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New Airline Pilots May Not Receive Sufficient Training to Cope With Airplane Upsets

A study conducted for the U.S. National Aeronautics and Space Administration says that, although pilots cannot be trained for all imaginable scenarios, current airplane upset-recovery training might be expanded to include more types of upset scenarios.

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From 1993 through 2002, loss of control in flight was the largest category of commercial jet fatal accidents worldwide, resulting in 2,131 fatalities.[1] One type of loss of control is an airplane upset, defined as "an airplane in flight unintentionally exceeding the parameters normally experienced in line operations or training."[2]

Precipitating factors in airplane upset accidents have included equipment failures and system anomalies, weather phenomena, inappropriate use of flight controls or systems, inappropriate control responses by the crew, or some combination of these factors. In some of these accidents, recovery from the initial upset attitude might have been possible if flight crews had promptly applied appropriate control inputs.

Recovery from airplane upsets is challenging, even for highly experienced airline pilots. The initial upset is generally sudden and unexpected; not only must the crew assess the situation quickly and correctly, but they also must implement appropriate recovery procedures. Moreover, time constraints — and, in some situations, altitude constraints — can require correct recovery procedures to be initiated with minimal delay.

Usually, the crew does not have time for the relatively slow cognitive processes of reasoning and problem solving; rather, the appropriate actions must be highly learned skilled responses that can be executed quickly. Under current airline training regimens, pilots rarely have opportunities to practice the appropriate recovery procedures. Also, recovery from some airplane upsets requires either recognizing the underlying problem that is causing the upset and is complicating the recovery or implementing a recovery technique that is robust in correcting for a broad range of underlying conditions.

The U.S. National Transportation Safety Board (NTSB) has recommended on several occasions that pilots be trained to recover from abnormal regimes of flight and unusual attitudes.[3] Both the U.S. Federal Aviation Administration (FAA) and the Air Transport Association of America (ATA; an industry association representing most U.S. major airlines and national airlines) encourage airlines to conduct airplane upset-recovery training. The FAA Handbook Bulletin for Air Transportation 95-10, *Selected Events Training*, encouraged airlines to provide training in "excessive roll attitude ... and high pitch attitude."

Many U.S. airlines now include limited training of this type, although the content and extent of the training vary widely. Typically, the training comprises a combination of classroom presentations and simulator training.

From 1996 through 1998, a consortium of three dozen organizations — including Flight Safety Foundation, manufacturers, international air carriers, pilot organizations, flight-training organizations and government and regulatory agencies — developed the *Airplane Upset Recovery Training Aid*, which includes approximately 160 pages of text and two videotapes. The content of the training aid, including recommended upset-recovery procedures, was based on a consensus among specialists. The training aid included recommended procedures for excessive nose-high attitudes and excessive nose-low attitudes.

Until recently, no formal study of the effectiveness of existing airplane upset-recovery training programs had been attempted. Supported by a contract from the U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Program, Veridian Corp. (acquired by General Dynamics in August 2003) completed a study examining some, but not all, of the relevant issues.[4] The primary objective of the study was to generate data to support decision making on the part of FAA and the airlines.

The study evaluated the flying performance of pilots in eight scenarios that were derived from upset accidents. Cost and time constraints limited the study to 40 new-hire airline pilots without military flight experience — a group of particular interest because they represent the majority of future airline pilots. The study did not address how airline captains or other more experienced pilots might perform in these scenarios.

As a group, the 40 pilots recovered more successfully from some scenarios than from others. In general, the pilots recovered most reliably from the upset scenarios that were relatively straightforward, uncomplicated and similar to the training that they had received repeatedly or early in their piloting careers. Results from these scenarios suggest that upset recovery training can be effective.

Nevertheless, most of the pilots did not recover control of the aircraft in most of the upset scenarios. Recovery was possible in each of these upsets, but some scenarios required techniques that were novel, counterintuitive or beyond the experience of airline pilots who have not been trained on the specific scenario recovery. The upset scenarios in which the pilots were least likely to recover aircraft control were scenarios for which airline pilots may receive only brief exposure or minimal training — and for which their predominant training actually conflicts with the necessary recovery procedure. Pilots in the study experienced problems in controlling the aircraft when they were surprised by the upset and when the available cues did not clearly inform them about the situation; in contrast, in most current training, the pilots are expecting upset scenarios, and the elements of surprise and ambiguity are not realistically simulated. Nevertheless, because of the difficulty of recovering aircraft control and the effects of surprise when an upset occurs during routine operations, airline pilots cannot realistically be expected to recover aircraft control with a high degree of reliability in all upset scenarios.

NASA's specific objectives in sponsoring the study were the following:

- Compare the relative effectiveness of no upset-recovery training; aerobatic training (in light aircraft); upset-recovery training in ground-based full-motion simulators; combined aerobatic training and ground simulation training; and in-flight simulation training on airplane upset recovery. (The hypothesis was that the more realistic the upset-recovery training, the better pilot performance would be.);
- Determine how well currently trained, new-hire airline pilots are able to respond to a representative set of airplane upset scenarios derived from actual accidents;
- Identify any specific weakness in pilots' upset-recovery techniques and identify areas in which current training should be improved; and,
- Determine whether recovery from some types of airplane upset scenarios is more difficult than recovery from others.

Pilots Flew the Test Aircraft in Eight Airplane Upset Scenarios

Veridian organized a workshop at the International Symposium on Aviation Psychology in May 1999 to solicit industry input to the design of this study. The workshop was attended by specialists from aircraft manufacturers, international air carriers, pilot organizations, FAA and NASA. Veridian formed a team to advise on selection of representative accident scenarios and appropriate upset-recovery procedures.

The team compiled data about potentially recoverable airplane upset accidents resulting in hull losses between 1988 and 1997 and evaluated the data for adequacy regarding the upset sequence and the ability to correctly simulate the upset sequences in flight. From these data, the eight scenarios were selected to provide a crosssection representative of the types of situations that have led to airplane upsets. The team also developed recovery procedures for each of the accident scenarios. The recovery steps identified by the team defined the "correct" recovery elements for the purpose of the study.

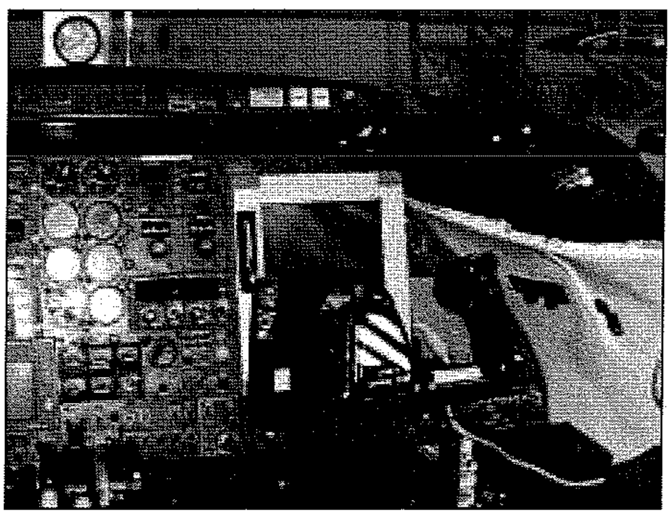
The 40 pilots who volunteered to participate in the study were questioned about their training and experience and then assigned to one of five groups. Each group was composed of eight pilots flying in their probationary year for airlines operating in the United States. Pilots were grouped as follows:

- No aero/no upset — Pilots without airplane upset-recovery training or aerobatic flight experience;
- Aero/no upset — Pilots without airplane upset-recovery training but with aerobatic experience. Aerobatic experience was defined as at least six hours of training and completing aileron roll, barrel roll, chandelle, cloverleaf, Cuban eight, Immelmann, lazy eight, loop, split S, and stall-turn maneuvers or experience performing in air shows or stunts in an aircraft with an FAA aerobatics waiver;
- No aero/upset — Pilots who had completed airplane upset-recovery training in both ground school and in a simulator. These pilots did not have aerobatics training or experience;

- Aero/upset — Pilots who had completed airplane upset-recovery training in both ground school and in a simulator and also had aerobatic flight experience, as defined above; and,

- In-flight — Pilots who received ground training and in-flight airplane upset-recovery training using an instrumented in-flight simulator, the Learjet 25B variable-stability in-flight simulator (IFS). The aircraft is equipped with a computer, which is programmed so that the Learjet's handling and performance characteristics resemble those of a generic swept-wing, large, twin-engine jet transport. This group did not have aerobatic experience, as defined above, or any other airplane upset-recovery training.

After the pilots were assigned to groups, their in-flight performance was evaluated in the Learjet. The right-seat pilot station has a wheel, column and rudder controls programmed to replicate the force and displacement characteristics of a large transport aircraft in pitch and roll. The aircraft's responses to control inputs were programmed to replicate the actual forces, motions and accelerations that pilots would experience in a large transport aircraft. The right seat instrument panel has an electronic visual display with attitude director indicator (ADI) and airspeed and altitude vertical readouts. Other controls (e.g., flaps) and displays (e.g., engine monitors) are standard Learjet equipment.



The right seat instrument panel of the Learjet 25B variable-stability in-flight simulator has an electronic visual display with attitude director indicator (ADI) and airspeed and altitude vertical readouts. Other controls, such as flaps, and other displays, such as engine monitors, are standard Learjet equipment. (Photo:U.S. National Aeronautics and Space Administration)

During the evaluations, the evaluation pilot (the subject in the experiment) sat in the right seat, and the safety pilot (an experienced test pilot) sat in the left seat. The safety pilot taxied and controlled the aircraft until after takeoff, set up the configuration to be simulated, monitored the aircraft and the evaluation pilot, assumed control of the aircraft if necessary, and performed final approach, landing and taxi-back. A flight-test engineer sat behind the right-seat pilot and controlled the simulation and data collection. The evaluation pilots in the study flew the aircraft using a standard vision-restriction device to simulate instrument flight rules (IFR) flight.

The Learjet has a safety monitoring system that returns configuration to normal Learjet operating and handling characteristics (Learjet safety trips), either when the safety pilot presses one of many buttons or automatically, when the aircraft exceeds preset values for various parameters. Safety trips of particular relevance to this study are acceleration limits of plus 2.8 g (i.e., 2.8 times standard gravitational acceleration) maximum and plus 0.15 g minimum, angle-of-attack limits of plus 10 degrees maximum and minus five degrees minimum, and side slip limits of plus or minus 12 degrees.

Pilots Received Familiarization Flights

The pilots in the first four groups received a 45-minute familiarization flight in the Learjet immediately before their evaluation flight. This equalized their familiarity with that of pilots in the fifth group, who received in-flight airplane upset-recovery training in the aircraft. Upset-recovery training for the in-flight group consisted of ground school instruction on relevant aerodynamic factors and appropriate upset-recovery techniques, followed by a 45-minute in-flight training session in the Learjet, with training in roll upsets, nose-low upsets, nose-high upsets, aircraft handling characteristics with degraded stability, flight control failures (including jams, hardovers and inoperative controls) and trim runaways.[5]

Pilots in all five groups completed a 1.4-hour evaluation flight in which airplane upsets were introduced during the performance of precision instrument-control tasks. The upsets were of three types (environment, component/system or aerodynamic) and were patterned after the representative set of hull-loss airplane upset accidents that had been developed by the team.

Ideally, groups should differ only on the dimension being studied (i.e., in this study, type of training). Because of practical constraints, however, the five experimental groups differed in several other dimensions. These differences occurred by chance because the study design did not control for the pilot's total flight hours, previous flight instruction or previous airline experience, type of aircraft flown or many other measures of experience that might be relevant to a pilot's ability to recover from airplane upsets. For example, the average total flight time ranged from 5,786 hours in the no aero/no upset group to 2,250 hours in the aero/upset group.

Partially as a result of the variability of pilot backgrounds within each group and among the five groups and the limited number of pilots in the study (for cost reasons), caution is required in interpreting the study's collected data. The dependent variable of greatest interest is the percentage of pilots from each training group who recovered control of the aircraft in each upset scenario. Control recovery is a dichotomous measure (i.e., pilots either recovered or failed to recover).

Typically, studies of dichotomous measures use relatively large samples to obtain statistically reliable results unless effects are quite large. The same is true for experiments, such as this one, in which a between-subjects design is used.

The performance of individual pilots varied so greatly within each group and among the five groups that there was no determination of whether the five groups differed statistically in their ability to recover control of the aircraft in these scenarios. For example, even though six of seven in-flight trained pilots recovered control of the aircraft in the "Pittsburgh" scenario and only one pilot or none of the pilots in the other four groups recovered aircraft control, this difference was not statistically significant.

Because the pilots were all newly hired pilots in their probationary year, they had limited experience in the aircraft they usually flew on the job. Hence, the results cannot be extended to make inferences about how captains and first officers with more line experience might have performed in the upset scenarios. In addition, the airplane upset-recovery training given to the evaluation pilots was brief and has been characterized as "exposure" rather than training.

The study obtained the following types of data:

- The computer recorded data about the position, motion and attitude of the aircraft; the position of controls; and the occurrence of safety trips;

- After the flight, measures of time to first control inputs, the number of first correct control inputs, the number of correct actions, time to recover control of the aircraft, the number of safety trips and altitude loss were calculated;

- For each upset-recovery attempt, whether the evaluation pilot recovered successfully was recorded;

- For each safety trip, the possibility that a safety trip might have prevented or interrupted the recovery of aircraft control was evaluated in flight by the safety pilots;

- Video and audio recordings were made of the evaluation pilot's upset-recovery actions;

- After the flight, the safety pilot rated the evaluation pilot's overall performance on four dimensions, using a five-point scale;

- The flight test engineer recorded brief comments about each pilot's performance during each scenario;

- A questionnaire was distributed to the evaluation pilots, who provided information about flight experience and training and rated forms of training. They also were given an opportunity to make comments about the evaluation flight; and,

- A post-flight debriefing was conducted in which evaluation pilots could comment on each scenario. Correct procedures for each scenario were presented to the evaluation pilot after the completion of all data collection, and interactive discussions were held, with the intention of ensuring that the evaluation would be a positive learning experience.

The assessment of successful recovery of aircraft control was performed as follows: Immediately after each recovery attempt, the safety pilot assessed the evaluation pilot's success or failure in returning the airplane safely to straight-and-level flight. Operationally, a successful recovery meant that either the safety trips were not activated, or if they were, the safety pilot believed that the evaluation pilot's control inputs would have been successful. Conversely, safety pilots classified failed recoveries as those in which the safety trips were activated without the evaluation pilot having initiated correct, positive actions, or those in which the safety pilot, noting the absence of a proper response by the evaluation pilot, took control prior to activation of a safety trip.

The upset-recovery success data were independent of the data on evaluation pilots' adherence to the individual steps of the upset-recovery procedures developed and agreed upon by the team. Further, there are no data on the accuracy of these upset-recovery procedures or on how closely pilots must adhere to the procedures (i.e., tolerances) to recover an aircraft to straight-and-level flight. In addition, data on the amplitude of pilot inputs were not collected or analyzed.

Although successful upset-recovery was the primary dependent variable in this study, performance data were collected on each of the steps appropriate for recovery of aircraft control in each of the eight scenarios; data on related variables also were collected. One example of these performance data is the elapsed time from the beginning of the upset to the first correct control input.

Researchers hoped that these data would provide a picture of the recovery actions that pilots performed well and the recovery actions that they failed to perform well. These data were intended to identify the critical differences between successful and unsuccessful recoveries. For these parameters, the data were continuous and the sample size was less problematic. Because there is a danger of random differences appearing significant when comparing groups across many variables, appropriate statistical caution was used in interpreting apparent differences in some of these variables.

In some situations, the measures of performance on individual steps in the recovery procedures did not correlate well with the overall measure of recovery/non-recovery. Part of the problem may have been that the study focused on single-point measures of control inputs and airplane dynamics and provided only limited information about the timing, sequencing and magnitudes of these pilot inputs and airplane responses.

In addition to the videotapes and audio recordings that were made of each flight and the data that were collected on control inputs and aircraft performance, the safety pilot also made brief comments after each flight. Nevertheless, the safety pilots had multiple tasks to perform during flight and could not provide detailed perspectives of each pilot's actions on each scenario.

Although these various methodological issues constrain interpretation of the data, they also provide guidance for future studies.

Scenarios Based on Eight Fatal Accidents

The eight scenarios with which pilots were evaluated in this study were based on the following fatal accidents: [6]

- Charlotte, North Carolina, U.S., July 2, 1994 — A Douglas DC-9 on an instrument landing system (ILS) approach was flown into a microburst with associated wind shear and high sink rate; [7]
- Birmingham, Alabama, U.S., July 10, 1991 — A Beech C99 on final approach was flown into a thunderstorm cell with strong vertical air shafts and associated turbulence and entered a nose-high attitude with a 45-degree left bank;[8]
- Toledo, Ohio, U.S., Feb. 15, 1992 — The captain flying a Douglas DC-8 on a second missed approach became spatially disoriented, apparently from a combination of physiological factors and a possible failed attitude indicator, and allowed the airplane to enter a nose-low steep bank. The first officer took control but was not able to recover control of the aircraft;[9]
- Shemya, Alaska, U.S., April 6, 1993 — The leading edge wing slats of a McDonnell Douglas MD-11 were inadvertently deployed in cruise flight, leading to reduced pitch stability, combined with light control forces, and resulting in violent, pilot-induced, pitch oscillations;[10]
- Nagoya, Japan, April 26, 1994 — The pilot manually flying an Airbus A300 on approach inadvertently triggered the GO lever, which changed the flight director to go-around mode and caused a thrust increase. The autopilots were subsequently engaged, while the pilot continued pushing against the control wheel. The horizontal stabilizer automatically trimmed to the full nose-up position, and the aircraft stalled;[11]
- Pittsburgh, Pennsylvania, U.S., Sept. 8, 1994 — During initial approach, pilots of a Boeing 737 experienced yaw/roll following uncommanded movement of the rudder to its blowdown limit, apparently in the opposite direction commanded by the pilots. (NTSB defined blowdown limit as "the maximum amount of rudder travel available for an airplane at a given flight condition/configuration" and said that rudder blowdown occurs "when the aerodynamic forces acting on the rudder become equal to the hydraulic force available to move the rudder.");[12]
- Roselawn, Indiana, U.S., Oct. 31, 1994 — During descent to 8,000 feet in icing conditions, the pilots of an Avions de Transport Régional ATR 72 experienced uncommanded roll and rapid descent resulting from sudden aileron hinge movement reversal caused by a ridge of ice accreted behind the deice boots;[13] and,
- Detroit, Michigan, U.S., Jan. 9, 1997 — Pilots of an Embraer EMB-120RT experienced an uncommanded roll and rapid descent caused by a thin, rough accretion of ice on the lifting surfaces.[14]

Appropriate upset-recovery techniques for each of the eight accident scenarios were developed, using the training procedures developed by American Airlines, United Air Lines, Delta Airlines and the *Airplane Upset Recovery Training Aid*. Two of the eight scenarios involved wing icing; the recovery for these two scenarios was based on advice from John Dow, an FAA aviation safety engineer.

The individual recovery steps for each scenario represent an idealized recovery technique that was developed for that specific scenario. The recovery steps were designed to facilitate data collection and analysis, and they are not necessarily consistent with the upset-recovery procedures that have been adopted by individual air carriers. Although data were collected about the pilot's performance on all of the recovery steps, some of the steps that were enumerated for each scenario were more critical than others for achieving recovery of aircraft control.

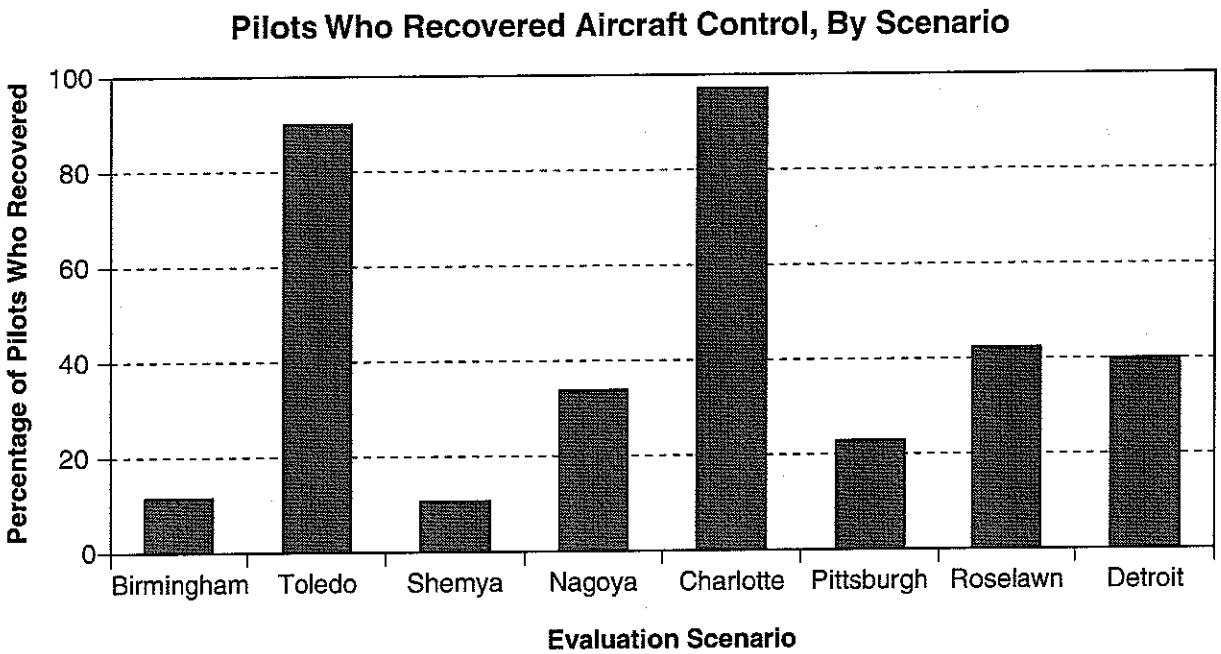
Pilot Performance Varied in Each Scenario

Performance differed considerably among the eight accident scenarios. For example, 98 percent of the evaluation pilots recovered control of the aircraft in the Charlotte scenario, compared with 11 percent in both the Shemya scenario and the Birmingham scenario (Figure 1, page 24).

Charlotte

The Charlotte scenario was presented to the pilots as a wind shear event on short final approach. The primary factor in achieving recovery was to obtain maximum thrust and maintain an angle-of-attack near stick-shaker (stall-warning) activation.

In this scenario, 97 percent of the pilots recovered control of the aircraft. The one pilot who did not complete a successful recovery was impeded by a safety trip. There were no reliable



Note: The evaluation scenarios were developed from eight airplane-upset accidents. Details of the accidents are in footnote 7 through footnote 14, beginning on page 31.

Source: U.S. National Aeronautics and Space Administration

Figure 1

differences among training groups, either with respect to recovery or to individual recovery techniques. All the pilots said that they had received substantial training in wind shear recovery. Thus, these results demonstrate the effectiveness of training for such situations.

During the recovery procedure, almost half of the pilots changed the landing-gear setting and/or the flap setting.[15] That some pilots changed flap configuration or landing-gear configuration shows that there may be (depending on aircraft type) wide margins of tolerance within which recovery of aircraft control may be achieved. None of the pilots pressed the autopilot-disconnect button, although such an action is emphasized during training on most aircraft types as an action to be taken early in any upset recovery. Pilots are encouraged to press the autopilot-disconnect button in an upset, regardless of whether the autopilot is engaged, to form a strong habit of disconnecting the autopilot before applying manual control inputs. (Pilots who overpower an engaged autopilot with their own manual inputs can, in many situations, further compromise aircraft handling and control.) The autopilot was not engaged at the beginning of the Charlotte scenario, and the pilots may have been aware of that as they began recovery procedures.

Birmingham

This scenario was presented to the pilots as an approach in the vicinity of thunderstorms with reports of moderate to severe turbulence. The underlying cause of the simulated upset was severe turbulence; the turbulence led to an airplane upset with a 45-degree bank and a nose-high attitude. The upset was not in the core of a microburst and did not require standard wind shear/microburst recovery techniques. In this scenario, holding pitch — rather than lowering the nose — resulted in stalling the airplane.

The initial conditions were a clean configuration with an airspeed of 180 knots. The aircraft was then upset with an uncommanded left roll and pitch-up, and light turbulence was simulated. The nose-up pitching moment in this scenario was strong enough that holding full nose-down elevator input was inadequate to control the pitch rate without being supplemented by applying nose-down pitch trim or rolling the airplane to divert the lift vector from the vertical.

In this scenario, 11 percent of the pilots recovered control of the aircraft. There were no reliable differences among training groups, either with respect to recovery or to individual recovery techniques.

Pilots who recovered control of the aircraft differed from those who did not only in that they had fewer encounters with safety trips. Safety pilots said that many of the safety trips that were experienced by non-recovering pilots occurred because of an absence of timely inputs. There were no significant differences in any measures of flight control inputs or other control responses.

Pilots typically responded by quickly applying aileron and rudder to correct the initial roll, but they failed to apply nose-down elevator in a timely manner, resulting in loss of airspeed that led to aerodynamic stall.

As a group, pilots appeared to respond consistently with their training to fly the airplane first for excessive bank and for microburst or wind shear recovery rather than to correct for high nose-up attitude. The introduction, as a thunderstorm scenario, apparently caused the pilots to prepare to conduct wind shear recovery procedures. Recovery from a high nose-up attitude requires applying nose-down pitch control to unload the aircraft and using bank angle to help reduce pitch attitude. Wind shear/microburst recovery emphasizes maintaining pitch near stick-shaker activation to extract as much lift as possible from a low-energy state and maintaining a wings-level roll attitude.

This scenario contrasts with the Charlotte scenario, which also was introduced as an approach in the vicinity of thunderstorms but which included a roll and high sink rate. The two scenarios require opposite pitch commands for recovery, with a similar series of precipitating events. Pilots appeared to diagnose the Charlotte scenario correctly and the Birmingham scenario incorrectly. The Charlotte scenario is consistent with wind shear/microburst training that is routinely provided throughout the industry. The Birmingham scenario, however, is consistent with airplane upset-recovery training, which is less often provided. With the thunderstorm scenario introduction, evaluation pilots appeared to initiate wind shear/microburst recovery procedures, and as a result, they did not implement corrective actions uniquely required for this accident scenario.

Toledo

The accident report said that the captain of this flight became disoriented and rolled the airplane into an upset. The first officer assumed control of the airplane and attempted recovery, but his roll-control inputs and pitch-control inputs were begun too late and were of inadequate magnitude. Investigators said that control of the airplane could have been recovered if, after rolling the airplane nearly level, the first officer had applied sufficient elevator input to obtain the airplane's maximum vertical g-load limit.

In this scenario, the evaluation pilots took over from the safety pilot as the airplane rolled from a normal level-off and left turn into a steeply banked, nose-low upset. The primary factors in recovery were to recognize the captain's incapacitation and assume control of the airplane, to roll the airplane aggressively toward wings level, to retard the throttles to avoid exceeding corner speed[16] and (only after the wings were nearly level) to apply column backpressure to obtain the airplane's maximum vertical g-load.

In this scenario, 86 percent of the pilots recovered control of the aircraft. Compared with the pilots who did not recover aircraft control, those who recovered control successfully from this scenario were more likely to reduce thrust to avoid excessive airspeed, to make the correct nose-up elevator input quickly and to impose less vertical g-loads during the recovery attempt.

Pilots who recovered control of the aircraft obtained significantly better performance on two measures of the outcome of the recovery attempt: They exceeded the 210-knot corner speed by fewer knots (35 knots, compared with 107 knots for the non-recovery group) and lost less altitude (996 feet, compared with 2,697 feet for the non-recovery group).

There were no reliable differences among training groups, either with respect to recovery or to individual recovery techniques.

After the transfer of control to the evaluation pilot was complete, this was a straightforward recovery from a nose-low, increasing-airspeed, steep-banked condition. This condition is addressed in all upset-training curricula, including the FAA instrument-rating curricula to which all pilots would have been exposed. The large percentage of pilots who successfully recovered control of the aircraft is consistent with their prior experience with this kind of upset. Most pilots in the recovery group and the non-recovery group managed the roll inputs well; however, the failure of any of the pilots in the non-recovery group to retard the throttles as airspeed exceeded the corner speed demonstrates the importance of this step in the nose-low upset-recovery procedure. The smaller values for airspeed gain and altitude loss that were obtained by the pilots who recovered successfully shows the positive effects of beginning the recovery in a timely manner.

The evaluation pilots who recovered control of the aircraft generated less vertical g-loading than those who did not recover control. Because the pilots who recovered aircraft control did not obtain the Learjet's maximum certificated (limit) load, they could have obtained somewhat better performance (i.e., less altitude loss) during recovery by pulling back farther on the column to obtain the limit load. Nevertheless, this group of pilots generated enough vertical g-loads, at the correct time, to recover control of the aircraft. The greater g-load generated by pilots who did not recover aircraft control demonstrates how use of only a single (maximum) value for g-load to represent the loads that were achieved throughout the entire recovery — as in this study — can be misleading; the timing of the g-load can be just as important as the maximum load achieved in recovering from an upset such as this one. Based on their greater altitude losses and greater airspeed deviations, the pilots who did not recover aircraft control probably obtained their maximum-recorded g-loads too late, just prior to a safety trip.

Shemya

This accident began with an uncommanded slat deployment, which caused the airplane to pitch up. The elevator control inputs made by the flight crew in response to this initial pitch-up induced nose-down and nose-up pitch-oscillation cycles. The airplane type that was involved in the accident had relatively light elevator-control forces, which were reproduced for the in-flight simulation.

The critical elements in the recovery were to disconnect the autopilot, then recognize the extreme pitch sensitivity of the airplane and recover aircraft control by using small, discrete, well-timed elevator inputs.

In this scenario, 11 percent of the evaluation pilots recovered control of the aircraft. There were no reliable differences among training groups, either with respect to recovery or to individual recovery techniques.

All the pilots who recovered aircraft control limited the magnitude of their pitch inputs, while all who failed to recover control made inputs of normal magnitude. Three of the four evaluation pilots who recovered aircraft control disconnected the autopilot prior to making their first elevator input, thereby avoiding the need to use force to overpower the autopilot while making the required, sensitive elevator inputs. One pilot recovered with the autopilot engaged through the first 25 seconds of the event.

Safety trips terminated the recovery attempt for all who failed to recover control of the aircraft. The most common reason for the safety trip was excessive positive vertical g or excessive negative vertical g.

The pilots' relatively low success rate in recovering aircraft control in this scenario is an indication of the difficulty of the scenario. There were no salient cues to the impending upset, and the required sensitivity to elevator inputs had to be recognized immediately. Comments by the pilots and the safety pilots indicated that, for best performance, the pilot would have had to anticipate the light pitch-control forces and relaxed stability characteristics of this aircraft type in high-altitude cruise flight. Failing that, pilots would have had to recognize these control characteristics from the airplane's response to their first input, and then immediately adjust the amplitude of their inputs to avoid inducing greater pitch oscillations.

Another factor in the low recovery rate may have been the lack of training for most pilots, including most of the evaluation pilots, in airplane upset recoveries that require light, careful and gentle use of the controls. In addition, most upset-recovery training emphasizes the need for maximum control inputs to obtain maximum aircraft performance, which may provide negative training for this specific recovery. Of the five groups in the study, only the in-flight training group had been exposed to reduced stability margins in actual flight, with the ability for the evaluation pilots to feel the airplane response to pitch inputs and the g-forces generated by these inputs. None of the groups, including the in-flight training group, obtained a high level of success in recovery or performed significantly better than any other group. This indicates that pilots trained under any of these programs might not be prepared to deal with an upset such as this one. Most pilots did not seem to have the knowledge or experience required to recover aircraft control after this high-altitude airplane upset.

Nagoya

The underlying cause of the simulated accident was the application of full nose-up trim, resulting from conflicting inputs from the autopilot and the first officer, combined with high thrust settings commanded by alpha floor protection (designed as wind shear protection that activates if specific parameters are exceeded) and the decision by the captain to conduct a go-around. This combination resulted in an aerodynamic stall. For the study, the entry to the upset was presented to participating pilots as an approach being conducted in an airplane that was being flown behind a heavy wide-body aircraft, with a caution for wake turbulence. In a configuration with the landing gear extended, the flaps at 20 degrees and the airspeed at 150 knots, the aircraft was upset by allowing the autopilot to apply full nose-up trim, then disconnect, resulting in excessive nose-up control forces.

The primary factors in recovery from this scenario were to input full nose-down elevator and then, recognizing that the available elevator authority was insufficient to control the airplane's nose-up pitching moment, to apply emergency trim and/or roll the airplane to divert the lift vector from the vertical.

In this scenario, 33 percent of the pilots recovered control of the aircraft. There were no reliable differences among training groups, either with respect to recovery or to individual recovery techniques.

Pilots who recovered aircraft control differed from those who did not only in the amount of time that elapsed before they called for emergency trim. Pilots who recovered aircraft control encountered no safety trips; two-thirds of those who did not recover aircraft control encountered safety trips resulting from excessive angle-of-attack. Pilots who recovered aircraft control were not statistically faster in announcing the problem or applying correct flight control inputs.

Pilots typically responded by applying elevator inputs within five seconds, with all but one applying full-forward elevator. The pilots were slower to announce the problem, however. Fourteen percent of the pilots applied aileron to control the lift vector; emergency trim was applied by less than half of the pilots, and those who applied emergency trim took an average of 12 seconds to do so.

As a group, pilots appeared to respond consistently with the training for nose-high attitudes that they had received since becoming student pilots — nose-down elevator. Nevertheless, most pilots did not implement additional corrective actions that were required for this accident scenario, resulting in safety trips for high angle-of-attack. That 86 percent of evaluation pilots (with no significant differences among the groups) did not roll the airplane to control the lift vector implies that the one-time training that the members of group three, group four and group five had received in this alternative control strategy was not effective. Also, most of the pilots were slow to recognize the need for emergency trim or to call for emergency trim. (The aircraft normally flown by some of the evaluation pilots were not equipped with an emergency-trim system similar to that installed on the Learjet, however. For these pilots, the briefing conducted before the evaluation flight about the Learjet's emergency trim constituted minimal training on this system.) Another corrective action that the pilots could have considered was to reduce thrust.

This scenario contrasts with performance observed in the Toledo accident scenario, which involved a nose-low, left-wing-down attitude possibly resulting from one pilot's spatial disorientation. There was no underlying mechanical cause or environmental cause for the upset, and all but one evaluation pilot recovered control of the aircraft. In the Toledo scenario, application of the normal control inputs solved the problem. In the Nagoya scenario, however, recovery occurred only with correction of the underlying runaway trim or use of a large bank angle to supplement full nose-down elevator input. Airplane upset-recovery training has focused on the recoveries from straightforward upset attitudes, rather than from upsets exacerbated by underlying malfunctions or other conditions that require alternatives to the application of normal control inputs. Two-thirds of the pilots failed to correct what was unique to the Nagoya scenario or to proceed to a necessary alternative strategy to regain control.

One interpretation of these data is that understanding and correcting the upset's underlying cause, which is unique to the scenario rather than generic to unusual-attitude recovery, was critical to recovery of aircraft control. Another interpretation is that the pilots generally were unable to proceed beyond their first reaction — nose-down elevator (to which all pilots are well-habituated from early stall training and for which they are reinforced by every pitch-control input) — to the second control reaction (roll to control pitch rate) that was required. More thorough training in a generic recovery that included rolling to control pitch might have provided better results without requiring pilots to understand the underlying cause of the upset.

Pittsburgh

This accident involved an uncommanded rudder deflection that led to a rapid yaw/roll to the left. The upset began with the airplane operating near the "crossover speed" for the existing configuration. (Crossover speed is the speed at which any further decrease in airspeed or increase in vertical g-load, even a full wheel input [full aileron/spoiler deflection] is not sufficient to overpower the yaw/roll moments from a fully deflected rudder.)

The primary elements in the recovery from this upset were to apply full wheel input to oppose the yaw/roll, to unload the pitch axis and to use differential-thrust inputs, if required, to regain roll control.

In this scenario, 22 percent of the pilots recovered aircraft control. There were no reliable differences among the groups, either with respect to recovery or to any individual recovery techniques. Six of the seven members of the in-flight training group, all of whom recovered aircraft control successfully, used differential thrust. This technique had been covered explicitly in the in-flight training curriculum. This training group had also been exposed to a rudder hard-over scenario.

Pilots who recovered control of the aircraft differed significantly from those who did not only in thrust delta (the difference in thrust produced by the two engines), which was an outcome of the differential-thrust technique. Of the eight pilots who recovered control of the aircraft, one unloaded pitch and increased airspeed, five used differential-thrust inputs, and two used a combined airspeed/differential-thrust method. One of the eight pilots flew the airplane at a bank angle that exceeded 70 degrees prior to regaining roll control. A primary error was failure to quickly reduce the angle-of-attack after the initial full-aileron-control input did not result in the desired effect. Few of the pilots experienced safety trips because few of the pilots used enough control input to cause a safety trip. The safety trip affected the recovery of the one evaluation pilot in the in-flight group who did not recover because of an excessive angle-of-attack.

This scenario involved an airplane upset attitude exacerbated by the malfunction of a primary flight control. Further, the crossover issue (in which adequate roll-control authority using roll control alone could be obtained and/or maintained only by unloading pitch) is not intuitively obvious to pilots. This may explain why a relatively low percentage of pilots recovered from this scenario. The success of some pilots in using the differential-thrust technique emphasizes the importance of training in the use of secondary flight controls to enhance the effectiveness of primary controls or to compensate for the failure of primary controls. The ability of the in-flight group to successfully apply this technique shows a positive training effect, although training and testing were separated by only one day. One evaluation pilot used differential thrust incorrectly, actually worsening the upset; this result explains the hesitancy of some operators to incorporate differential thrust into the recovery procedure for uncommanded yaw excursions.

The data appeared to show that the pilots who did not recover lost less altitude (603 feet) than those who recovered successfully (939 feet). This resulted from the termination of data-recording when a recovery attempt ended with a safety trip. The result implies that many pilots who failed to recover control of the aircraft would have exceeded safe operating parameters relatively early in their recovery attempts.

Roselawn

This accident scenario was presented to the evaluation pilots as a descent in icing conditions. The underlying cause of the accident was an uncommanded roll resulting from buildup of ice behind the leading edge deicing boots on the wings. For the study, with landing gear retracted and flaps extended to

20 degrees, the aircraft was upset with an aileron deflection, followed by an uncommanded roll simulating wing-ice-induced asymmetric lift.

The primary factor in recovery of aircraft control was to unload the pitch axis with nose-down elevator input. Throughout the recovery, an important response was to apply and maintain the nose-down elevator required to keep the angle-of-attack below the critical value at which the aileron deflection occurred.

Forty-three percent of the evaluation pilots recovered from this scenario. Nearly half of these were in the in-flight group, which was given training on a similar scenario in the aircraft prior to testing. (Seven of eight pilots in that group recovered.) There were no reliable differences among training groups, either with respect to recovery or to individual recovery techniques.

The actions of pilots who recovered control of the aircraft differed from the actions of those who did not in the maximum airspeed flown during recovery. Pilots who recovered aircraft control averaged 19 knots greater airspeed than pilots who did not recover control.

On average, pilots responded by quickly applying correct aileron and rudder inputs, but they were slow to apply nose-forward elevator to reduce angle-of-attack.

The pilots appeared to respond in accordance with their training for excessive bank and stall recovery, but they did not implement corrective actions uniquely required for icing-induced roll and uncommanded control movement: These two types of recoveries require different responses. Normal stall-recovery training (which trains pilots in recovering from the approach to stall) emphasizes applying maximum power and minimizing loss of altitude. In contrast, recovery from icing-induced rolls and more complete stalls requires trading altitude for airspeed.

Detroit

This accident scenario was presented to the pilots as a roll upset during approach in icing conditions. The underlying cause of the simulated accident was asymmetric lift caused by icing. The primary factor in recovery was to increase aileron effectiveness by reducing angle-of-attack and increasing airspeed.

In this scenario, 44 percent of the pilots recovered control of the aircraft. There were no reliable differences among training groups, either with respect to recovery or to individual recovery techniques.

The actions of pilots who recovered control of the aircraft differed from the actions of those who did not in that they flew the aircraft at greater airspeed. Although no other differences were statistically reliable, on average, those who recovered control of the aircraft took more time on each measure (e.g., time to announce problem, time to first correct control input).

The pattern of results in this scenario is similar to that of the Roselawn scenario, which also involved icing-induced roll. In each of the two scenarios, less than half of the pilots recovered control of the aircraft. The comparison between those who were able to recover control in these two events and those who were not underscores the importance of sacrificing altitude for airspeed, and the importance of increasing airspeed and reducing angle-of-attack for effectiveness of control when surfaces are contaminated with ice.

Pilots in both the Roselawn scenario and the Detroit scenario commented on the inadequacy of standard stall-recovery training and the conflict between their training for stall recovery and the actions required in icing conditions. They described how standard training programs emphasize response to stick-shaker activation and minimal loss of altitude. Uncommanded roll and stalls resulting from ice-contaminated surfaces can occur at angles-of-attack well below stick-shaker activation and in situations in which sacrificing altitude may be the only way to reduce angle-of-attack and gain airspeed quickly enough to recover control of the aircraft.

Pilots Performed Best in Wind Shear, Nose-low Spiral

Characteristics of the accident scenarios accounted for most of the variance in recovery performance in the study. Most pilots in all five groups successfully recovered control of the aircraft in two scenarios: Charlotte and Toledo.

The Charlotte scenario was a wind shear scenario. Most airlines now provide wind shear training, and all pilots in this study had received wind shear training — some of them repeatedly — outside of upset-recovery training. Thus, the recovery data suggest that training for a specific scenario can be very effective.

In the Toledo scenario, the pilots had to take control of the aircraft from an incapacitated captain and recover the aircraft from a nose-low spiral. The data indicate that most first officers would be able to take control and recover from a nose-low, steep bank situation in which the cues are unambiguous. (The first officer who was involved in the accident probably received more ambiguous cues than the pilots in the study.)

The Charlotte scenario and the Toledo scenario required textbook application of aircraft recovery techniques (for microburst and unusual attitudes) that are reinforced throughout pilots' careers. In both scenarios, the airplane responded when the pilot used the flight controls in the normal way, as long as the pilot applied adequate control force to achieve the performance required from the airplane. The recovery rate in these scenarios was extremely high, regardless of the type of upset-recovery training or aerobatic training received by the pilots.

In contrast, the Birmingham scenario and the Shemya scenario required application of recovery techniques that were essentially different from those that have been included in training throughout pilots' careers.[17]

In the Birmingham scenario (nose-high attitude induced by strong thunderstorm turbulence), many evaluation pilots appeared to try to conduct a wind shear recovery. Applying those recovery techniques, a pilot would level the wings and hold near-stick-shaker pitch; the control-column force needed to maintain the desired pitch would vary from moment to moment depending on gusts, but the airplane would respond to the pilot's elevator inputs. But in this scenario, full nose-down column had to be applied and held. Then, immediately upon realizing that full nose-down elevator could not reduce the angle-of-attack, the pilot had to proceed to an alternative control strategy to prevent a stall (i.e., rolling the airplane to control its pitch attitude).

In the Shemya scenario (uncommanded pitch-up induced by slat deployment) — because of the light pitch-control forces, the reduced aerodynamic damping caused by low air density at high altitude — the aircraft required gentle use of the controls. Most airplane upset-recovery training emphasizes aggressively moving the aircraft back to a straight-and-level attitude. When applied in this scenario, that action leads to increasing oscillations about the pitch axis.

The recovery rate in these two scenarios was low. This is consistent with the complexity of the scenarios, the brief time available for applying the correct recovery inputs and the far lesser degree to which the pilots had obtained relevant prior training and experience.

Standard Recovery Techniques Not Always Effective

In other scenarios, the standard "textbook" recovery techniques were ineffective because of underlying changes in normal control response that initiated the upset and also complicated the recovery attempts. These scenarios required either that the pilot quickly understand the underlying cause of the upset and immediately adopt an alternative recovery procedure or that the standard recovery procedure be robust enough to be effective despite the altered control response.

For example, the Detroit scenario and the Roselawn scenario required positively reducing angle-of-attack, sacrificing altitude for airspeed during the recovery from an icing-induced stall or uncommanded roll. This is inconsistent with the typical approach-to-stall training, which emphasizes minimizing altitude loss. Pilots made proper aileron and rudder inputs in both scenarios but were slow to reduce angle-of-attack.

Similarly, the Pittsburgh scenario required reducing angle-of-attack and reducing vertical g-load to enable roll-control effectiveness or the application of alternate mechanisms for roll control because of a fully deflected and jammed rudder. Further, Nagoya required not only manipulating the controls toward an appropriate attitude but also correcting the underlying configuration problem of full nose-up trim. An alternative to correcting the trim was using roll to divert the lift vector from the vertical.

Recovery in these four scenarios ranged from 23 percent to 42 percent (in the five groups combined) and was unrelated to the type of airplane upset-recovery training or aerobatic training that the pilots had received. Most pilots had difficulty transitioning to an alternative control technique when confronted with ineffective response from the normal controls or recovery procedures.

Similar Errors Found in Multiple Scenarios

Regardless of pilots' ability to recover aircraft control, this study provides data about the kinds of errors made by evaluation pilots in all five training groups while attempting to recover from the upset scenarios. For example, each of the six scenarios in which the majority of pilots failed to recover control of the aircraft required reducing angle-of-attack.

In nose-high scenarios, the most common mistake was failing to use bank angle to change the direction of the lift vector as an alternative to the normal pitch controls. Many of the pilots had received at least some training in the use of roll to recover from a nose-high upset, but this training did not appear to have been effective. Similarly, pilots also generally failed to use secondary controls to enhance recovery (e.g., differential thrust to enhance roll control).

Most pilots in the Shemya scenario used overly aggressive control inputs. Aggressive inputs were consistent with most upset types and the associated recovery procedures, and few evaluation pilots appear to have received significant prior training or experience with the high altitude/high speed aircraft handling techniques that were more appropriate for recovering from the Shemya scenario and similar situations.

Pilots were inconsistent in pressing the autopilot-disconnect button before applying recovery control inputs. The autopilot was engaged during entry in only the Shemya scenario, but pressing the autopilot-disconnect button is trained as an immediate recovery action regardless of automation status (on most transport types). In the Toledo scenario and the Pittsburgh scenario, most pilots failed to press the autopilot-disconnect button. In the Shemya scenario and the Charlotte scenario, most pilots pressed the autopilot-disconnect button. In the Nagoya scenario, more than half of the pilots who recovered aircraft control pressed the autopilot-disconnect button; those who did delayed pressing the button for an average of 10 seconds after they tried to control the airplane's pitch-up with the elevator.

We do not know why the evaluation pilots pressed the autopilot-disconnect button in some scenarios but not others. The classroom upset-recovery training received by three groups of pilots emphasized the importance of pressing the autopilot-disconnect button, but perhaps they had not practiced sufficiently for this action to become an automatic, highly learned response that would be performed in conditions involving surprise and confusion.

In general, the pilots who failed to recover control of the aircraft displayed confusion and other stress reactions. In some situations, they appeared to freeze on the controls; in other situations, they made rapid switches between power settings, inadvertently activated controls or initiated roll oscillations. These confused reactions suggest that airplane upset-recovery training should place greater emphasis on surprise in the initial encounter with conditions that lead to upsets, rather than only emphasizing the practice of recovery techniques.

The pilots in all five groups showed substantial differences in performance, perhaps because of the substantial differences in the amount and nature of their flight experience before being hired by their current airlines. For example, the number of scenarios in which an individual pilot recovered aircraft control ranged from zero to seven; the average was 3.2 (out of eight scenarios). The variability in experience among the evaluation pilots reflects the current distribution in new-hires in U.S. airlines.

No statistically significant differences in recovery performance were found among the five groups. Nevertheless, because of the small number of pilots in this study and the large variability in performance among individual pilots, we can draw no conclusions about the question of whether the type of training received by these pilots affects performance in these types of scenarios. These results appear to indicate that current training is not adequate to enable new-hire pilots to reliably recover from all upset scenarios.

The pilots who had received upset training in ground simulators were exposed to a single session of generic training. The upset-recovery training currently provided by major airlines typically consists of four hours to eight hours of classroom training and a simulator session in which pilots are taught general methods of recovering from nose-high attitudes, nose-low attitudes and excessive bank attitudes rather than being taught more specific methods of recovery from a variety of upset scenarios. In this study, six of the eight scenarios presented the pilots with unfamiliar situations for which they had not been specifically trained; many pilots reacted to these situations with confusion and were not able to recover control of the aircraft.

The results of the study suggest methods in which current upset-recovery training might be expanded to help pilots deal with a number of unfamiliar situations.

Although it is not possible to train for all imaginable situations, a relatively small number of the classes of upset scenarios that might be relevant in most situations could be identified and pilots could be trained in how to respond to those classes of scenarios. For example, reducing vertical g-load and angle-of-attack improves control response and airplane performance in the recoveries from many scenarios.

Classroom training can help pilots identify the cues for recognizing conditions that precede classes of upsets and for distinguishing the type of recovery required. Distinguishing between situations that superficially appear similar but require fundamentally different responses should be emphasized during training. For example, recovery from fully developed stalls should be distinguished from recovery from incipient stalls, and wind shear recovery should be distinguished from recovery from nose-high situations that require reducing angle-of-attack aggressively.

Simulation training could place greater emphasis on exposing pilots to the conditions that precede upsets and to the onset of upsets, so that they can practice recognizing cues that distinguish different classes of upset. Further, if — in a particular situation — pilots would be unlikely to identify the underlying factors in the upset, they could practice control responses that are effective in recovery from a number of classes of upsets. Simulation training also should present upsets in unexpected ways so that pilots experience surprise and learn to cope with initial confusion. This would require integrating upset training with other forms of training so that pilots cannot always anticipate the upset scenario.

Upset-recovery training could be part of both initial qualification training and recurrent training, which would provide recency of experience and reinforcement.

The study leaves some basic questions unanswered:

- How extensively must pilots practice recovery maneuvers to obtain proficiency?
- How often must pilots train to maintain proficiency?
- To what extent does generic training enable pilots to recover from a wide variety of potential upset attitude scenarios?
- What are the best ways to address, in training, the factor of surprise that occurs in actual upsets?
- To what extent will training in ground-based simulators transfer appropriately to pilot performance in actual upset situations?
- What degree of fidelity is required of training simulators in reproducing the aerodynamic responses of aircraft outside normal operating parameters, and what are the methods of achieving the required fidelity?

These questions suggest areas for further research.♦

The opinions expressed in this article are those of the authors alone and do not necessarily represent the views of NASA, General Dynamics or San Jose State University. Tom Chidester and Immanuel Barshi contributed to the preparation of this article.

Notes

1. Boeing Commercial Airplanes. *Statistical Summary of Commercial Jet Airplane Accidents, Worldwide Operations, 1959–2002*. Boeing Commercial Airplanes, Seattle, Washington, U.S., 2003.

2. *Airplane Upset Recovery Training Aid*. May 12, 1998. The text portion of the training aid is available on the U.S. Federal Aviation Administration (FAA) Internet site at <www2.faa.gov/AVR/afs/afs200/afs210/index.cfm>.

   The training aid says that the following unintentional conditions generally describe an airplane upset: "Pitch attitude greater than 25 degrees nose-up, pitch attitude greater than 10 degrees nose-down, bank angle greater than 45 degrees [or] within the above parameters but flying at airspeeds inappropriate for the conditions."

3. For example, Safety Recommendation A-96-120 recommended training to recognize and recover from unusual attitudes and upsets that can occur from flight control malfunctions and uncommanded flight control surface movement.

4. Gawron, V.J. *Airplane Upset Training Evaluation Report*, U.S. National Aeronautics and Space Administration (NASA) Contractor Report 2002-211405. Moffett Field, California, U.S.: NASA-Ames Research Center, 2002. The study is available online at <www.ntis.gov>.

5. Pilots in group five (the in-flight training group) received two days of training and evaluation at Veridian facilities in Buffalo, New York, U.S. Ground school instruction was given in the morning of day one, followed by the training flight in the Learjet 25B variable-stability in-flight simulator in the afternoon. The evaluation flight was given the morning of day two. For group two, group three and group four, the interval between training and testing was much longer, ranging from seven days to 14 years.

6. Evaluation pilots were presented with the eight scenarios in counterbalanced order during their Learjet flights.

7. This accident is presented out of chronological order for convenience in discussing the results.

   The Douglas DC-9 struck trees and a private residence after the flight crew conducted a missed approach. The airplane was destroyed; 37 people in the airplane were killed, 16 received serious injuries and four received minor injuries.

   The U.S. National Transportation Safety Board (NTSB) said, in its final report, that the probable causes of the accident were "1) the flight crew's decision to continue an approach into severe convective activity that was conducive to a microburst; 2) the flight crew's failure to recognize a wind shear situation in a timely manner; 3) the flight crew's failure to establish and maintain the proper airplane attitude and thrust setting necessary to escape the wind shear; and 4) the lack of real-time adverse weather and wind shear hazard information dissemination from air traffic control, all of which led to an encounter with and the failure to escape from a microburst-induced wind shear that was produced by a rapidly developing thunderstorm located at the approach end of Runway 18R."

   The report said that contributing factors were "1) the lack of air traffic control procedures that would have required the controller to display and issue airport surveillance radar … weather information to the pilots …; 2) the Charlotte tower supervisor's failure to properly advise and ensure that all controllers were aware of and reporting the reduction in visibility and runway visual range value information and the low-level wind shear alerts that had occurred in multiple quadrants; 3) the inadequate remedial actions by [the operator] to ensure adherence to standard operating procedures; and 4) the inadequate software logic in the airplane's wind shear warning system that did not provide an alert upon entry into the wind shear."

8. The Beech C99 struck houses during an instrument landing system (ILS) approach. The airplane was destroyed; 13 people in the airplane were killed, and two received serious injuries.

   NTSB said, in its final report, that the probable cause of the accident was "the decision of the captain to initiate and continue an instrument approach into clearly identified thunderstorm activity, resulting in a loss of control of the airplane from which the flight crew was unable to recover and subsequent collision with obstacles and the terrain."

9. The Douglas DC-8 struck terrain during the second missed approach. The airplane was destroyed; four people in the airplane were killed.

   NTSB said, in its final report, that the probable cause of the accident was "the failure of the flight crew to properly recognize or recover in a timely manner from the unusual aircraft attitude that resulted from the captain's apparent spatial disorientation, resulting from physiological factors and/or a failed attitude director indicator."

10. The leading edge wing slats of the McDonnell Douglas MD-11 deployed during cruise flight at Flight Level 330 (approximately 33,000 feet). The airplane received no external structural damage, but the passenger cabin was damaged substantially; two people in the airplane were killed, 60 received serious injuries, 96 received minor injuries, and 97 were not injured.

    NTSB said, in its final report, that the probable cause of the accident was "the inadequate design of the flap/slat actuation handle by the Douglas Aircraft Co. that allowed the handle to be easily and inadvertently dislodged from the UP/RET position, thereby causing extension of the leading edge slats during cruise flight. The captain's attempt to recover from the slat extension, given the reduced longitudinal stability and the associated light control force characteristics of the MD-11 in cruise flight, led to several violent pitch oscillations. Contributing to the violence of the pitch oscillations was the lack of specific MD-11 pilot training in recovery from high-altitude upsets and the influence of the stall warning system on the captain's control responses."

    The report said that a factor contributing to the severity of the injuries was "the lack of seat restraint usage by the occupants."

11. A translation of the report by the Aircraft Accident Investigation Commission of the Japanese Ministry of Transport said that the Airbus A300 struck the ground during final approach to land at Nagoya Airport. The airplane was destroyed; 264 people in the airplane were killed and seven people received serious injuries.

    The report said that causes of the accident were the following:

    "While the aircraft was making an ILS approach to Runway 34 of Nagoya airport, under manual control by the [first officer], the [first officer] inadvertently activated the GO lever, which changed the FD (flight director) to GO-AROUND mode and caused a thrust increase. This made the aircraft deviate above its normal glide path.

"The APs [autopilots] were subsequently engaged, with GO-AROUND mode still engaged. Under these conditions, the [first officer] continued pushing the control wheel in accordance with the [captain's] instructions. As a result of this, the THS (horizontal stabilizer) moved to its full nose-up position and caused an abnormal out-of-trim situation.

"The crew continued [the] approach, unaware of the abnormal situation. The [angle-of-attack] increased, the alpha floor function was activated, and the pitch angle increased.

"It is considered that, at this time, the [captain] (who had now taken the controls) judged that landing would be difficult and opted for go-around. The aircraft began to climb steeply with a high pitch-angle attitude. The [captain] and the [first officer] did not carry out an effective recovery operation, and the aircraft stalled and [struck terrain]."

12. The B-737 struck terrain during the approach to landing at Pittsburgh (Pennsylvania, U.S.) International Airport. The airplane was destroyed; all 132 people in the airplane were killed.

    NTSB, in its final report, said that the probable cause of the accident was "a loss of control of the airplane resulting from the movement of the rudder surface to its blowdown limit. The rudder surface most likely deflected in a direction opposite to that commanded by the pilots as a result of a jam of the main rudder power control unit servo valve secondary slide to the servo valve housing offset from its neutral position and overtravel of the primary slide."

13. The Avions de Transport Régional ATR 72 struck terrain after a rapid descent following an uncommanded roll excursion. The airplane was destroyed; all 68 people in the airplane were killed.

    NTSB, in a 2002 revision of the probable cause that was included in the original 1996 accident report, said that the probable cause was "the loss of control, attributed to a sudden and unexpected aileron hinge moment reversal, that occurred after a ridge of ice accreted beyond the deice boots while the airplane was in a holding pattern during which it intermittently encountered supercooled cloud and drizzle/rain drops, the size and water content of which exceeded those described in the icing certification envelope. The airplane was susceptible to this loss of control, and the crew was unable to recover."

    NTSB said that factors contributing to the accident were "1) the French Directorate General for Civil Aviation's (DGAC's) inadequate oversight of the ATR 42 and [ATR] 72, and its failure to take the necessary corrective action to ensure continued airworthiness in icing conditions; 2) the DGAC's failure to provide the FAA with timely airworthiness information developed from previous ATR incidents and accidents in icing conditions; 3) the [FAA's] failure to ensure that aircraft icing certification requirements, operational requirements for flight into icing conditions and FAA published aircraft icing information adequately accounted for the hazards that can result from flight in freezing rain; 4) the FAA's inadequate oversight of the ATR 42 and [ATR] 72 to ensure continued airworthiness in icing conditions; and 5) ATR's [i.e., the manufacturer's] inadequate response to the continued occurrence of ATR 42 icing/roll upsets, which, in conjunction with information learned about aileron control difficulties during the certification and development of the ATR 42 and [ATR] 72, should have prompted additional research, and the creation of updated airplane flight manuals, flight crew operating manuals and training programs related to operation of the ATR 42 and [ATR] 72 in such icing conditions."

14. The Embraer EMB-120RT struck the ground during an approach to land at Detroit (Michigan, U.S.) Metropolitan Airport. The airplane was destroyed; 29 people in the airplane were killed.

    NTSB said, in its final report, that the probable causes of the accident were "the [FAA's] failure to establish adequate aircraft certification standards for flight in icing conditions, the FAA's failure to ensure that at Centro Tecnico Aeroespacial/FAA-approved procedure for the accident airplane's deice system operation was implemented by U.S.-based air carriers, and the FAA's failure to require the establishment of adequate minimum airspeeds for icing conditions, which led to the loss of control when the airplane accumulated a thin, rough accretion of ice on its lifting surfaces. Contributing to the accident were the flight crew's decision to operate in icing conditions near the lower margin of the operating airspeed envelope (with flaps retracted) and [the operator's] failure to establish and adequately disseminate unambiguous minimum airspeed values for flap configurations and for flight in icing conditions."

15. FAA Advisory Circular (AC) 00-54, *Pilot Windshear Guide*, says that during recovery from a wind shear encounter on approach, pilots should "maintain flap and gear position until terrain clearance is assured."

16. Corner speed is the lowest speed at which maximum g-force is available for maneuvering. A pilot recovering from a high speed, nose-low upset will obtain the minimum altitude loss by operating the airplane at corner speed and limiting g-loading.

17. The authors are indebted to Tom Chidester for suggesting this idea.

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