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An Experiment to Evaluate Transfer of Upset-Recovery Training Conducted Using Two Different Flight Simulation Devices

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16. Abstract

Air transport training programs provide simulator-based upset-recovery instruction for company pilots. However, no prior research demonstrates that such training transfers to an airplane in flight. We report on an FAA-funded research experiment to evaluate upset-recovery training transfer. Two groups of participants were given simulator-based training in upset-recovery, one in a high-end centrifuge-based device, the other using Microsoft Flight Simulator running on desktop computers. A third control group received no upset-recovery training at all. All three groups were then subjected to serious in-flight upsets in an aerobatic airplane. Pilots from both trained groups significantly outperformed control group pilots in upset-recovery maneuvering. However, performance differences between pilots from the two trained groups were less distinct. Moreover, pilot performance in both trained groups fell well short of the performance exhibited by pilots experienced in all attitude flight. Although we conducted flight testing in a general aviation airplane, our research has important implications for heavy aircraft upset-recovery trainers.

17. Key Words
Airplane Upset-Recovery Training; Flight Simulation; Training Transfer; Centrifuge-Based Flight Simulator; Microsoft Flight Simulator

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AN EXPERIMENT TO EVALUATE TRANSFER OF UPSET-RECOVERY TRAINING CONDUCTED USING TWO DIFFERENT FLIGHT SIMULATION DEVICES

1. INTRODUCTION

An upset occurs when an airplane enters an unexpected attitude that threatens loss of control (LOC) and subsequent ground impact. For the years 1998 - 2007 inclusive, LOC was the leading cause of hull losses and passenger fatalities in worldwide air transport operations, causing almost 25% of all crashes and nearly 40% of all fatalities.[1] During the years 1991 - 2000, statistics for general aviation (GA) accidents in the United States are similar, while in Australia, LOC accounted for an even greater proportion of GA accidents and fatalities.[2]

Since LOC threatens passengers and flight crews as well as potential victims on the ground, air transport training programs typically contain a module instructing pilots how to recover an airplane from an upset. However, the effectiveness of such simulator-based training remains uncertain. Rogers et al. (2009) report significant training transfer using low-cost simulation to teach upset-recovery maneuvering to general aviation pilots with no prior aerobatic experience. Participant pilots were trained using Microsoft Flight Simulator running on low-cost desktop computers, then tested in an aerobatic Super Decathlon airplane.[3] Our research addresses the question of whether use of a more sophisticated fight-simulation device—the Environmental Tectonics Corporation GyroLab-2000 (GL2000) centrifugal flight simulator—might significantly improve training transfer. In what follows, we:

- Report on relevant prior research.
- Describe our research experiment.
- Present and interpret experimental results.
- Provide concluding remarks.

2. PRIOR RESEARCH[4]

We have found only a few research articles related to the transfer of simulator-based upset-recovery training. Several reports result from research at the Calspan In-Flight Upset-Recovery Training Program in Roswell, NM.[5] A second set of articles focuses on centrifuge-based flight simulators manufactured by the Environmental Tectonics Corporation. A third group discusses human factors considerations in upset-recovery training. Finally, we are aware of just one article related to training transfer when upset maneuvering is taught using low-cost simulation.

2.1 Calspan-Related Research

Calspan provides *in-flight* simulator-based upset-recovery training in a variable stability Learjet 25 modified to simulate the control characteristics of an air transport airplane. The Calspan Lear can simulate various accident scenarios that, in the past, have resulted in air transport upsets leading to uncontrolled crashes.

Gawron 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, hypothesizing 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.[6]

Kochan 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 analyze 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.[7]

Kochan and Priest 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 program] on a pilot's ability to respond to an in-flight upset."[8]

Kochan, Breiter, Hilscher, and Priest surveyed retention of knowledge in Calspan trained pilots. Although participants in retrospect "rated their ability to recover from loss-of-control situations as being greatly improved by the training," most were unable to recall various specific details about upset-recovery maneuvering taught during their training.[9]

2.2 Centrifuge-Based Flight Simulation

The Calspan Learjet in-flight simulator 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 centrifuge-based flight simulators capable of generating continuous G forces.

Such simulators bring to ground-based upset-recovery training a degree of realism unachievable even in Level D simulators. Three ETC proprietary technical reports (available from Dick Leland at dletc@aol.com) detail the capabilities of the company's current generation of centrifugal simulators.[10,11,12] One 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."[13,14] In a related article on motion-based flight simulation, Szczepanski and Leland argue that "simulator data analysis suggests that motion cueing is necessary when training *ab initio* pilots or pilots who have limited or no experience in the particular flying task that is being trained."[15]

2.3 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, Breiter, and Jentsch (2004) found pilots often miss cues that might lead to avoiding an emergency that later arrives as a surprise.[16] In a follow-on paper, the same researchers develop "a conceptual framework for the study of unexpected events in aviation."[17] Kochan, Priest, and Moskal use a model for the "cognitive process of surprise"[18] to study "how an unexpected event can escalate to a loss-of-control situation." They conclude that in-flight [as opposed to ground-based] simulator training may be necessary to teach pilots to deal adequately with their perceptual biases in processing information during a surprise upset.[19,20] In a related paper, Kochan argues 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).[21]

2.4 Low-Cost Simulation

Roessingh studied training transfer from low-fidelity ground-based flight simulators to control of an actual airplane during aerobatic flight. Two experimental groups received ground-based instruction in aerobatic maneuvering 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." Then the two trained 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 maneuvering of trained and control group pilots. [22]

3. THE RESEARCH EXPERIMENT

Our research experiment involves a partnership between Environmental Tectonics and Embry Riddle Aeronautical University (ERAU) in Daytona Beach, Florida. It continues an upset-recovery training transfer experiment performed at ERAU in Spring 2008. In this section we summarize the ERAU experiment, then describe our own research experiment and explain how its design expands the results of the original experiment.

3.1 The ERAU Research Experiment

Rogers et al. (2009) report the results of an experiment to test the hypothesis that simulator-trained pilots will outperform untrained pilots in recovering an actual airplane from a serious upset. The researchers trained a group of participant pilots in upset-recovery maneuvering using Microsoft Flight Simulator (MFS). Participants in the experiment were student pilots at ERAU Daytona Beach. All held a current instrument rating and had completed an academic course in basic aerodynamics for pilots. None had prior aerobatic experience or upset-recovery training beyond that required for FAA flight certificates and ratings.

As reflected in Table 1, the ERAU experiment is a 2 x 4 repeated measures factorial. The degree of training

Table 1. The 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 Classroom / Simulator (Trained Group)	Trained pilots	Trained pilots	Trained pilots	Trained pilots
	None (Control Group)	Untrained pilots	Untrained pilots	Untrained pilots	Untrained pilots

Table 2. Levels of the Upset Attitude Independent Variable †

Upset	Pitch	Bank	Airspeed	Thrust
Nose-high Upright	60° Nose-high	45° Left Wing Down	65 MPH	Idle
Nose-low Upright	45° Nose-low	70° Right Wing Down	130 MPH	Full
Nose-high Inverted	60° Nose-high	180° (Inverted, Wings Level)	65 MPH	Idle
Nose-low Inverted	20° Nose-low	180° (Inverted, Wings Level)	110 MPH	Full

† Nose-high airspeeds were set 12 mph above the Decathlon 1G stall speed (Vs=53mph); nose-low airspeeds were set at a maximum safe value considering pitch and roll angles and the Decathlon redline speed (Vne=200mph).

independent variable has two levels—trained and untrained. Trained participants received ten hours of classroom and ten hours of MFS upset-recovery training. Untrained participants—control group pilots—received no classroom or simulator training. The upset attitude independent variable has four levels corresponding to the four upsets each participant is subjected to during flight testing. Upset attitudes were categorized as nose-high or nose-low and as upright or inverted. An inverted attitude is one where the bank angle exceeds 90°. Table 2 presents the upset attitudes used in flight testing.

Research participants trained in aerobatic and upset-recovery maneuvering on MFS were flight tested in an Embry-Riddle aerobatic Super Decathlon airplane, as were control group participants. Participant pilots closed their eyes while the Decathlon safety pilot induced an upset, then—when instructed to do so—opened their eyes and attempted to bring the airplane under control. 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 unsuccessful. A good recovery was one where a pilot respected aircraft operating limitations while returning the aircraft to straight and level flight with the minimum possible loss of altitude. Minimum altitude loss results from promptly applying full thrust in nose high and idle thrust in nose-low upsets; rolling without delay toward a wings-level upright attitude; unloading during inverted rolls or when airspeed is below V_S; using high G forces in dive pullouts; and recovering quickly. Dependent variables—shown in Table 3—were chosen to measure these factors.

Table 3. Dependent Variables

Dependent Measure
Recovery Altitude Loss in Feet
Time to First Throttle Response in Seconds
Time to First Roll Response in Seconds
Minimum G Force Unloading During Rolls †
Maximum G Force in Dive Pullout
Time to Recover in Seconds

† Not applicable to the nose-low upright upset, since trained pilots were taught to use rolling pullouts during dive recovery.

Data were collected using a battery-operated video camera focused on the Decathlon's instrument panel. A high resolution palm-size video recorder captured cockpit voice communications and the camera's output (Figure 1). An installed battery operated Appareo GAU-1000 flight data recording system proved erratic in aerobatic attitudes. Although the unit records aircraft position, altitude, airspeed, attitude (pitch and bank), G forces (x, y, and z), and yaw angle (ß) at 3-4 Hz, only the G force reading was reliable.

During Decathlon flight testing, data were collected for 25 trained and 26 control participants. Six trained pilots and eight control group pilots experienced unsuccessful recoveries during the nose-low inverted upset as a result of threatening the Decathlon's redline speed. Data for these recoveries were discarded. One-way MANOVAs were used to compare trained and control group participant performance for each of the four upsets.[23] The difference between trained and control group participants was significant in all four cases. Table 4 reports samples sizes and Wilks' Lambda values for each of the four MANOVAs. For each of the dependent variables, subsequent univariate t-tests with the Bonferroni adjustment were conducted. In Table 5, an X indicates where univariate analysis revealed that trained pilots significantly outperformed control group pilots on the dependent measure and upset indicated.[24]

Statistical analysis confirmed that low-cost simulator-based upset-recovery training improves pilot performance in recovering an airplane from a serious upset. Trained pilot performance exceeded untrained pilot performance in 16 of 23 dependent measure categories, or 69.6% of the time. Trained participants lost less altitude than control group pilots in all four upsets, and two of the four altitude differences were statistically significant. In general, trained pilots initiated rolls toward a wings level upright attitude sooner and applied more Gs in dive pullouts than untrained pilots, both critical factors in minimizing altitude loss. In addition, trained pilots also applied throttle more promptly than untrained pilots. These differences, in turn, resulted in a quicker return to straight-and-level flight.

At the same time, research results suggest the limitations of low-cost ground-based simulator training in

Figure 1. Sample Decathlon Video Recorder Output

Table 4. Multivariate Wilks' Lambda Values and Group Sizes for Each Upset (**Bolding** = Significant Difference)

Upset	Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
Trained Group Size	n=25	n=25	n=19	n=24
Control Group Size	n=26	n=26	n=17	n=26
Combined Group Size	n=51	n=51	n=36	n=50
Wilks Lambda Value	**F (5,45) =9.59** **p = .0001** **η^2 = .0.52**	**F(6,44) = 4.47** **p = .001** **η^2 = 0.38**	**F (6,29) =9.11** **p = .0001** **η^2 = 0.653**	**F (6,43) =10.26** **p = .0001** **η^2 = 0.60**

Table 5. Significant Performance Differences (**X**) between MFS-Trained and Control Group Participants as Determined by 2-Group Multivariate Analyses with Follow-Up Protected Univariate Tests

Dependent Measure	Upset			
	Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
Altitude Loss	**X**		**X**	
Minimum Unload G in Rolls	Not Applicable			
Maximum G Load in Dive Pullout	**X**	**X**	**X**	**X**
Seconds to First Throttle	**X**		**X**	**X**
Seconds to First Roll	**X**	**X**	**X**	**X**
Seconds to Recover	**X**	**X**		**X**

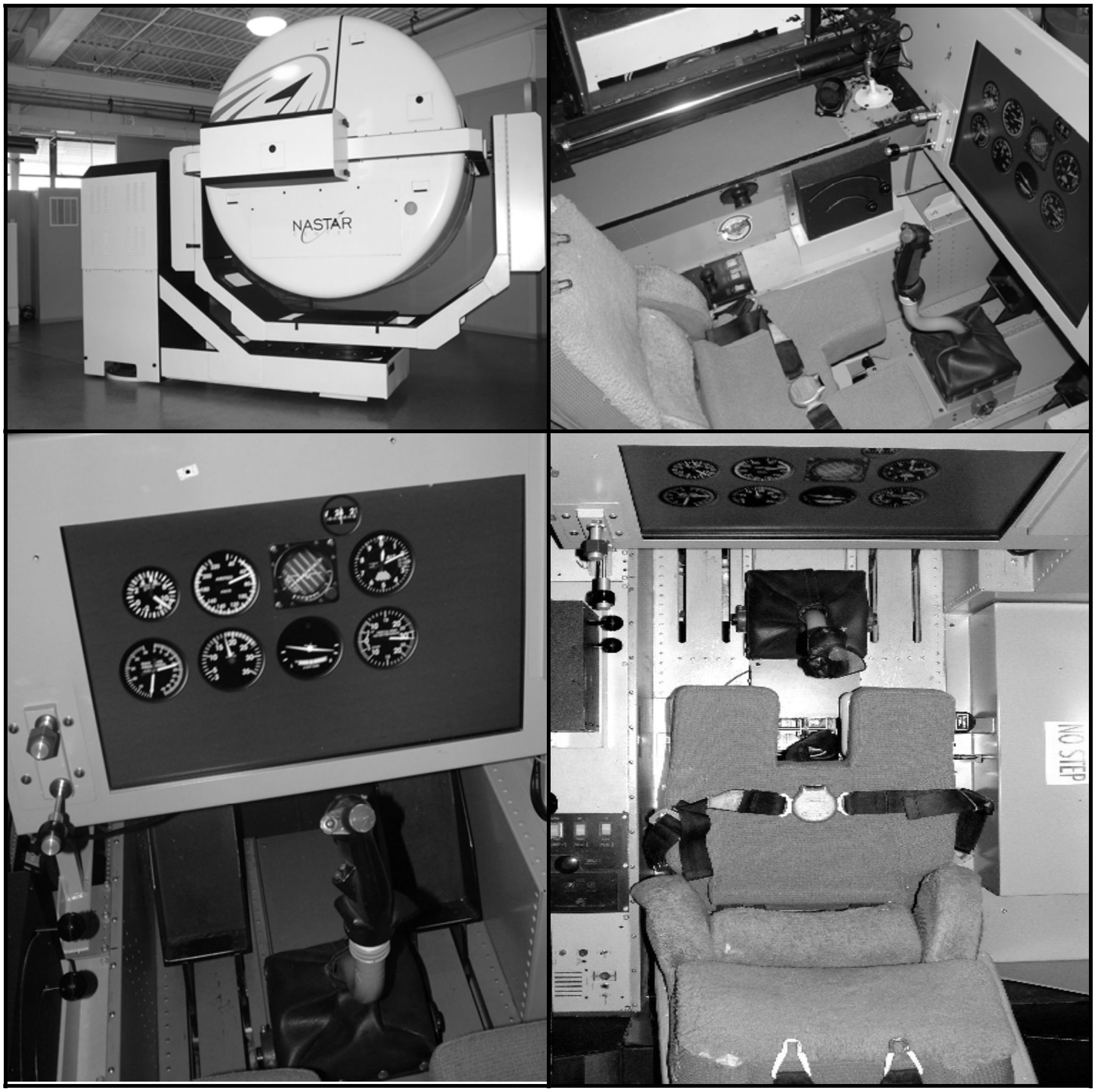

Figure 2. Exterior and Interior Views of the GL2000 Simulator

developing upset-recovery maneuvering skills. There was no significant difference in altitude loss between trained and control group pilots in both nose-high upsets. Moreover, even when trained pilots significantly lost less altitude than control group pilots, there was a large disparity between research participant altitude losses and the far smaller altitude losses achievable by pilots experienced in all-attitude maneuvering. We return to this subject in Section 5.2 below.

3.2 The ETC Expanded Research Experiment

Our experiment expands the original research design described above by adding one level to the Degree of Training independent variable. It is designed to determine the added value of upset training in a motion based flight simulator capable of generating continuous G-forces.

Twenty-five Embry-Riddle flight students received the same ten hours of classroom training that trained participants received in the original ERAU experiment. They also received five hours of MFS training (aerobatic maneuvering only), then traveled in small groups to Pennsylvania to receive five hours of upset-recovery training in Environmental Tectonics' proprietary GL2000 flight simulator. The GL2000 was modified to give it the flight characteristics of a Super Decathlon airplane and to make its basic flight instruments replicate the layout on a Decathlon's instrument panel. Figure 2 presents external and interior views of the GL2000 simulator with the cockpit modified to replicate a Super Decathlon cockpit.

Upon completion of their classroom and simulator training, the 25 research participants were subjected to Super Decathlon flight testing identical to that received earlier by MFS-trained and control group participants.

Table 6. The 3 x 4 Repeated Measures Factorial Design of the Expanded Research Experiment

3 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 GyroLab-2000	GL2000/MFS-Trained Pilots	GL2000/MFS-Trained Pilots	GL2000/MFS-Trained Pilots	GL2000/MFS-Trained Pilots
	10 Hours Classroom / 10 Hours MFS Training	MFS-Trained Pilots	MFS-Trained Pilots	MFS-Trained Pilots	MFS-Trained Pilots
	None Control Group Pilots	Untrained Pilots	Untrained Pilots	Untrained Pilots	Untrained Pilots

Table 7. Group Sizes for the Three Participant Groups

Upset	Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
GL2000-Trained Group Size	n=22	n=23	n=21	n=22
MFS-Trained Group Size	n=25	n=25	n=19	n=24
Control Group Size	n=26	n=26	n=17	n=26
Combined Group Size	n=73	n=74	n=57	n=72

Performances of the three groups were then compared. We hypothesized that pilots trained in the GL2000 simulator would outperform MFS-trained and untrained pilots in upset-recovery maneuvering. Table 6 reflects the fact that our experiment is a 3x4 repeated measures factorial.

4. RESULTS

4.1 Data Collected

As in previous flight testing sessions, various factors including airsickness and equipment malfunction precluded our obtaining complete data sets for every GL2000-trained pilot.[25] Table 7 reports the total number of participants for whom we obtained usable data for each of the four upsets. Table 8 presents mean and *standard deviation* values for data collected during flight testing. Data for MFS-trained and control group participants were collected in March 2008, data for GL2000-trained participants in November 2008.

4.2 Data Analysis

Execution of the experiment resulted in one deviation from the experimental design. Motion sickness and other logistic difficulties resulted in participant pilots receiving only 2.5 hours (on average) of five scheduled GL2000 training hours. To compensate, participants were allowed to observe the training sessions of other participants. An unavoidable execution drawback was that the ERAU class schedules required GL2000 training to take place during intensive two-day weekends. Five participants were trained each weekend for five successive weekends. This training schedule resulted in some GL2000 participants completing training as much as four weeks prior to flight testing. By contrast, MFS-trained participants received one hour of simulator training per week over a span of ten weeks and were tested in a two-week period immediately following the conclusion of their training.

4.2.1 *A Priori* Analyses on Altitude Loss

MANOVAs are the conventional choice for analyzing our data. Nevertheless, we first conducted *a priori* t-tests to determine altitude loss differences between pairs of groups for each upset. A number of factors justified this decision:

1. Altitude loss is the most important of the six dependent variables. As explained in Section 2.1, performance on the other five dependant measures directly influences how much altitude is lost.

2. Other variables affect altitude loss but could not be included in our experimental measurements:
   - Roll and pitch rates
   - Magnitude of elevator, aileron, and rudder inputs, especially rudder input to roll at low airspeeds
   - Use of available G in dive pullout
   - Promptness and uniformity of appropriate G input

   Data for these measures would improve our ability to discriminate between trained and untrained pilot

Table 8. Mean and Standard Deviation Values for Each Upset and Dependent Variable

Upset	**Nose-Low Upright**			**Nose-High Upright**		
	GL2000	**MFS**	**Control**	**GL2000**	**MFS**	**Control**
Altitude Loss in Feet	600.00 *181.29*	565.20 *75.28*	728.46 *169.51*	213.04 *157.87*	331.20 *225.56*	340.38 *184.75*
Min Unload G in Rolls	Not Applicable			0.10 *0.06*	0.00 *0.12*	-0.04 *0.15*
Max G in Dive Pullout	3.78 *0.57*	3.70 *0.64*	2.90 *0.49*	1.87 *0.42*	2.41 *0.90*	1.82 *0.30*
Seconds to First Throttle	2.45 *1.68*	3.0 *1.66*	5.19 *2.43*	1.83 *2.01*	2.12 *1.62*	3.27 *2.97*
Seconds to First Roll	1.32 *0.57*	1.28 *.46*	1.85 *.68*	1.91 *0.90*	2.28 *.89*	3.15 *1.38*
Seconds to Recover	5.27 *1.24*	5.40 *1.38*	7.04 *1.64*	10.26 *1.57*	11.16 *1.43*	12.88 *2.98*

Upset	**Nose-Low Inverted**			**Nose-High Inverted**		
	GL2000	**MFS**	**Control**	**GL2000**	**MFS**	**Control**
Altitude Loss in Feet	884.76 179.41	948.95 *167.03*	1069.41 *139.08*	368.18 *169.19*	382.08 *200.65*	464.62 *169.59*
Min Unload G in Rolls	0.57 *0.90*	0.99 *0.86*	1.41 *.63*	-0.39 *0.18*	-0.47 *.28*	-0.43 *.26*
Max G in Dive Pullout	4.42 0.57	4.74 *0.62*	3.98 *0.50*	2.65 *0.49*	2.90 *0.84*	2.34 *0.45*
Seconds to First Throttle	2.90 *2.10*	2.79 *1.78*	4.41 *2.81*	2.14 *4.02*	1.48 *.68*	3.31 *3.21*
Seconds to First Roll	2.48 *1.78*	1.68 *.67*	4.88 *3.30*	4.41 *2.48*	3.04 *1.30*	6.15 *2.98*
Seconds to Recover	7.05 *0.97*	7.11 *1.29*	7.88 *.99*	12.00 *2.91*	13.33 *1.74*	15.23 *2.27*

performance. However, we lacked funding to purchase and install a sophisticated flight data recorder in our test aircraft. Moreover, Embry-Riddle policy precludes the use of invasive instrumentation in a university airplane used for flight training.

3. High G force applied during dive pullout from a nose-high recovery is not invariably a reliable indication of superior performance. In an optimal nose-high upset-recovery in the Decathlon, the pilot immediately sets full throttle and unloads the airplane, then applies full rudder and aileron to roll the airplane toward an upright wings-level attitude. As the airplane continues to climb, airspeed decreases toward zero rapidly. The airplane remains unloaded as the nose falls slowly through the horizon and airspeed begins to increase. At 15°-20° nose-low, the wings are level and airspeed has increased to 65-70 mph. At this point the pilot applies available G in the range of 1.25-1.5 to raise the nose gently to the horizon. Altitude loss is typically 100-200 feet; in some cases, an altitude gain actually results.

High G force during the low-speed shallow dive recovery is neither required nor available. However, novice pilots often apply inappropriate control inputs, resulting in a steep nose-down attitude and high airspeeds. At this point, a large altitude loss is inevitable, and high G is available and required to avoid losing additional altitude. GL2000-trained pilots were more successful on average than MFS-trained pilots or control group pilots in avoiding a steep nose-down, high speed dive recovery in nose-high upsets. This success is reflected in a statistically significant smaller altitude loss paired with a lower pullout G for the nose-high upright recovery.

4. There is considerable "noise" (high variability) in the data we collected. High standard deviations, of course, decrease the power of MANOVA and ANOVA analyses to detect significant differences among the three groups.

Table10 presents the results of pairwise t-tests to determine significant altitude loss differences between every two groups—GL2000-Trained vs. Control, GL2000-Trained vs. MFS-Trained, and MFS-Trained vs. Control. GL2000-trained participants lost significantly less altitude than MFS-trained participants in the nose-high upright upset. Otherwise the two trained groups performed equally in

Table 9. Altitude Loss and *Standard Deviation* by Group for Each of Four Upsets

Upset	Nose-Low Upright			Nose-High Upright		
	GL2000	MFS	Control	GL2000	MFS	Control
Altitude Loss in Feet	600.00 *181.29*	565.20 *75.28*	728.46 *169.51*	213.04 *157.87*	331.20 *225.56*	340.38 *184.75*
Upset	**Nose-Low Inverted**			**Nose-High Inverted**		
	GL2000	**MFS**	**Control**	**GL2000**	**MFS**	**Control**
Altitude Loss in Feet	884.76 *179.41*	948.95 *167.03*	1069.41 *139.08*	368.18 *169.19*	382.08 *200.65*	464.62 *169.59*

Table10. Statistically Significant Differences in Altitude Loss Between Paired Groups, as Determined by *A Priori* Univariate Analysis

Dependent Measure	Upset			
	Nose-Low Upright	Nose-High Upright	Nose-Low Inverted	Nose-High Inverted
Altitude Loss	GL2000 < Control t(1,70) = 2.985 p = 0.004 MFS < Control t(1,70) = -3.924 p = 0.000	GL2000 < Control t(1,71) = 2.315 p = 0.024 GL2000 < MFS t(1,71) = 2.128 (p = 0.037	GL2000 < Control t(1,54) =3.447 p = 0.001 MFS < Control t(1,54) = -2.198 p = 0.032	

altitude loss, exceeding control group performance in both nose-low upsets. For ease of understanding the information in Table 10, Table 9 recapitulates altitude loss and *standard deviation* by group for each of the four upsets.

4.2.2 Multivariate Analyses

We also conducted MANOVAs for each of the four upsets. The results reflect a significant difference between the three groups at p = 0.000 for all four upsets. Table 11 reports the Wilks Lambda, Alpha, and Partial Eta-squared values for each of the four analyses. The remarkably consistent Eta-squared values indicate that about one-third (30%, 33%, 41%, 33%) of the variance detected by the MANOVAS is accounted for by the model; i.e., approximately one-third of the performance difference in each upset stems from differences in *average* performances *among* the three groups, while the remaining two-thirds results from differences in *individual* performances *within* each of the three groups.

Since the MANOVAs revealed a significant difference between the three groups for all four upsets, we conducted univariate analyses to assess the contribution of each of the dependent variables to statistical differences detected by the MANOVAs. The results of these ANOVAs are presented in Table 12, where bolding indicates a significant difference between the three groups for the upset and dependent variable indicated.

Whenever an ANOVA value in Table 12 indicated that a dependent variable contributed to a statistically significant difference between the groups, we conducted protected pairwise comparisons—GL2000-Trained vs. Control; MFS-Trained vs. Control; GL2000-Trained vs. MFS-Trained—using the Bonferroni adjustment to ascertain the nature of the difference. Table 13 presents the results of these pairwise tests. It reflects the fact that GL2000-trained participants and MFS-trained participants significantly outperformed control group participants in many areas. However, the only significant differences between GL2000- and MFS-trained participants occurred in the nose-high upright upset, where MFS-trained pilots unloaded more efficiently and applied more Gs in the dive pullout.

4.3 Implications of Univariate and Multivariate Analyses

We hypothesized that GL2000-trained pilots would outperform control group pilots. This hypothesis was confirmed. Univariate and multivariate statistical analysis of the data in Table 8 indicates that the overall performance of GL2000-trained pilots and MFS-trained pilots exceeded the performance of untrained control group pilots.[26] Our results suggest that classroom and simulator training improves a pilot's ability to maneuver an airplane out of serious upset.

We also hypothesized that GL2000-trained pilots would outperform MFS-trained pilots. This hypothesis was not confirmed. Although *a priori* univariate analyses reveal GL2000-trained pilots were superior to MFS-trained pilots in altitude loss on the nose-high upright upset, considering both statistical analyses one must conclude that the differences between the performances of GL2000-trained and MFS-trained pilots were minimal.

Table 11. Group Sizes, Wilks Lambda, Alpha, and Partial Eta-Squared Values for Each of the Four Upsets

Upset	**Nose-Low Upright**	**Nose-High Upright**	**Nose-Low Inverted**	**Nose-High Inverted**
Wilks Lambda Value	F(10,132) = 5.67 p = 0.000 $\eta^2 = 0.300$	F(12,132) = 5.308 p = 0.000 $\eta^2 = 0.325$	F (12,98) = 5.718 p = 0.000 $\eta^2 = 0.412$	F (12,128) =5.211 p = 0.000 $\eta^2 = 0.328$

Table 12. Univariate Test F and Alpha Values for Each of the Four Upsets (**Bold** = Significant Difference)

Dependent Measure	**Upset**			
	Nose-Low Upright	**Nose-High Upright**	**Nose-Low Inverted**	**Nose-High Inverted**
Altitude Loss	**F(2,70)=8.515 p = 0.000**	**F(2,71) = 3.252 p = 0.045**	**F(2,54) = 6.022 p = 0.004**	F(2,69) = 2.063 p = 0.135
Minimum Unload G in Rolls	Not Applicable	**F(2,71) = 10.053 p = 0.000**	**F(2,54) = 4.931 p = 0.011**	F(2,69) = 0.607 p = 0.548
Maximum G Load in Dive Pullout	**F(2,70) = 18.147 p = 0.000**	**F(2,71) = 7.404 p = 0.001**	**F(2,54) = 7.959 p = 0.001**	**F(2,69) = 5.216 p = 0.008**
Seconds to First Throttle	**F(2,70) = 13.280 p = 0.000**	F(2,71) = 2.769 p = 0.069	F(2,54) = 2.911 p = 0.063	F(2,69) = 2.447 p = 0.094
Seconds to First Roll	**F(2,70) = 7.618 p = 0.001**	**F(2,71) = 8.509 p = 0.000**	**F(2, 54) = 10.863 p = 0.000**	**F(2,69) = 10.787 p = 0.000**
Seconds to Recover	**F(2,70) = 11.670 p = 0.000**	**F(2,71) = 9.574 p = 0.000**	**F(2, 54) = 3.269 p = 0.046**	**F(2,69) = 11.669 p = 0.000**

Table 13. Statistically Significant Differences Between Paired Groups for All Dependent Variables

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

† As explained earlier, the finding that MFS-trained pilots pulled significantly more Gs than GL2000-trained pilots while recovering from the nose-high upright upset does not necessarily indicate superior performance.

5. CONCLUDING REMARKS

5.1 Proposed Improvements to Training Syllabus

Rogers et al. (2007) report training shortcomings in the use of MFS as an upset-recovery trainer, stressing in particular the importance of teaching aircraft-specific maneuvering techniques to minimize altitude loss, and conjecturing that improved use of the simulator would result in better flight testing results. The conjecture was verified in Rogers et al. (2009), where a second group of MFS-trained pilots performed much better than the first MFS-trained group after improved training procedures were implemented.

Similarly, we believe that if we conducted our experiment a second time with simulator training modified by what we learned during the research, flight testing results might reflect a much stronger performance by GL2000-trained pilots.[27] We had a limited amount of time in which to conduct the GL2000 training—two days per group—and during the first day, GL2000 training time was limited when participants experienced varying degrees of motion sickness and reached a point where further training was ineffective. Nevertheless, participants adapted quickly to GYROLAB motion, and we were able to conduct motion training more aggressively on the second day. In the course of the research, we modified our GL2000 training approach slightly to provide both no-motion and motion time during the first day. The no-motion time was used to teach certain "rote" skills that are not motion critical. The limited motion time was used to teach the motion critical skills while simultaneously allowing participants to adapt gradually to simulator motion.

It appears that rote responses in upset-recovery maneuvering can be taught as effectively with MFS as with the motion based GL2000 simulator. The first of these responses involves using visual cues to determine pitch and bank angles during an upset. As shown in Figure 3, MFS, as implemented at ERAU, provides three simultaneous views outside the cockpit: 90° left, forward, and 90° right. The forward view is used to categorize an upset as nose-high or nose-low, while the two side views allow a pilot to determine bank angle, including whether the aircraft is upright or inverted. The second rote response is proper use of throttle—application of full thrust in nose-high upsets and reduction of throttle to idle in nose-low upsets. It is possible that participant pilots might have been better prepared for GL2000 training had they previously practiced these rote responses on MFS or received more GL2000 no-motion practice. Repetition is a powerful learning reinforcement for such responses.

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N22* 1.33'  W159* 24.38'  ALT  1507 FT  MSL  HDG 133   85 KIAS  WIND 349 / 00 Mag
FRAMES/SEC = 039.7 (LOCKED AT 40FPS)    +2.0 Gs  FUEL  87 %
SIMULATION PAUSED - Press P to continue.
```

Figure 3. Screen Captures of MFS Windows Configuration for Upset-recovery Training

The second change we would implement to our training syllabus involves utilization of the GL2000 simulator. Given the time required to adapt to GL2000 motion, our goal of giving participants five hours of GL2000 training in two days proved to be optimistic. Training had to be suspended for participants who experienced motion sickness until they could recover, since learning ends once a pilot becomes distressed. This slowed the training process significantly. As explained previously, we experimented with flying the GL2000 without planetary motion during the first training session for each participant, then introduced the use of G forces incrementally during subsequent sessions. Interestingly, we found a significant degree of adaptation to planetary motion between the first and second days of weekend training and, not infrequently, between successive sessions on the first day.

Were we to repeat our experiment, we would plan one-half hour GL2000 training sessions and alternate planetary motion sessions with non-motion sessions depending on how well an individual participant tolerates the resulting G forces. Additionally, we would extend the training period to three days. Under these circumstances, we believe five hours of GL2000 training per participant would be possible while training five pilots per group. The remaining five of a total of ten simulator hours would still be accomplished on the Microsoft Flight Simulator. We would also introduce upset-recovery maneuvering on MFS, as opposed to limiting the use of this desktop simulator to aerobatic training only.

5.2 Limitations of Ground-Based Simulators for Upset-Recovery Training[28]

Statistical analysis confirms our hypothesis that GL2000-trained participants would outperform control group participants in upset-recovery maneuvering. Although GL2000-trained pilots lost less altitude in three of the four upsets and recovered faster in all four, they did not statistically outperform MFS-trained participants to the degree anticipated. More important, perhaps, neither trained group performed as well in altitude loss as we would have expected.

Table 14 summarizes altitude losses for GL2000-trained, MFS-trained, and control group pilots for all four upsets. The bottom row of the table reports minimum observed altitude loss for each upset during safety pilot training. Despite the fact that our research suggests that simulator training significantly improves a pilot's ability to recover an airplane from a serious upset, there is a large disparity between trained participant altitude losses and the far smaller altitude losses achievable by pilots experienced in all-attitude maneuvering in an actual airplane.

The altitude disparities reflected in Table 14 seem to call in question the implicit assumption that airline simulator-based upset-recovery training programs impart flying skills sufficient to make it probable that a typical line pilot can recover an airliner from a serious upset with minimum altitude loss. U.S. airline pilots no longer come primarily from military flight backgrounds where training afforded them extensive opportunity to perform aerobatic flight maneuvers. For military trained pilots there are no *unusual* attitudes, only *unexpected* attitudes. By contrast, most air transport pilots flying today have never experienced the extreme pitch and bank angles and high G forces associated with severe airplane upsets. Indeed, most have never been upside-down in an airplane even once. Informal conversations with current airline pilots suggest that while virtually all regard the company-provided 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. Although aerobatic training has not so far been authoritatively related to upset-recovery success in a transport type airplane, aerobatic flight in a light airplane would provide an opportunity for pilots to practice maneuvering in extreme attitudes across wide airspeed and energy level ranges. This might in turn lead to greater confidence and maneuvering proficiency in an actual upset situation.[29]

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 that inevitably will occur from time to time in air transport operations. Although our research implies that simulator-based upset-recovery training is a value-added activity and that introducing higher levels of fidelity may to some extent enhance skills transfer, additional work is needed to optimize ground-based flight training devices and their utilization to ensure they provide highly effective upset-recovery training.

Table 14. Average and Observed Minimum Altitude Losses for Each of the Four Upsets

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
Control Group Pilots Average	728	340	1069	465
Observed Minimum during Safety Pilot Training	220	-50	350	-30

6. ENDNOTES

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2. Rodney O. Rogers, Albert Boquet, Cass Howell, and Charles DeJohn (2007), "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. 20591, p. 1. Available at www.faa.gov/library/reports/medical/oamtechreports/2000s/2007/.
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4. Most of this section is reproduced verbatim from Rogers et al. (2009). A more detailed summary may be found in Rogers et al. (2007), pp. 2-4.
5. www.calspan.com/upset.htm.
6. Valerie Gawron, (2004), *Aircraft Upset Training Evaluation Report (revision 20),* National Aeronautics and Space Administration (NASA): NAS2-99070.
7. 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, FL, 2005.
8. 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, OK: Wright State University, 2005.
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13. 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.
14. ETC officials advise that "experience shows disorientation can occur but does not always occur."
15. Cezary Szczepanski and Dick Leland (2000), "Move or Not to Move? A Continuous Question," Southampton, PA: Environmental Tectonics, 200l. ©2000 ETC, published by the American Institute of Aeronautics and Astronautics with permission (AIAA Paper 0161). Copy provided by the first author.
16. 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, LA: Human Factors and Ergonomic Society, 2004.
17. 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, OK: Wright State University, 2005.
18. Based on Kochan (2005).
19. 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.
20. 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, FL: Flight Safety Foundation and National Business Association, 26-28 April 2005.
21. 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.

22. 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.

23. The decision to forego a more traditional 2 x 4 mixed-model analysis derives from the nature of the upset data themselves, which argues against the direct comparisons that characterize 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.

24. See Rogers et al. (2009) p. 7 for univariate F values associated with significant effects in Table 5.

25. There were, however, no unsuccessful recoveries; without exception, GL2000-trained participants returned the aircraft to straight and level flight without assistance from the safety pilot.

26. As reported in Section 3.1, prior two-group analysis had previously established the result that MFS-trained pilots outperformed control group pilots.

27. The fact that univariate analysis showed GL2000-trained participants superior to MFS-trained participants in altitude loss on the nose-high upright upset supports this possibility. So perhaps does the fact that multivariate analysis showed GL2000-trained participant superior to control group participants in altitude loss on the nose-low upright upset when MFS-trained participants were not.

28. Some of the ideas expressed in this subsection are reproduced from Rogers et al. (2009), pp. 10-11.

29. Paul Ransbury, President, APS Emergency Maneuver Training (www.apstraining.com), has adduced evidence supporting this possibility. Ransbury and his colleagues formulated a set of objective criteria for evaluating in-flight upset-recovery maneuvering pilot skills. Using these criteria, they conducted pre-training and post-training flight testing of a group of 75 pilots currently flying air carrier turbojet or turboprop aircraft. The testing was conducted in an Extra-300 aerobatic general aviation aircraft. Eighty-eight percent of the 75 pilots had in excess of 1500 hours of flight experience; more than four-fifths had fewer than 10 hours of aerobatic experience. The flight testing rated participant pilot performance as ideal, safe, unsafe, or severe error on each of five upset scenarios, with ideal or safe considered successful performances. During pre-training testing, only about 40% of the pilots recovered successfully from any given scenario. Post-training success rates were 92.3% in one of the five scenarios and 97.5% in the other four.

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