
- Summarize prior research.
- Describe the research experiment.
- Explain data collection difficulties encountered in Phase-One flight testing.
- Report the results of Phase-One flight testing.
- Discuss the implications of these results.
- Explain plans for Phase-Two training and testing.
- Describe future (follow-on) research.
- Provide concluding remarks.

MOTIVATION

An upset occurs when an airplane enters an unexpected attitude that threatens loss-of-control in-flight (LOC) and subsequent ground impact. It is well known that LOC causes many fatal air transport accidents. For the years 1991-2000 inclusive, 33 of 112 total accidents worldwide—almost 30%—were attributable to LOC in-flight. Of the 7071 total onboard fatalities resulting from these 112 accidents, 2359—one-third—resulted from LOC in-flight accidents.[1] The percentages of general aviation fatalities due to LOC are strikingly similar to those for commercial jets. Between 1990 and 2002, LOC accounted for 1485 of 4982 general aviation (GA) fatal accidents in the United States (29.8%) and 2617 of 8895 fatali-ties (29.4%). In Australia during the years 1991-2000, uncontrolled flight into terrain (UFIT)—defined as LOC in-flight followed by ground impact—accounted for 46% of all GA accidents and 56% of all general aviation fatalities.[2]

Since LOC is a major factor in commercial jet and general aviation fatal accidents worldwide, and since the vast majority of commercial and general aviation pilots have no aerobatic experience in any type of airplane, a cost-effective approach to teaching pilots how to recover from an upset is clearly desirable. In-flight upset-recovery instruction is both expensive and potentially hazardous. Moreover, FAA regulations prohibit air transport and most general aviation airplanes from intentionally assuming aerobatic attitudes. As a consequence, pilots are typically given upset-recovery training in ground-based flight simulation devices. Yet it remains unproven that skills developed in such training devices improve a pilot's ability to regain control of an actual airplane during an in-flight upset. Moreover, because of flight simulator limitations such as unrealistic control input responses or lack of control force feedback, the potential for negative training exists. Even Level D flight simulators, for example, are known to present pilots with unreliable models of actual airplane performance when flown near the limits of, or outside of, the normal air transport operating envelope.[3] Finally, almost all ground-based flight simulation devices—including all Level D flight simulators—lack the ability to replicate the high G forces pilots likely will encounter in upset-recovery maneuvering.

In short, the degree to which simulator-based upset training is effective, if at all, is not known. Under the circumstances, a study of upset-recovery training transfer from a simulator to an actual airplane seems justified. Accordingly, the Civil Aerospace Medical Institute of the U.S. Federal Aviation Administration provided a research grant to fund such a study.

[1] *Boeing Airplane Upset Recovery Training Aid*, available on CD from the Boeing Airplane Company, www.boeing.com. Congruent but slightly more current information is available from Boeing's 2004 Statistical Summary. We present the earlier statistics to provide year-span coherence with data for GA LOC accidents.

[2] R.O. Rogers, C. Howell, A. Boquet, and C. DeJohn (2006). "The Effect of Simulator-Based Upset Recovery Training on a Pilot's Ability to Recovery an Airplane From an In-Flight Upset," *Proceedings of the 2006 Air Transport Research Society World Conference*, Nagoya, Japan, (May 2006): Rogers-NR17, pp. 2-4.

[3] R.O. Rogers (2005). "The Crash of American Airlines Flight 587: Its Effect on Air Transport Upset Recovery Training," *Proceedings of the 2005 Air Transport Research Society World Conference*, Rio de Janeiro, Brazil, (July 2005): Rogers-NR24, pp. 7-12. The article references a number of authorities on this subject.

UPSET-RECOVERY LITERATURE

Although the literature of flight simulation is voluminous and spans a period of 80 years or more, we have not found a plethora of research articles on transfer of simulator-based upset-recovery training. Several reports originate from the Calspan (formerly Veridian) In-Flight Upset-recovery Training Program at Roswell, N. M.[4] This FAA-funded program provides upset training in an aerobatic Beech Bonanza and in Calspan's variable stability Learjet 25, an airplane modified using computer automation to provide right-seat occupants with the control characteristics of an air transport type airplane, for example a B-737. The Learjet is also capable of simulating upset-inducing wake turbulence, effects of weather phenomena that can lead to LOC, and various aircraft malfunctions that in the past have caused air transport upsets resulting in hull losses.

Gawron (2004) studies the relationship between pilot experience and upset-recovery proficiency. Using the Calspan Learjet, she subjected five groups of airline pilots with varying degrees of upset-recovery training and/or aerobatics experience to a series of eight in-flight upsets, hypothesizing that pilots with more training or experience would recover more expertly than those with less. However, Gawron found no statistically significant differences in the performances of the five groups. These negative results may in part be explained by small sample sizes and large variability in the total flight times of the pilot participants. A third likely explanation—not mentioned in Gawron's report—is that six of the eight upsets involved simulated aircraft malfunctions—rudder hard over, frozen aileron, runaway nose-up trim, etc. Few of the participant pilots in Gawron's experiment were able to recover from any of these very serious "sick airplane" upsets, regardless of the degree of their prior training.[5] The first author of this paper, a former Naval aviator with 14 years' experience flying carrier based jet airplanes, attended Calspan upset training in Roswell in 2003 and can personally vouch for the difficulty of recovering from such upsets.

Kochan (2005) examines 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 analyze and learn from an in-flight upset-recovery experience. Kochan subjected four groups of participant pilots to a series of three in-flight upsets in the Calspan Learjet. Statistical analyses revealed that judgment was a significant factor in

successful upset recovery, especially when a pilot has low domain knowledge, i.e., when he or she is not trained to proficiency in upset recovery.[6]

Kochan and Priest (2005) study the effect of Calspan's In-Flight Upset-recovery Training Program on U.S. air carrier pilots. Their repeated measure experimental design involved pre-training and post-training pilot testing in the Learjet using a single performance measure: pilot self-evaluation employing a modified Cooper-Harper rating scale. The authors acknowledge that the validity of this performance measure is not known. Moreover, the study does not account for the possibility that initial flight testing resulted in pilot learning and improved performance in the second flight testing period. With these caveats, and assuming validity of the rating instrument, statistical analysis implied "a strong positive influence of the [program] on a pilot's ability to respond to an in-flight upset."[7] However, the effects of such training may be ephemeral. Kochan, Breiter, Hilscher, and Priest (2005) studied retention of knowledge in pilots subjected to Calspan training. They found that "although [participant] pilots rated their ability to recover from loss-of-control situations as being greatly improved by the training, the vast majority reported remembering only between 52% of the academics and 83% of the [upset-recovery] techniques….Eighty percent of the participants recalled less than half of the procedural steps for yaw upsets and 73% recalled less than half of the [steps for] roll events."[8]

A number of related papers examine the "surprise" or "startle" factor of an upset. Surprise during flight can lead to action-inhibiting stress and anxiety and a resultant inability to respond appropriately to an emergency situation. Kochan, Breiter, and Jentsch (2004) group instances of various in-flight surprises—including but not limited to upsets—into five causal categories. All five categories reflect the fact that unobserved cues are a potential but unacknowledged source of information for apprehending and dealing with an unusual flight situation before it arrives as a surprise. The researchers state their intent in future research to develop "a conceptual framework

[4] www.calspan.com.

[5] Valerie Gawron (2004). *Aircraft Upset Training Evaluation Report* (revision 20), National Aeronautics and Space Administration (NASA): NAS2-99070.

[6] J.A. Kochan (2005). *The Role of Domain Expertise and Judgment in Dealing with Unexpected Events*, Ph.D. Dissertation, Department of Psychology, University of Central Florida, Orlando, Florida, Summer Term 2005.

[7] J.A. Kochan and J.E. Priest (2005). "Program Update and Prospects for In-Flight Upset Recovery Training," *Proceedings of the 13th International Symposium on Aviation Psychology,* Oklahoma City, Oklahoma: Wright State University.

[8] J.A. Kochan, E. Breiter, M. Hilscher, and J.E. Priest (2005). "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: September 26-30, 2005.

for the study of unexpected events in aviation."[9] The authors of the current paper are aware of a follow-on to this study by the same researchers,[10] but have been unable to obtain a copy.

Kochan, Priest, and Moskal (2005, 2005a) extend these ideas in two articles that address the human factors aspects of loss-of-control to the end of determining the role of surprise in upset recovery.[11, 12] The authors develop "a model representing the cognitive process of surprise" which constitutes a basis for discussing "how an unexpected event can escalate to a loss-of-control situation."[13] They argue that in-flight training may be necessary to teach pilots to deal adequately with their *perceptual biases* in processing information during a surprise upset. The *context* of such an event and a pilot's *perception* about the *probability* of its occurring are also important issues in upset recovery. The more recent of the two articles presents an informative summary of current trends in upset recovery and a brief history of the use of flight simulation in aviation training.

Kochan categorizes factors where surprise contributed to an aviation-related event, incident, or accident. Statistical analysis reveals that surprise is not clustered in certain categories, suggesting "that potentially any [surprise] event or combination of events could produce a situation with an unwanted outcome."[14] Pilot 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).[15] These ideas seem

conceptually sound, but one wonders how challenging it might prove to implement such training at air transport companies or to evoke line pilot support for it.

Research involving participants in the Calspan In-Flight Upset-Recovery Training Program evaluates transfer of *in-flight* simulator-based upset training. *In-flight simulation* allows pilots to experience upset maneuvering G forces that very few *ground-based flight simulators* can replicate. The Environmental Tectonics Corporation (ETC) of Southampton, Pennsylvania, manufactures and markets centrifuge-based flight simulators to military organizations worldwide. Such simulators are capable of generating continuous G forces and motion cueing information that even 6 degrees-of-freedom (6 DoF)[16] level D flight simulators cannot produce, allowing them to bring to ground-based upset-recovery training an added degree of realism. Three proprietary technical reports—graciously furnished by Dick Leland (dlect@aol.com), Director of the ETC AeroMedical Training Institute—detail the capabilities of the company's current generation centrifugal simulators.[17, 18, 19] A drawback of such simulators, however, is that "if a pilot moves his head while under G in a centrifuge, strong feelings of disorientation (the Coriolis illusion) result because of the small rotation radius needed to create the G forces artificially."[20]

In a related article on motion-based flight simulation, Szczepanski and Leland (2000) assert that "simulator data analysis suggests that motion cueing is necessary when training *ab initio* pilots or pilots who have limited or no experience in [whatever] flying task...is being trained."[21] While this undocumented assertion seems creditable, the NTSB Investigation of the crash of American Airlines Flight 587 in New York on November 12, 2001 expressed an alternative view by finding that "the use of lower levels of automation, such as simulators without motion or simple computer screen displays, may be more appropriate [than Level D simulators] to provide the

[9] J.A. Kochan, E.G. Breiter, and F. Jentsch (2004). "Surprise and Unexpectedness in Flying: Database Reviews and Analysis," *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, New Orleans, Louisiana: Human Factors and Ergonomic Society.

[10] J.A. Kochan, E.G. Breiter, and F. Jentsch (2005). "Surprise and Unexpectedness in Flying: Database Factors and Features," *Proceedings of the 13th International Symposium on Aviation Psychology*, Oklahoma City, Oklahoma: Wright State University.

[11] J.A. Kochan, J.E Priest, and M. Moskal (2005a). "The Application of Human Factors Principles to Upset Recovery Training," *50th Annual Corporate Aviation Safety Seminar,*" Orlando, Florida: Flight Safety Foundation and National Business Association, 26-28 April, 2005.

[12] J.A. Kochan, J.E Priest, and M. Moskal (2005). "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.

[13] Based on Kochan (2005).

[14] This parallels a similar finding in Kochan, Breiter, and Jentsch (2004) with different event categories.

[15] J.A. Kochan (2006). "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.

[16] The 6 DoF characterizing level D flight simulators are termed pitch, roll, yaw, heave, sway, and surge.

[17] Environmental Tectonics Corporation. "ATFS-400 Authentic Tactical Flight Simulator Model 400 Executive Summary."

[18] Dick Leland, C. Spenney, T. Chelette, and E. Lewis (2003). "Opportunities in Flight Simulation: Tactical Flight Simulation."

[19] Zulkeffeli Mat Jusoh and D. Leland (2006). "Tactical Flight Simulation in the Royal Malaysian Air Force: the ATFS-400 Authentic Tactical Flight Simulator."

[20] Ian W. Strachan (2001). "Motion Cueing in the Real World and in Simulators: Principles and Practice," *Janes Simulation and Training Systems 2000-2001*, pp. 149-175.

[21] Cezary Szczepanski and D. Leland (2000). "Move or Not to Move? A Continuous Question," Southampton, Pennsylvania: Environmental Tectonics, 200l. ©2000 ETC, published by the American Institute of Aeronautics and Astronautics with permission (AIAA Paper 0161). Copy provided by the second author.

necessary [upset] awareness training with less danger of introducing incorrect information."[22]

Roessingh (2005) reports on a study to measure training transfer from low-fidelity ground-based flight simulators to control of an actual airplane during aerobatic flight.[23] Research participants were divided into two experimental groups and a control group. All three groups received in-flight aerobatic training during ten half-hours periods. In addition, prior to in-flight training the two experimental groups received ground-based instruction in aerobatic maneuvering using desktop flight simulators. The simulator syllabus was the same for both experimental groups, but one experimental group's simulator training was enhanced with a more "realistic layout of stick, rudder pedals, and throttle" than the simulator training of the other experimental group. During fight testing requiring performance of five sequential aerobatic maneuvers without interruption, Roessingh collected data on each participant's performance using a flight data recorder. He also obtained instructor pilot ratings for each participant in 25 binary categories. The data revealed no significant difference in the aerobatic maneuvering of experimental and control group pilots. Small group size (seven participants in each of the two experimental groups and the control group) may have contributed to a failure to detect training transfer. Inconsistencies among the grading criteria of three different instructor pilots may also have affected statistical results. Trained pilot performance did exceed control group pilot performance in the total number of aerobatic maneuvers completed during each half-hour flight, although the importance of this result is clouded because weather and other uncontrollable factors affected pilot performance potential on any given flight.

THE EXPERIMENT

Purpose

This purpose of our investigation is to determine experimentally whether or not upset-recovery training in a low-fidelity flight simulator increases the likelihood of a pilot's recovering from an upset. Our experiment is designed to test the hypothesis that a group of trained participants will outperform a group of untrained participants in recovering an actual airplane from an upset

situation. Hereafter, we refer to these two groups of pilots as the *experimental* (i.e. trained) group and the *control* (i.e. untrained) group respectively.

Participants

Participants (n = 60) were flight students recruited from Embry-Riddle Aeronautical University (ERAU) in Daytona Beach, Florida, with 30 pilots assigned to the experimental group and 30 to the control group. However—as explained later—only 28 control group pilots were actually flight tested; moreover, some of the 58 test flights failed to produce reliable data. All participants held a current instrument rating and had completed an academic course in Basic Aerodynamics. None had any prior aerobatic experience or upset-recovery training beyond that mandated by the FAA for the Private Pilot rating. The total flight hours for the 58 subjects who were flight tested ranged from 90 to 700 hours (mean = 256.3 hours, SD = 108.5 hours). The control group had slightly more total time than the trained group (277.3 vs. 235.9 hours), although this disparity was offset by greater variability in the control group when compared to the trained participants (124.1 vs. 88.5 hours). Participant flight hour data is summarized in Table 1.

Table 1. Flight Hour Data for 58 Flight-Tested Participants

Group	Group Size	Mean Flight Hours	Standard Deviation
Control	28	277.3	124.1
Experimental	30	235.9	88.5
Combined	58	256.3	108.5

Training

While it might seem preferable to conduct upset-recovery training using a sophisticated Level D flight simulator, prudence and cost considerations dictate otherwise. Level D training, very expensive in itself, would imply flight testing in an air transport airplane, a prohibitively costly undertaking. In addition, it is both illegal and unsafe to subject pilots to serious upsets— extreme pitch and bank angles, or inverted flight attitudes, for example—in a multi-engine jet transport. Accordingly, we chose to train using low-cost desktop simulation and to test our research hypothesis in an aerobatic general aviation airplane.

We trained the 30 experimental group pilots in an academic course where they received ten hours of classroom and ten hours of simulator-based upset-recovery instruction.[24] We conducted simulator training using Microsoft

[22] NTSB (2004). *Aircraft Accident Report NTSB/AAR-04/04*, p. 160. Retrieved April 20, 2005, from www.ntsb.gov/publictn/2004/AAR0404.pdf.

[23] Jan J. M. Roessingh (2005). "Transfer of Manual Flying Skills from PC-Based Simulation to Actual Flight—Comparison of In-Flight Data and Instructor Ratings," *The International Journal of Aviation Psychology*, 15 (1), 67-90.

[24] Training materials may be viewed online at faculty.erau.edu/rogersr/as471. The site contains extensive information on upset-recovery training. The MS Word document at the *Course Text (Spring / Fall 2006)* link and the Bonanza training videos at the *Aerobatic Videos* link are of particular interest with respect to Phase-One research.

Flight Simulator 2002 (MFS) software[25] running under the Windows 2000 operating system on Dell desktop computers with high end graphics cards. Four of the ten hours of simulator time were devoted to aerobatic maneuvers—loops, Immelmans, full and half Cuban 8s, aileron rolls, barrel rolls, and wingovers. The remaining six hours were devoted to upset-recovery maneuvering. Both aerobatic and upset-recovery maneuvering were practiced under simulated VMC and IMC conditions. (MFS software facilitates simulating IMC conditions by reducing cockpit visibility.) The 30 participants in the control group received no classroom or simulator training.

Testing

For flight testing, we used an aerobatic E33C Beech Bonanza provided and operated by the Calspan Corporation Flight Research Group. The aircraft was fitted with both a flight data recording (FDR) system and a video recording (VR) system. The FDR was a Calspan proprietary Miniaturized Flight Data Recording System able to record 27 in-flight parameters on a digital memory card. The VR consisted of a commercial off-the-shelf portable digital video recorder (Micro DVR P/N PV-390-2) connected to an over-the-shoulder mounted Advanced Technology video camera (Model KPC-650CH) equipped with a Varifocal lens (Model KLC-2812DC). As illustrated in Figure 1, the VR focused on the participant's instrument panel and allowed us to view airspeed, vertical speed, altitude, attitude, G force, manifold pressure, and yoke rotation. However, whereas the FDR furnished yoke rotation in degrees and rudder pedal displacement in inches, the VR furnished no rudder pedal information and only non-quantitative information about yoke rotation.

During testing, each participant was subjected to four randomly ordered upsets, described in detail later. For each upset, a participant was told to close his or her eyes while the safety pilot induced the upset. Then—when instructed to do so—the now open-eyed participant assumed control of the airplane and attempted to recover it to straight and level flight. A participant remained in control until recovery was completed or the safety of the aircraft came into question, for example when it appeared that the Bonanza's never-exceed speed would be surpassed unless the safety pilot intervened. If a participant pilot returned the aircraft to straight and level flight without verbal or physical assistance from the safety pilot, the recovery was deemed successful; otherwise, it was deemed unsuccessful.

Experiment Design

We define a good upset recovery as one where a pilot respects the aircraft operating limitations while returning the aircraft to straight and level flight with a minimum loss of altitude. We anticipated that minimum altitude loss would result from:

1. Prompt and correct throttle and control inputs in response to an upset situation.

Figure 1. Screen Capture of Video Recorder Output During an Actual Flight Test Upset

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[25] The United States Navy uses Microsoft Flight Simulator in both basic and advanced flight training of student Naval aviators.

2. Appropriate unloading and high roll rate to an upright attitude to orient the lift vector toward the sky.
3. Appropriate use of available/allowable G to achieve level flight after the airplane is upright.

To assess a participant's performance in these areas, we used a 2 x 4 mixed-model design (n = 60) with group as a between factor and type of upset as the repeated measure, as reflected in Table 2. The design subjects every participant in two groups, each of size 30, to a series of four in-flight upsets. Table 3 displays attitude, airspeed, and throttle parameters for the four upset attitudes. Upright refers to a bank attitude not exceeding 90°. In an inverted upset, the bank angle is such that the cockpit is pointed toward the ground. Nose-high entry airspeeds are ten knots above the Bonanza 1G stall speed. Nose-low entry airspeeds reflect a safe maximum given the Bonanza's linear acceleration characteristics, its never-exceed speed of 196 KIAS, and the presumption that a participant will initiate a prompt recovery from a high energy nose-low upset. The specified thrust settings ensure that a participant must make a throttle adjustment to achieve minimum altitude loss during recovery.

Dependent measures are displayed in Table 4. Some of the data resulted from safety pilot (SP) observations, while others were derived from FDR or VR information. Column 2 in Table 4 indicates the source of a datum and how it is measured. Number in Column 3 refer to the three factors influencing a good upset recovery, as defined previously: 1) prompt and correct throttle and control inputs; 2) appropriate unloading and high roll rate; and 3) appropriate use of maximum available/allowable G. Interestingly, when we examined the data we collected, we found a very poor correlation between safety pilot ratings and quantitative data derived from the FDR for roll control input and control of G forces during recovery. As a consequence, we decided not to use safety pilot data for these measures.

DATA COLLECTION DIFFICULTIES IN PHASE-ONE FLIGHT TESTING

As previously explained, we started Phase-One flight testing with 30 experimental group and 30 control group participants available for testing. After completing 58 sorties, the Bonanza suffered a generator failure. With no replacement readily available, we decided to terminate flying with two control group pilots yet untested. Moreover, due to a variety of difficulties, we failed to obtain reliable data on some of the 30 experimental group and 28 control group pilots who actually flew during Phase-One.

One difficulty involved establishing the prescribed initial upset-recovery attitudes reflected in Table 3. Positioning the aircraft precisely proved to be more challenging than we had anticipated. Variations as small as 15 KIAS or 15° of pitch in a nose-high upset—for example—can dramatically affect the altitude loss encountered in recovery from the upset. Since we see minimum altitude loss as a primary indication of good upset recovery, we had anticipated tolerances of ±10° of pitch, ±15° of roll, and ±10 KIAS. We discarded data for any upset that, as reflected in VR information, deviated significantly beyond these limits.

A second difficulty stemmed from flights where FDR and/or VR data were not recorded. A heavy safety pilot work load, together with difficult-to-reach FDR and VR control switches, resulted in failure to record some upset recoveries with one or both systems. Obviously, no data were obtained when both recordings were missing. Moreover, the VR did not record rudder input or quantitative yoke deflection, resulting in two missing dependent measures when FDR data not available. Finally, since the FDR did not record aircraft attitude, without VR data we could not verify that the Bonanza achieved a proper initial upset attitude. However, we ultimately decided to use FDR data in the absence of VR data, since doing otherwise would have dramatically reduced the amount of information available for analysis.

A third and related difficulty resulted from the inability of the FDR to record altitude and airspeed accurately. A comparison of VR altitude values with corresponding FDR altitude values revealed that the two differed significantly, often by hundreds of feet. Upon further investigation, we found that the VR was recording airspeed and altitude calculated by the primary pitot-static system, while the FDR was obtaining airspeed and altitude from a secondary pitot-static system. We determined that FDR altitude readings were erroneous.[26] However, we were able to establish a strong correlation between VR and FDR altitude losses for all four upsets, as reflected in Table 5. Encouraged by these relationships, we estimated missing VR altitude information from existing FDR altitude losses and used the resulting figures in our statistical analyses. While this compromise was not ideal, it did allow us to preserve enough data to produce meaningful statistical results.

As a result of these three difficulties, we failed to obtain or discarded a significant amount of data. We also

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[26] The FDR uses a separate pitot tube and cabin pressure (rather than pressure at an external static port) to compute airspeed and altitude. Calspan engineers explained that this design enables the Bonanza to be FAA approved for utility category instrument flight. Since the VR was installed to facilitate Phase-One flight testing, the severity of this known FDR limitation had not previously been observed.

Table 2. 2 x 4 Factorial Design

2 x 4 Factorial		Upset Attitude (Repeated Measure)			
		Nose-High Upright	Nose-Low Upright	Nose-High Inverted	Nose-Low Inverted
Training	10 Hours Simulator + 10 Hours Classroom	30 pilots	30 pilots	30 pilots	30 pilots
	None (Control Group)	30 pilots	30 pilots	30 pilots	30 pilots

Table 3. Upset Attitudes, Airspeeds, and Throttle Settings

Number	Upset Name	Pitch	Bank	Airspeed	Thrust
1	Nose-High Upright	60° Nose-High	15° Left Wing Down	70 KIAS	Idle
2	Nose-Low Upright	30° Nose-Low	75° Left Wing Down	120 KIAS	Cruise
3	Nose-High Inverted	60° Nose-High	135° Right Wing Down	70 KIAS	Idle
4	Nose-Low Inverted	20° Nose-Low	135° Left Wing Down	100 KIAS	Cruise

Table 4. Dependent Variables

Dependent Measure	How Measured	C
Time to First Roll Response	(Input – Start) Time in Seconds (VR)	1
Initial Roll Direction	0 – Incorrect; 1 – Correct (SP, VR)	1
Time to First Throttle Response	(Input – Start) Time in Seconds (VR)	1
Initial Throttle Response	0 – Incorrect; 1 – Correct (SP, VR)	1
Use of Ailerons for Roll Authority	1-5 Rating Scale (SP); yoke position (FDR)	2
Use of Rudder for Roll Authority	Rudder Pedal Displacement in Inches (FDR)	2
Unloading during Rolls	1-5 Rating Scale (SP); Measured G force (FDR)	2
Use of Available/Allowable G in Pullout	1-5 Rating Scale (SP); Measured G force (FDR)	3
Time to Complete Recovery	(Recovery– Start) Time in Seconds (VR)	1,2,3
Altitude Loss[†]	(Final – Initial Altitude) in Feet (FDR, VR)	1,2,3
Success of Recovery	0 – Unsuccessful; 1 – Successful (SP, VR)	1,2,3

[†]As discussed later, some nose-high upset recoveries actually resulted in small altitude gains, i.e., in a negative altitude loss.

Table 5. Correlation Values Between Observed VR and FDR Altitude Losses (p = .001)

Upset	Nose-High Upright	Nose-Low Upright	Nose-High Inverted	Nose-Low Inverted
Correlation	r = .84	r = .91	r = .88	r = .90

omitted data for 14 unsuccessful upset recoveries, as discussed later. After supplying missing VR altitude loss data, calculated as explained above, we ended up with complete data for 69% of the upsets attempted (160 of 232). Table 6 displays the number of upsets resulting in reliable data for both control and trained groups for each of the upsets. Note that the table reflects the number of individual upsets with reliable data, not the number of participants with complete datasets for all four upsets.

RESULTS

Initially we planned to analyze data using two-group repeated measures multivariate analyses of variance (MANOVA). However, because data collection difficulties produced incomplete datasets for many participants, we decided to analyze each upset separately to preserve a reasonable sample size. While this approach is unconventional in a within-subjects design, using a repeated measures MANOVA resulted in so much data loss that a meaningful analysis was impossible. For each upset individually, we determined the corresponding Wilks' Lambda. Table 7 reports the result of the Wilks' Lambda analysis for each upset. Table 8 presents the nine dependent measures used to produce the Wilks' Lambda values in Table 7.

Since the Wilks' Lambda values in Table 7 reflect a significant multivariate effect in all four upsets, we used T-Tests with the Bonferroni adjustment to assess the contribution of individual dependent measures in each upset. We report results of the univariate analyses below and display them graphically in Figures 2, 3, 4, and 5. Table 9 records the means and standard deviations (in *italics*) for each reliable dependent measure value contributing to the multivariate analyses. **Bolding** in Table 9 indicates a significant effect, as determined by univariate analysis.

Nose-High Upright Upset Results
The Wilks' Lambda value was significant, with the model explaining 61% of the variance between the groups ($F_{(9, 29)} = 5.04$, $p = .000$; $\eta^2 = .61$). Univariate tests revealed that the experimental group outperformed the control group in three areas:
- Average G during dive pullout ($F_{(1, 37)} = 37.98$, $p = .000$)
- Yoke rotation during rollout ($F_{(1, 37)} = 9.90$, $p = .003$)
- Seconds to first throttle response ($F_{(1, 37)} = 5.04$, $p = .031$)

Figure 2 displays these results graphically.

Table 6. Group Size for Each Upset After FDR to VR Altitude Loss Mappings

Group	Upset			
	Nose-High Upright	Nose-Low Upright	Nose-High Inverted	Nose-Low Inverted
Control	16	17	19	19
Experimental	23	23	22	21
Total	39	40	41	40

Table 7. Wilks' Lambda Values for Each Upset

Nose-High Upright	Nose-Low Upright	Nose-High Inverted	Nose-Low Inverted
$F_{(9, 29)} = 5.04$	$F_{(9, 30)} = 4.45$	$F_{(9, 31)} = 3.24$	$F_{(9,30)} = 3.04$
$p = .000$	$p = .001$	$p = .007$	$p = .010$
$\eta^2 = .610$	$\eta^2 = .572$	$\eta^2 = .484$	$\eta^2 = .477$

Table 8. Dependent Measures Used to Compute Wilks' Lambda Values

	Dependent Measure Used to Compute Wilks' Lambda
1	G Force in Pullout
2	Ratio of Available to Allowable G in Pullout
3	G Force Unloading during Rolls
4	Recovery Altitude Loss in Feet
5	Time to First Throttle Response in Seconds
6	Time to First Roll Response in Seconds
7	Time to Recover in Seconds
8	Use of Ailerons for Roll Authority in Degrees of Yoke Rotation
9	Use of Rudder for Roll Authority in Inches of Rudder Pedal Displacement

Table 9. Means and *Standard Deviations* for Reliable Dependent Measures
(Bolding Indicates a Significant Effect.)

Upset	Control Group				Experimental Group			
	Nose-High Upright	Nose-Low Upright	Nose-High Inverted	Nose-Low Inverted	Nose-High Upright	Nose-Low Upright	Nose-High Inverted	Nose-Low Inverted
G Use in Dive Recovery	**1.36** *0.20*	**2.50** *0.38*	**2.00** *0.57*	**2.92** *0.58*	**1.88** *0.29*	**3.13** *0.50*	**2.56** *0.82*	**3.49** *0.59*
Average G / Target G	0.91 *0.12*	**.63** *0.09*	**.64** *0.16*	**.75** *0.20*	.93 *0.14*	**.79** *0.13*	**.84** *0.15*	**.87** *0.15*
Unload G	0.23 *0.20*	**1.72** *0.34*	0.66 *0.81*	**1.71** *0.63*	0.34 *0.26*	**1.37** *0.28*	0.52 *0.59*	**1.34** *0.52*
Altitude Loss	-119.38' *226.41'*	1001.76' *223.53'*	538.95' *380.63'*	1243.68' *338.68'*	12.17' *188.39'*	918.26' *225.70'*	563.18' *481.43'*	1290.95' *371.82'*
Seconds to First Throttle	**4.38** *5.25*	3.12 *2.34*	**4.79** *4.34*	**2.74** *1.52*	**1.91** *0.51*	2.13 *1.10*	**2.45** *1.77*	**1.57** *.51*
Seconds to First Roll	2.06 *0.99*	2.18 *1.01*	2.58 *1.68*	2.11 *1.56*	2.30 *1.11*	2.00 *0.85*	2.36 *0.85*	1.76 *0.94*
Seconds to Recover	12.31 *1.77*	**8.18** *2.21*	**12.00** *3.27*	8.32 *1.45*	11.08 *2.86*	**5.96** *1.07*	**9.14** *2.34*	7.43 *1.69*
Roll Input	**46.38°** *13.77°*	**17.18°** *4.79°*	40.00° *18.46°*	23.16° *9.60°*	**63.30°** *18.16°*	**24.22°** *13.73°*	40.64° *20.44°*	25.67° *13.54°*
Rudder Input	.75" *0.58"*	.20" *0.15"*	0.79" *0.76"*	0.23" *0.20"*	0.91" *0.28"*	0.18" *0.12"*	1.05" *0.58"*	0.33" *0.24"*

Average G During Pullout
$F (1, 37) = 37.98, p = .000$

Yoke Input in Degrees During Roll to Wings Level
$F (1, 37) = 9.90, p = .003$

Seconds to First Correct Throttle Response
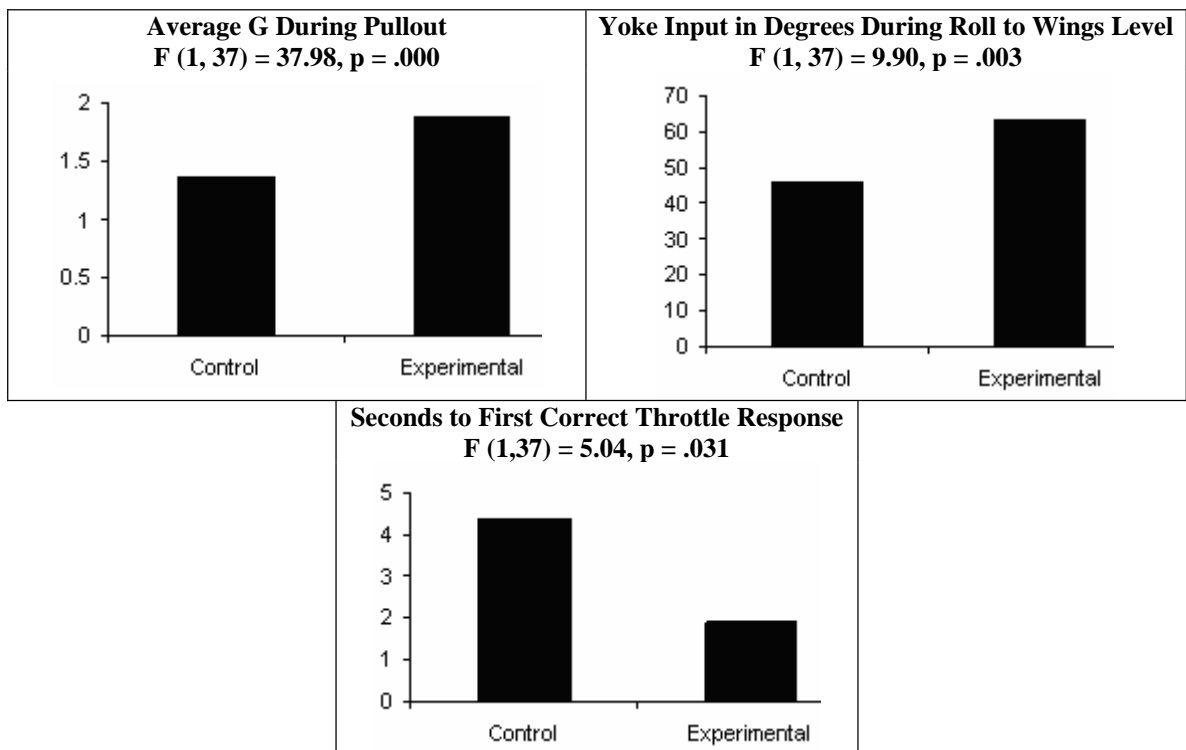$F (1,37) = 5.04, p = .031$

Figure 2. Graphical Display of Significant Differences for Nose-High Upright Upset

Nose-Low Upright Upset Results

The Wilks' Lambda value was significant, with the model explaining 57% of the variance between the groups ($F_{(9, 30)} = 4.45$, $p < .001$; $\eta^2 = .572$). Univariate tests revealed that the experimental group outperformed the control group in five areas:

- Average G during dive pullout ($F_{(1, 38)} = 18.66$, $p = .000$)
- Ratio of average G to target G ($F_{(1,38)} = 19.93$, $p = .000$)
- Unloading during roll ($F_{(1, 38)} = 12.79$, $p = .001$)
- Yoke rotation during rollout ($F_{(1, 38)} = 4.08$, $p = .050$)
- Seconds to recover ($F_{(1, 38)} = 17.70$, $p = .000$)

Figure 3 displays these results graphically.

Nose-High Inverted Upset Results

The Wilks' Lambda value was significant, with the model explaining 48% of the variance between the groups ($F_{(9, 31)} = 3.24$; $p < .007$; $\eta^2 = .484$). Univariate tests revealed that the experimental group outperformed the control group in four areas:

- Average G during dive pullout $F_{(1, 39)} = 6.29$, $p = .016$)
- Ratio of average G to target G ($F_{(1, 39)} = 18.06$, $p = .000$)
- Seconds to first throttle ($F_{(1, 39)} = 5.36$, $p = .026$)
- Seconds to recover ($F_{(1, 39)} = 10.64$, $p = .002$)

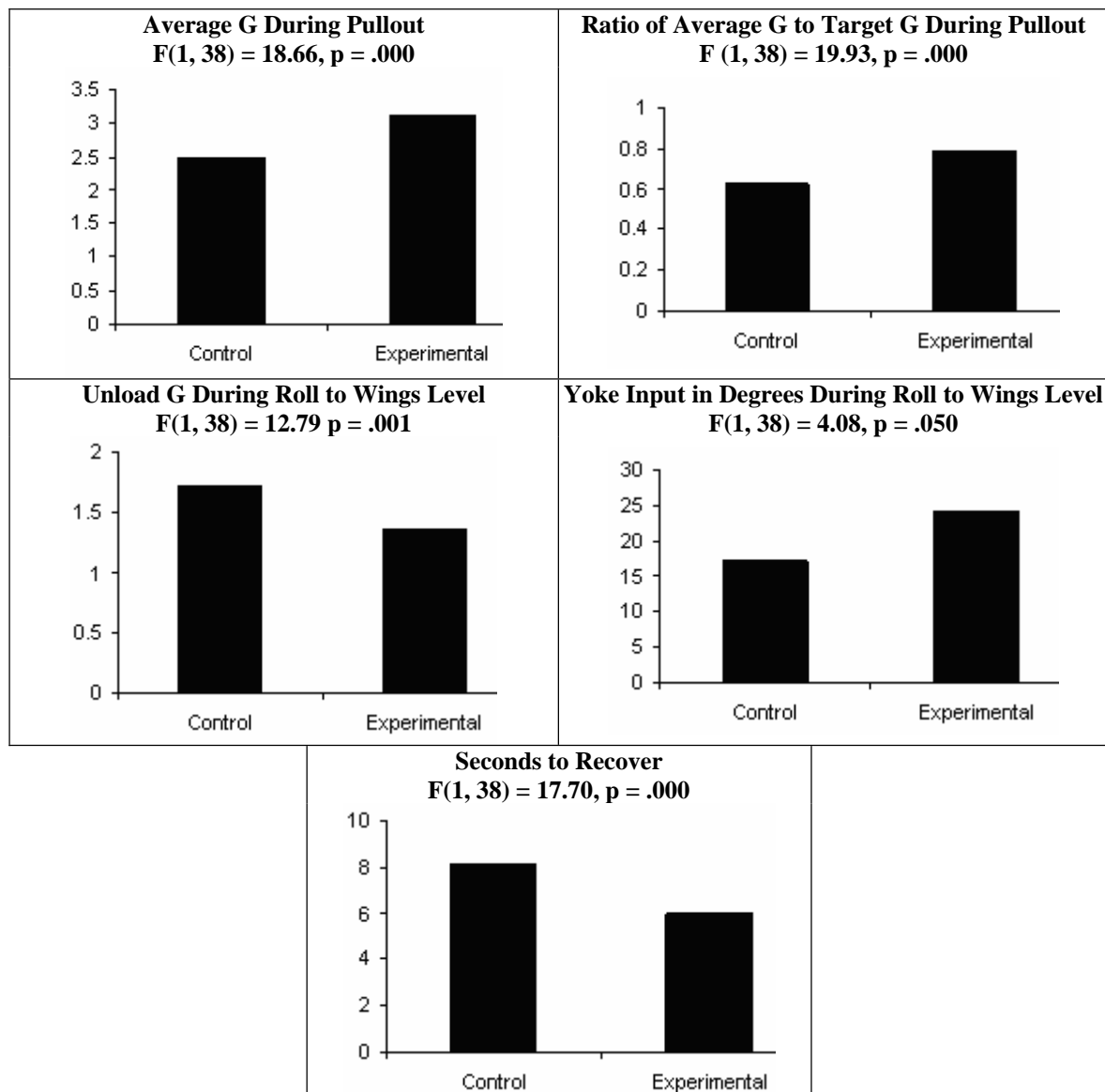Figure 4 displays these results graphically.

Figure 3. Graphical Display of Significant Differences for Nose-Low Upright Upset

Nose-Low Inverted Upset Results

The Wilks' Lambda value was significant, with the model explaining 48% of the variance between the groups ($F_{(9, 30)}$ = 3.04, $p < .010$; $\eta^2 = .477$). Univariate tests revealed that the experimental group outperformed the control group in four areas:
- Average G during dive pullout ($F_{(1, 38)}$ = 9.08, $p = .005$)
- Ratio of average G to target G ($F_{(1, 38)}$ = 4.71, $p = .036$)
- Unloading during roll ($F_{(1, 38)}$ = 4.10, $p = .050$)
- Seconds to first throttle ($F_{(1, 38)}$ = 10.99, $p = .002$)

Figure 5 displays these results graphically.

Successful vs. Unsuccessful Recoveries

The number and percentages of unsuccessful recoveries by group are reported in Table 10. Most unsuccessful recoveries resulted when safety pilot intervention was required to prevent violating the Bonanza's never-exceed speed of 196 KIAS. With respect to overall success in recovering the aircraft, no real differences between the two groups emerged. While some differences are apparent, especially in the nose-low inverted upset, the cell sizes were too unbalanced to compute reliable Chi-Square statistics on these data. In total, 14 out of all 232 upset recoveries (6.03%) were unsuccessful. The experimental group experienced an overall recovery failure rate of 5.00% (6 of 120), while the control group failure rate was 7.14% (8 of 112). As explained previously, we omitted from statistical analysis the data for all 14 unsuccessful upset recoveries.

IMPLICATIONS OF STATISTICAL RESULTS

Eta squared values in all four multivariate analyses suggest a strong relationship between training in low-cost flight simulators and subsequent control responses in a real airplane experiencing a serious upset situation. As seen previously, Table 9 contains 72 datum values reflecting experimental group performance and control group performance for each of the nine dependent measures. These results should be viewed as 36 paired mean data values, nine data pairs for each of the four upsets. Table 11 summarizes paired data values from Table 9 for dependent measures where experimental group pilots outperformed control group pilots (those Table 9 values shown in **bolding**). The table reveals that experimental group performance exceeded control group performance 44.4% of the time, i.e., for 16 dependent measure paired data values of a total of 36. This superiority appeared in all four upsets and in six of the nine dependent measures. By contrast, in three dependent measures—altitude loss, seconds to first roll, and rudder input—there was never a significant difference between experimental and control group performance.
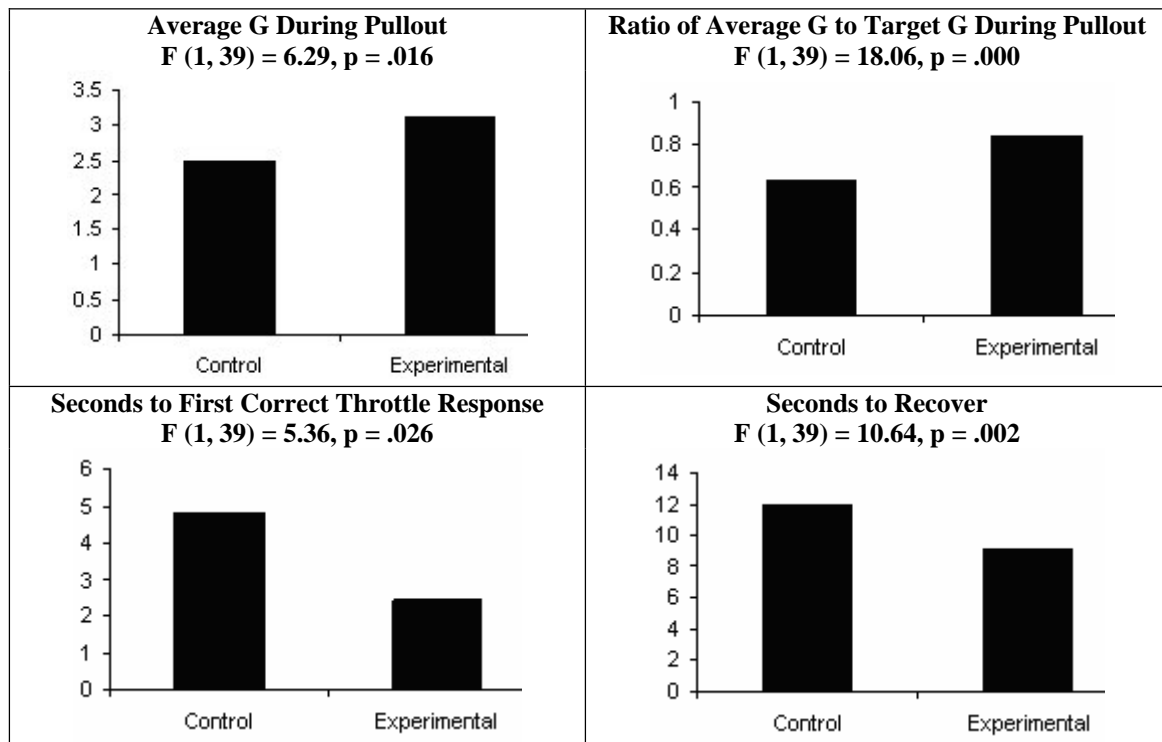

Figure 4. Graphical Display of Significant Differences for Nose-High Inverted Upset
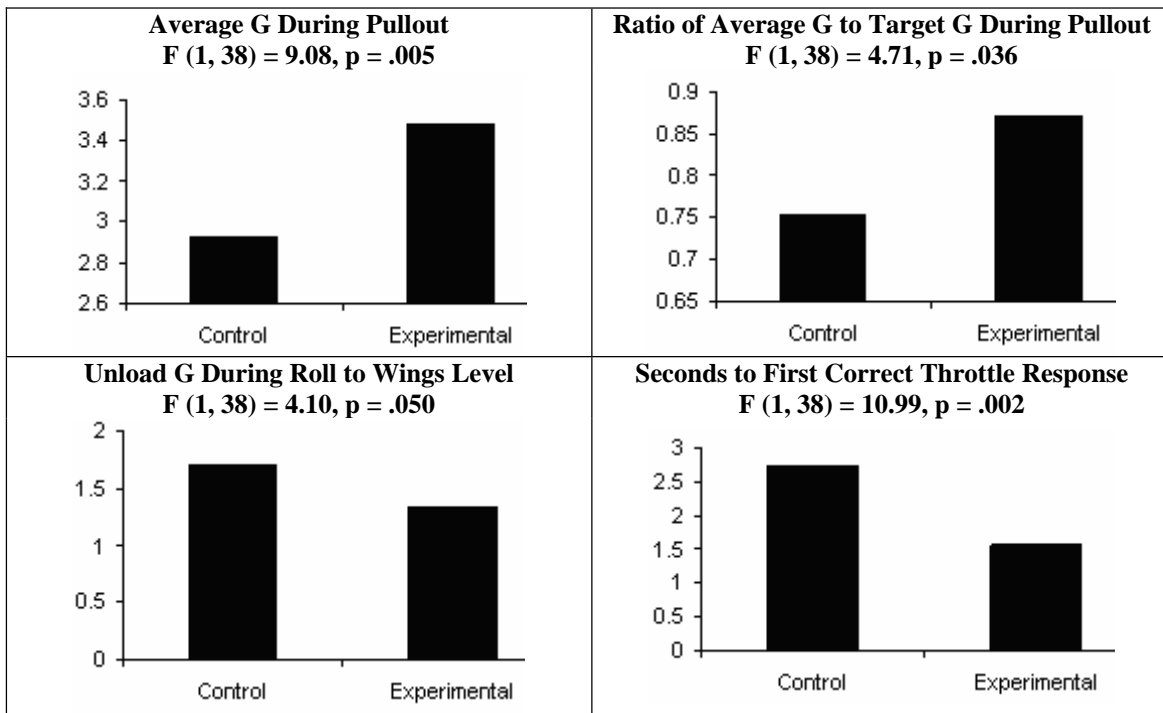
Figure 5. Graphical Display of Significant Differences for Nose-Low Inverted Upset

Table 10. Percentages of Unsuccessful Recoveries by Group for Each of Four Upsets

Group	Size	Upset			
		Nose-High Upright	Nose-Low Upright	Nose-High Inverted	Nose-Low Inverted
Control	28	2 (7.14%)	0 (0.00%)	1 (3.57%)	5 (17.86%)
Experimental	30	1 (3.33%)	2 (6.66%)	2 (6.66%)	1 (3.33%)
Totals	58	3 (5.17%)	2 (3.44%)	3 (5.17%)	6 (10.3%)

Table 11. Experimental vs. Control Group Performance Mean Values and *Standard Deviations* for Statistically Significant Performance Differences

Response Category	Upset			
	Nose-High Upright $F_{(9, 29)} = 5.04$ $p = .000, \eta^2 = .610$	Nose-Low Upright $F_{(9, 30)} = 4.45$ $p = .001, \eta^2 = .572$	Nose-High Inverted $F_{(9,31)} = 3.24$ $p = .007, \eta^2 = .484$	Nose-Low Inverted $F_{(9, 30)} = 3.04$ $p = .010, \eta^2 = .477$
Use of High G in Dive	1.88 G vs. 1.36G *0.29G vs. 0.20 G*	3.13 G vs. 2.50 G *0.50 G vs. 0.38 G*	2.56 G vs. 2.00 G *0.82 G vs. 0.57 G*	3.49 G vs. 2.92 G *0.59 G vs. 0.58 G*
Use of Available G (Ratio)		0.79 vs. 0.63 *0.13 vs. 0.09*	0.84 vs. 0.64 *0.15 vs. 0.16*	0.87 vs. 0.75 *0.15 vs. 0.20*
Unloading During Rollout		1.37 G vs. 1.72 G *0.28 G vs. 0.34 G*		1.34 G vs. 1.71 G *0.52 G vs. 0.63 G*
Large Yoke Roll Input	63.30° vs. 46.38° *18.16° vs. 13.77°*	24.22° vs. 17.18° *13.73° vs. 4.79°*		
Rapid Throttle Input	1.91 sec vs. 4.38 sec *0.51 sec vs. 5.25 sec*		2.45 sec vs. 4.79 sec *1.77 sec vs. 4.34 sec*	1.57 sec vs. 2.74 sec *0.51 sec vs. 1.52 sec*
Rapid Recovery		5.96 sec vs. 8.18 sec *1.07 sec vs. 2.21 sec*	9.14 sec vs. 12.00 sec *2.34 sec vs. 3.27 sec*	

The dependent measure data pairs in Table 11 can be grouped into three pilot performance categories: 1) superior control of G forces; 2) increased willingness to use large roll control inputs, and 3) quicker throttle responses. In addition, the table reveals that experimental group pilots tended to return the aircraft to straight-and-level flight faster than control group pilots.

Control of G Forces

Superior control of G forces by experimental group pilots is an important indication of training transfer in our experiment. This superiority is reflected in the use of high G during dive pullout and in G unloading during roll to a wings-level attitude.

In all four upsets, simulator training enabled experimental group pilots to apply significantly higher G forces during dive pullouts than control group pilots and to use a higher percentage of available G in all but the nose-high upright upset. However, few pilots in either group made full use of the allowable G force established for the experiment. In the interest of structural safety, we arbitrarily limited pilots to 4.0 Gs during flight testing, even though the Bonanza's maximum allowable G is 6.0. Experimental group pilots were taught to use 4.0 Gs in dive pullout at 118 KIAS and above, airspeeds where 4.0 Gs are available in the Bonanza. We attribute their reluctance to apply this learning during flight testing to the fact that general aviation pilots without aerobatic experience have rarely if ever experienced much more than 2.0 Gs. The unfamiliar sensation of high G—which of course cannot be replicated by a desktop flight simulator—apparently was sufficient to inhibit the trained pilots from applying the full 4.0 G force they had practiced in a simulator by referencing the G meter. In addition, 4.0 Gs is very easy to obtain in MFS, where there is no realistic control force feedback to the yoke. By contrast, to achieve the same G force in the Bonanza during a dive, a pilot must pull back very hard on the yoke to overcome the large control forces generated by high dynamic pressures on the elevator.

In both nose-low upsets, experimental pilot performance exceeded control group pilot performance in roll unloading. Experimental group pilots were taught to unload the airplane to low G while rolling to a wings-levels upright attitude—to zero G in nose-high recoveries, and to one-half G or less during nose-low recoveries. Both groups unloaded below 1 G during nose-high rolls. Pilots in both groups tended to make rolling pullouts from dives, although experimental group pilots were significantly less likely than control group pilots to apply a high G force during a rolling pullout. As explained below, the tendency of experimental group pilots to unload while rolling to a wings-level attitude during the nose-high inverted recovery

and both nose-low recoveries likely increased the altitude loss they experienced in these three recoveries. [27]

Roll Control Yoke Input

Experimental group pilots used significantly more roll input than control group pilots in both upright upsets. This reflects training that encouraged large, authoritative control roll inputs to roll the airplane to an upright wings-level attitude, especially during nose-high recoveries, where rapidly decreasing airspeed ensures slow roll response to aileron input. However, with more than 100° of yoke rotation available in the Bonanza, it is apparent that neither experimental nor control group pilots used available roll input during any upset recovery. We attribute this behavior to what we call *General Aviation Syndrome*, by which we mean a general aviation pilot's long-reinforced habit of using small control inputs when maneuvering an airplane. [28] It is one thing to practice large roll inputs in a non-threatening simulator environment but another thing entirely to apply this practice under the stress of a severe upset situation in an actual airplane. In short, although experimental group pilots outperformed control group pilots in appropriate use of roll input, their roll control input fell short of what is required for an optimal upset recovery. Note that *General Aviation Syndrome* behavior also reflects participant pilot reluctance—as discussed previously—to apply maximum allowable G forces during dive recovery.

Rapid Throttle Responses

Experimental group pilots were taught to add full throttle in nose-high upsets and to reduce the throttle to idle in high-energy nose-low situations. In flight testing, these pilots performed exactly as trained, and their performance in this respect significantly exceeded the performance of control group pilots in all but the nose-low upright upset, where—although the difference was not statistically significant—trained pilots nevertheless reduced thrust a second faster than control group pilots (in 2.13 seconds, as opposed to 3.12 seconds). Differences in throttle response times were particularly significant in the two nose-high upsets (Table 11). Relatively low standard deviations for experimental group times to apply throttle

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[27] While it is possible to recover from the 60° nose-high inverted upset without incurring a steep dive angle, virtually all recoveries from this upset resulted in a significant nose-low attitude prior to recovery.

[28] Perhaps the tendency to use small control inputs in upset recovery should be termed *Straight-and-Level Syndrome*, as it appears to characterize pilots at all levels who lack aerobatic experience. Two authors of this paper—Rogers and Howell—have attended upset training at four legacy airline companies. At each airline, we heard trainers remark that the difficulties they experience in persuading line pilots to use full yoke deflection when rolling a Level D simulator in an inverted upset to an upright, wings-level attitude.

reflect the fact that all trained pilots made a quick throttle adjustment in every upset. The large standard deviation values for control group pilots derive from the fact that a number of untrained pilots failed to adjust the throttle at all during some upset-recovery maneuvers.

Altitude Loss

Experimental group exceeded control group pilot performance in management of G forces, applying throttle correctly, and using larger roll control inputs. Why are these superiorities not reflected in the altitude loss data, as we hypothesized they would be?

For the nose-high inverted and the two nose-low upsets, the answer may be that control group pilots initiated rolling pullouts from dives, while experimental group pilots tended to follow their training by maintaining a lower G-force while rolling wings-level before initiating a hard pull-up from a nose-low attitude. Altitude is lost rapidly in a dive; for example, at 150 KTAS in a 45° dive, altitude loss exceeds 179 feet per second. Moreover, while the airplane remains unloaded, low induced drag causes airspeed to increase rapidly, increasing kinetic energy and ultimately increasing altitude loss. Of course, allowable G during rolling maneuvers is typically about 20% less than allowable G when no rolling moment is present, because rolling produces more lift and thus a higher G-force on the wing away from the roll than on the wing into the roll. However, since we limited participant pilots to 4.0 Gs in-flight testing, a 4.0 G rolling pullout in the 6.0 G Bonanza was safe. Under the circumstances of our experiment, then, rolling pullouts were not inappropriate, and assuming equal G-forces during dive recovery, a pilot who initiated a rolling pullout from a dive would lose less altitude than a pilot who rolled wings-level before pulling the nose-up hard. We will incorporate this observation into our training during Phase-Two of our research.

For nose-high recoveries, experimental group pilots were taught the canonical recovery—apply full thrust, unload completely, roll to achieve a bank angle of 45° – 60°, allow the nose to fall, roll unloaded to wings-level as airspeed increases and the nose approaches the horizon, then break the descent only after airspeed is sufficient to allow positive Gs to be generated. This recovery contrasts with the nose-high upset recovery taught candidates for the private pilot certificate, which is to increase throttle, roll the wings-level, and lower the nose toward the horizon at a reduced G force. Ironically, in the Calspan aerobatic Bonanza, the private pilot "incorrect" recovery worked better than the canonical recovery for the nose-high upright upset criteria specified in our experiment.

During experiment design, we practiced upset recoveries in a standard E33A Beech Bonanza. At 70 KIAS, it is impossible to recover this airplane with minimum altitude loss from a 60° nose-high, 15° bank upset without increasing bank angle

to lower the nose. Even under full power, attempting to level the wings and fly over the top will lead to near zero airspeed and a sudden and severe nose-down pitch. Accordingly, we trained pilots to lower the nose smoothly in such a circumstance by initially increasing bank angle—the industry-wide standard procedure for severe nose-high upsets. After training was complete, we discovered that additional horsepower and a three blade propeller on the Calspan EA33C aerobatic Bonanza allow a pilot to recover from our nose-high upright upset by applying full throttle, unloading, and leveling the wings. The higher horsepower and more efficient prop provide the capability to power the airplane over the top with an altitude gain, especially if the entry airspeed exceeds the specified 70 KIAS, as was not infrequently the case. Untrained pilots who applied this "incorrect" general aviation recovery procedure for our nose-high upright upset sometimes achieved a smaller altitude loss than trained pilots who increased bank angle during the recovery. When we train in the future, we will teach both methods of nose-high recovery—explaining that the "incorrect" recovery method may succeed in a high thrust-to-weight ratio airplane and cautioning trainees that very few non-aerobatic general aviation airplanes develop thrust adequate to complete an over-the-top recovery from a serious nose-high upright upset.

During Phase-One testing, video recording of upsets revealed that many trained pilots made throttle adjustments before initiating the appropriate rolling maneuver. To minimize altitude loss, these events should occur simultaneously, not sequentially. Even a one-second delay in initiating a roll is likely to increase altitude loss significantly, especially in nose-low upsets, where throttle reduction has far less effect on minimizing altitude loss than an immediate and rapid roll rate to a wings-level upright attitude.

General Aviation Syndrome

During pilot debriefing in Phase-One Flight testing, we asked trained participants why they so often failed to apply the large control inputs they had practiced in the simulator. The typical reply indicated that the stress of the upset experience resulted in their being minimally aware of how much control input they were using. In other words, stress to some extent made them turn the blind eye to their training, with the result that they instinctively used the small control inputs practiced during several hundred hours of general aviation upright flight. As we have seen, there was some indication of training transfer in roll control input and control of G forces. However, the degree to which a modest amount of ground simulator training can help pilots overcome *General Aviation Syndrome* during an initial upset-recovery experience is an open question. Long reinforced behavior combined with significant stress is indeed a strong cognitive inhibitor.

PHASE-TWO TRAINING AND TESTING

During Phase-Two, we will repeat the Phase-One experiment with 25 new experimental pilots and 25 new control group pilots in the hopes of obtaining stronger results. A new control group is required because we plan to use a different flight-test aircraft. Prior to Phase-Two flight testing, we will work more closely with our aircraft provider to ensure that the flight data and video recorders are accurate and are operated properly, and that safety pilots standardize upset entry profiles to ensure closer adherence to specified airspeeds, attitudes, and throttle settings. In addition, Phase-Two experimental group pilots will benefit from an improved training program based on insights deriving from Phase-One testing outcomes.

During Phase-One flight testing, we came to understand that minimum altitude loss upset-recovery techniques are somewhat more airplane-specific than we previously had acknowledged. We will incorporate lessons learned from the first flight testing period when we train experimental pilots during Phase-Two. Specifically, we will:

- For nose-high upsets, continue to teach the canonical approach suitable for low thrust-to-weight general aviation airplanes. In addition, we will teach the "power over the top" recovery for nose-high upright recoveries that will succeed with high thrust-to-weight aerobatic airplanes.
- For nose-low recoveries, continue to teach pilots to avoid rolling pullouts if the dive pullout G force will approach the symmetric wing-loading allowable G limit. However, we will also advise participants that when dive pullout will not exceed the rolling pullout G limit, less altitude loss will result by applying maximum available/allowable G as soon as the roll toward a wings-level attitude points the lift vector toward the sky.
- Be more emphatic in teaching pilots to unload completely during rolls in nose-high recoveries.
- Be more emphatic in teaching pilots to use large yoke roll inputs when rolling at low airspeed during nose-high upsets.
- Be more emphatic in teaching pilots to use rudder as well as aileron to achieve rapid roll rates in nose-high recoveries.
- Be more emphatic in teaching pilots to initiate throttle changes and yoke roll control inputs simultaneously rather than sequentially.
- Reinforce more strongly the need during flight testing to resist control input behavior reflecting *General Aviation Syndrome*.

FOLLOW-ON RESEARCH

Regardless of the outcome of Phase-Two of our experiment to determine the value of upset training using low-cost desktop flight simulation, an interesting question will remain: would a better flight simulation device produce superior results?

To address this question, the Environmental Tectonics Corporation (ETC) has obtained FAA funding to train 25 ERAU student pilots in an ETC centrifugal flight simulator, then flight-test them and compare their performance to our Phase-Two experimental and control group pilots. Flight testing of ETC trained pilots will be conducted by ERAU in Daytona Beach and will be identical to our currently planned Phase-Two flight testing. ERAU will give ETC participants the same ten hours of classroom training our experimental group pilots receive. In addition, they will receive five hours of aerobatic training on MFS. However, the ETC participants will not receive MFS upset-recovery training. Instead, after completing the 15-hour training syllabus at ERAU, they will travel to Pennsylvania, where they will receive five hours of upset-recovery training in the centrifugal flight simulator. ETC will modify the centrifuge to replicate the flight characteristics of a general aviation airplane.

ETC's research is designed to determine the added value of upset training in a motion based flight simulator capable of generating continuous G-forces. ETC hypothesizes that pilots trained in a centrifuge will outperform MFS trained pilots, as well as pilots trained in 6 DoF conventional air transport simulators. However, funding restraints dictate that only the former portion of this hypothesis will be tested in the follow-on research.

CONCLUDING REMARKS

We are uncertain whether the data we will collect in Phase-Two flight testing will provide stronger support for our hypothesis that low-cost, simulator-based upset-recovery training improves a pilot's ability to recover from an actual upset. It seems quite intuitive that such training will increase a pilot's *knowledge* of upset-recovery maneuvering, and Phase-One testing did reveal a measure of training transfer. What is problematic is whether ground-based training also provides the ability to *apply* this knowledge confidently and completely during a pilot's first serious in-flight upset experiences. Based on what trained participants said about their Phase-One testing experience, we will not be surprised if more complete Phase-Two data supports

only a modest rather than a large difference in performance between trained and untrained participants. It may well be the case that simulator-trained pilots need all attitude flight experience in a real airplane to hone their simulator-based upset-recovery skills to an acceptably high level.

The results of our research should be of interest to air transport upset trainers, as well as to the general aviation community. Confirmation of our research hypothesis might provide a basis for training airline pilots in upset recovery using desktop simulation, while reserving very expensive Level-D simulators for training where cockpit verisimilitude is a requirement. On the other hand, if we find little significant difference between trained and control group pilots, one might logically ask if current airline simulator-based upset-recovery training programs impart flying skills sufficient to make it probable that typical line pilots can recover an airliner from a serious upset.

The changing demographics of airline pilots imply an increasingly important need to provide them with adequate upset-recovery training. Thirty years ago, U.S. airline pilots typically came from military flight backgrounds that afforded them extensive opportunity to perform aerobatics and routinely to experience all attitude flight. By contrast, most air transport pilots flying today lack military backgrounds and have never experienced the extreme pitch and bank angles associated with severe airplane upsets. Indeed, most have never even been upside-down in an airplane. Informal conversations with current airline pilots suggest that while virtually all regard the upset training they receive as useful, a significant number also perceive it as a *pro forma* approach to a serious safety problem—better than nothing but far from what would be desirable if training costs were not a paramount consideration.

Upsets are known to be a primary cause of fatal commercial air transport accidents. Passenger and air crew safety considerations mandate that air transport pilots be able to recover from the infrequent but potentially catastrophic upsets which inevitably will occur from time to time in routine operations. What kind of training they need to develop the necessary piloting skills is an open question. Perhaps current training programs are adequate. Perhaps training in centrifuge based simulators is a desirable improvement over current methods. Perhaps in-flight aerobatic and upset-recovery training at the commercial and/or ATP certification level is required for acceptably high upset-recovery proficiency. Currently, little is known about the efficacy of simulator-based upset-recovery training. We hope our study will advance knowledge in this somewhat neglected area of aviation safety research.

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