Avionics that could save lives aboard an airliner at the brink of collision with the ground or another aircraft — overriding, at the last possible second, the inadequate response or loss of control by the flight crew — show promise in early flight technology demonstrations. Such *auto-recovery systems,* however, likely will have to prove their safety value to airlines and flight crews through reliable operation on millions of flights, says Don Bateman, chief engineer, flight safety avionics, at Honeywell.

The rationale behind research on these systems, including how they would address pilot noncompliance with cockpit warnings and loss of control accidents, was the subject of Bateman's presentation to the Flight Safety Foundation International Air Safety Seminar in October 2007 in Seoul, Korea. He noted that it reflected only his personal views.

The motivation for this research and development also includes a number of accidents in which an aircraft system provided a warning but the flight crew hesitated too long, ignored or incorrectly responded to the warning. "We have seen long delays in which a warning goes off and nothing happens — as much as 30 seconds goes by before, maybe, one of the pilots takes action," Bateman said. "Aircraft should 'refuse to be destroyed,' for example, by loss of control."

Attempts to prevent loss of control accidents, controlled flight into terrain (CFIT), midair collisions and other catastrophic events are hindered by factors such as too many operational warnings; multiple confusing warnings; flight crew fatigue; crew distraction; intense concentration on one task or multiple tasks with inadequate alertness to warnings; visual fixation outside the airplane, such as on the runway environment; lack of appropriate pilot training or lapses in training; failure to follow standard operating procedures (SOPs); spatial disorientation including somatogravic illusion — that is, the acceleration-induced false sensation of aircraft pitch-up; strong belief by a pilot that the procedures or the instruments are correct and the warning is false; misplaced confidence by a pilot that the situation will become safer without intervention by the crew; and weaknesses in flight instrument design, according to Bateman.

Auto-Recovery Design

Proponents of auto-recovery systems expect initial designs to be capable of saving lives without imposing differences

Helping Hand

BY WAYNE ROSENKRANS

Auto-recovery systems would 'refuse to be destroyed' by a flight crew's inaction, delay or incorrect response to an imminent collision.

on the flight deck or in how the airplane is flown, except for a *disable switch,* a new method of crew intervention. Basic assumptions are that:

- The system would activate only when seconds remain before a collision and there has been no flight crew response to a warning, or the flight crew response has been incorrect or too late.
- Tactile feedback to the pilots and training on the auto-recovery system would prevent its activation from surprising the flight crew.
- At some future date, auto-recovery systems would not provide a disable switch for override by the flight crew — assuming that trouble-free operation had been demonstrated by analysis of data from millions of flights.
- Unwanted activations of the auto-recovery system would be limited by designers to fewer than one per 1 million flights.
- The system would be compatible with real-world airline operations.
- Auto-recovery would be immune to sensor anomalies.
- This backup function would be "invisible" to the flight crew during routine flight operations.

Airframe manufacturers, including Airbus and Boeing, have been working on related research and development, Bateman said. Technological feasibility and user acceptance will require an extremely low rate of false activation of auto-recovery systems. "I think the industry can do that," he said. "We can make it activate using a terrain database. We also need to be compatible with real-world operations — that is the greatest problem that engineers have with designing auto-recovery systems."

As currently conceived, if the threat is terrain or obstacles in the flight path of the airplane, the auto-recovery system would not activate until a relatively long time after the series of warnings by a Honeywell enhanced ground-proximity warning system (EGPWS) or other terrain awareness and warning system (TAWS). "We would wait a long time after the 'Caution, terrain' alarm, a long time after the 'Pull up, pull up' alarm and, finally, we would wait at least six, seven, eight or nine seconds or even longer before the auto-recovery system does the pull-up," Bateman said.

Auto-recovery would involve a level of system reliability yet to be achieved in other cockpit warning systems for flight crews. "Pilots ask me, 'With auto-recovery, aren't you taking control away from me?'" Bateman said. "My answer is, 'No, we're not. You should be able to fly the airplane any way you want. But just don't do something stupid.' As long as we have to have a disable switch, we are going to have pilots who won't trust this system — and rightly so — but we can hardly design systems without a disable switch until after millions of hours and millions of flights."

In the development of auto-recovery systems, typical accident/incident scenarios considered have included continued takeoff after the activation of a configuration warning horn; subtle flight crew incapacitation by hypoxia after a cabin-altitude warning horn; shutdown of the incorrect engine after a fire warning; selection of an incorrect crossing altitude to be flown by the autopilot; crew attention focused only on entering flight management system data, distracting them from a cockpit warning; failure to understand the meaning of an aural warning annunciated in English; selection of incorrect global positioning system (GPS) coordinates or faulty/weak procedure for this task; and critical delays in crew response to alerts from TAWS/EGPWS.

Honeywell researchers have conducted tests of a prototype for an auto-recovery system aboard a modified Airbus A319. "We demonstrated it along the Monterey [California, U.S.] peninsula," Bateman said. "We took three flights toward a mountain … asking the test pilot *not* to recover in response to the EGPWS alerts. The mountain got bigger and bigger in the windscreen. At first, when the EGPWS said 'Pull up, pull up,' the pilot did not want to ignore it. But the auto-recovery worked." If the same capability had been aboard a Boeing 747 freighter that crashed in February 1989 near Kuala Lumpur, Malaysia, hardly any altitude would have been lost during a successful automated escape maneuver based on a computer re-creation of the scenario, he said.

Three Relevant Accidents

Bateman's review of the Kuala Lumpur accident report emphasized the criticality of immediate response to a ground-proximity warning. "This accident also can be characterized as one in which the crew did not comply with the SOPs," he said. "The first ground-proximity warning came on at approximately 18 seconds from impact. They were way late in their checklist, they were still talking about what radio frequencies to set in, and so on. When the warnings went off, they were still trying to get the radios set. The warnings went on and on. The only one who realized that something was wrong was the flight engineer. That was too late."

An A320 accident in May 2006 — during a missed approach to Sochi

(Russia) Airport (*ASW,* 10/07, p. 44) at about 0200 local time — can be characterized as a "subtle" loss of control accident, Bateman said. Among causal factors cited in the accident report were spatial disorientation, inadequate control inputs by the captain, lack of monitoring by the copilot and the failure of both pilots to respond to a TAWS warning. Several aspects of the scenario have relevance to inadequate pilot response to warnings, instrument interpretation during a cockpit warning and auto-recovery, he said. "They were not following the SOPs, and they turned the autopilot off," Bateman noted. "The captain got a flap overspeed indication — the master warning light — and he pushed the nose over. The copilot was trying to help him with the sidestick — his own sidestick — but never took over control."

An A320 accident near Bahrain International Airport in August 2000 (*Accident Prevention,* 12/02) also involved a missed approach at night. "Again, they got a master warning light for flaps exceedance speed," Bateman said. "The captain pushed the airplane over … into the water. There were about 11 seconds of pull-up warnings but no pilot response. Nothing from the copilot. Why?" Counterintuitive instrument display of flap overspeed has come into play in such scenarios, he said.

Diagrams showed the predicted performance of an auto-recovery system in re-creations of the Kuala Lumpur, Sochi and Bahrain accidents. In the Bahrain re-creation, the EGPWS 'Sink rate, sink rate' alarm and 'Pull up, pull up' alarm occurred just as during the accident flight. The auto-recovery system waited six seconds after these warnings — approximately four seconds from impact — to conduct a standard autopilot escape maneuver. "Hardly any altitude is lost doing that," Bateman said. "Nobody gets hurt."

In re-creating the Sochi scenario, researchers allowed about 18 seconds to elapse after the "Sink rate, sink rate" alarm without a pilot response (Figure 1). "The 'Pull up, pull up' alarm sounded and researchers waited until five seconds from impact. Then the machine made the recovery," Bateman said.

Loss of Control

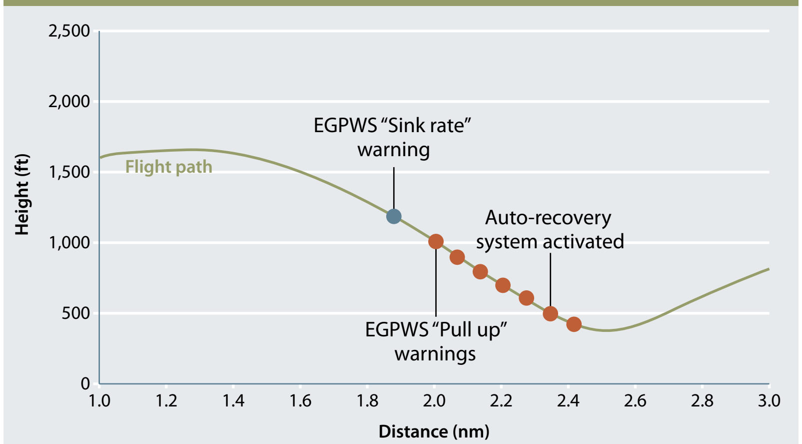
A high priority for global airline safety professionals should be risk management to address loss of control, Bateman said. "Airplane designs with built-in automatic flight envelope protection or flight control limiters are driving down the loss of control risk," Bateman said. "Examples are Mach limiters, pitch-trim compensators, artificial feel mechanisms, stick shakers/pushers and fly-by-wire aircraft such as those by Airbus, Boeing and others." Auto-recovery systems would represent a logical evolutionary step.

"Loss of control remains a major risk … the number one killer in 2007, although airplane designs have really been improved through the years," Bateman said, urging Flight Safety Foundation to help direct more industry attention to loss of control. "Let's get serious about this. There is a whole variety of things we can do at reasonable cost, hopefully."

Excessive/Unwanted Warnings

Bateman made a side-by-side comparison of rates of cockpit warnings including traffic-alert and collision avoidance system (TCAS II) resolution advisories (RAs), stall warnings, EGPWS alerts,

Auto-Recovery Envisioned: Airbus A320, Sochi, Russia



EGPWS = enhanced ground-proximity warning system

Note: In a computer recreation of this accident scenario, researchers found that a proposed auto-recovery system responded successfully. In reality, the aircraft descended into the Black Sea during a missed approach on May 3, 2006.

Source: Don Bateman

Figure 1

engine fire warnings, wind shear alerts, smoke alerts and takeoff configuration warnings. The data showed that RAs by an airborne collision avoidance system (ACAS), or a TCAS, occur at a rate about 400 times greater than fire warnings or EGPWS alerts. "Frequent false operational warnings seriously impair pilot response," he said.

For comparison, there were eight TCAS RAs in North America and 0.8 TCAS RAs in Europe per 1,000 departures. "There are more RAs in North America than any other region; I don't know why," he said. "We need to methodically collect the data, figure out what's going on and fix it."

Significant variation has occurred among the rates of different types of cockpit warning per the number of large international airliner departures (Figure 2). "I added in the engine fire rate — 0.04 — as a monitor," Bateman said. "I believe that a good rate for an airplane cockpit warning is something like 0.04, less than about one in every 40,000 or 50,000 flights."

The industry could eliminate many of the unwanted RAs by universal adoption of automatic dependent surveillance–broadcast (ADS-B) "out," which airplanes can use to broadcast their intended flight path as entered in a flight management system. "Now we can expand auto-recovery to midair collision threats," Bateman said. "We have ADS-B on most new Boeing and Airbus airplanes going out into the airline fleet, and on many other airplanes soon — a better system that could reduce the unwanted RAs by at least 10 times what they are today." The result will be an expanded threat-detection envelope enabling earlier traffic warnings.

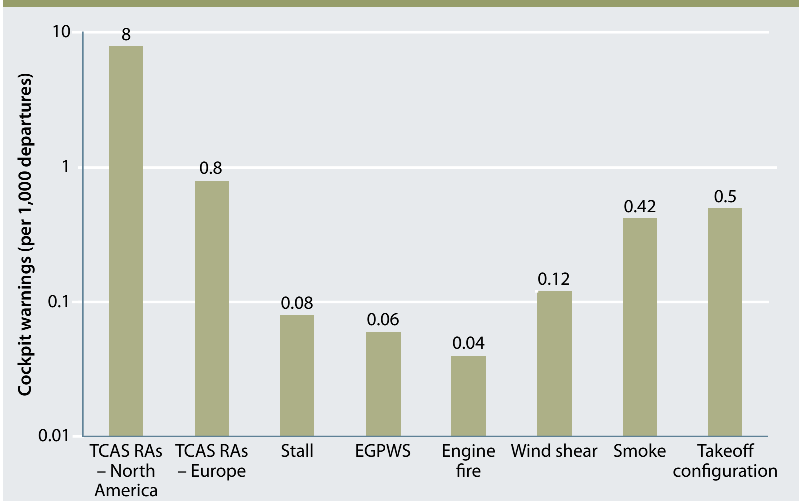
Substantial reduction of unwanted cockpit warnings is just one of many opportunities to reduce risk. "We have beautiful flight instrument displays, but I still think we can do more to improve them," Bateman said. "Pilot training to recognize and address weaknesses in displays is important. Airplane upset recovery training to cope with spatial disorientation/illusions also remains critical to pilot response."

Another risk-reduction opportunity can be the presentation of information. Among the flight instrument indications added over many years — such as the yellow speed trend arrow on the airspeed presentation of the primary flight display — instrument designers have chosen to indicate the flaps exceedance speed range using diagonal red stripes on a vertical tape that moves downward. The red stripes disappear from view during flight at relatively low airspeeds.

"In the cockpit … red means danger, don't go there," Bateman said. "Pilots don't want to go near red … on a weather radar display or a terrain display. I'm not a human factors engineer, but years ago that tape should have been turned around the other way so that red would come up from the bottom during a flaps overspeed, so the pilot would want to pull the nose up to fly away from red, and vice versa for low speed."

Nevertheless, redesign of this widely adopted "barber pole" presentation of the flap overspeed tape is unlikely. "We need to rethink how we train pilots to use it and what we can do to prevent another accident," Bateman said.

Cockpit Warning Incidence Varies Widely



TCAS = traffic-alert and collision avoidance system II; RA = resolution advisory;
EGPWS = enhanced ground-proximity warning system

Note: Numbers comprise a combination of de-identified aggregate data from 500,000 airline flights with other sources.

Source: Don Bateman

Figure 2

EGPWS Refinements

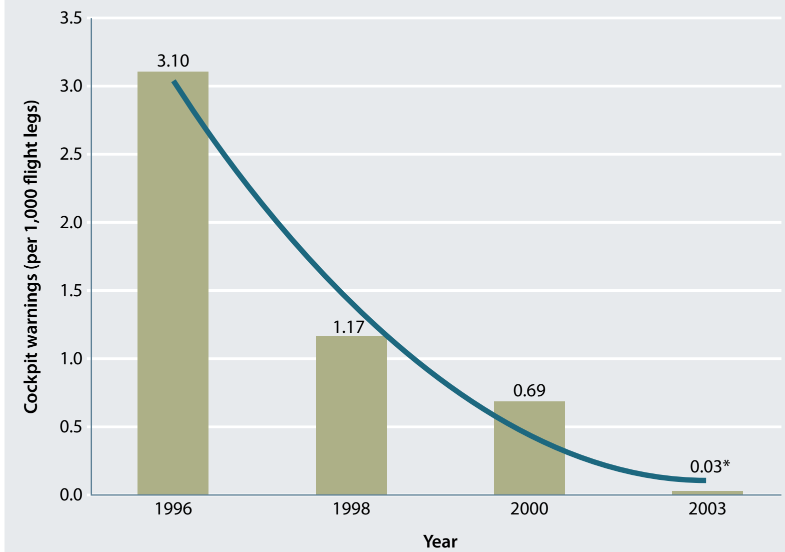
Safety initiatives since 1996 — when 3.1 unwanted EGPWS alerts occurred per 1,000 flight legs — have been effective (Figure 3), and the effort to keep them as low as possible continues, Bateman said. "Using de-identified flight history data, EGPWS warnings have been decreased," he said. "Methodical collection and examination of data concerning warnings is key, and cooperation from the pilots and controllers is very important. Ten years ago, there were 1.17 hard pull-up warnings or terrain warnings per 1,000 flight legs, and in 2003 we got it down to 0.03 — that's more than a 100-fold improvement in less than 10 years."

Despite the importance of actual flight data to avionics manufacturers, such data often seem to designers to have fallen into an inaccessible "black hole" because of restricted usage, he said. Yet flight operational quality assurance (FOQA) programs at airlines, also known as flight data monitoring programs, could help designers to improve hardware/software performance. "Maybe the airline knows about an event and some of the pilots know what's going on, but flight data typically are not shared outside the airlines. The designers of equipment need to know what the unwanted-warning rates are and also the pilot response time for the event. If pilots take 15 seconds or longer, for example, something's wrong."

Ideally, designers would have access to de-identified aggregate data containing all relevant flight parameters for 20 seconds prior to a cockpit warning and the same parameters for the 10 seconds immediately afterward. Some flight parameters of special interest are the accelerations induced by a pilot's control inputs within this time frame, pilot response time (Figure 4) and where the recovery occurred. For example, at distances of 35 to 45 nm (65 to 83 km) from an arrival/departure airport, pilots induced more than + 0.3 g to more than + 0.8 g (i.e., 0.3 to 0.8 times standard gravitational acceleration). "When pilots are close to the airport, pulling a quarter of a g is rather routine" during an escape maneuver, Bateman said. By comparison, the autopilot of an Airbus airplane will induce acceleration of + 0.3 g or + 0.5 g in response to TCAS RAs.

The traveling public today would not tolerate the thousands of fatalities that occurred for decades in 19th-century steamboat accidents in the United States, he said. Contemporary passengers likewise expect the airline industry to implement the best solutions available to reduce the current rate of loss of control accidents and the risks of unheeded warnings by flight crews. ●

Fewer Unwanted EGPWS Warnings in Global Air Transport



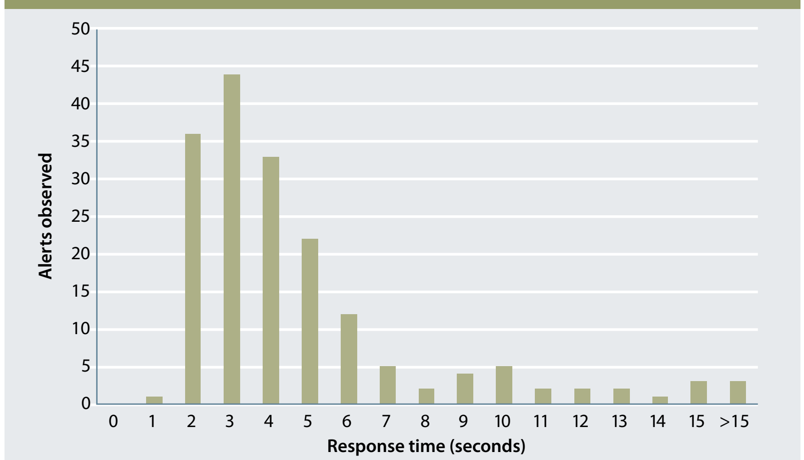
EGPWS = enhanced ground-proximity warning system

* Data for 2003 assumed that the latest EGPWS software (–218) and database (–435) were installed and the aircraft had global positioning system navigation.

Source: Don Bateman

Figure 3

Pilot Responses to EGPWS Look-Ahead Alerts



EGPWS = enhanced ground-proximity warning system

Note: Look-ahead alerts comprise cautions and warnings.

Source: Don Bateman

Figure 4