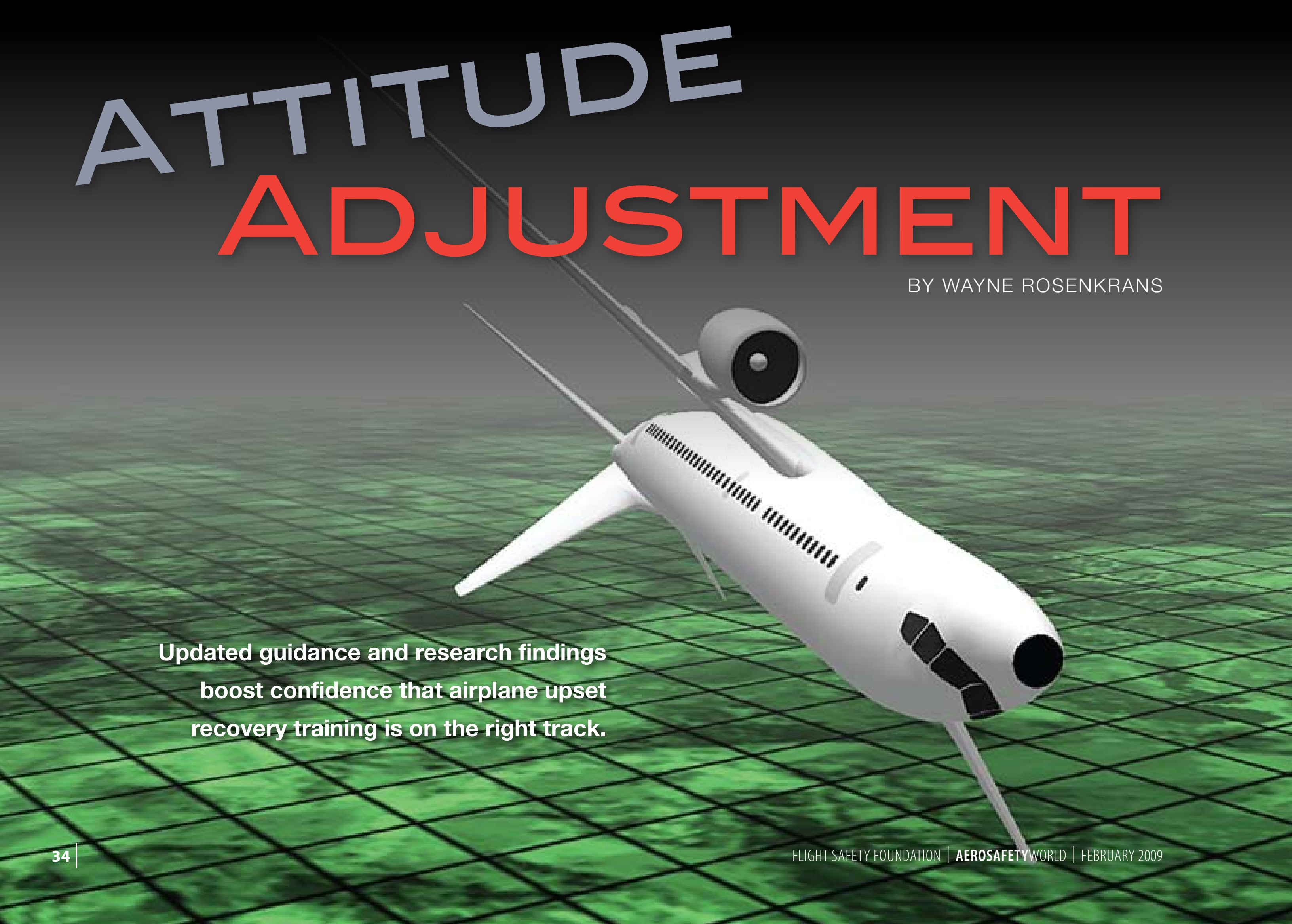
ATTITUDE ADJUSTMENT

BY WAYNE ROSENKRANS

Updated guidance and research findings boost confidence that airplane upset recovery training is on the right track.



Advances in standardization and new evidence of effectiveness make airplane upset recovery training a more robust element of airline strategies for managing the risk of loss of control accidents than 10 years ago (see "Steady State," p. 18). Although ongoing research and development efforts expect to improve existing aircraft-based solutions, many specialists still see technology as complementary to pilot training — not an alternative. Urgency about addressing loss of control risk (Table 1) was reflected during 2008 in more than 40 scientific papers on relevant issues presented at conferences of the American Institute of Aeronautics and Astronautics (AIAA) alone.[1]

Technology promises improvements in, and wider use of, flight envelope protection provided by the software in fly-by-wire airplanes; an aural "overbank" alert when a transport category airplane reaches an angle of bank exceeding normal operating parameters; directed guidance, an immediate aural message to pilots about required control inputs; micro-tactile alerts about incipient unusual attitudes from electronic devices in a seatback or clothing; and perhaps a pilot-activated automatic recovery switch that would transfer airplane control to a future autopilot designed for this purpose, specialists say.

"Enhanced training and procedures are a countermeasure relatively easy to implement, but might be only partially effective," says William Bramble, senior human performance investigator, U.S. National Transportation Safety Board (NTSB), and a presenter at Flight Safety Foundation's International Air Safety Seminar (IASS) in October 2008 in Honolulu. "Recent accidents suggest that [automation] might improve safety for civil transports. Solutions such as modified attitude displays and directed guidance … [also] might only be partially effective."

Various NTSB safety recommendations in recent years have urged the U.S. Federal Aviation Administration (FAA) to require upset recovery training for air transport pilots. Among risk scenarios of concern have been stalls caused by airframe icing, stalls without

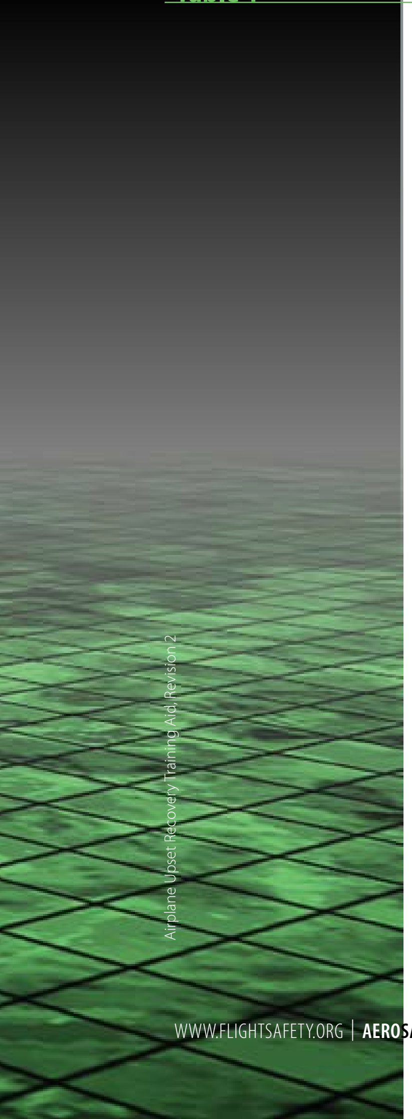
Major Causes of Airplane Upset and Loss of Control Accidents, Worldwide Air Transport, 1993–2007

Causal Category	Accidents/Aircraft Included	Accidents in Category	Fatalities
Aerodynamic stall	9 events involving contaminated airfoils, 6 events involving autopilot-induced stalls (only common factor was no flight envelope protection)	27 (36%)	848 (26%)
Flight control system	7 events involving flight control malfunctions or failures, 6 events involving autopilot malfunctions or failures (excluding autopilot-induced stalls), 3 events involving flight control software issues	16 (21%)	604 (19%)
Spatial disorientation	5 events involving spiral dives (only common factor was no flight envelope protection), 3 events involving upset/misjudged flight path	8 (11%)	630 (19%)
Contaminated airfoil (ice)	9 events involving contaminated airfoils were listed instead among the 27 events in the "Aerodynamic stall" causal category	8 (11%)	200 (6%)
Atmospheric disturbance	3 events involved wake encounters	6 (8%)	477 (15%)
Other causes combined	Not specified	6 (8%)	122 (4%)
Undetermined causes	Not specified	4 (5%)	380 (12%)
	Total accidents	**75**	**3,261**

Note: Total of percentages may not equal 100 because of rounding error.

Source: Lambregts, A.A.; Nesemeier, G.; Wilborn, J.E.; Newman, R.L. "Airplane Upsets: Old Problem, New Issues." American Institute of Aeronautics and Astronautics Modeling and Simulation Technologies Conference and Exhibit, Aug. 18-21, 2008, Honolulu. AIAA 2008-6867.

Table 1



Airplane Upset Recovery Training Aid, Revision 2

icing, wake encounters, spatial disorientation leading to a spiral dive or misjudged flight path, and mechanical failures. Although this training has yet to be required, the FAA has collaborated with airlines, manufacturers and academic institutions on a common reference aid for upset recovery training, simulator fidelity requirements and proposed training standards.

High Altitude Supplement

Among valuable resources for airlines contemplating or updating upset recovery training is the November 2008 release of Revision 2 of the *Airplane Upset Recovery Training Aid* — including a new "High Altitude Operations" supplement (*ASW*, 1/09, p. 10). An international industry team led by Airbus, Boeing Commercial Airplanes and Flight Safety Foundation began work on the revision in 2007. The supplement focuses on known safety issues in the high altitude environment — above Flight Level 250 (approximately 25,000 ft) — and particularly on knowledge gaps identified among pilots who routinely operate there. Revision 2 initially was distributed on paper and compact disc in a binder, but the component elements are more readily available, either together or separately, as free electronic documents that can be downloaded from <www.flightsafety.org/upset_recovery.html>.

In a transmittal letter to the FAA, the team's co-chairmen said, "This [supplement] was developed in response to an FAA request for us to convene an industry and government working group to develop guidance to flight crews as it pertains to issues associated with operations, unintentional slowdowns and recoveries in the high altitude environment. … No reference material published is of value unless it is used. To that end, we implore the FAA to produce language to support implementation of this material that will motivate operators to use it."

Unlike the full training aid, which addresses airplanes with 100 or more seats, the information in the supplement also is directly applicable to pilots of nearly all jet airplanes that routinely operate at high altitudes. Aviation professionals familiar with Revision 1 of the training aid will find a limited number of changes called out for review in Revision 2 — many for consistency with the supplement content.

The second update since 1998 has been designed so that adoption, integration or adaptation by airlines can be simple and straightforward. "Loss of control accidents can have widely varying causes and solutions, so our goal is to get to all the pilots — wherever they might be — to give them the knowledge, the understanding and the training necessary to address this killer in aviation," David Carbaugh, chief pilot for flight operations safety at Boeing Commercial Airplanes and a team co-chairman, told IASS attendees. "What is lacking today is a consistency of application throughout the industry of this training. … Only when such training becomes mandatory will air carriers be getting knowledgeable and fully trained pilots who can handle these situations consistently."[2]

One aim is to help airline pilots avoid repeating the errors of others, such as selecting maximum cruise thrust rather than maximum continuous thrust in response to a gradual, environmentally induced slowdown at high altitude, or selecting inappropriate automation modes that can lead to excessive banking and a stall during routine high altitude operations, such as navigating around en route weather.

A forceful nose-down pitch input can be essential to some upset recoveries.

The supplement emphasizes practical ways to apply aerodynamic principles, such as avoiding high altitude flight in the slow flight speed range, any speed less than L/D Max;[3] recognizing gradual airspeed decay and its effects; expecting slow cruise speeds to shorten time available to respond to an inadvertent slowdown; avoiding inappropriate vertical speed modes during high altitude climbs; and responding correctly to a thrust-limited condition.[4] Also covered are the risks of operating at maximum altitude, such as reduced bank angle capability and insufficient thrust to maintain altitude (Figure 1); the advantages of operating at optimum altitude; the importance of recognizing airplane buffet as the first indicator of a high altitude stall; the differences between responding to an impending stall versus a full aerodynamic stall; the criticality of exchanging altitude for airspeed during upset recovery; and the threats in inadvertent excursions into extremely high speeds.


Airplane Upset Recovery Training Aid, Revision 2

A longstanding issue is that the aerodynamic envelopes of simulators — specifically the angle of attack range and sideslip range — simply are not extensive enough.[5] One NTSB scientist has noted that fidelity of simulators for upset recovery training becomes a significant practical issue only in the post-stall flight regime, whereas many loss of control accidents have occurred after upsets within the nominal aerodynamic data envelope (Figure 2).[6]

Evidence of Effectiveness

When Alteon Training, a Boeing company, recently planned to introduce upset recovery training into all of its initial, transition and recurrent simulator training courses, the course developers could find no scientific study showing that such training would achieve what was intended, according to William Roberson, a senior safety pilot for Boeing Commercial Airplanes and an IASS presenter.

Another research goal was to identify significant negative training in light of findings about a pilot's rudder inputs in the NTSB investigation of the November 2001 in-flight separation of the vertical stabilizer of an Airbus A300, operating as American Airlines Flight 587, in Belle Harbor, New York, U.S.[7] "That accident did, in fact, have a chilling effect on upset recovery training throughout the world," Roberson said.

Alteon hypothesized that Boeing 737 pilots who completed academic work and simulator exercises derived from the training aid would be more successful in coping with upset events than they were before they participated in the study. Thirty-three 737-qualified Boeing pilots received academic training with videos and a simulator session, in which they trained to proficiency — until common errors were eliminated — on each recovery technique.

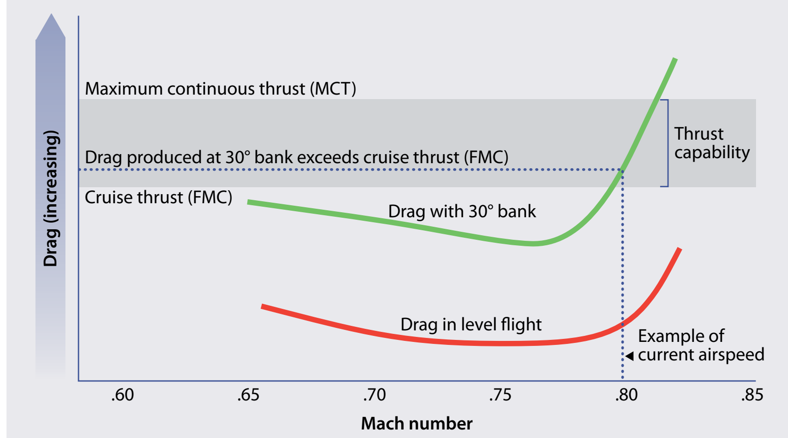
Each pilot was told to "just fly the airplane — do what you would do if you had this event," which meant to keep the airplane inside the aerodynamic envelope, not induce a stick shaker warning of approach to stall, and not stall. "We re-evaluated each pilot to see if performance had improved one to six months after this training, using the exact same initial test and scoring method," he said. Performance on each test element and overall was quantified by subtracting points — for example, for failure to disconnect the autothrottle, a stall, excessive speed or excessive altitude loss — from a perfect score of 10.

Upset events in the simulator comprised one scenario of a 737 that was 40 degrees nose high with zero degrees of bank and twice the amount of aft trim required for normal flight; one scenario with the airplane 25 degrees nose low with 60 degrees of bank and trim neutral; and one scenario with the airplane 25 degrees nose low, with 120 degrees of bank and trim neutral.

"Pilots who scored zero, one or two points on the first nose-high [scenario] predominantly used the roll recovery technique versus the push recovery technique; those who scored eight, nine or 10 points on that [scenario] predominantly used the push recovery technique," Roberson said.

Taking these pilot decisions and other factors — such as adequate control of airspeed and altitude loss — into consideration, the study concluded that for the nose-high scenarios, training made a positive difference, three points on average. For the nose-low and medium-bank angle scenario, training made a positive difference, two points on average. "Improvement occurred because of better recovery technique [after training], such as rolling to level more quickly and pulling more positively once they got the wings level," Roberson said. "For the nose-low and high-bank-angle scenario, considered the most difficult recovery, training made a small — 0.4 point — positive difference. Qualitatively, this was important because this result was not expected given the relative difficulty."

Typical Commercial Jet Operating at Maximum Altitude

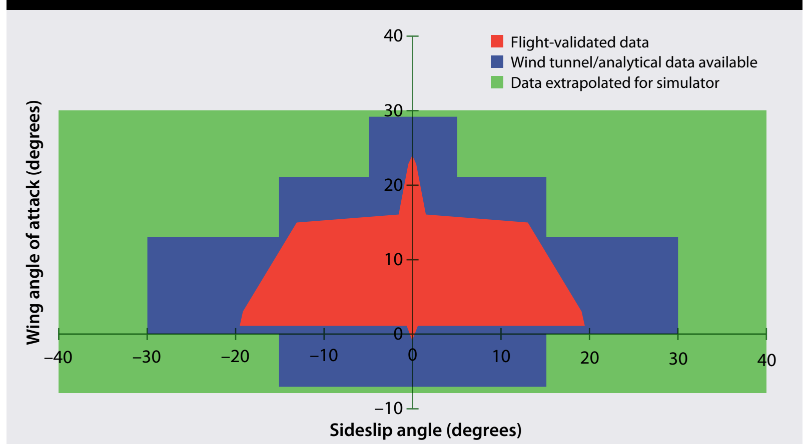


Note: Maximum continuous thrust would be required to maintain altitude under some conditions.

Source: Airplane Upset Recovery Training Aid, Revision 2

Figure 1

Data Sources for Boeing 737 Full Flight Simulator



Note: U.S. Federal Aviation Regulations Part 60 since 2007 has restricted training exercises in which pilots would have to "go beyond the flight-test validated flight envelope," which real-world upset recoveries may require.

Source: Airplane Upset Recovery Training Aid, Revision 2

Figure 2

U.S. National Aeronautics and Space Administration

The NASA Vertical Motion Simulator, shown here in a multiple-exposure photo, exceeds capabilities of conventional full flight simulators.

The researchers said they were encouraged by the results. "Each of the maneuvers showed higher scores after training for the majority of the pilots, but not all the pilots," Roberson said. "Twenty-nine out of 33 pilots did better on the second test, four did worse … and those whose overall scores deteriorated went from 25.8 to 23.0 points [out of a possible 30 points]. These pilots demonstrated the largest increase in average score for the nose-high and zero-bank-angle scenario, requiring the most difficult and challenging maneuver. … We did not expect to see that. There also was a much higher level of consistency of performance among all the pilots after the training."

A second report presented at IASS had been eagerly anticipated by the upset recovery research community.[8] FedEx Express and Calspan Flight Research Group developed the "advanced maneuver–upset recovery training program" using full flight simulators with motion and an in-flight simulator — a Learjet 25 — then evaluated the program's effectiveness in a simulator and in flights in the airplane, said copresenters Brian Ward, managing director of training, Federal Express, and Bob Moreau, experimental test pilot, Federal Express Flight Test.

"Over the past six years, FedEx has experienced six upset events that could have led to loss of control," Ward said. "[One goal,] for the first time in the industry, was to 'connect the dots' by evaluating transfer of training from the full flight simulator to the real world of the airborne environment."

Ten FedEx pilots from the A300 fleet and 10 FedEx pilots from the MD-11 fleet participated. Performance evaluations were conducted before each of three portions of training: aerodynamics, full flight simulator training and airborne training. Training events comprised unusual attitude recoveries, in which the evaluator maneuvered the simulator or airplane to a nose-high unusual attitude and a nose-low unusual attitude; and preprogrammed upset recovery events in the roll axis and the yaw axis of the simulator and airplane.

The A300 pilot group and MD-11 pilot group were divided into two subgroups, a full-program group that received academic training, then advanced maneuver upset recovery training in a simulator, and a control group that received the academics but with equal time in a simulator focused on scenarios unrelated to upset recovery.

The study found that training in the full flight simulator — despite the deficiency in motion cuing and g (load) cuing — produced the largest cumulative training effect, especially in teaching aircraft-specific techniques; airborne training produced a relatively small training effect; and prior experiences exerted a relatively large training effect on performance even compared with the academic work.

For the study, the full flight simulator was equipped with a g-meter display as a reference for the pilots during recovery maneuvers. The meter showed, for example, some pilots exceeding g limits — with up to 8 g displayed on video recordings — while incorrectly performing a rolling pullout maneuver that would have subjected a real airplane to the maximum aerodynamic loads.

The upset recovery training in general revealed pilots' inadequate knowledge about the relevant aerodynamic principles and how to apply them. Therefore, the academic portion of the program alone produced a large increase in training effect. "What stood out was a lack of [understanding of] fundamental aerodynamic concepts, as well as alternate control strategy concepts, among the pilots — concepts required for upset recoveries," Moreau said.

Little of the improvement in pilot test scores on upset recoveries could be attributed to the full flight simulator; instead, the lack of adequate motion cuing worked against pilots in identifying what type of event, such as a yaw event or roll event, was occurring. "This often led to the incorrect technique being applied, and that aggravated the situation," Moreau said. "In comparison, the in-flight simulator provided critical motion cues, and the pilots were better able to correctly identify the event and respond with the correct control technique."

In the tests of unusual attitude recoveries in the simulator, the group with full training showed "markedly better" results than the control group. This difference disappeared when each group flew the Learjet, and this was attributed to pilots having had equivalent motion-cue experiences from earlier unusual attitude training in airplanes.

For airlines to make effective use of full flight simulators, their programs must emphasize pilot understanding of simulator limitations compared with control inputs that may be required for upset recovery in the airplane, the researchers concluded. "Motion cues also should be de-emphasized due to the limitations of the motion cues that we have in simulators today," Ward said. "A g-meter readout is essential for effective training."

Conducting upset recovery training in a full flight simulator with motion off — as some airlines already do — is still advocated by some specialists to sidestep misgivings about insufficient fidelity and unrealistic spatial disorientation practice. "When you enter an upset or have an illusion, your inner ear already is telling you the wrong thing, so our simulator training [with motion on] is about making the picture look right," Boeing's Roberson said. "You cross-check your displays to make sure you don't have a display that is lying to you. The fact that the simulator will give you the wrong vestibular cue, although problematic, is another opportunity for the pilots to override what their vestibular senses are telling them, and to do the correct recovery no matter how they feel."

Airlines cannot afford to wait for perfect hardware, however, or access for thousands of line pilots to the advanced motion and sustainable g-load fidelity of one-of-a-kind simulators such as the Vertical Motion Simulator at the U.S. National Aeronautics and Space Administration Ames Research Center; the generic large transport/757 configuration of the GyroLab-2000 simulator, which is used for upset recovery training at the U.S. National Aerospace Training and Research (NASTAR) Center; or the Desdemona research and demonstration simulator developed by TNO Defence, Safety and Security and AMST Systemtechnik in the Netherlands.

Glenn King, chief operating officer of the NASTAR Center, expects his facility to be part of the solution to loss of control. "Granted, not all airliner upset situations place the aircraft in an inverted attitude, but some upsets have, and it is for these extreme situations that only a full, multi-axis simulator with sustained g [loads] will have a positive transfer of training," King said. "Our advantage is the ability to provide sustained motion cues and g forces during an upset or loss of control in flight. We have the ability to physically place pilots in an inverted flat spin, hanging in the harness, while sustaining up to 2.5 g. When a pilot is hanging in the straps, suffering from facial suffusion and disorientation, legs dangling off the rudder pedals, etc., all this affects the response time and ability to quickly effect a safe and proper recovery. Being able to feel and know the 'energy state' of the aircraft determines the pilot's course of action. The ability to provide sustained g cues to pilots is critical in their upset recovery training/loss of control decision-making process."

Boeing's Roberson expects the updated training aid to enable airlines to sufficiently prepare pilots for the recent types of scenarios. "In most of the loss of control accidents and incidents that we have seen in the last five years, simply leveling the wings and putting the thrust where it needed to be would have solved the [problem]," he said. "They were not really complicated events — at least at the outset."

Notes

1. Bürki-Cohen, Judith; Sparko, Andrea L. "Airplane Upset Prevention Research Needs." In proceedings of the AIAA Modeling and Simulation Technologies Conference and Exhibit, Honolulu, Aug. 18–21, 2008. AIAA 2008-6871.
2. Carbaugh, David. "Simulator Upset Recovery Training and Issues." AIAA 2008-6866.
3. The training aid notes that on a graph plotting lift (L) and drag (D) values against airplane speed values, the lowest point on the total drag curve is called L/D Max (or V_{MD}, minimum drag speed).
4. The training aid notes that some environmental conditions, such as a temperature increase or a mountain wave, may cause a jet to enter a thrust-limited condition in which the desired altitude cannot be maintained and/or airspeed may decay, requiring a descent.
5. Crider, Dennis A. "The Need for Upset Recovery Training." AIAA 2008-6864.
6. Crider.
7. Ibid.
8. Bürki-Cohen; Sparko.