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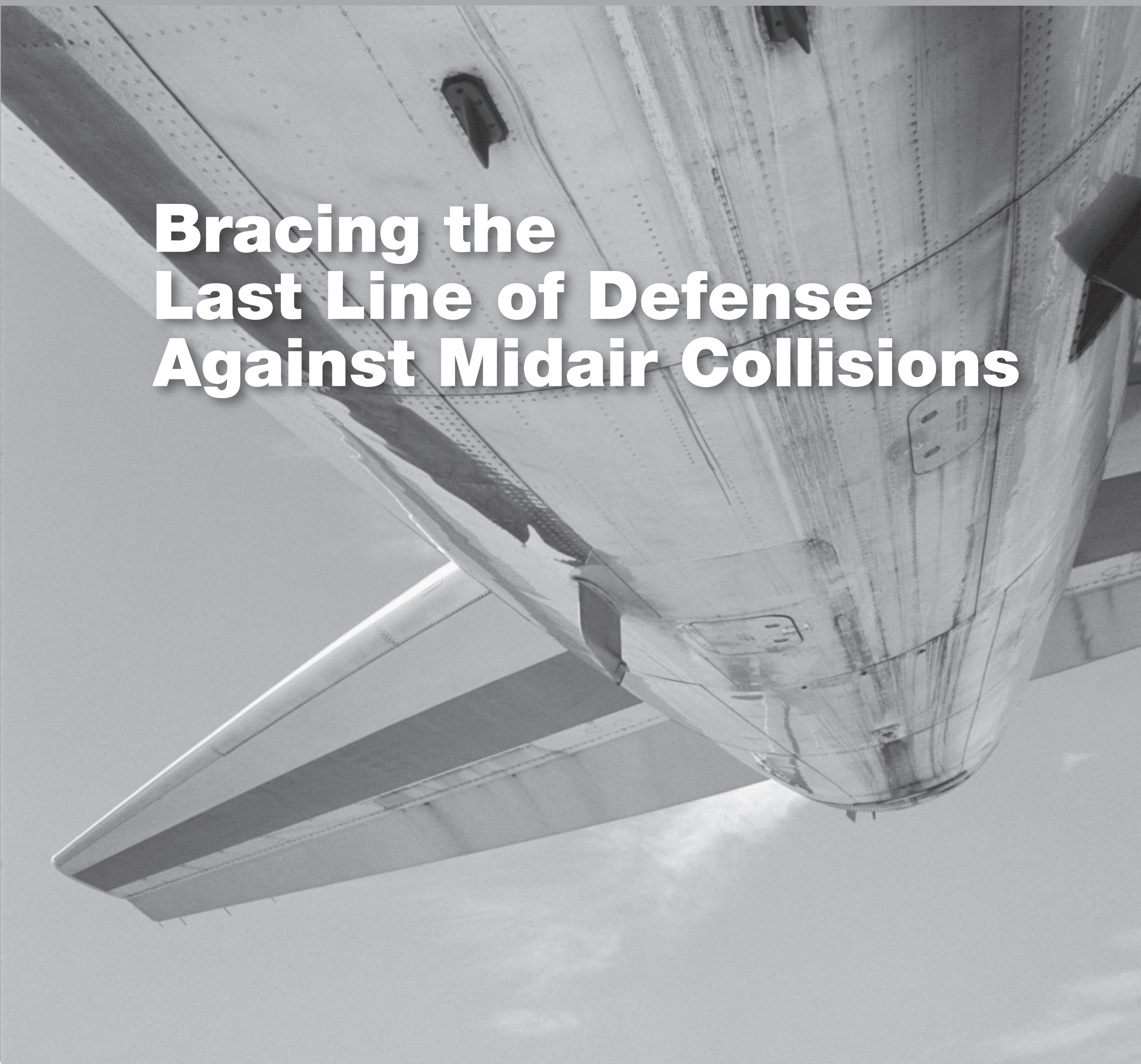

Bracing the Last Line of Defense Against Midair Collisions

Flight Safety Digest

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Bracing the Last Line of Defense Against Midair Collisions

Recent accidents have prompted the International Civil Aviation Organization to clarify that pilots must comply immediately with airborne collision avoidance system resolution advisories, even when contradictory instructions are issued by air traffic control.

— FSF EDITORIAL STAFF

A resolution advisory displayed on a vertical speed indicator advises the flight crew to climb between 1,500 feet and 2,000 feet per minute.

The International Civil Aviation Organization (ICAO) in November 2003 amended its air-navigation procedures to require flight crews to respond immediately to — and in compliance with — resolution advisories (RAs) generated by airborne collision avoidance system (ACAS) equipment.

The new procedures require flight crews to comply with RAs even when instructions that contradict the advisories are received from air traffic control (ATC).

ACAS, also called the traffic-alert and collision avoidance system (TCAS II), uses information received from transponders in other aircraft to calculate the relative motion of the aircraft. When ACAS detects that another aircraft is converging, a traffic advisory (TA) is issued. If the other aircraft continues to converge, an RA is issued. An RA typically consists of aural instructions and visual instructions to climb, descend or adjust vertical speed.

Only stall warnings, wind shear warnings and ground-proximity warning system (GPWS) warnings have precedence over ACAS RAs, ICAO said.[1]

ICAO's review and amendment of the procedures related to ACAS operation were spurred by the midair collision between a Boeing 757-200 and a Tupolev Tu-154M in Germany in 2002 and the near midair collision between a B-747-400D and a Douglas DC-10-40 in Japan in 2001.

"Factors common to both accidents were that [ATC] had issued instructions which conflicted with an [RA] and flight crews had maneuvered their aircraft in the opposite sense [e.g., conducted a descent, rather than a climb] to the RAs that had been issued," ICAO said.[2]

B-757, Tu-154 Paths Crossed Over Intersection

The investigation of the midair collision over Germany, which occurred July 1, 2002, was ongoing as of March 20, 2004. The following information is from an August 2002 status report on the accident investigation by the German Bundesstelle fur Flugunfalluntersuchung (Federal Bureau of Aircraft Accidents Investigation [BFU])[3] and from Airclaims.[4]

The B-757, with two pilots aboard, was being operated by DHL International on a scheduled cargo flight from Bergamo, Italy, to Brussels, Belgium. The flight had originated in Bahrain.

Only stall warnings, wind shear warnings and GPWS warnings have precedence over ACAS RAs.

The Tu-154 was being operated by Bashkirian Airlines as a charter flight from Moscow, Russia, to Barcelona, Spain, with 12 crewmembers and 57 passengers aboard.

Both airplanes were being flown on area navigation routes that intersected near Uberlingen, Germany, which is on the northern shore of Lake Constance. The intersection was in an ATC sector in German airspace that was controlled by a Swiss ATC facility. The B-757 was approaching the intersection from the south. The Tu-154 was approaching the intersection from the east.

The B-757 was being flown at Flight Level (FL) 260 (approximately 26,000 feet) when the flight crew established radio communication with Zurich Area Control Center (ACC) at 2320 local time. The controller told the crew to climb to FL 320. The crew requested clearance to climb to FL 360, and the controller told the crew to climb to FL 360. The B-757 reached FL 360 at 2329.

The Tu-154 was being flown at FL 360 when the flight crew established radio communication with Zurich ACC at 2330. The crews of both airplanes communicated with Zurich ACC on the same radio frequency.

Both airplanes were carrying the same type of ACAS equipment (TCAS II equipment with the latest software version [Version 7]).

"Both operators had provided training programs for TCAS, and the crews had completed the corresponding training," BFU said.

At 2334:42, the ACAS equipment in both airplanes issued TAs. Seven seconds later, the controller told the Tu-154 crew to "expedite descent to FL 350."

"The crew did not confirm this instruction but initiated a descent," BFU said. "Simultaneously, the airborne TCAS issued the command [an RA] to climb. Another seven seconds later, the radar controller repeated his instruction to the [Tu-154] crew to conduct an expedited descent to FL 350. This instruction was immediately acknowledged by the crew."

B-757 Crew Followed RA

The ACAS equipment in the B-757 issued an RA to conduct a descent about the same time the controller repeated his instruction to the Tu-154 crew to descend.

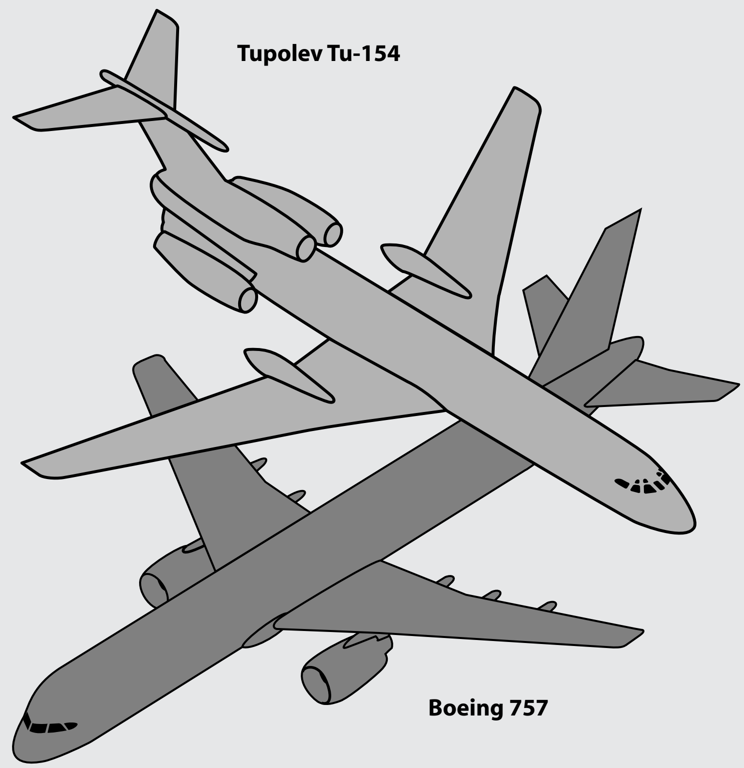
"[The B-757 crew] immediately followed this command and, after a further 14 seconds, received the command to increase the [rate of] descent," BFU said. "The crew told the controller that they were complying with a TCAS RA at 2335:19."

Five seconds after the B-757 crew received the "increase descent" RA, the Tu-154 crew received an "increase climb" RA. Nevertheless, the Tu-154 crew continued the descent. About 17 seconds later, at 2135:32, the airplanes collided at about FL 350.

The B-757 was on a heading of 004 degrees, and the Tu-154 was on a heading of 274 degrees when the collision occurred. Initial contact was between the B-757's vertical tail and the Tu-154's left fuselage, forward of the left wing (Figure 1). BFU said that the Tu-154 broke into four pieces (the fuselage, right wing, left wing and tail, with the three engines attached) and that both engines separated from the B-757 before it struck the ground.

The flight data recorders (FDRs) from both airplanes were recovered the day after the accident. BFU said that data recorded by the FDRs indicated that the crews of both airplanes flew evasive maneuvers before the collision occurred.

Figure 1
Collision Over Uberlingen, Germany; July 1, 2002



Source: Adapted from Bundesstelle für Flugunfalluntersuchung (German BFU)

ATC Equipment Not Fully Functional

BFU said that two minutes before the collision occurred, a controller at the Karlsruhe Radar facility made several attempts to advise Zurich ACC of a collision advisory issued by the facility's short-term conflict alert (STCA) system but was not able to establish telephone communication with the facility.

"The radar controller … tried several times to contact ACC Zurich via the direct telephone line," BFU said. "It was not possible to establish a connection."

Airclaims said that on the night of the accident, maintenance was being performed on the Swiss ATC radar system and on the primary telephone system at the Zurich ACC. Because of the radar maintenance, the STCA system at Zurich ACC was not operational, and minimum aircraft-separation standards had been increased from five nautical miles (nine kilometers) to seven nautical miles (13 kilometers). Zurich ACC controllers also had only a backup telephone system to communicate with controllers at neighboring ATC facilities.

Two controllers were on duty at the Zurich ACC. When the collision occurred, one controller was taking a rest break; the other controller was monitoring two radio frequencies and two radar screens while controlling five aircraft. Between 2325:43 and 2333:11, the controller made several attempts to telephone another ATC facility to coordinate the arrival of an aircraft at Friedrichshafen, Germany.

Two JAL Jumbos Have Close Call

The Aircraft and Railway Accidents Investigation Commission of Japan (ARAIC) said, in its final report, that ATC errors and a flight crew's maneuver in the direction opposite that specified by an RA were among the factors involved in the Jan. 31, 2001, near midair collision between the

B-747 and the DC-10 over the Pacific Ocean, south of Yaizu, Japan.[5]

Both airplanes were being operated by Japan Airlines (JAL). The B-747, Flight 907, was climbing to cruise altitude after departing from Tokyo for a scheduled two-hour, 22-minute flight to Naha, Okinawa Islands (Figure 2). Aboard the airplane were 411 passengers and 16 crewmembers.

Four pilots were on the B-747's flight deck. The captain was in the left front seat. The captain, 40, had 7,446 flight hours, including 3,758 flight hours in type. The first officer (FO) was in the left observer's seat (jump seat), behind the captain. The FO, 28, had 569 flight hours, including 288 flight hours in type. In the right front seat was a 26-year-old pilot with 303 flight hours who was being trained to upgrade to first officer; the report referred to him as the "FO-trainee." Another pilot receiving FO-upgrade training was in the right observer's seat.

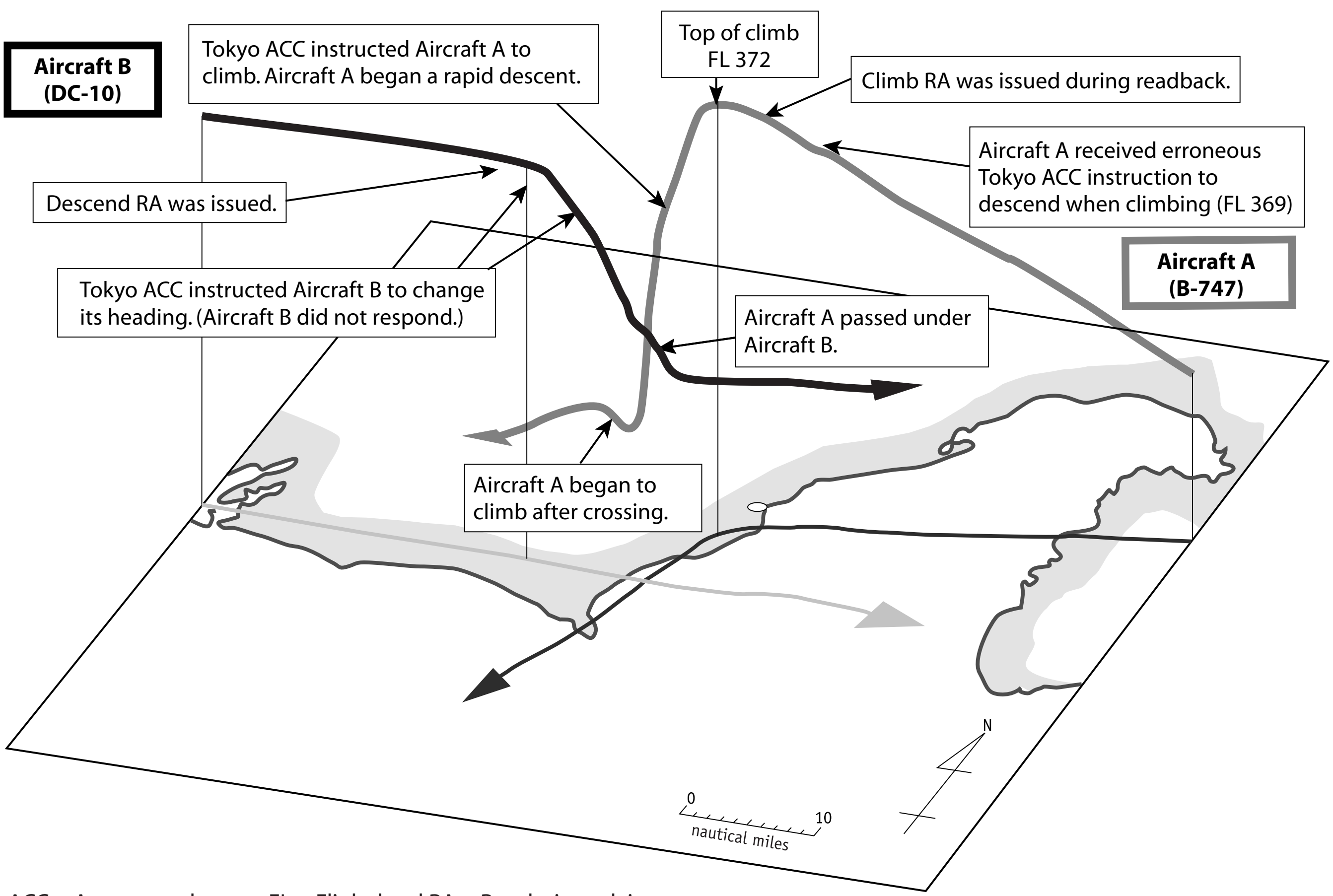
The DC-10, Flight 958, was in cruise flight at FL 370 during a scheduled flight with 237 passengers and 13 crewmembers to Tokyo from Pusan, South Korea.

The DC-10 flight crew comprised three pilots. The captain, 45, had 6,584 flight hours, including 5,689 flight hours in type; he was in the right front seat. The FO, 49, had 4,333 flight hours, including 3,873 flight hours in type. The FO, who was being trained to upgrade to captain, was in the left front seat. The flight engineer, 43, had 8,336 flight hours, all in DC-10s.

The Tokyo ACC sector in which the airplanes were being flown — the Kanto South C sector — was

Figure 2

Near Midair Collision Near Yaizu, Japan; Jan. 31, 2001



ACC = Area control center FL = Flight level RA = Resolution advisory

Source: Adapted from Aircraft and Railway Accidents Investigation Commission of Japan being controlled by three controllers. The radar console was manned by a controller receiving familiarization training for the sector. Also on duty were an ATC watch supervisor and an ATC coordinator.

At 1541 local time, the B-747 crew told Tokyo ACC that they were flying the airplane through 11,000 feet in a climb to FL 390. The controller told the crew to fly directly to the Yaizu nondirectional beacon (NDB) and to climb to FL 350. The report said that the altitude restriction was required because another airplane, American Airlines Flight 157, was in cruise flight, southwestbound, at FL 390.

The B-747 captain told investigators that at this time, he observed a contrail at a relative bearing of 11 o'clock.

"It was at a higher altitude and approximately 40 nautical miles [74 kilometers] from our position," the captain said. "I talked with the trainee pilot about how close the traffic would come before being displayed [as a TCAS symbol] on the navigation display. The traffic was displayed … when it reached 25 nautical miles [46 kilometers]. The TCAS-indicated altitude was FL 370. The cockpit crew discussed that we should keep an eye on the traffic."

Traffic Was 'About the Level I Could Handle'

The report said that between 1543 and 1552, the controller handled 14 aircraft and made 37 radio transmissions under the guidance of the ATC watch supervisor.

The controller told investigators, "The traffic volume at the time of the on-the-job training was at about the level I could handle."

The B-747 was east of the Yaizu NDB and was being flown through about 21,600 feet at 1546, when the controller told the crew to climb to FL 390.

At 1547, the controller told the crew of Flight 157 to descend to FL 350. The controller repeated the instruction, but there was no response from Flight 157. The report said that the crew of Flight 157 had not yet been instructed by their current sector controller to establish radio communication with the Kanto South C sector.

At 1548:14, the DC-10 flight crew established radio communication with the Kanto South C sector and said that they were at FL 370. At the time, the DC-10 was west of the Yaizu NDB.

The crew of Flight 157 established radio communication with the Kanto South C sector at 1548:37 and told the controller that they were at FL 390. The controller told the crew to descend to FL 350. The crew acknowledged the instruction and said that they were beginning the descent.

> **"I talked with the trainee pilot about how close the traffic would come before being displayed."**

The report said that between 1552 and 1554:22, the controller made four radio transmissions to three aircraft.

Near the Yaizu NDB at 1553:50, the B-747 crew began a climbing left turn, from a heading of 270 degrees to a heading of 207 degrees.

The DC-10 was on a heading of 095 degrees, and its groundspeed was 567 knots, when the FO told the captain that he saw traffic at their 10 o'clock to 11 o'clock position. The report said that at 1554:00, the DC-10's ACAS display showed a symbol corresponding to the B-747 with an arrow indicating that the B-747 was climbing.

"The traffic was displayed on the TCAS screen beyond the 10-nautical-mile [19-kilometer] arc at between 12 [nautical miles] and 13 nautical miles [22 kilometers and 24 kilometers]," the DC-10 captain said. "As we saw the other aircraft turning over Yaizu, a TCAS 'traffic, traffic' TA sounded while we were about 10 nautical miles distant at FL 370. The other aircraft's altitude was also displayed as FL 370. The PF [pilot flying (the FO)] disengaged the autothrottles in anticipation of an RA."

Controllers Receive Conflict Alert

The ATC watch supervisor was providing comments to the controller about the tasks he had performed and was discussing the traffic situation with the controller at 1554:18, when a conflict alert was displayed on the controller's radar screen.

"I don't recall at what time I received the hand-off of [the DC-10] from the adjacent sector," the controller said. "I first became aware of [the DC-10's] presence when the conflict alert operated and the letters 'CNF' flashed in the data blocks of [the B-747 and the DC-10]."

The ATC watch supervisor said, "I was in a flurry because I had forgotten about the presence of [the DC-10]. At that time, I deemed that the best decision was to [issue an instruction to the DC-10 crew to] descend."

The controller, however, told the B-747 crew to descend to FL 350.

The B-747 crew used their call sign when they acknowledged the instruction. The crew also told the controller, "Traffic in sight."

Nevertheless, the ATC watch supervisor said that she was "convinced" at the time that the controller had issued the descent instruction to the DC-10 crew.

The report said, "Although [the B-747 crew] read back the instruction and stated their flight number, neither the ATC trainee nor the ATC watch supervisor noticed that the flight number in the readback was that of [the B-747], not that of the intended aircraft [the DC-10]."

The B-747 captain said, "Since we had been instructed to descend during a climb, I disengaged the autopilot and autothrottles, and reduced the power to idle while commencing the descent. Our aircraft ascended to around FL 371 due to inertia [before beginning to descend]."

Both Crews Receive RAs

At 1554:34, the DC-10 crew received an RA calling for a descent at 1,500 feet per minute (fpm). One second later, the B-747 crew received an RA calling for a climb at 1,500 fpm.

The DC-10 captain said, "The PF disengaged the autopilot, set power to idle and lowered the nose little by little. Since the descent rate at this time was less than 1,000 feet per minute, I exerted forward pressure on the control wheel while advising, 'Lower it further.'"

The B-747 captain said that his airplane had begun to descend when the climb RA was issued and that he decided to continue the descent.

"At that time, I observed the other aircraft approaching from the forward right at about the same altitude, but I had already initiated a descent and, judging that the best way to avoid a collision at that altitude would be to continue descending contrary to the TCAS command, I continued descending to FL 350," the captain said. "Further, I also considered the risk of stalling if we pitched up, given the insufficient thrust, leading to an even more dangerous situation."

"I was in a flurry because I had forgotten about [the DC-10]."

The B-747 FO (who was in the observer's seat) told investigators that the captain announced to the crew that because the airplane had already been placed in a descent, they would continue the descent. The FO said that he believed the captain's actions were timely and without irregularity.

"At that time, following the TCAS RA, reapplying maximum power and pitching up to comply with the RA command, at an altitude of what I thought was around 37,000 feet, would have been extremely dangerous," the FO said.

Investigators calculated that under the existing conditions, the B-747's stall speed was 215 knots. The airplane was descending at about 280 knots.

"Therefore, it is considered that [the B-747] had a small margin of speed over the above-mentioned stall speed," the report said. "It is estimated that [the airplane] would have been able to gain altitude to some extent using this airspeed margin for climb by transforming kinetic energy into potential energy."

The B-747 FO-trainee told investigators, "I felt that [the other aircraft] would pass in front of or just above my eyes, and I thought that if we continued as we were, we would collide. The captain applied further pitch-down [control input], at which time I felt as if I were being lifted."

At 1554:38, the controller, who believed that he had told the DC-10 crew to descend, told the DC-10 crew to turn to a heading of 130 degrees for spacing.

"[The DC-10's] altitude did not change, so the trainee [controller] instructed it to fly heading 130 degrees," the ATC watch supervisor said. "Although I thought that the first thing was to provide vertical separation, I did not think it necessary to dare to correct his instruction."

The DC-10 crew did not acknowledge the instruction; they told investigators that they had not heard the instruction.

"The flight crew may have had their attention focused on coping with the RA," the report said.

DC-10 Crew Receives 'Increase Descent' RA

At 1554:49, the DC-10 was descending through FL 369 when the crew received an "increase-descent" RA, calling for a descent at 2,500 fpm.

"Judging that we had to descend rapidly, I called, 'I'm pulling speed brakes,' while pulling the speed brakes to full," the DC-10 captain said. "The PF lowered the nose further. I switched on the seat belt sign. Glancing outside at that time, I saw the other aircraft approaching from the forward left."

The DC-10 FO told investigators, "There was no time to look at the instruments. It felt as if the other aircraft was rapidly rushing toward us, and I wondered why, since our aircraft was following the TCAS descent command."

The controller told the DC-10 crew to turn to a heading of 140 degrees. The DC-10 crew did not respond; the crew told investigators that they had not heard the instruction. The ATC watch supervisor then took over radio communication. The ATC watch supervisor told "JAL 957" to begin a descent. The report said that there was no aircraft with that call sign in the sector's airspace.

The report said that between 1554:51 and 1555:11, the B-747 descended from about 36,900 feet to about 35,500 feet, and the DC-10 descended from about 36,900 feet to about 35,700 feet.

The report said that the B-747 FO told the captain that the DC-10 also appeared to be descending. At 1555:06, the B-747 crew received an "increase-climb" RA, calling for a 2,500-fpm climb. The B-747 captain continued the descent.

The DC-10 captain said, "I could visually see the top of the [B-747's] fuselage, and I judged that it was increasing its descent rate. I felt that the situation was extremely dangerous. I think the PF felt the same, but we had no time to communicate, and we both pulled back on the yokes almost simultaneously. … A big aircraft passed below our aircraft in an instant."

The DC-10 FO said, "I saw the other aircraft become larger and lower its nose when it was just off the tip of our left wing. … The other aircraft was so close that I thought its tail would snag our aircraft."

The B-747 captain said, "While we were maneuvering to pass just below the DC-10, it appeared to fill the [windshield], but we were able to avoid a midair collision."

At about 1555:11, the airplanes passed by each other about seven nautical miles (13 kilometers) south of the Yaizu NDB. The report said that analysis of recorded ATC radar data and recorded ACAS data indicated that the airplanes came within about 135 meters (443 feet) of each other. At the time, the groundspeed of the B-747 was about 490 knots, and the groundspeed of the DC-10 was about 550 knots.

"I saw the other aircraft become larger and lower its nose."

B-747 Maneuvering Results in Injuries

As the B-747 was flown beneath the DC-10, its nose-down pitch attitude changed from 10.8 degrees to 7.0 degrees, and peak vertical accelerations ranged from –0.55 g (0.55 times standard gravitational acceleration) to 1.59 g.

"Because [the B-747] pitched down around the time that the aircraft crossed and afterward pulled up, its vertical acceleration varied considerably between positive and negative," the report said. "Consequently, persons and objects were tossed and fell, and as a result many persons were injured and ceiling panels, etc., in the cabin were damaged."

One galley cart went through the cabin ceiling and lodged in the space between the cabin ceiling and the upper fuselage. Seven passengers and two cabin attendants aboard the B-747 received serious injuries; 81 passengers and 10 cabin attendants received minor injuries. The report said that four of the passengers who received serious injuries did not have their seat belts fastened; they struck the ceiling and fell into the aisle or onto armrests.

"On the other hand, the vertical acceleration of [the DC-10] remained positive, so there were no injuries to the passengers or crew and no damage to the cabin," the report said.

The B-747 captain stopped the descent at about FL 348. The crew told the controller that a near midair collision with a DC-10 had occurred and requested clearance to return to Tokyo because occupants had been injured. The crew landed the airplane at Tokyo International Airport at 1644.

The DC-10 descended to about FL 353 before the crew told the controller that they had descended in response to an RA and were initiating a climb back to their assigned altitude. The crew landed the airplane at New Tokyo International Airport at 1632.

Investigation Results in Call for Clarification

The report said that if the B-747 flight crew had complied with the RA to climb and had continued the climb, the airplanes would have been separated by about 1,600 feet vertically when they passed by each other.

Japanese Civil Aeronautics Regulations require TCAS II equipment in aircraft with more than 30 passenger seats and in turbine aircraft with a maximum takeoff weight (MTOW) of more than 15,000 kilograms/33,000 pounds.

The report said that at the time of the near midair collision, an aeronautical information circular (AIC) published by the Civil Aviation Bureau of Japan on the operation of ACAS included the following information from ICAO's *Procedures for Air Navigation — Aircraft Operations* (PANS-OPS):[6]

- "In the event of a resolution advisory to alter the flight path, the search for the conflicting traffic shall include a visual scan of the airspace into which [your] aircraft might maneuver;
- "The alteration of the flight path shall be limited to the minimum extent necessary to comply with the resolution advisories; [and,]
- "Pilots who deviate from an air traffic control instruction or clearance in response to a resolution advisory shall promptly return to the terms of that instruction or clearance when the conflict is resolved and shall notify the appropriate ATC unit as soon as practicable of the deviation, including its direction and when the deviation has ended."

The report said that JAL's operations manual required that a pilot "immediately comply with the RA unless he considers it unsafe to do so" and that "the deviation from the authorized flight level shall be limited to the minimum extent necessary to comply with the RA."

Based on the findings of its investigation of the near midair collision, ARAIC made the following recommendations to ICAO:

- "Amend [PANS-OPS] to express explicitly that pilots should always comply with [an RA]. … In particular, when pilots simultaneously receive conflicting instructions to maneuver from [ATC] and [an RA], pilots should comply with the [RA];
- "Describe in [PANS-OPS] the dangers of maneuvering contrary to the indication of [an RA]; [and,]
- "Amend [PANS-OPS] to specify explicitly that, [when] a pilot executes evasive maneuvers in response to [an RA], the notification of the deviation to ATC shall be made promptly *before* the conflict is resolved, unless it is difficult to do [so because of] the execution of the evasive maneuvers."

RAs Require Immediate Response

ICAO amended PANS-OPS to require a flight crew who receives an ACAS RA to "respond immediately by following the RA as indicated, unless doing so would jeopardize the safety of the airplane."[7]

ICAO said that the flight crew should follow an RA even if they believe that they have the other aircraft in sight and determine that it is not a collision threat.

"Visually acquired traffic may not be the same traffic causing an RA," ICAO said. "Visual perception of an encounter may be misleading, particularly at night."

The new international procedures also require the flight crew to "follow the RA even if there is a conflict between the RA and an [ATC] instruction to maneuver."

ICAO said that because ATC controllers do not know when the flight crews of aircraft under their control receive RAs, or what maneuvers the RAs are calling for, controllers might issue instructions that conflict with the RAs. Thus, the new procedures require that "as soon as possible, as permitted by flight crew workload, [the crew] must notify the appropriate ATC unit of the RA, including the direction of any deviation from the current [ATC] instruction or clearance."

Flight crews must not maneuver their aircraft in the "opposite sense to an RA."

"In the case of an ACAS-ACAS coordinated encounter, the RAs complement each other in order to reduce the potential for collision," ICAO said. "Maneuvers, or lack of maneuvers, that result in vertical rates opposite to the sense [direction] of an RA could result in a collision with the threat aircraft."

The procedures require that when the conflict has been resolved, the crew must "promptly return to the terms of the ATC instruction or clearance" and "notify ATC when returning to the current clearance."

Operators Must Provide Pilot Training

ICAO recommends that *all* airplanes be equipped with ACAS.[8] International standards and recommended practices have required since the beginning of 2003 that ACAS be installed in all turbine airplanes with an MTOW of more than 15,000 kilograms or authorized to carry more than 30 passengers. After 2004, ACAS will be required in all turbine airplanes with an MTOW of more than 5,700 kilograms/12,500 pounds or authorized to carry more than 19 passengers.

Citing deficiencies in pilot-training programs that have caused "several operational issues," ICAO established guidelines for training all pilots who fly aircraft with ACAS equipment.[9] The training topics include theory of operation, preflight operations, general in-flight operations, response to TAs and response to RAs.

"In developing this material, no attempt was made to define how the training program should be implemented," ICAO said. "Instead, objectives were established that define the knowledge a pilot operating ACAS is expected to possess and the performance expected from a pilot who has completed ACAS training."

ICAO said that pilots who fly aircraft equipped with ACAS must understand the capabilities and limitations of the equipment. For example, the surveillance range of ACAS can be reduced in areas with a high volume of traffic. Other limitations listed in the ICAO ACAS-training guidelines include the following:

- "ACAS will neither track nor display non-transponder-equipped aircraft, nor aircraft with an inoperable transponder, nor aircraft with a Mode A [non-altitude-reporting] transponder;
- "ACAS will automatically fail if the input from the aircraft's barometric altimeter, radio altimeter or transponder is lost;
- "Some aircraft within 116 meters (380 feet) above ground level … will not be displayed. If ACAS is able to determine that an aircraft below this altitude is airborne, it will be displayed;
- "ACAS may not display all proximate transponder-equipped aircraft in areas of high-density traffic; however, it will still issue RAs as necessary;
- "Because of design limitations, the bearing displayed by ACAS [on the traffic display] is not sufficiently accurate to support the initiation of horizontal maneuvers based solely on the traffic display;
- "Because of design limitations, ACAS will neither display nor give alerts against intruders with a vertical speed in excess of [10,000 fpm]; [and,]
- "Stall warnings, [GPWS]/enhanced ground-proximity warning system [EGPWS][10] warnings and wind shear warnings take precedence over ACAS advisories. When either a GPWS/EGPWS or wind shear warning is active, ACAS will automatically switch to the TA-only mode of operation, except that ACAS aural annunciations will be inhibited. ACAS will remain in TA-only mode for 10 seconds after the GPWS/EGPWS or wind shear warning is removed."

ACAS Development Driven by Collisions

ICAO said that pilots who fly aircraft equipped with ACAS must understand how the system works.

ACAS is considered the last line of defense against midair collisions, behind the responsibility of pilots to see and avoid other aircraft when possible and behind the responsibility of ATC to keep aircraft safely separated.

Development of a collision avoidance system independent of ATC began in the 1950s and gained impetus after the June 30, 1956, collision between a United Airlines Douglas DC-7 and a Trans World Airways Lockheed Super Constellation over Grand Canyon, Arizona, U.S.[11] The DC-7, which was en route to Chicago, Illinois, had departed from Los Angeles, California, three minutes after the Constellation. The airplanes collided at 21,000 feet, killing all 58 occupants of the DC-7 and all 70 occupants of the Constellation. The U.S. Civil Aeronautics Board (CAB) said that the probable cause of the collision was that "the pilots did not see each other in time to avoid the collision."

"It is not possible to determine why the pilots did not see each other, but the evidence suggests that it resulted from any one or a combination of the following factors: Intervening clouds reducing time for visual separation, visual limitations due to cockpit visibility and preoccupation with matters unrelated to cockpit duties such as attempting to provide the passengers with a more scenic view of the Grand Canyon area, physiological limits to human vision reducing the time opportunity to see and avoid the other aircraft, or insufficiency of en route area traffic advisory information due to inadequacy of facilities and lack of personnel in air traffic control," CAB said.[12]

Reaction by the U.S. Congress to a midair collision of an airliner and a private single-engine airplane over Cerritos, California, on Aug. 31, 1986, resulted in the United States becoming the first nation to require ACAS (TCAS) aboard specific aircraft. A Douglas DC-9 operated by Aeronaves de Mexico was en route to Los Angeles from Tijuana, Mexico. A Piper PA-28-181 was en route under visual flight rules from Torrance to Big Bear, both in California. The airplanes collided at 6,560 feet in the Los Angeles Terminal Control Area (TCA [now called Class B airspace]). All 65 occupants of the DC-9, the three occupants of the PA-28 and 15 people on the ground were killed. The U.S. National Transportation Safety Board (NTSB) said that the probable cause of the accident was "the limitations of the [ATC] system to provide collision protection, through both [ATC] procedures and automated redundancy."

"Factors contributing to the accident were the inadvertent and unauthorized entry of the PA-28 into the Los Angeles TCA and the limitations of the 'see and avoid' concept to ensure traffic separation under the conditions of the conflict," NTSB said.[13]

After the Cerritos collision, the U.S. Congress passed legislation requiring installation of TCAS equipment in specific aircraft. The U.S. Federal Aviation Administration (FAA) in 1989 published requirements for installation of TCAS II equipment, on a phased schedule between 1990 and 1993, in large airplanes (with MTOWs more than 12,500 pounds) with more than 30 passenger seats. FAA also required that by the end of 1995, all airplanes with 10 to 30 passenger seats used in air carrier operations be equipped either with TCAS II or TCAS I.[14]

(TCAS I equipment provides TAs only and was developed primarily for regional airliners and general aviation aircraft.)

In Europe and in the United States, research and development of ACAS/TCAS III equipment, which would provide RAs that include horizontal collision avoidance maneuvers as well as vertical collision avoidance maneuvers, has been terminated, because the automatic dependent surveillance–broadcast (ADS-B) system, which is under development, has the potential to help provide this capability.

ACAS is both a surveillance system and a collision avoidance system.

ADS-B involves broadcast of position information at regular time intervals by aircraft on the ground and in the air. The technology is being developed for several uses, such as the airborne separation assistance system (ASAS), which might enable flight crews to participate with ATC in traffic spacing and separation. ICAO said that ADS-B data might be used to improve ACAS collision logic.

How ACAS Works

ACAS is both a surveillance system and a collision avoidance system. The equipment typically comprises a radio transceiver, directional antennas (one on top of the aircraft, another on the bottom), a computer, a control panel, a traffic display and an RA display.

The traffic display is either a stand-alone unit or is integrated with other displays, such as digital color weather radar, an electronic horizontal situation indicator or a multi-function display. The RA display typically is a dedicated electronic instantaneous vertical speed indicator (IVSI). RAs also are issued as a VSI display on a primary flight display (PFD) or as pitch cues on an electronic attitude director indicator (EADI).

Like ATC secondary surveillance radar, ACAS works with information provided by Mode A transponders, Mode A/C (altitude-encoding) transponders and Mode S (selective address) transponders. ACAS transmits an "all-call" interrogation signal that causes Mode A/C transponders in aircraft within about 14 nautical miles (26 kilometers) to transmit replies. The system also detects "squitters" transmitted once each second by Mode S transponders within about 30 nautical miles (56 kilometers). A squitter includes the transponder's selective address. When a squitter is detected, ACAS transmits an interrogation signal that causes the Mode S transponder to reply.

From the information received in the reply from a transponder, ACAS computes the range, bearing and altitude of the aircraft in which the transponder is installed. From successive replies by an altitude-encoding (Mode C or Mode S) transponder, ACAS calculates the other aircraft's closure rate and its closest point of approach (CPA).

'Protection' Varies With Altitude

ACAS is designed to simultaneously track up to 45 aircraft, display information on up to 30 aircraft and to provide collision avoidance advisories for up to three aircraft with closure rates of up to 1,200 knots and vertical rates as high as 10,000 fpm.[16] Advisories are based on both vertical alert thresholds and horizontal alert thresholds, and a theoretical "protected volume" around the aircraft in which the equipment is installed.

The vertical thresholds are designed to provide advisories for aircraft at the same altitude. The vertical thresholds are 850 feet above and below the aircraft for TAs and 700 feet above and below the aircraft for RAs (Figure 3, page 11).

The protected volume, which is roughly spherical in shape, varies with the sensitivity level of the ACAS equipment. There are seven sensitivity levels. Sensitivity level 1 is the "standby mode," in which the ACAS equipment does not transmit interrogations. The other six sensitivity levels vary with altitude. In sensitivity level 2, used below 1,000 feet, ACAS transmits interrogations but issues TAs only. The protected volume of the aircraft increases as sensitivity levels increase with altitude, from sensitivity level 3 at 1,000 feet to 2,350 feet, to sensitivity level 7 above FL 200.

TAs and RAs are issued when the CPA of another aircraft is projected to be within the aircraft's protected volume. The advisories are based on time. Below 1,000 feet, a TA is issued when another aircraft (an "intruder") is projected to reach the CPA within 20 seconds. The advisory times increase with altitude. Above FL 200, for example, a TA is issued when the intruder is projected to reach the CPA within 48 seconds (Figure 4, page 12).

No RAs are issued below 1,000 feet. Five seconds are added to RA-issuance times to accommodate flight crew response. RA-issuance times increase with altitude, from 15 seconds between 1,000 feet and 2,350 feet, to 35 seconds above FL 200. The aircraft for which an RA is issued is called a "threat aircraft."

Crew Receives Visual and Aural Advisories

Aircraft that are being tracked by ACAS are depicted on the display as colored shapes. "Proximate" traffic — aircraft 1,200 feet above or below the aircraft's altitude or more than six nautical miles (11 kilometers) away — are displayed as open white diamonds or open cyan (greenish blue) diamonds.[16]

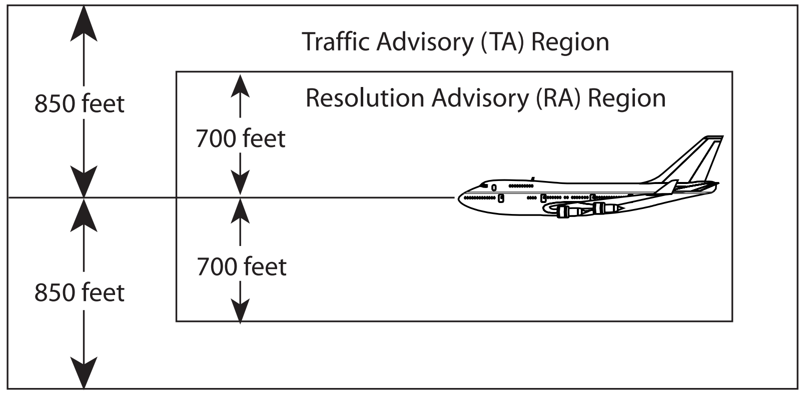
The relative altitudes of the tracked aircraft with altitude-reporting transponders are shown next to their symbols in digital format, rounded off to the nearest hundred feet. For example, "05" would indicate that the other aircraft is 500 feet above; "–06" would indicate that the other aircraft is 600 feet below.

An arrow pointing up or down also would be displayed next to the symbol to indicate that the other aircraft is climbing or descending, respectively, at a rate greater than 500 fpm.

If a proximate aircraft comes within 1,200 feet of the aircraft's altitude or within six nautical miles, the symbol changes to either a closed white diamond or a closed cyan diamond.

Figure 3

Vertical Thresholds for ACAS Advisories



Source: Adapted from Rannoch Corp.

Intruders are displayed as closed amber circles; and if the aircraft is above 500 feet above ground level (AGL), an aural advisory, "traffic, traffic," is issued.

"TAs are intended to alert pilots to the possibility of an [RA], to enhance situational awareness and to assist in visual acquisition of conflicting traffic," said ICAO.[17] "On receipt of a TA, pilots shall use all available information to prepare for appropriate action if an RA occurs."

The flight crew should not maneuver the aircraft in response to a TA.

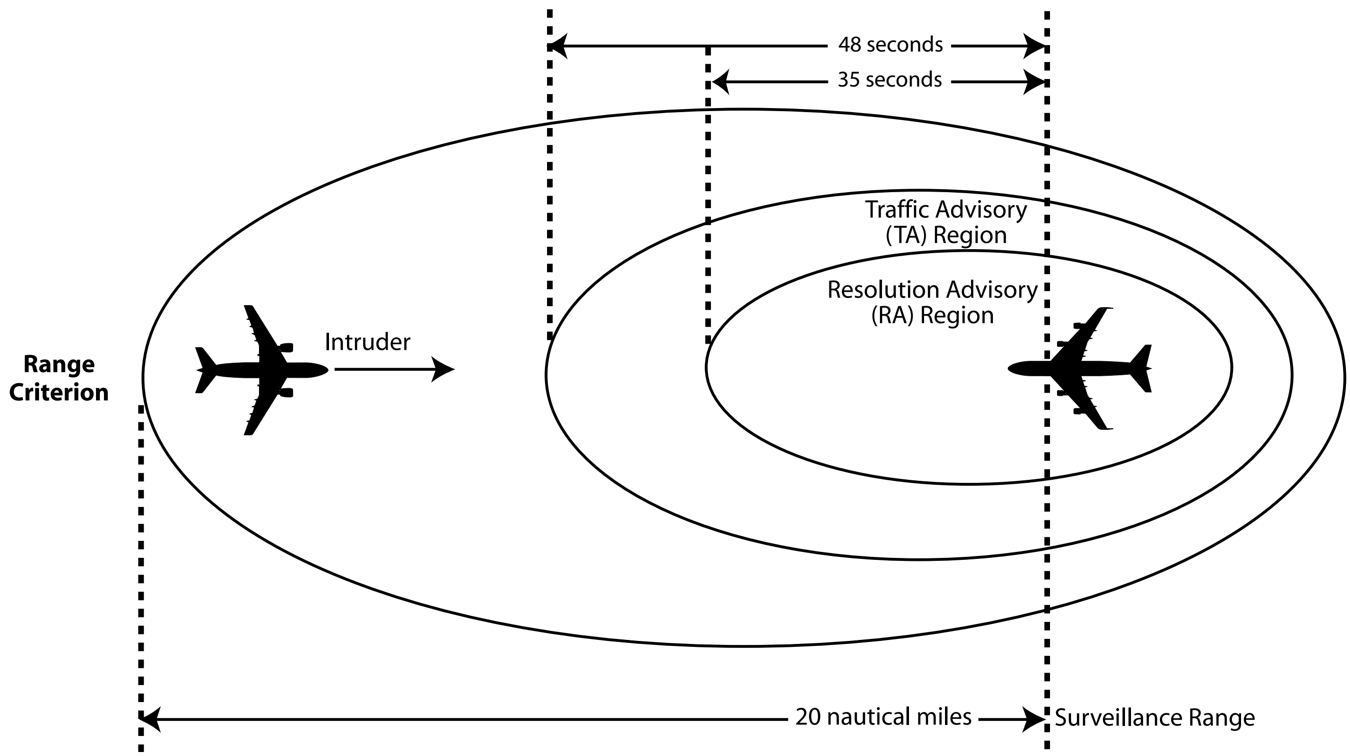
"Respond to TAs by attempting to establish visual contact with the intruder aircraft and other aircraft which may be in the vicinity," FAA said.[18] "Coordinate to the degree possible with other crewmembers to assist in searching for traffic. Do not deviate from an assigned clearance based only on TA information."

The U.K. Civil Aviation Authority (CAA) said, "ACAS equipment [is] not capable of resolving the bearing, heading or vertical rates of intruders accurately. For this reason, pilots should not attempt to maneuver solely on the basis of TA information."[19]

Five Seconds to Respond

When another aircraft becomes a threat, the symbol changes to a closed red square, and the flight crew receives an aural advisory — typically, "climb, climb," or "descend, descend" or "adjust vertical speed."

Figure 4
Horizontal Thresholds for ACAS Advisories Above Flight Level 200



Source: Adapted from Rannoch Corp.

In specific circumstances, however, ACAS might determine that a conflict with a threat aircraft will be resolved if the crew of the aircraft maintains the current flight path; an aural advisory such as "maintain vertical speed" or "do not climb" will be issued.

If both aircraft are equipped with ACAS, the ACAS units in each aircraft issue coordinated RAs. The ACAS unit that first detects the threat transmits an RA "sense" (i.e., an indication that it will advise its crew to climb or descend) to the ACAS unit in the other aircraft, which then will select the opposite sense. (If two ACAS units detect the threat at the same time and transmit the same sense, the ACAS unit with the highest Mode S selective address reverses its sense.)

Arcs created by red lights and green lights on the IVSI scale show the crew what to do — and what not to do — to resolve the conflict. A green arc indicates the vertical rates that must be achieved to comply with the RA; red arcs indicate vertical rates that must be avoided.

RAs are intended to provide a minimum vertical separation between the aircraft at the CPA; minimum vertical separation varies with altitude, from 300 feet at low altitude to 700 feet at high altitude.

An RA typically calls for a climb or descent at 1,500 fpm, which would require pitch adjustments ranging from about five degrees to seven degrees during an approach with airspeed below 200 knots to about two degrees during cruise at 0.80 Mach.[20] (The target pitch attitude can be estimated by dividing 1,000 by true airspeed.)[21]

"For TCAS to provide safe vertical separation, initial vertical speed response is expected within five seconds of when the RA is displayed," FAA said. "Excursions from assigned altitude, when responding to an RA, typically should be no more than 300 [feet] to 500 feet to satisfy the conflict."[22]

The U.K. CAA said, "It should be stressed that excessive pitch rates should not be made unless the approaching aircraft is seen and the situation requires such a response. … The change of pitch is unlikely to exceed seven degrees for most aircraft, and the rate at which this is achieved should not result in other than moderate accelerations (g forces) being felt by passengers and crew."

ICAO procedures require that the flight crew tell ATC as soon as practicable that they are deviating from a clearance to respond to an RA. The correct phraseology is "TCAS climb" or "TCAS descent."[24]

If ATC issues an instruction that contradicts the RA, the crew must tell ATC, "Unable, TCAS resolution advisory."

"Once an aircraft departs from its ATC clearance in compliance with an RA, the controller ceases to be responsible for providing separation between that aircraft and any other aircraft affected by the RA maneuver," said Kevin Moore, an ICAO Navigation Bureau technical officer and secretary of the ICAO Operations Panel.[25] "Procedures require that the pilot notify ATC as soon as practicable of any deviation from an ATC instruction or clearance in response to an RA, including the direction of the maneuver and an indication when it is over.

"When aware that an aircraft is maneuvering in response to an RA, the controller must not attempt to modify the aircraft flight path, but can provide traffic information. The controller resumes responsibility for providing separation for all the affected aircraft after the pilots involved have advised that their aircraft are resuming the current clearance or will comply with an alternative clearance issued by the controller."

An RA May Change to Resolve Conflict

A "corrective RA" will be issued if ACAS projects that minimum vertical separation will not be achieved at the CPA. The crew will receive an aural advisory to "increase climb" or to "increase descent." A corrective RA typically requires the vertical rate to be increased to 2,500 fpm.

In specific circumstances, an RA might be reversed. For example, if a descent RA was issued to avoid a conflict with a threat aircraft in level flight but the threat aircraft suddenly begins a descent also, ACAS will instruct the crew of the aircraft to "climb, climb now."

A "reversed RA" is based on crew response within 2.5 seconds. The crew should not exceed 0.3 g when changing from a climb to a descent, or vice versa.

"If a reversed-sense RA is given, no time should be lost initiating the change of pitch attitude, care being taken not to use excessive vigor," the U.K. CAA said.

When the conflict has been resolved, the aural advisory "clear of conflict" is issued, the green lights and red lights disappear from the IVSI, and the symbol of the threat aircraft changes from a red square to a yellow circle, and eventually to a white or cyan diamond.

The flight crew must "promptly return to the terms of the ATC instruction or clearance when the conflict is resolved and notify ATC when returning to the current clearance," ICAO said.[26]

An example of the correct phraseology is: "Returning to Flight Level 350." In this case, after leveling at FL 350, the crew should tell ATC, "TCAS climb [or descent] completed, Flight Level 350 resumed."

ICAO recommends that pilots who fly ACAS-equipped aircraft receive initial training and recurrent training. The recurrent training should include practicing RA maneuvers every four years in a flight simulator or every two years in a computer-based trainer.

Eurocontrol Cites Misuse of ACAS

The European Organization for the Safety of Air Navigation (Eurocontrol) in 1995 adopted a policy requiring ACAS to be installed by Jan. 1, 2000, in turbine airplanes with MTOWs of more than 15,000 kilograms or with more than 30 passenger seats. The policy also requires ACAS to be installed by Jan. 1, 2005, in turbine airplanes with MTOWs of more than 5,700 kilograms or with more than 19 passenger seats.

Monitoring of ACAS performance in Europe has shown some recurring problems.[27] Eurocontrol said that the following are examples:

- "An RA sometimes causes pilots to deviate from their ATC clearance far more than necessary or required. Deviations greater than 1,000 feet have been recorded, and the mean deviation is around 650 feet;

- "Pilots are often slow to report the initial deviation to the controller and subsequently to return to the given ATC clearance. The official phraseology is sometimes not used, and a distracting and disturbing dialogue about the event may begin on the frequency; [and,]

- "Some pilots request information or refuse a clearance based upon aircraft data on the traffic display. … Aircraft have also been observed turning, on the basis of the data shown on the traffic display, without visual acquisition by the aircrew."

Eurocontrol said that despite the problems, ACAS has been beneficial (see "ACAS Provides an Effective Safety Net When Procedures Are Followed," page 15).

"The evaluation of [ACAS] performance in Europe and the monitoring of its implementation have demonstrated that this equipment has already improved flight safety," Eurocontrol said.■

Notes

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9. ICAO. PANS-OPS. Volume 1. Chapter 3. 3.2. Attachment A to Part VIII, "ACAS II Training Guidelines for Pilots."

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15. Eurocontrol.

16. Honeywell. *TCAS II/ACAS II Collision Avoidance System User's Manual*. ACS-5059, Revision 5. February 2000.

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FSF Editorial Staff. "Traffic Conflict Near Australian Airport Prompts Call for Airborne Collision Avoidance Systems." *Airport Operations* Volume 27 (July–August 2001).

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FSF Editorial Staff. "Factors in Near Midair Collisions Show Controller-Pilot Interdependence." *Airport Operations* Volume 25 (May–June 1999).

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ACAS Provides an Effective Safety Net When Procedures Are Followed

Airborne collision avoidance system performance monitoring in Europe shows that the significant safety benefit of ACAS can be diminished by improper procedures, such as failures to comply with resolution advisories.

— JOHN LAW, EUROCONTROL

Recent safety studies by the European Organization for the Safety of Air Navigation (Eurocontrol) have confirmed the significant safety benefit afforded by the airborne collision avoidance system (ACAS; also called the traffic-alert and collision avoidance system [TCAS II]), but they also have revealed that it can be degraded by improper procedures, such as deficient response to resolution advisories (RAs). Operational monitoring programs have highlighted, in numerous actual events, the significant ACAS contribution to improved flight safety. It has also been shown that in some events where the responses of pilots to RAs have been inadequate and where maneuvers opposite to the RAs have been identified, the safety benefit is diminished.

Events 1–5 show that inadequate response to RAs degrades safety. Nevertheless, events 6 and 7 illustrate that accurate response to RAs greatly improves safety.

Follow the RA

Flight crews should operate ACAS at all times, and all flight crews should follow RAs. Training courses should be reviewed to ensure that these areas are addressed.

Event 1: ATC Avoidance Instruction Opposite to RA

Two aircraft level at Flight Level (FL) 70 (approximately 7,000 feet) are being radar vectored by the approach controller:

- An Avions de Transport Regional (ATR) 72 is heading 185 degrees; and,
- A Boeing 737 (B-737) is on an opposite track, heading 345 degrees (Figure 1, page 16).

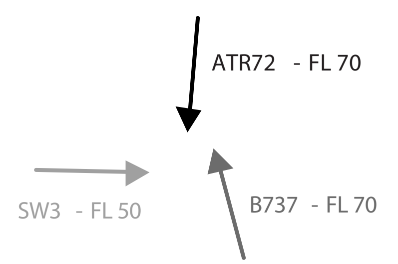
A third aircraft, a Swearingen Merlin 3 (SW3) level at FL 50, is heading east. All aircraft are in instrument meteorological conditions (IMC).

Because the controller is occupied with the resolution of another conflict, the B-737 is instructed, late, to descend to FL 60 when the aircraft are slightly less than 5.0 nautical miles (9.3 kilometers) head-on.

Both aircraft are at the same level and converging quickly. The ACAS of each aircraft triggers a coordinated RA a few seconds later (Figure 2, page 16):

- The ATR 72 pilot receives a "descend" RA that he follows; and,

Figure 1



Source: Adapted from Eurocontrol

- The B-737 pilot receives a "climb" RA that he does not follow. He continues to comply with the air traffic control (ATC) instruction.

The ATR 72 pilot immediately informs the controller, using the standard phraseology, that he has a "descend" RA. Nevertheless, just after, the controller repeats to the B-737 the instruction to descend to FL 60 for avoiding action.

The B-737 pilot, who reported afterwards that he "had to avoid TCAS alert," descends through FL 60. This opposite reaction to his "climb" RA induces an "increase descent" RA aboard the ATR 72, which leads the pilot to deviate much more than initially required by ACAS. This large vertical deviation induces a new ACAS conflict with the SW3 level at FL 50.

If the B-737 pilot had responded correctly to his "climb" RA, the vertical separation between the ATR 72 and the B-737 would have been 600 feet (i.e., 300 feet vertical deviation for each).

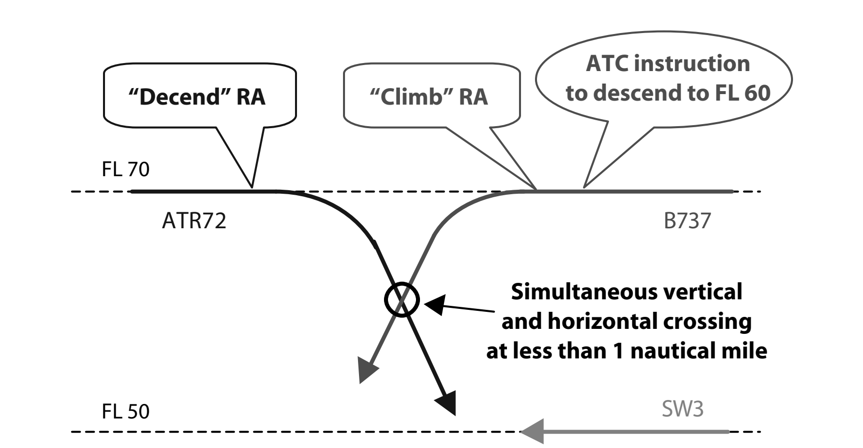
When a loss of separation is likely to occur or has occurred, the controller has to:

- Detect the conflict using the available tools (e.g., radar display, short-term conflict alert [STCA] system);
- Assess the situation;
- Develop a solution in a very short period of time; and,
- Communicate this solution to the aircrew as quickly and clearly as possible.

The detection of the conflict may be delayed due to tasks with other aircraft under his or her control. Communication with conflicting aircraft may also be delayed due to RTF (radiotelephone) congestion or misunderstandings between the controller and the pilots.

ACAS automatically detects any risk of collision with transponder-equipped aircraft. When a risk of collision is detected, it calculates the necessary maneuver and communicates the solution directly to the flight crew via the RA display and an aural-message attention-getter. It does this in less than one second.

Figure 2



Source: Adapted from Eurocontrol

Whenever both aircraft are operating ACAS in RA mode, ACAS coordinates the RAs.

Event 2: ATC Avoidance Instruction Opposite to RA

A B-737 is level at FL 280 and flying a northwest route. An Airbus A321 is climbing to FL 270 and flying a southbound route. Due to a misunderstanding with the controller, the A321 pilot busts (deviates from) his assigned altitude, FL 270, and continues to climb to FL 290.

The controller detects the altitude bust and takes corrective actions. He instructs the A321 (displayed on the radar at FL 274) to descend immediately to FL 270 and the B-737 to climb to FL 290. The B-737 pilot initiates the climb maneuver, but the A321 pilot continues to climb, instead of descending back to FL 270.

A few seconds later, the ACAS of each aircraft triggers a coordinated RA: a "climb" RA for the A321 (it is now 300 feet above the B-737) and a "descend" RA for the B-737.

The B-737 pilot follows his RA and starts to descend. The A321 pilot eventually complies with the ATC instruction, stops the climb and starts to descend despite his "climb" RA. In addition, the A321 pilot reported that he preferred to avoid the B-737 visually.

As a result, both aircraft pass less than 2.0 nautical miles (3.7 kilometers) apart, with only 100 feet of vertical separation.

Event 3: Erroneous Traffic Information and Incorrect Visual Perception

Two aircraft are departing from the same airport, on the westerly runway. The first one is a long-haul B-747, which is turning right to heading 150 degrees. The second one is a short-haul British Aerospace BAe 146, which is turning to the east, after a steep initial climb. Both aircraft are cleared to FL 190.

Due to the good climb performance of the BAe 146, the controller gives it an early right turn. This clearance induces a conflict between the BAe 146 and the B-747 (Figure 3).

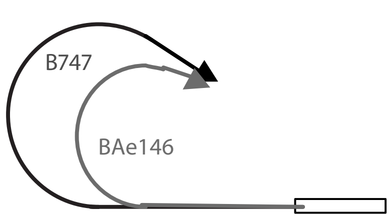
The controller detects the conflict and provides the B-747 with traffic information about the BAe 146. The pilot replies, "We are passing 6,000 feet." Then, the controller instructs the BAe 146 to "stop climb Flight Level 60" and advises the pilot that a B-747 is "1,000 feet above, climbing." Nevertheless, two elements have not been taken into account:

- The pressure is high (QNH 1032 millibars), so that the 6,000 feet altitude is actually FL 54, and FL 60 is 6,600 feet altitude; and,
- Both aircraft are ACAS equipped, and the ACAS of each aircraft triggers a coordinated RA.

The B-747 pilot receives a "descend" RA that he follows: He stops his climb and starts to descend (Figure 4).

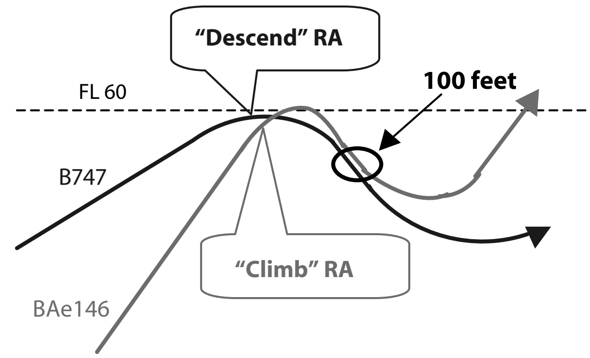
The BAe 146 pilot has the B-747 in visual contact. Nevertheless, due to the actual B-747 flight configuration, the descent maneuver is difficult to detect visually (positive pitch). Because he is also misled by the erroneous traffic information, he decides to descend visually to avoid the B-747 despite his "climb" RA.

Figure 3



Source: Adapted from Eurocontrol

Figure 4



Source: Adapted from Eurocontrol

As the B-747 is also descending in response to his "descend" RA, the aircraft continue to get closer.

Because the BAe 146 pilot did not follow his "climb" RA, the B-747 deviated by 1,200 feet. Nevertheless, despite this large vertical deviation, the B-747 pilot reported that the two aircraft passed "very, very, very close" (i.e., 100 feet vertically and 0.5 nautical mile [0.9 kilometer] horizontally).

Event 4: Inefficient Visual-avoidance Maneuver

A B-747 and a McDonnell Douglas DC-10 flying on converging tracks are both cleared to FL 370 by mistake. When the controller detects the conflict, he tries to instruct the DC-10 to descend to FL 350 but uses a mixed call sign.

The B-747 pilot wrongly takes the clearance and initiates a descent. At the same time, his ACAS issues a "climb" RA. Nevertheless, the pilot decides not to follow the RA because he has visual acquisition of the DC-10 (at the time of the incident, his airline's standard operating procedures stated that maneuvers based on visual acquisition took precedence over RAs), and he continues to descend.

The DC-10 pilot, who has the B-747 in sight, receives a coordinated "descend" RA that he follows. He stops his descent when he perceives the B-747 to be at the same altitude and descending.

The B-747 pilot performs a sudden and violent escape maneuver, injuring a number of passengers and flight attendants.

As a result, the B-747 passes just beneath the DC-10 (by 10 meters [33 feet] reported), with no lateral separation.

ACAS Altitude Data Is Better Than ATC's

ATC radar displays are usually provided with data by a radar data processing system (RDPS), whose inputs come from secondary surveillance radars (SSRs) with:

- An update rate of several seconds (from four seconds to 10 seconds); and,
- Altitude data in 100-foot increments.

Sudden vertical maneuvers may not be displayed immediately. For instance, the altitudes displayed for a maneuvering aircraft may lag by as much as 500 feet. In addition, the displayed vertical tendency may be erroneous in some cases.

ACAS interrogates all surrounding transponders every second, making the update four times to 10 times quicker than SSRs. Mode S-equipped aircraft provide

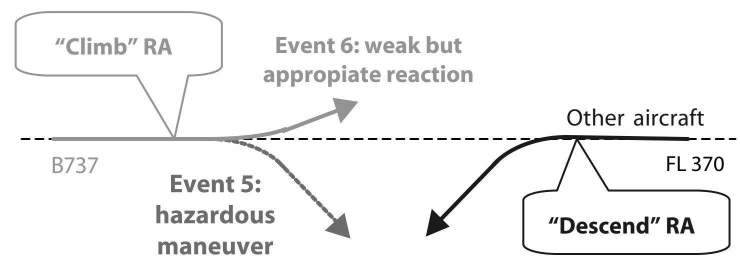
ACAS with 25-foot increments, making it four times more accurate.

Therefore, for aircraft in close proximity, the ACAS knowledge of the vertical situation is much better than ATC's knowledge of the situation. It can be considered to be at least four times more accurate and four times more up-to-date.

Moreover, there are limitations to visual acquisition of traffic:

- The visual assessment of traffic can be misleading. At high altitude, it is difficult to assess the range and heading of traffic, as well as its relative height. At low altitude, the attitude of a heavy aircraft at low speed makes it difficult to assess whether it is climbing or descending.
- Visual acquisition does not provide any information about the intent of other traffic.
- The traffic in visual contact may not be the threat that triggers the RA. A visual maneuver relative to the wrong visual traffic may degrade the situation against the real threat.

Figure 5



Source: Adapted from Eurocontrol

Event 5 and Event 6: 'Climb' RA at the Maximum Certified Flight Level

Two events involving B-737s cruising at FL 370, the maximum certified flight level for this specific aircraft type, have been identified where the pilot reaction to the "climb" RA was different. In both events, the B-737 was flying toward another aircraft level at the same altitude due to an ATC mistake and the ACAS generated a "climb" RA (Figure 5).

Event 5: The B-737 pilot decided not to climb in response to the RA because the aircraft was flying at the maximum certified flight level. Nevertheless, because he wanted to react to the ACAS alert, he decided to descend. He did not take into account that the other aircraft would receive a coordinated "descend" RA. As a result, the B-737 pilot descended toward the other aircraft, which was correctly descending in accordance with its own RA.

Event 6: The B-737 pilot climbed in response to his RA; but, as one could expect, he was not able to comply with the normal 1,500 feet-per-minute vertical rate requested by the RA. He climbed only about 100 feet. Nevertheless, even this slight climb was beneficial because the other aircraft received a coordinated "descend" RA, which was correctly followed by the pilot. The vertical separation achieved was the vertical deviation of the descending aircraft *plus* the 100 feet achieved by the B-737.

Do not react contrary to an RA: If there is some doubt about the ability to respond to a "climb" RA because of a possible stall, at least remain level, do not descend.

Event 7: Correct Responses to RAs by Both Pilots

An A340 and an A319, which are departing from two different airports, are in contact with different controllers but in the same airspace.

The A340, in contact with the departure controller, is cleared to climb to FL 150 with an initial heading of 090 degrees. The A340 climbs slowly and is planned to climb above the A319. The A319, which is level at FL 90 and also heading east, is already in contact with the en route center.

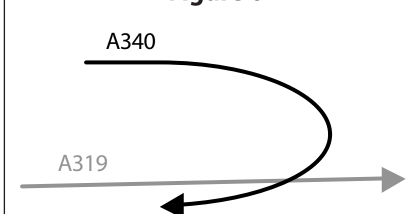
When passing through FL 100, the A340 is turned to the right by the departure controller (Figure 6). At the same time, the A319 is cleared by mistake by the en route controller to climb to FL 210, which creates a conflict with the A340. The en route controller detects the conflict and instructs the A319 to stop the climb at FL 100. The A319 pilot replies that he has already passed FL 100 and that he is descending back to FL 100.

Nevertheless, because of the simultaneous horizontal and vertical convergence, the ACAS of each aircraft triggers a coordinated RA (Figure 7, page 19).

In this event, the correct responses to the RAs by both pilots provide more than the ACAS vertical separation objective:

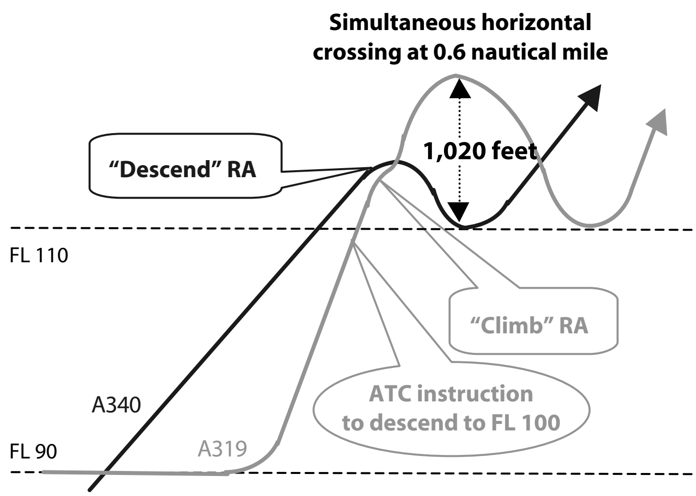
- The A340 receives a "descend" RA that he follows correctly, despite the clearance to climb to FL 150; and,

Figure 6



Source: Adapted from Eurocontrol

Figure 7



Source: Adapted from Eurocontrol

- The A319 receives a "climb" RA that he follows correctly, even though he has already started his maneuver to descend back to FL 100.

ACAS is a last-resort system, which operates with very short time thresholds before a potential midair collision. It assesses the situation every second, based on accurate surveillance in range and altitude. For maximum efficiency, when both aircraft are operating ACAS in RA mode, ACAS coordinates the RAs. ACAS is extremely effective.

It is important that pilots follow all RAs even when there is:

- An opposite avoiding instruction by the controller. If the RA is not followed, it can adversely affect safety when the other aircraft responds to a coordinated RA;

- Conflict close to the top of the operating envelope. If a "climb" RA is generated, it may be possible to climb at least a little, but do not descend, opposite to the RA;

- The slower update rate of the radar display, even with RDPS multiradar data, means that the vertical situation seen by the controller may be inaccurate, particularly when aircraft are rapidly climbing or descending; and,

- The wrong aircraft could be identified, and the situation may be assessed incorrectly.

Workload is often high during an ACAS RA encounter; nevertheless, pilots shall notify ATC as soon as possible using the standard phraseology (e.g., "[call sign] TCAS climb").

This information will help the controller in his task (see International Civil Aviation Organization [ICAO] Document 4444, *Procedures for Air Navigation Services – Air Traffic Management*). When a controller is informed that a pilot is following an RA, the controller shall not attempt to modify the aircraft flight path until the pilot reports returning to the clearance. The controller shall provide traffic information as appropriate.

RAs and 1,000-foot Level-off Maneuvers

One common type of RA is that which is issued when aircraft are expected to level off 1,000 feet apart and, at the same time, are crossing horizontally.

This method of vertical separation has been used safely — from an ATC standpoint — for years. Therefore, these RAs, often subsequently classed as "operationally unnecessary," can be perceived as disturbing by controllers and by some pilots.

Events 8 and 9 illustrate RAs triggered in 1,000-foot level-off encounters. Event 10 (without ACAS) and Event 11 (with ACAS) illustrate the situation where one aircraft has busted its level — failed to level off. These events highlight the effectiveness of ACAS and the necessity for it.

Event 8: RA Generated in a 1,000-foot Level-off Encounter

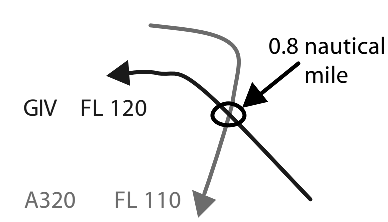
After takeoff, an ACAS-equipped A320 is climbing to FL 110 on the SID (standard instrument departure). Its rate of climb is 4,300 feet per minute.

A Gulfstream IV is descending to FL 120 on the standard approach procedure. Its rate of descent is 3,200 feet per minute.

Both trajectories are converging so that the aircraft will pass 0.8 nautical mile (1.5 kilometers) apart, just at the moment where they will reach their respective cleared flight levels (Figure 8).

The simultaneous horizontal and vertical convergence, combined with the high vertical rates, cause ACAS to trigger an RA even though the standard separation is being correctly applied according to the procedure.

Figure 8



Source: Adapted from Eurocontrol

The A320 pilot receives an "adjust vertical speed" RA when passing through FL 97 (i.e., 1,300 feet below the cleared flight level) with a high rate of climb (4,300 feet per minute). This RA requires that the rate of climb be limited to not more than 2,000 feet per minute (Figure 9).

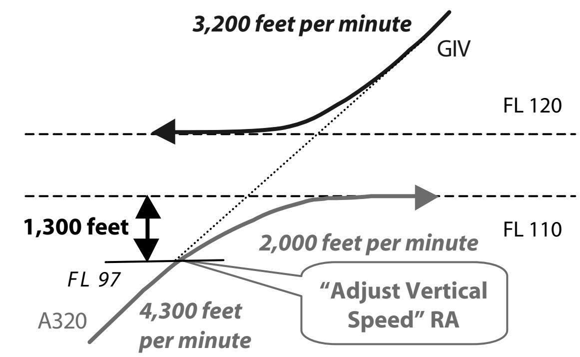
The A320 pilot reduces the rate of climb in accordance with his RA and levels off at FL 110, as cleared by the controller.

In the event, both aircraft successfully leveled off, and subsequently this RA was considered as operationally unnecessary. Nevertheless, the RA reinforced the controller's clearance, and had only one of the aircraft failed to level off, there would have been 20 seconds or less until the aircraft were at the same altitude. ACAS also effectively provided a last-resort protection against level bust.

High vertical rates (greater than 3,000 feet per minute) are very often achieved by modern aircraft like the A320, A330, B-737, B-767, MD-80, etc.

Scenarios such as illustrated by event 8 are common, particularly around FL 100 between arrivals and departures in TMAs (terminal areas). For instance, locations where this type of scenario is recurrent (RA "hotspots") have been identified in several major European TMAs. Figure 10 shows an RA hotspot in the Paris (France) TMA.

Figure 9



Source: Adapted from Eurocontrol

ACAS Processing of 1,000-foot Level-off Encounters

ACAS issues RAs when it calculates a risk of collision within a time threshold whose value depends on the aircraft's altitude.

In 1,000-foot level-off encounters, ACAS detects simultaneous horizontal and vertical convergence.

When the vertical closure rate is high, ACAS can compute a risk of collision and generate an RA before a level-off maneuver is initiated by the aircraft.

Figure 11 (page 21) shows a single level-off encounter. The RA time threshold is 30 seconds for the climbing aircraft.

With this vertical closure rate of 3,400 feet per minute, 30 seconds corresponds to 1,700 feet. Therefore, an RA is generated.

If both aircraft were maneuvering to level off, the vertical convergence would be greater. Therefore, the likelihood for an RA to be triggered would be higher.

Although this type of RA is often considered operationally unnecessary, it is not possible to further reduce the RA time threshold without degrading ACAS safety performance.

Background of 1,000-foot Vertical Separation

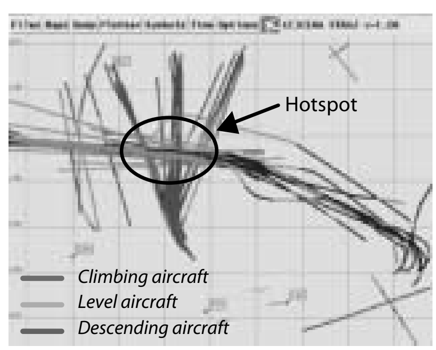
ATC vertical separation of 1,000 feet is the standard vertical separation applied between aircraft. Therefore, controllers can find it difficult to understand why ACAS triggers RAs while the job is being done correctly. Furthermore, sometimes they do not understand why, even when traffic information is provided, flight crews still follow RAs.

From the pilots' perspective, studies show that about half of the pilots consider that these RAs are useful or even necessary although everything is correctly done.

The 1,000-foot vertical-separation value was determined 50 years ago and was computed for aircraft in level flight. At that time, most airliners were nonpressurized, piston-engine aircraft that could climb or descend only at 500 feet per minute. In this case, 1,000 feet represented two minutes of flight time.

Now, modern jet aircraft have high vertical performance, and they can climb or descend at 5,000 feet per minute (or more). With such a vertical rate, 1,000 feet represents only 12 seconds of flight time, which is too short for taking effective corrective action if the level-off maneuver fails for whatever reason.

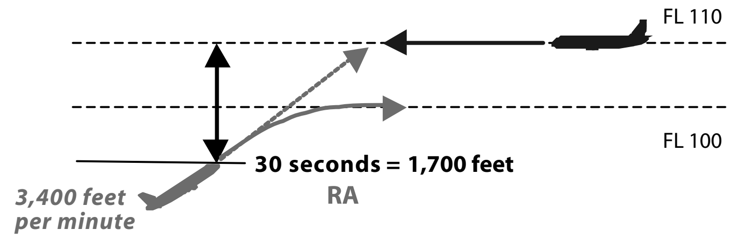
Figure 10



Example of RA "Hotspot" in Paris TMA

Source: Adapted from Eurocontrol

Figure 11



Source: Adapted from Eurocontrol

Currently, the potential operational constraint caused by an RA in a 1,000-foot level-off encounter is the price to pay for significantly improved safety overall.

TCAS II Version 7 includes features to reduce the number and the severity of RAs triggered in 1,000-foot level-off encounters:

- Some RA time threshold values are reduced for level aircraft to give ACAS time to detect the start of a level-off maneuver by the other aircraft;
- The vertical tracking is improved to enable earlier detection of the level-off maneuver of the intruder;
- The RAs triggered in coordinated ACAS–ACAS encounters are more compatible with the ATC clearance encouraging a correct level-off; and,
- Crossing RAs (i.e., RAs requiring the pilot to cross the intruder altitude) can be generated only if a level bust actually occurs.

Operational monitoring programs have confirmed that TCAS II Version 7 generates fewer RAs, particularly for level aircraft in single level-off encounters.

Nevertheless, RAs are still generated in 1,000-foot level-off encounters, although a very high percentage of these RAs are compatible with the ATC clearances.

Event 9: Excessive Vertical Rate Approaching Cleared Flight Level

A Saab 340 (SF340) is level at FL 180 and flying a northeast route. An Embraer ERJ-145 (E145) is climbing to FL 170 and flying a southeast route. Both aircraft are converging toward the same point (the minimum distance is 1.0 nautical mile [1.9 kilometer]).

As the E145 is climbing with a very high vertical rate (about 7,000 feet per minute), the ACAS of each aircraft triggers a coordinated RA (Figure 12).

The E145 pilot receives a traffic advisory (TA) when passing through FL 128. Then, 18 seconds later, at FL 149, an "adjust vertical speed" RA, to reduce the rate of climb to 2,000 feet per minute, is generated. The SF340 receives a "climb" RA six seconds later, while the E145 passes through FL 156 still with a very high vertical rate (6,600 feet per minute).

Excessive vertical rates may trigger RAs, which may also induce deviation of the level aircraft. This can be disruptive.

ACAS Is Effective in Level Busts

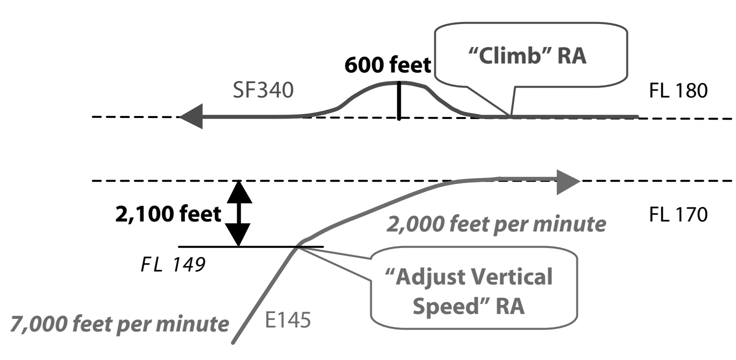
These two events illustrate the effectiveness of ACAS in level-bust scenarios. Event 10 occurred before the European ACAS mandate; Event 11 occurred after the mandate.

Event 10: Aircraft Without ACAS

An MD-81 and a B-737, both inbound to a major European airport, are in a holding pattern.

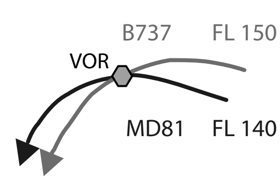
The MD-81 is level at FL 140, and the B-737 is cleared to descend to FL 150. The B-737 pilot acknowledges this instruction correctly, but the aircraft does not level off at FL 150 as expected (Figure 13).

Figure 12



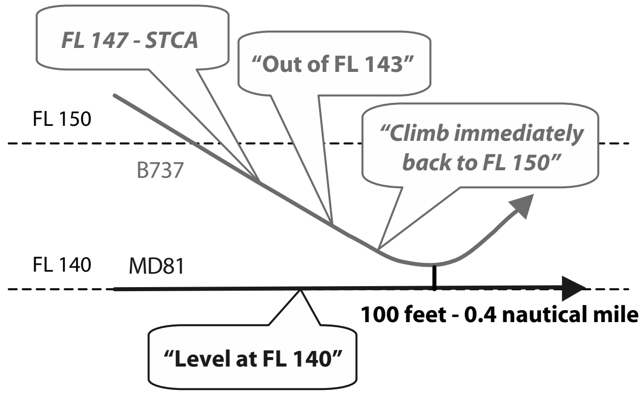
Source: Adapted from Eurocontrol

Figure 13



Source: Adapted from Eurocontrol

Figure 14



Source: Adapted from Eurocontrol

When the B-737 passes FL 147, still descending, the STCA system triggers an alert. As data blocks are overlapped on his display, the controller questions both pilots about their flight level, then he instructs the B-737 to climb immediately back to FL 150 (Figure 14).

The conflict could not be detected by ATC before the level bust. In addition, the controller had to spend some valuable seconds asking both pilots for their respective flight level. As a result, the minimum distance between the aircraft was 0.4 nautical mile (0.7 kilometer) and 100 feet.

Event 11: Aircraft With ACAS

A B-767 is level at FL 320. An A320, level at FL 340, is on a converging track (Figure 15).

The A320 is cleared to descend to FL 330. The pilot reads back "320." Nevertheless, it sounds like "330," and the controller does not detect the mistake. Consequently, the A320 does not level off at FL 330 and conflicts with the B-767.

When the A320 passes FL 328, still descending, the A320 receives a "climb" RA. The B-767 pilot receives a coordinated "descend" RA four seconds later (Figure 16, page 23).

Both pilots followed the RAs, so that their coordinated maneuvers resulted in a vertical separation of 1,570 feet at the closest point (i.e., 1.0 nautical mile). Moreover, the vertical separation was never less than 700 feet.

Level Busts Remain a Reality

A U.S. National Aeronautics and Space Administration (NASA) study found that there are 10 opportunities for level bust per altitude-change instruction. In addition, a U.K. study concluded that, on average, there is one level bust per commercial aircraft each year.

Many statistical analyses confirm the high number of level busts:

- More than 500 level busts reported per year in a major European state since 1998; and,
- A total of 498 level busts reported by a major European airline from July 2000 to June 2002 (i.e., 21 reported level busts per month).

Figure 15

Source: Adapted from Eurocontrol

It is very unlikely that the situation is different in other European states and for other European operators.

There are multiple causes for level busts. One of the main causes is an autopilot deficiency or failure (about 20 percent of the reported level busts for two major European airlines). Other causes are clearance misheard, incorrect altimeter setting, taking another aircraft's clearance, etc.

A level bust, which occurs in a 1,000-foot level-off encounter scenario, can be critical and result in a risk of collision. ACAS is an effective protection in the event of a level bust.

Controllers and pilots consider that too many RAs are generated in 1,000-foot level-off encounters. Some solutions can be envisaged to avoid these RAs or at least to reduce their number.

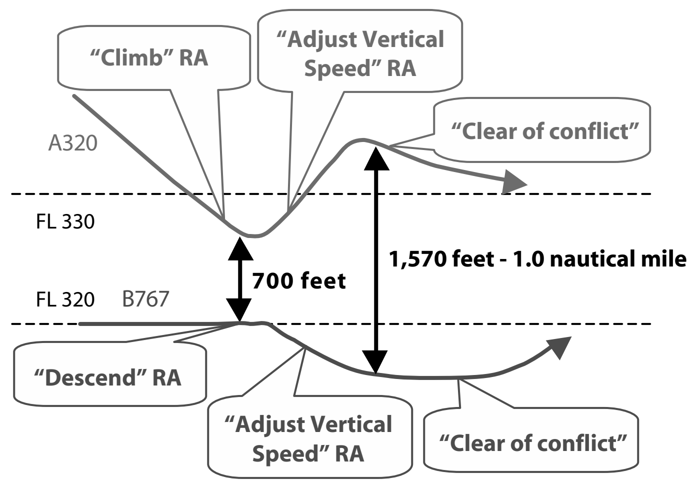
To increase safety and to minimize the likelihood of RAs in 1,000-foot level-off encounters, it is proposed that aircraft have a reduced vertical rate when approaching their cleared level. Recommendations or rules already exist.

The Eurocontrol ACAS Program recommends that pilots climb or descend at a rate less than 1,000 feet per minute in the last 1,000 feet to level-off. The Eurocontrol RVSM (Reduced Vertical Separation Minimums) Program also recommends a similar rate for RVSM operations.

Two core-area European states have published regulations in their aeronautical information publications (AIPs) that require the vertical rate, in the last 1,000 feet before level-off at the cleared altitude, to be below 1,500 feet per minute. This can be expected to improve the compatibility of ACAS with ATC and bring improvements in safety.

In addition, a proposal for a recommendation to reduce the vertical rate to less than 1,500 feet per minute in the last 1,000 feet before level-off at the cleared altitude is under discussion within ICAO for inclusion in Annex 6, *Aircraft Operations.*

Figure 16



Source: Adapted from Eurocontrol

Modification of ACAS Procedures

Two solutions could be adopted near-term to improve operations in locations where RA hotspots have been identified:

- To increase the vertical separation between aircraft to 2,000 feet in specific cases (e.g., between arrivals and departures); and,
- To avoid simultaneous horizontal and vertical convergence of aircraft by modifying either the horizontal route or the vertical trajectory.

These proposals, which could be implemented in a relatively short term, are also likely to provide improvements in safety.

Two procedure modifications in line with these proposals have already been implemented by one air navigation service provider (ANSP) to address RA hotspots. Neither of these procedure modifications has had any significant effect on capacity:

- A 2,000-foot vertical separation is now applied between Geneva (Switzerland) arrivals and Lyon (France) departures;
- In the Paris TMA, the MOSUD arrival descent point from FL 140 to FL 120 is delayed by 4.0 nautical miles (7.4 kilometers) on a tactical basis. Thus, RAs are avoided with the departures climbing to FL 110. As a bonus, an STCA hotspot has been suppressed.

Long-term technical modifications include a modification of aircraft autoflight systems and a TCAS logic modification:

- Modification of the altitude-capture laws of the autopilot by an earlier reduction of vertical rate. This would reduce the probability of RAs during level-off. Although this solution will require a lengthy development and certification process, it is expected to provide a significant contribution to safety; and,
- Radical redesign of the ACAS logic to use own-aircraft selected flight level. This would require a lengthy development and certification process. Unlike the other proposed solutions, overall air traffic management (ATM) safety would not be improved.

These modifications must be viewed as long-term solutions.

Despite several specific features, ACAS still generates some RAs in 1,000-foot level-off encounters, which can be perceived as operationally unnecessary. This perception results from the fact that 1,000 feet is the standard ATC vertical separation applied between aircraft. Some of these RAs are necessary, particularly in the case of level busts, which are not infrequent events. Therefore, pilots must follow all RAs.

RAs in 1,000-foot level-off encounters generally are due to high or very high vertical rates. Therefore, it can be easily appreciated that these RAs contribute to the prevention of some level busts where there would be a risk of collision. These RAs are justified from an ACAS standpoint, and are not false alerts.

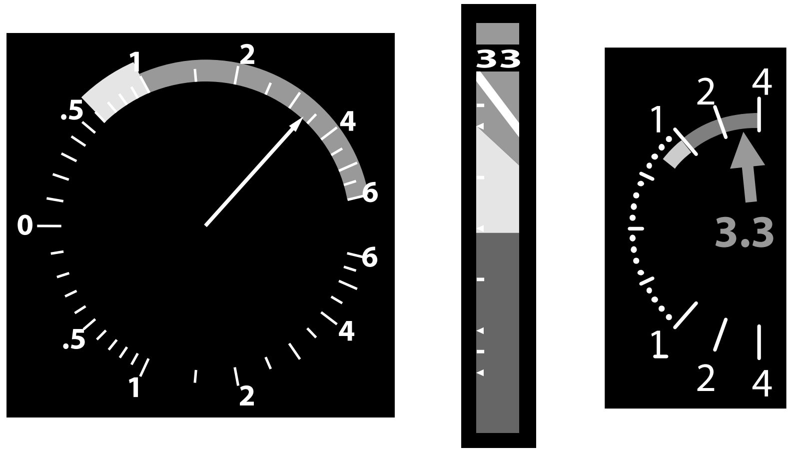
Where 1,000-foot level-off RAs are recurrent, it could serve to highlight a potential safety issue in ATM design or procedures.

This issue involves all ATM actors:

- Pilots — ACAS is an effective protection in the event of level busts: Follow the RA. Where possible, the vertical rate should be reduced in the last 1,000 feet before level-off;
- Aircraft operators — Where feasible, operational procedures should be implemented requiring a vertical rate less than 1,500 feet per minute in the last 1,000 feet from a cleared altitude;

- Aircraft manufacturers — Autoflight system designs should take into account ACAS performance when determining vertical rates for altitude capture;
- Controllers — It should be noted that these RAs are justified from an ACAS standpoint. Traffic information may improve the pilots' situational awareness; and,
- Aviation authorities and service providers — Airspace design and procedures should take into account any potential safety issues highlighted by ACAS monitoring.

Figure 17



Source: Adapted from Eurocontrol

Wrong Reaction to 'Adjust Vertical Speed' RAs

The ACAS operational monitoring programs have shown that the ACAS RA display is occasionally misinterpreted by flight crews. Occurrences seem to be linked to the type of RA with the aural, "adjust vertical speed, adjust." This RA is posted either as an initial RA or as a weakening RA that can follow a "climb" RA or "descend" RA.

"Adjust vertical speed" RAs are the most frequent RAs triggered by ACAS. It is essential that these RAs are followed accurately.

ACAS is designed to generate an "adjust vertical speed" RA, instead of a stronger "climb" or "descend" RA, whenever possible.

The objective is to solve a predicted risk of collision by a reduction of the current vertical speed, either in climb or in descent, while maximizing compatibility with the ATC clearance. The reduction is associated with four different values: 0, 500, 1,000 or 2,000 feet per minute.

This type of RA is mainly issued when an aircraft is climbing or descending to level off 1,000 feet from another aircraft. It reinforces the controller's clearance and helps to ensure successful level-off at the cleared flight level. Operational monitoring in coordination with a major European airline has confirmed that 90 percent of RAs in 1,000-foot level-off encounters were "adjust vertical speed" RAs.

RAs are often displayed on vertical speed indicators (VSIs). There are three types of VSIs (Figure 17): the dedicated instantaneous VSI, the vertical-speed tape on the primary flight display (PFD) and the semicircular VSI on the PFD.

The vertical speeds to be avoided are displayed with a red area and the required ones with a green area. The reduction of rate of climb will put the vertical-speed needle into the green area.

On some aircraft, RAs are displayed with a pitch cue, which corresponds to the required vertical speed, on the electronic attitude director indicator (EADI; Figure 18).

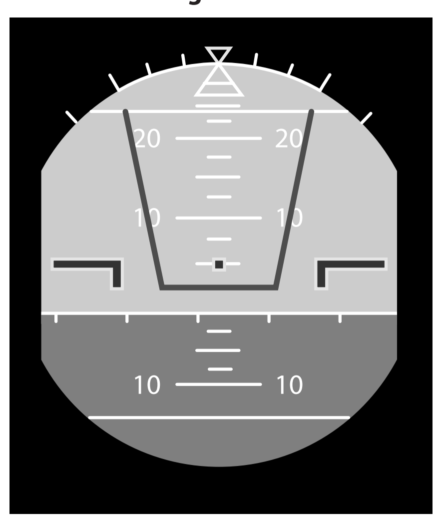
Only the pitch attitudes to avoid are displayed with a red area (i.e., no green area). The reduction of rate of climb will put the current pitch marker outside the red trapezoid.

(Note: The RA displays depicted have been slightly modified for clarity.)

Misinterpretation of Initial 'Adjust Vertical Speed' RAs

In a period of 14 months, operational monitoring programs have identified at least 12 events where the flight crew maneuvered the aircraft opposite to the sense of an initial "adjust vertical speed" RA (other possible occurrences are still to be confirmed). In these events, the flight crew of an aircraft cleared to level off 1,000 feet from another aircraft misinterpreted the RA and increased, rather

Figure 18



Source: Adapted from Eurocontrol

than reduced, the aircraft's vertical speed.

These wrong reactions caused altitude busts and losses of standard ATC separation. Nevertheless, a vertical distance was maintained between the two aircraft because the other flight crew received and followed "climb" or "descend" RAs.

The RA display of the aircraft involved in all of these events was either a vertical-speed tape or a semicircular VSI on the PFD. Nevertheless, a similar event recently has been identified involving an aircraft where an RA was displayed using a pitch cue on the EADI.

Event 12: Misinterpretation of Initial 'Adjust Vertical Speed' RA

An A320 is level at FL 270, heading south.

Another A320, heading north, is cleared to climb to FL 260; its rate of climb is about 3,300 feet per minute. When passing through FL 253, its ACAS triggers an initial "adjust vertical speed" RA, requiring a reduction in the rate of climb to 1,000 feet per minute (Figure 19).

Nevertheless, the flight crew misinterprets the RA and reacts opposite to it: The rate of climb is increased to more than 6,000 feet per minute, instead of being reduced. The closure rate increases between the two aircraft, and the RA is strengthened to a "descend" RA. The flight crew follows this second RA, but the maneuver takes time to be effective.

As a result of the wrong reaction to the "adjust vertical speed" RA, the climbing A320 busts its flight level by 1,200 feet and the level A320 receives a "climb" RA, which the flight crew follows. The vertical distance is 300 feet with 0.8 nautical mile (1.5 kilometers) horizontally.

If the flight crew had correctly reduced the rate of climb as required by ACAS, simulations show that not only would the climbing A320 have leveled off correctly, the level A320 would not have received an RA.

Investigation of this incident revealed that two factors combined to contribute to misinterpretation of the RA:

- The RA display on the vertical-speed tape is small and could be difficult to interpret and to follow; and,
- The "adjust vertical speed, adjust" aural message does not specify the sense (direction) of the required maneuver.

Several occurrences have been identified by operational monitoring programs.

Event 13: Correct Reactions to Initial 'Adjust Vertical Speed' RAs

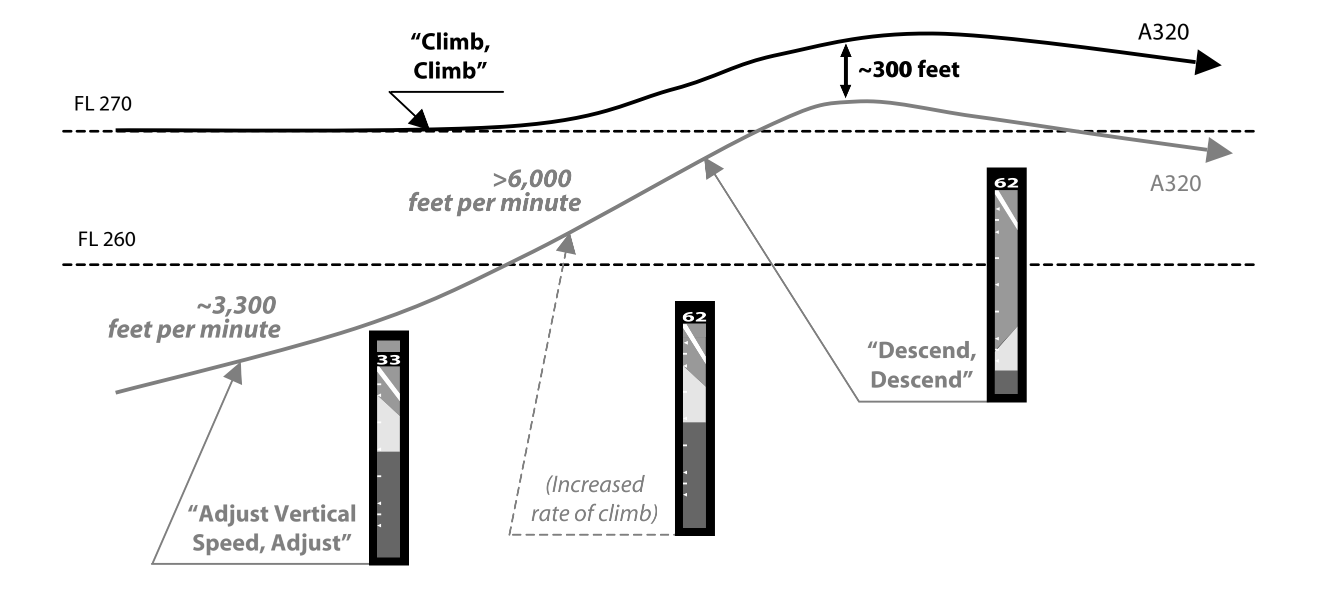
An A340 on approach is descending from FL 140 to FL 120 with a moderate vertical speed (about 1,400 feet per minute).

An A319 is climbing on departure to FL 110 with a high vertical speed (about 4,000 feet per minute).

The aircraft are converging and will pass 0.1 nautical mile (0.2 kilometer) apart but at cleared flight levels separated by 1,000 feet.

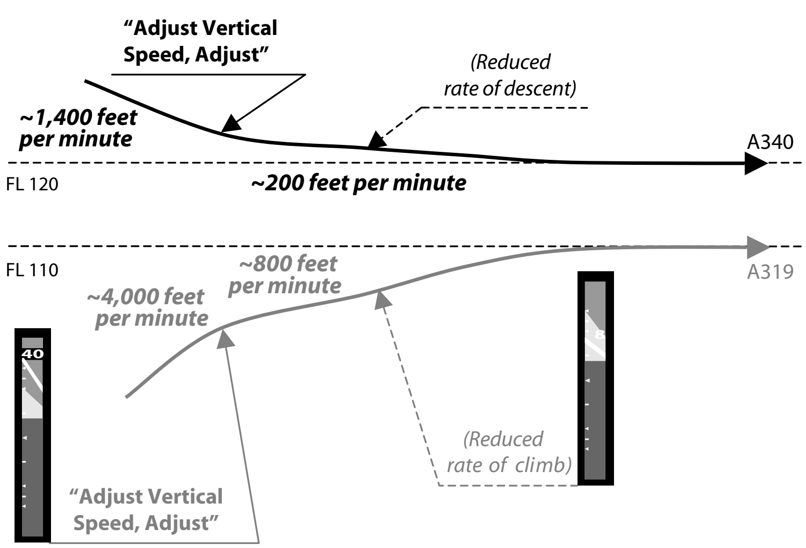
The simultaneous horizontal convergence and high rate of vertical convergence

Figure 19



Source: Adapted from Eurocontrol

Figure 20



Source: Adapted from Eurocontrol

causes ACAS to trigger "adjust vertical speed" RAs before the aircraft have leveled off at their cleared flight levels (Figure 20):

- The A340 is required to reduce its rate of descent to 1,000 feet per minute; and,
- The A319 is required to reduce its rate of climb to 2,000 feet per minute.

The flight crews correctly follow these RAs, reducing their vertical speeds below the maximum value required by ACAS.

As a result, both aircraft continue to climb and descend with reduced vertical speeds. Then, they level off at their cleared flight levels. There is no disruption to ATC.

'Adjust Vertical Speed' as a Weakening RA

This RA is generated after a "climb" RA or a "descend" RA, when a safe vertical distance has been achieved. It prompts the flight crew to stop the climb or descent to minimize the overall vertical deviation from the cleared flight path.

The objective is to improve compatibility with ATC by avoiding excessive deviations from clearance, which could potentially generate subsequent conflicts.

The "adjust vertical speed" RA prompts the flight crew to level off after a reaction to a "descend" RA.

On a VSI, the vertical speed needle is outside the red area (Figure 21). Flying the aircraft to put the vertical-speed needle into the green area will achieve a level-off.

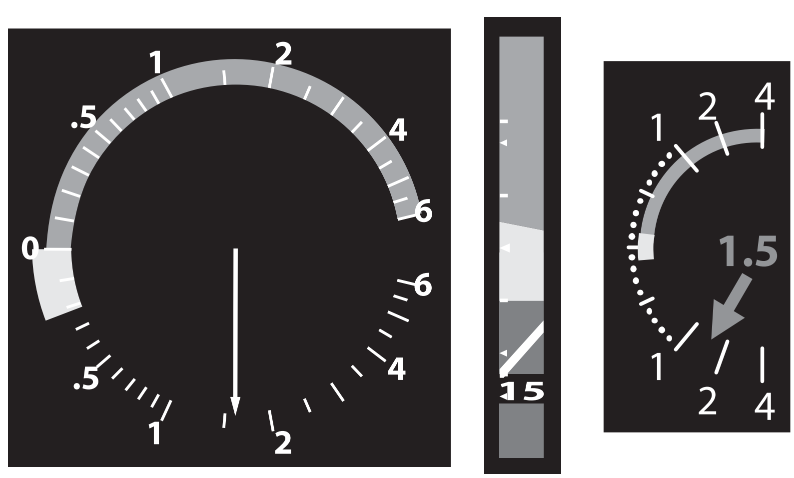
On an EADI, the current-pitch marker is outside the red-trapezoid area (Figure 22, page 27). Flying the aircraft to put the current-pitch marker on the bottom line of the red trapezoid will achieve a level-off.

From the introduction of ACAS, operational monitoring programs have highlighted that a significant proportion of deviations from clearance in response to RAs are excessive.

Analysis showed that some flight crews did not respond to weakening RAs and maintained the vertical rate required by the initial RA until ACAS advised "clear of conflict." They then returned to the initial clearance. Disregarding the weakening RA often causes an unnecessarily large deviation, which has occasionally induced a conflict with a third aircraft.

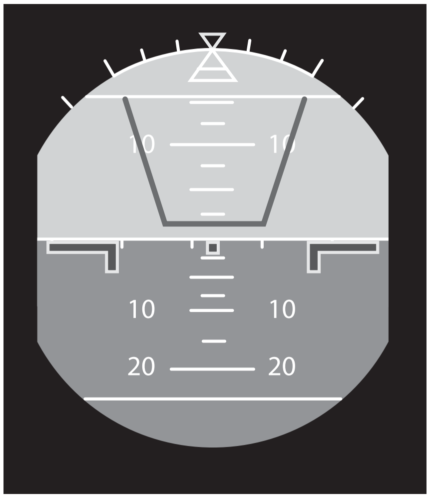
The current ACAS (i.e., TCAS II Version 7) addressed this issue on VSI and vertical-speed tape RA displays by adding a green area to the indication of the weakening RA.

Figure 21



Source: Adapted from Eurocontrol

Figure 22



Source: Adapted from Eurocontrol

The aural annunciation was also changed from "monitor vertical speed" to "adjust vertical speed, adjust." These changes are designed to encourage flight crews to react correctly to weakening RAs.

Nevertheless, in 2002, about 30 percent of deviations were still greater than 600 feet (and some more than 1,000 feet). Although a few of them were indeed necessary, a very large proportion were not.

Event 14: Weakening 'Adjust Vertical Speed' RA Not Followed

A Fokker 100, cleared to descend to FL 110, levels off at the cleared flight level.

A Cessna 182 (C182), on an opposite route, is cleared to climb to FL 100. Nevertheless, it busts its flight level by 700 feet before starting to descend back to FL 100.

Because of the horizontal convergence and the small vertical distance between the aircraft, the Fokker 100 receives a "climb" RA, which the flight crew follows (Figure 23).

Ten seconds after the "climb" RA, a weakening "adjust vertical speed" RA is generated because a safe vertical distance has been achieved and the aircraft are diverging vertically.

Nevertheless, the flight crew continues to climb and only stops climbing when the "clear of conflict" is issued.

This excessive deviation was unnecessary and resulted in an eventual deviation of 1,100 feet. Although not the case here, it could have generated a subsequent conflict.

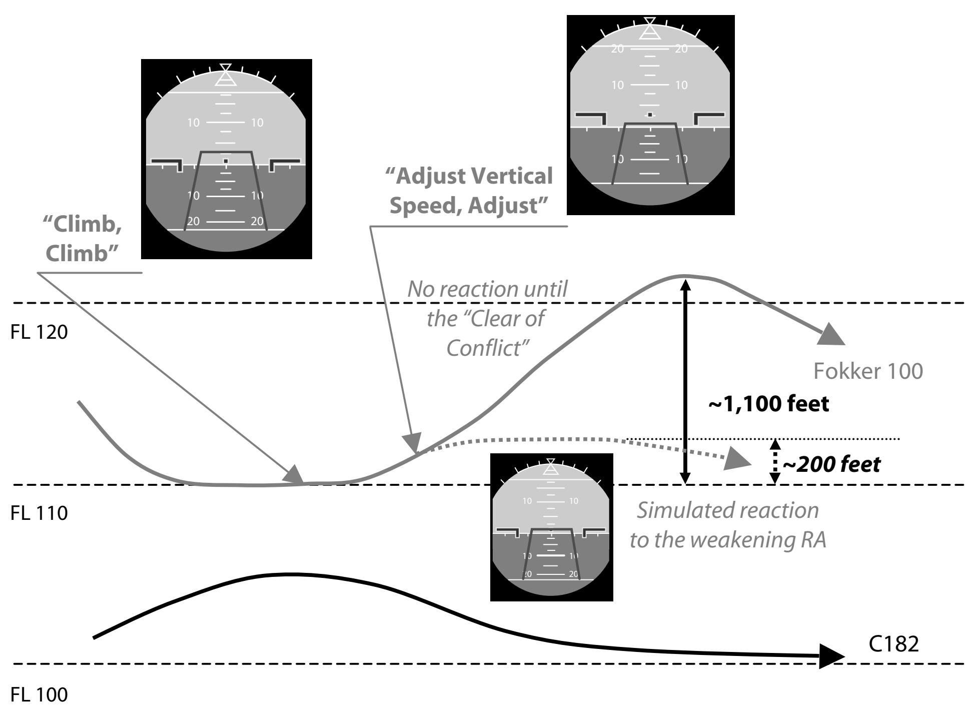
Simulations indicate that if the Fokker 100 flight crew had followed the weakening RA, the deviation would have been approximately 200 feet.

Airline Operational Feedback on Initial 'Adjust Vertical Speed' RAs

A major European airline is routinely monitoring flight crew responses to RA indications. It has identified an issue related to the "adjust vertical speed" RAs:

- About 4 percent of initial responses are wrong and opposite to the RAs; and,

Figure 23



Source: Adapted from Eurocontrol

- Most of the errors are quickly corrected, but a few serious events have occurred.

Some contributing factors have been identified by this operator:

- Only "climb" RA scenarios and "descend" RA scenarios are exercised on its flight simulators. An "adjust vertical speed" RA can only be generated subsequently, depending upon the pilots' reactions;

- The aural "adjust vertical speed, adjust" does not specify the direction of the maneuver required; and,

- Interpretation of the RA display on the vertical-speed tape of the PFD is less intuitive than the pitch cue.

This experience is shared by some other major European airlines.

Advantages of a Combined VSI and EADI RA Display

The RA display on the PFD vertical-speed tape is reported to be sometimes difficult to interpret. This seems to have been true in some "adjust vertical speed" RAs. A problem of interpretation may also exist for "increase climb" RAs, "increase descent" RAs or "maintain vertical speed" RAs.

On the other hand, the RA display on the EADI also can be difficult to interpret in the case of a weakening RA, because of the absence of a green area. In addition, it does not inform the flight crew of the vertical speed required by the RA.

Nevertheless, many aircraft operators and pilots consider that the RA display using pitch cue on the EADI is superior to other types of RA displays.

An RA display on both the EADI and the vertical-speed tape could improve the interpretation by flight crews of "adjust vertical speed" RAs and other RA types. Figure 24 shows a possible combined RA display on both the EADI and the vertical-speed tape.

"Adjust vertical speed" RAs can be misinterpreted. As a consequence, a number of opposite maneuvers have occurred, and excessive deviations from clearance also have occurred.

Two factors contributing to the misinterpretation of "adjust vertical speed" RAs have been identified:

- The aural message "adjust vertical speed, adjust" does not specify the direction of the required maneuver; and,

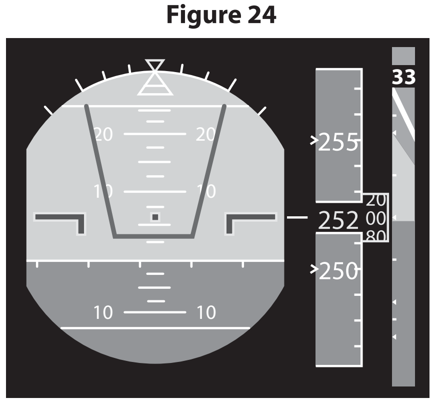
- The RA display on the vertical-speed tape and on the semicircular VSI on the PFD may sometimes be difficult to interpret.

Therefore, it is necessary to observe carefully the RA display when maneuvering, bearing in mind that an "adjust vertical speed" RA always requires a reduction of the vertical speed.

Aircraft operators and training organizations should ensure that "adjust vertical speed" RAs are:

- Explained clearly in ACAS training courses, together with the expected pilot response; and,

Figure 24



Source: Adapted from Eurocontrol

- Included in flight-simulation scenarios.

It is essential that pilots follow these RAs accurately, both when issued as an initial RA (the most frequent RA issued) and as a weakening RA.

Prompt and accurate response to:

- An initial "adjust vertical speed" RA will maximize safety, help to minimize the severity of the RA encounter and improve compatibility with ATC; and,

- A weakening "adjust vertical speed" RA will minimize any ATC disruption and help to prevent any potential subsequent conflict.

"Adjust vertical speed" RAs always require a *reduction* of the vertical speed.

The operational issues that have been highlighted by the monitoring of ACAS performance in Europe emphasize the relevance of the information contained in Eurocontrol ACAS training material, which is in line with the provisions and guidance of ICAO and the Joint Aviation Authorities. ACAS training material and related issues were discussed during several seminars on ACAS operation in Europe; the results of those seminars also reinforced the need to follow established procedures — chief among them the need to follow RAs. ■

[FSF editorial note: This article was adapted from the European Organization for the Safety of Air Navigation (Eurocontrol) *ACAS II Bulletin,* July 2002; *ACAS II Bulletin,* March 2003; and *ACAS II Bulletin,* October 2003. <www.eurocontrol.int/acas/>. FSF editorial staff assumes responsibility for any errors or omissions. John Law is manager of the Eurocontrol ACAS Program.]

Australian High-capacity Aircraft Sector Reduces Accident Rate in 2002

The preliminary 2002 data showed a rate of 0.3 accidents per 100,000 departures, the lowest of the non-zero rates reported since 1993. No fatal accidents occurred in this sector during the 1992–2001 period.

— FSF EDITORIAL STAFF

Reported Australian aircraft occurrences (accidents and incidents combined) increased 50 percent from fiscal year 1996–1997 to 2002–2003 (Table 1, page 30), said a report by the Australian Transport Safety Bureau (ATSB). The number of accidents showed a decreasing trend, and the number of incidents showed an increasing trend. Although incidents increased steadily during a 10-year period, the recent sharp increase can be attributed to the 1998 introduction of electronic safety incident reports from Air Services Australia, increased reporting by airlines because of "a growing safety culture within the airlines" and ATSB's own more comprehensive incident-recording policy, which includes "all reported bird strikes instead of only those significantly damaging aircraft," the report said.

A decrease in occurrences in 2002–2003 — compared with the peak 2000–2001 fiscal year — was attributed to possible factors including "statistical variation, the cessation of operations by Ansett Australia and a decline in tourism and aviation activity" involving the effects of terrorist attacks in the United States on Sept. 11, 2001, and in Bali, Indonesia, on Oct. 12, 2002, and the effect of the severe acute respiratory syndrome (SARS) virus, the report said.

"High-capacity aircraft operations continue to be the safest, with extremely low accident rates [Table 2, page 30]," the report said. "While caution needs to be exercised because of the small

> **"High-capacity aircraft operations continue to be the safest."**

Table 1

Aircraft Occurrences Reported to Australian Transport Safety Bureau, Fiscal Years 1996 to 2003

Occurrence Type	1996–1997	1997–1998	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003
Accidents	251	244	226	203	215	179	151
Incidents[1]	3,710	3,985	5,686	5,274	5,918	5,468	5,797
Total	3,961	4,229	5,912	5,477	6,133	5,647	5,948

Note: Occurrences comprise aircraft registered in Australia.

[1]This occurrence type includes serious incidents.

Source: Australian Transport Safety Bureau

Table 2

Australian Accident Rates for High-capacity,[1] Low-capacity[2] and Charter Aircraft, 1993 to 2002

Year	HCA Accidents per 100,000 Departures	HCA Accidents per 100,000 Hours Flown	LCA Accidents per 100,000 Departures	LCA Accidents per 100,000 Hours Flown	CA Accidents per 100,000 Hours Flown[3]
1993	0.4	0.2	1.6	2.2	11.1
1994	0.7	0.3	1.3	1.6	11.5
1995	0.3	0.2	1.3	1.6	9.0
1996	0.3	0.1	0.6	0.8	7.0
1997	0.0	0.0	0.0	0.0	10.1
1998	0.3	0.1	0.6	0.7	8.2
1999	2.4	1.0	0.9	1.1	4.1
2000	0.9	0.4	0.9	1.1	5.4
2001	0.9	0.4	1.1	1.2	6.8
2002[4]	0.3	0.1	1.8	1.9	4.3

Note: Accidents comprise aircraft registered in Australia.

[1]High-capacity aircraft have a seating capacity of more than 38 seats or a maximum payload of more than 4,200 kilograms (9,260 pounds) in Australian regular public transport.

[2]Low-capacity aircraft have a seating capacity of fewer than 39 seats or a maximum payload of 4,200 kilograms in Australian regular public transport.

[3]Departure data for charter aircraft were unavailable.

[4]Preliminary data.

HCA = High-capacity aircraft LCA = Low-capacity aircraft CA = Charter aircraft

Source: Australian Transport Safety Bureau

numbers involved, [Table 3, page 31] shows a low and stable pattern for accidents in both the high[-capacity] and low-capacity regular public transport [sectors].” (High-capacity aircraft have a seating capacity of more than 38 seats or a maximum payload of more than 4,200 kilograms [9,260 pounds] in Australian regular public transport operations. Low-capacity aircraft have a seating capacity of fewer than 39 seats or a maximum payload of 4,200 kilograms in Australian regular public transport operations.)

Relatively low rates of incidents per 100,000 hours flown by charter aircraft (Table 4, page 31) were inconsistent with total accidents involving charter aircraft; the discrepancy indicates a more effective reporting culture in the high-capacity aircraft sector and the low-capacity aircraft sector of regular public transport, the report said.

Accident data and incident data also were reported using ATSB’s investigation categories. Each ATSB investigation initially is categorized as investigation category 4, then upgraded or downgraded as required on a scale from category 1 to category 5.

“In broad terms, the higher the number, the less serious the occurrence,” the report said. “Categories 1 and 2 are applied if there is a significant threat to

Continued on page 32

Table 3

Australian Accidents and Fatal Accidents, High-capacity[1] and Low-capacity[2] Aircraft, 1992–2001

	Year									
Category	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
High-capacity Aircraft										
All accidents	1	2	1	1	0	1	7[3]	3	3	1
Fatal accidents	0	0	0	0	0	0	0	0	0	0
Low-capacity Aircraft										
All accidents	5	4	4[4]	2	0	2	3	3	3	4
Fatal accidents	1	0	1	0	0	0	0	1	0	0

Note: Accidents comprise aircraft registered in Australia.

[1]High-capacity aircraft have a seating capacity of more than 38 seats or a maximum payload of more than 4,200 kilograms (9,260 pounds) in Australian regular public transport.

[2]Low-capacity aircraft have a seating capacity of fewer than 39 seats or a maximum payload of 4,200 kilograms in Australian regular public transport.

[3]Data include five accidents in which aircraft were on the ground with passengers on board.

[4]Data include one accident involving two fatalities during a training flight in regular public transport.

Source: Australian Transport Safety Bureau

Table 4

Australian Incident Rates for High-capacity,[1] Low-capacity[2] and Charter Aircraft, 1993 to 2002

Year	HCA Incidents per 100,000 Departures	HCA Incidents per 100,000 Hours Flown	LCA Incidents per 100,000 Departures	LCA Incidents per 100,000 Hours Flown	CA Incidents per 100,000 Hours Flown[1]
1993	260.3	121.6	115.7	153.2	80.7
1994	301.3	133.4	108.7	138.0	71.9
1995	264.5	116.5	103.2	129.0	75.9
1996	242.0	102.9	109.6	137.9	75.1
1997	285.6	117.4	134.4	157.9	69.9
1998	465.1	192.4	173.9	200.7	81.6
1999	548.8	226.9	203.1	235.8	80.6
2000	528.1	219.6	242.4	277.2	89.6
2001	501.4	213.3	266.6	294.5	73.4
2002[3]	553.9	238.8	245.5	259.5	88.0

Note: Incidents comprise aircraft registered in Australia.

[1]High-capacity aircraft have a seating capacity of more than 38 seats or a maximum payload of more than 4,200 kilograms (9,260 pounds) in Australian regular public transport.

[2]Low-capacity aircraft have a seating capacity of fewer than 39 seats or a maximum payload of 4,200 kilograms in Australian regular public transport.

[3]Departure data for charter aircraft were unavailable.

HCA = High-capacity aircraft LCA = Low-capacity aircraft CA = Charter aircraft

Source: Australian Transport Safety Bureau public safety, while category 4 is normally used for occurrences where the facts do not indicate a serious safety deficiency or where the deficiency is well-known. Occurrence categories have varied over time, with the balance between categories 4 and 5 in particular influenced by resource availability and investigator workload. For the period 1993 to 2002, most high-capacity, low-capacity and charter accidents [were] category 4."

ATSB's investigation category 1 comprises the following:

- An accident involving one or more high-capacity air transport (scheduled and nonscheduled) passenger aircraft with fatalities;

- An accident involving one or more high-capacity air transport (scheduled and nonscheduled) passenger aircraft without fatalities where there was a significant risk of fatalities or serious injuries, a substantial commitment of investigative resources is likely to significantly mitigate future high-capacity air transport accidents, and funding is available for an investigation under this category; or,

- A serious incident involving one or more high-capacity air transport (scheduled and nonscheduled) passenger aircraft where there was a significant risk of fatalities or serious injuries and a substantial commitment of investigative resources is likely to significantly mitigate future high-capacity air transport (scheduled and nonscheduled) accidents, and funding is available for an investigation under this category.

From 1998 through 2002, no accidents or incidents were assigned to category 1.

Category 2 comprises the following:

- An accident involving one or more high-capacity air transport cargo aircraft with fatalities and serious injuries;

- An accident involving one or more high-capacity air transport cargo aircraft without fatalities and serious injuries where there was a significant risk of fatalities or serious injuries, a substantial commitment of investigative resources is likely to significantly mitigate future high-capacity air transport cargo aircraft accidents, and funding is available for an investigation under this category;

- An accident involving one or more low-capacity air transport (scheduled) passenger aircraft with a significant number of fatalities (for example, more than five fatalities) and serious injuries;

- An accident involving one or more low-capacity air transport (scheduled) passenger aircraft without fatalities or with a relatively low level of fatalities (for example, fewer than five fatalities) and serious injuries where there was a significant risk of more fatalities or serious injuries, a substantial commitment of investigative resources is likely to significantly mitigate future low-capacity air transport (scheduled) accidents, and funding is available for an investigation under this category;

- A serious incident involving one or more low-capacity air transport (scheduled) passenger aircraft where there was a significant risk of multiple fatalities (for example, more than five fatalities) and serious injuries, a substantial commitment of investigative resources is likely to significantly mitigate future low-capacity air transport (scheduled) accidents, and funding is available for an investigation under this category; or,

- An accident involving one or more low-capacity charter (nonscheduled) aircraft with fare-paying passengers and multiple fatalities and serious injuries (for example, more than five fatalities), a substantial commitment of investigative resources is likely to significantly mitigate future low-capacity air transport (scheduled) and charter (non-scheduled) accidents, and funding is available for an investigation under this category.

From 1998 through 2002, the following were reported in category 2:

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- One high-capacity aircraft accident in 1999;
- One low-capacity aircraft accident in 2000;
- One charter aircraft accident in 1998, one in 2000 and one in 2001;
- No high-capacity aircraft incidents;
- One low-capacity aircraft incident in 1998, one in 2000 and one in 2002; and,
- No charter aircraft incidents.

Category 3 comprises the following:

- An accident involving one or more low-capacity air transport passenger (scheduled) or charter (nonscheduled) aircraft with fare-paying passengers with fatalities and/or serious injuries not classified as a category 2 investigation;
- An accident involving air transport cargo operations with fatalities;
- An accident involving one or more training aircraft with fatalities, investigation is likely to significantly mitigate future accidents, and funding is available for an investigation under this category;
- An accident without fatalities involving one or more high-capacity air transport aircraft or low-capacity air transport aircraft not classified as a category 1 or category 2 investigation, investigation is likely to significantly mitigate future accidents, and funding is available for an investigation under this category;
- An accident involving one or more general aviation aircraft (other than sport aviation) with fatalities where investigation is likely to significantly mitigate future accidents and funding is available for an investigation under this category;
- An accident involving one or more charter aircraft or other general aviation aircraft, a significant risk of fatalities or serious injuries and a substantial commitment of investigative resources would significantly mitigate accidents, and funding is available for an investigation in this category;
- A serious incident involving one or more high-capacity air transport aircraft or low-capacity air transport aircraft not classified as a category 1 or category 2 investigation, investigation is likely to significantly mitigate future accidents, and funding is available for an investigation under this category; or,
- A serious incident involving one or more air transport cargo, charter or training aircraft where investigation is likely to significantly mitigate future accidents and funding is available for an investigation under this category.

From 1998 through 2002, the following were reported in category 3:

- Two high-capacity aircraft accidents in 1999 and one in 2000;
- One low-capacity aircraft accident in 1999;
- Three charter aircraft accidents in 1998, two in 1999, three in 2000, two in 2001 and two in 2002;
- Two high-capacity aircraft incidents in 1998, one in 1999, four in 2000, 10 in 2001 and two in 2002;
- Two low-capacity aircraft incidents in 1998, two in 1999, four in 2000 and four in 2001; and,
- One charter aircraft incident in 1998, three in 1999 and one in 2001.

Category 4 comprises the following:

- An accident involving a non-Australian-registered aircraft covered by Article 26 of the Chicago Convention that is not being investigated as category 1, category 2 or category 3;
- An accident involving aircraft (other than sport aviation) with fatalities where available resources and future safety considerations do not allow for a more detailed investigation;

- An accident or serious incident involving Australian-designed and Australian-manufactured aircraft types on the Australian Register with international safety implications not being investigated as category 1, category 2 or category 3;

- An accident or serious incident involving one or more high-capacity air transport aircraft or low-capacity air transport aircraft not being investigated as category 1, category 2 or category 3 and funding is available for an investigation;

- An accident involving one or more charter aircraft or general aviation aircraft without fatalities where a limited commitment of investigative resources could significantly mitigate future aviation accidents and funding is available for an investigation; or,

- A serious incident involving one or more non-air-transport aircraft where a limited commitment of investigative resources could significantly mitigate future accidents and funding is available for an investigation.

From 1998 through 2002, the following were reported in category 4:

- One high-capacity aircraft accident in 1998, three in 1999, two in 2000 and one in 2001;

- Two low-capacity aircraft accidents in 1998, two in 1999, two in 2000 and two in 2001;

- Thirty-seven charter aircraft accidents in 1998, 19 in 1999, seven in 2000, seven in 2001 and four in 2002;

- A total of 580 high-capacity aircraft incidents in 1998, 551 in 1999, 76 in 2000, 33 in 2001 and 26 in 2002;

- A total of 313 low-capacity aircraft incidents in 1998, 289 in 1999, 37 in 2000, 15 in 2001 and six in 2002; and,

- A total of 187 charter aircraft incidents in 1998, 173 in 1999, 16 in 2000, seven in 2001 and four in 2002.

Category 5 comprises the following:

- An accident (including an accident with fatalities) or serious incident involving a sport aviation aircraft unless a non-Australian-registered aircraft is involved and is required to be investigated under Article 26 of the Chicago Convention;

- An accident involving aircraft without fatalities where the potential safety lessons do not, after initial review, justify the commitment of investigative resources within available funds (basic incident data will be filed for statistical purposes); or,

- A serious incident or incident involving aircraft where the potential safety lessons do not, after initial review, justify the commitment of investigative resources within available funds (basic incident data will be filed for statistical purposes).

From 1998 through 2002, the following were reported in category 5:

- One high-capacity aircraft accident in 1999, two in 2001 and one in 2002;

- One low-capacity aircraft accident in 2001 and four in 2002;

- Fifteen charter aircraft accidents in 2000, 22 in 2001 and 13 in 2002;

- A total of 781 high-capacity aircraft incidents in 1998, 1,058 in 1999, 1,627 in 2000, 1,661 in 2001 and 1,690 in 2002;

- A total of 257 low-capacity aircraft incidents in 1998, 382 in 1999, 750 in 2000, 715 in 2001 and 534 in 2002; and,

- A total of 218 charter aircraft incidents in 1998, 233 in 1999, 414 in 2000, 336 in 2001 and 385 in 2002.■

[This article, except where specifically noted, is based on *Annual Review 2003* by the Australian Transport Safety Bureau (ATSB) and on definitions of terms published on the ATSB Internet site, <www.atsb.gov.au>.]

STATS

Report Cites Turbulence, Convection Factors as Prominent in FARs Part 121 Weather-related Accidents

Weather-related-accident reduction in FARs Part 91 operations appears to be on target for meeting 10-year program goals.

— FSF LIBRARY STAFF

Reports

National Aviation Weather Program, Mid-course Assessment: Accident Reduction Trends Confirm Value of Coordinated R&D Programs. U.S. Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM). August 2003. FCM-R20-2003. 80 pp. Figures, tables, appendixes, images, references. Available from OFCM.*

Midway through a 10-year U.S. National Aviation Weather Program, designed to reduce fatal weather-related aviation accidents, statistics show the following trends, according to the OFCM report:

- U.S. Federal Aviation Regulations (FARs) Part 121 aircraft experienced only two weather-related fatal accidents in the 1994–2001 period, preventing trend analysis. Nevertheless, there was a downward trend in all weather-related Part 121 accidents;
- Part 91 aircraft showed strong downward trends in numbers of fatal accidents, and the 80-percent reduction goal appears attainable by 2006; and,
- Overall, Part 135 aircraft are not experiencing the same risk reductions as Part 91 aircraft and Part 121 aircraft, mainly because of factors unique to Part 135 aircraft, such as range of operations and types of services.

In 1997, recommendations from the U.S. White House Commission on Aviation Safety and Security called for an 80-percent reduction in fatal aviation accidents from all causes as a 10-year national goal. The U.S. Federal Aviation Administration (FAA) adopted the 80-percent reduction goal and initiated the "Safer Skies" plan. In parallel, the U.S. National Aviation Weather Program Council recommended an 80-percent reduction in weather-related accidents as the overall measure of success for its coordinated research-and-development (R&D) programs.

To assess progress toward reducing weather-related risks to aviation safety, this report examined accident data obtained from FAA and the U.S. National Transportation Safety Board and compared accidents in which weather was identified as a factor to accidents with non-weather-related factors. The report contains data tables comparing accidents (fatal and nonfatal) by types of weather hazards, meteorological conditions, frequency per 100,000 flight hours and program goals. Using 1996 accident levels as the benchmark, the report identifies trends in weather-related accidents for operations conducted under Part 91, Part 121 and Part 135 and offers recommendations for continuing initiatives.

The report says, concerning Part 121 weather-related accidents, "The most notable feature in the data is the prominence of … turbulence and convection hazards, in the citations each year. … These turbulence and convection hazards dominate the weather conditions that continue to contribute to accidents

— albeit not usually fatal ones — for the major air carriers."

Trends do not indicate that accident-reduction goals for Part 135 aircraft will be met in the categories of restricted visibility and ceiling hazards, precipitation (nonicing) hazards and icing conditions, the report said. Trends in other Part 135 weather-related accident categories are ambiguous. "The aircraft category regulated under [FARs] Part 135 displays weather-related accident-rate trends distinct from both the Part 91 and Part 121 categories," says the report. "Aviation-weather initiatives and programs should consider special factors relevant to this category, rather than assuming it is partly like the large commercial air carriers and partly like general aviation."

What Aircrews Should Know About Their Occupational Exposure to Ionizing Radiation. Friedberg, Wallace; Copeland, Kyle. U.S. Federal Aviation Administration (FAA) Office of Aerospace Medicine (OAM). DOT/FAA/AM-03/16. October 2003. 11 pp. Tables, references. Available on the Internet at <www.cami.jccbi.gov> or from NTIS.**

Flight crews are occupationally exposed to ionizing radiation, which causes subatomic particles to interact with an atom, resulting in the loss of an electron or even breakage of the nucleus. When such changes occur in body tissues, health issues can arise, principally a small increase in the lifetime risk of fatal cancer.

Exposure of flight crews to potentially excessive ionizing radiation results mainly from galactic cosmic radiation. The report defines ionizing radiation and identifies ionizing radiation doses from natural sources within the United States. Health risks to crewmembers and their children irradiated *in utero* and the risk of genetic defects in future generations are explained.

The report suggests ways that flight crewmembers may determine their exposure using computer software provided by FAA or dosing tables based on altitude, flight time and total trip time.

The Effects of Laser Illumination on Operational and Visual Performance of Pilots Conducting Terminal Operations. Nakagawara, Van B.; Montgomery, Ron W.; Dillard, Archie; McLin, Leon; Connor, C. William. U.S. Federal Aviation Administration (FAA) Office of Aerospace Medicine (OAM). DOT/FAA/AM-03/12. August 2003. 13 pp. Figures, references. Available on the Internet at <www.cami.jccbi.gov> or from NTIS.**

In response to hundreds of reported incidents involving the illumination of flight crewmembers by laser light, the FAA revised *FAA Order 7400.2, Part 6, Miscellaneous Procedures: Outdoor Laser Operations* to protect flight crewmembers and passengers from biological tissue damage and temporary visual impairment resulting from exposure to visible laser beams in designated zones of navigable airspace.

To validate FAA recommendations, 38 multiengine-rated civilian and military pilots participated in tests to evaluate their performance during simulated approach and departure maneuvers in the critical flight zone (CFZ), one of the designated zones of navigable airspace defined in relation to an airport reference point, while exposed to laser radiation.

Results validated the FAA recommendations for limits on laser light exposure in the CFZ. Pilots reported a "slight" effect on their operational and visual performance in the CFZ. Altitude of aircraft above the ground and distance from the landing area in the CFZ provided adequate time for visual recovery after laser exposure. Pilots noted that familiarization with the aircraft, instrument training and familiarization with effects of laser exposure appeared to improve the ability to tolerate laser events.

The report says, "Laser illumination at a higher level of exposure resulted in an unacceptable number of visual and operational problems."

Civil and Military Aircraft Accident Procedures for Police Officers and Emergency Services Personnel. Australian Transport Safety Bureau (ATSB) and the Directorate of Flying Safety–Australian Defence Force (DFS-ADF). August 2003. Edition 2. 40 pp. Tables, photographs, checklist. Available from DFS-ADF.***

This booklet provides guidance to civil aviation authorities, military and emergency personnel, and others who may be the first to arrive at an aircraft-accident site. Essential procedural steps are outlined and address notification; site coordination and security; protection of wreckage; recording eyewitness accounts; rescue and recovery; dangerous materials; and site hazards. A checklist of reminders for emergency-services personnel is included.

This edition supersedes Edition 1, dated November 2002, making minor corrections and reflecting the new Transport Safety Investigation Act 2003.

Books

100 Years of Civil Aviation. International Systems and Communications Limited (ISC); International Civil Aviation Organization (ICAO). London, U.K.: ISC, 2003. 312 pp. Photographs.

Articles about the first 100 years of civil aviation emphasize contributions made by individuals and organizations in developing aircraft, systems and safety. Articles reflect upon visions held by aviation pioneers and aviation organizations; contributions of science and technology; socio-economic and cultural influences upon the aviation industry; standards and recommended practices; and programs initiated by ICAO and its members. Challenges to the aviation industries of today and tomorrow also are discussed.

The publication includes a chapter on the late Jerome F. "Jerry" Lederer, "Mr. Aviation Safety," founder of Flight Safety Foundation.

The Plane Truth: Airline Crashes, the Media, and Transportation Policy. Cobb, Roger W.; Primo, David M. Washington, D.C., U.S.: Brookings Institution Press, 2003. 217 pp. Figures, tables, appendix, notes, index.

The book says that an airline accident brings two competing human responses into play. The first response, reinforced by media images of aircraft debris and human casualties, is fear and the question, "Is flying safe?" The second response, acceptance of the relative safety of flying, is based on logic. "The media stress the first response, while officials focus on the second," says the book. "Fear, however, usually trumps logic as a prime reaction to disaster situations."

Using several significant U.S. aircraft accidents as examples, the book describes how media reporting influenced reactions and investigations by government and industry, and, ultimately, airline transportation policy. The appendix lists accidents by date, indicating airline name, cause of accident and resulting policy changes.

[The Brookings Institution is a private, nonprofit organization devoted to research, education and publication on issues of U.S. domestic and foreign policy.]

Encyclopedia of Technical Aviation. Bristow, Gary V. New York, New York, U.S.: McGraw-Hill, 2003. 463 pp. Figures.

Aviation terminology is as varied and diverse as the aviation topics it describes — aerodynamics, human factors, engines, meteorology, satellite navigation, rules of the air, instrument flight rules and aircraft performance. The text is presented in dictionary-style, A-Z format, starting with "absolute ceiling" and ending with "zero-fuel weight."

The book is written as a reference resource for pilots in all stages of their careers, from pilots in training to early-career pilots to experienced pilots desiring to expand or refresh knowledge of the ever-changing, technologically advancing aviation world.

Regulatory Materials

Airworthiness Approval of Global Navigation Satellite System (GNSS) Equipment. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 20-138A. Dec. 22, 2003. 68 pp. Tables, appendixes. Available from GPO.****

This AC provides guidance for obtaining airworthiness approval of GNSS equipment, specifically the following:

- GNSS sensors, including those incorporating wide area augmentation system (WAAS), local area augmentation system (LAAS) or the Russian Global Navigation Satellite System (GLONASS); and,

- GNSS stand-alone navigation equipment for en route, terminal or approach operations (including Category I precision approaches).

The document summarizes the approval process, covers GNSS as an aid to visual flight rules navigation and instrument flight rules navigation, and addresses equipment performance and function. Samples of quick reference guides as training aids and samples of supplements to flight manuals are included.

[This AC cancels AC 20-138, *Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for Use as a VFR and IFR Supplemental Navigation System*, dated May 25, 1994.]

Parts 91, 121, 125, and 135 Flightcrew Procedures During Taxi Operations. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 120-74A. Sept. 26, 2003. 44 pp. Appendixes. Available from GPO.****

Getting to and from a runway has become increasingly complex because of the increased numbers of aircraft and adherence to scheduled departure times, variously combined with weather, aircraft type, language usage and time of day, the AC says. The AC focuses on activities occurring within the cockpit (planning, communicating and coordinating), rather than actual control of the aircraft, to reduce the potential for runway incidents and accidents.

The AC's intended use is development and implementation of standard operating procedures (SOPs) for safe aircraft operations during taxiing and is directed to persons operating aircraft under U.S. Federal Aviation Regulations (FARs) Part 91, Part 121, Part 125 and Part 135 with two or more pilots on the flight deck. The AC recommends that these guidelines become an integral part of all SOPs, flight operations manuals and formal flight crew training programs.

Guidelines are grouped into six major categories: planning; situational awareness; use of written taxi instructions; intra-flight deck and cockpit verbal coordination; air traffic control and flight crew communication; and taxiing. Examples of SOPs appear in the appendixes.

[This AC cancels AC 120-74, *Parts 121, 125, and 135 Flightcrew Procedures During Taxi Operations*, dated June 18, 2001.]

Turbine Engine Continued Rotation and Rotor Locking. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 33.74/92-1A. July 23, 2003. 6 pp. Available from GPO.****

The safety objective of this AC is to ensure that airplane and helicopter turbine engines that continue to rotate after shutdown will not create hazards to the aircraft. This AC provides guidance to engine manufacturers, modifiers, foreign regulatory authorities, FAA engine-type-certification engineers and their designers regarding failure conditions, fire hazards, fatigue assessment and rotor-locking devices.

[This AC revises AC 33.74/92, *Turbine Engine Continued Rotation and Rotor Locking*, dated Feb. 14, 1997.] ■

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* Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM)
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Error in Airspeed Calculations Cited in B-747 Tail Strike

The accident report by the New Zealand Transport Accident Investigation Commission said that the airplane's rotation speed had been calculated using an aircraft weight that was 100 metric tons (220,460 pounds) less than the actual takeoff weight.

— FSF EDITORIAL STAFF

The following information provides an awareness of problems through which such occurrences may be prevented in the future. Accident/incident briefs are based on preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be entirely accurate.

AIR CARRIER

Rotation Speed Was 33 Knots Too Slow, Report Says

Boeing 747-400.
Substantial damage. No injuries.

As the captain rotated the airplane for takeoff from an airport in New Zealand on a flight to Singapore, the tail struck the runway and scraped the surface for about 490 meters (1,608 feet) until the airplane became airborne.

An investigation found that the tail strike occurred because the airplane's rotation speed was 33 knots less than the 163 knots required for the airplane's weight. The accident report said that the rotation speed had been calculated incorrectly, based on an airplane weight that was 100 metric tons (220,460 pounds) less than the actual weight of the accident airplane.

"A takeoff weight transcription error, which remained undetected, led to the miscalculation of the takeoff data, which in turn resulted in a low-thrust setting and excessively slow takeoff reference speeds," the report said. "The system defenses did not ensure [that] the errors were detected, and the airplane flight management system itself did not provide a final defense against mismatched information being programmed into it."

The report said that, during the takeoff, the airplane had moved near the edge of the runway and the pilots had not responded correctly to a stall warning.

"The airplane takeoff performance was degraded by the inappropriately low thrust and reference speed settings, which compromised the ability of the airplane to cope with an engine failure and hence compromised the safety of the airplane and its occupants," the report said.

Faulty Slat Configuration Cited in Rejected Takeoff

McDonnell Douglas DC-10. Minor damage. No injuries.

Visual meteorological conditions prevailed for the morning takeoff from an airport in the United States. The airplane was taxied from the gate to the departure runway — a distance of about six miles (10 kilometers). During acceleration, the takeoff warning horn sounded and the crew rejected the takeoff.

As the airplane decelerated, air traffic control said that smoke — and then fire — was coming from the left-main landing gear. The airplane was stopped on the runway, the flight crew conducted appropriate checklists, and the seven people in the airplane disembarked using an evacuation slide. Aircraft rescue and fire fighting equipment were sent to the scene.

A preliminary investigation indicated that the takeoff warning horn had sounded because of "a configuration problem with the inboard/outboard slats," the accident report said. "An inspection of the center-inboard slat-drive mechanism revealed the inboard slat-drive keel-beam support-rod end had popped off the bushing."

Airplane Door Damaged During Pushback

Airbus A330. Minor damage. No injuries.

In preparation for departure on a domestic flight in Australia, the two forward-left aircraft doors had been closed, the airbridges had been retracted and the ground engineer had been told that departure was imminent. Because aircraft weight-and-balance data differed from what had been expected, passenger seats were reassigned; an airbridge servicing door was returned to the airplane, and a cabin-crew customer service manager reopened the door to allow ground-based service agents to board the aircraft to supervise re-seating. The door was opened without the permission of the captain — whose permission was required by the operator.

The ground engineer was not told that the airbridge had been returned to the door, "and clearance to open the door was not sought," a report said. The only indication to the flight crew that the door had been opened was the appearance of an amber light on the door symbol on the electronic centralized aircraft monitoring system. Nevertheless, because the flight crew already had verified that the doors were closed, there was no requirement to check the doors again before pushback began.

"The flight crew obtained clearance for pushback from air traffic control, and the pushback from the terminal was commenced," the report said. "As the aircraft moved rearwards, the opened door … impacted the airbridge. The door and airbridge were deflected into the aircraft fuselage, causing significant damage to the fuselage skin and associated structure. Damage to the airbridge was limited to surface scraping and associated paint loss."

After the incident, the operator reviewed its procedures for airbridge return and door opening and took steps to improve communication and coordination among those responsible for dispatching aircraft.

Faulty Starter Generator Cited in EFIS Failures

Saab Aircraft SF 340B. No damage. No injuries.

The airplane was being flown through Flight Level 180 (approximately 18,000 feet) after departure from an airport in Australia when the first officer's two electronic flight information system (EFIS) screens, on the right side of the instrument panel, failed.

The crew conducted the EFIS "Failure/disturbances" checklist, and then the central-warning-panel ice-protection annunciator light and the cabin-pressure annunciator light illuminated. The crew began an emergency descent and declared pan pan, an urgent condition.

"During the descent, a number of other cockpit warnings and cautions activated, and some aircraft systems failed," the accident report said. "The crew became aware that the right DC [direct current] generation system was operating abnormally. Their attempts to rectify that situation were unsuccessful."

They diverted the airplane to an en route airport, where they conducted a landing.

The failure of the EFIS screens and the subsequent problems were "consistent with a right-system voltage drop from the rated 28 volts DC to below 18 volts," the report said. "During the investigation, it became apparent that in some Saab 340 aircraft, a starter generator could fail without taking the generator off line and alerting the crew, resulting in low system voltage."

The report said that the crew had overlooked a checklist item that required a check of generator voltage.

"Consequently, the crew did not recognize the developing low voltage condition that led to the cascading series of warnings, cautions and failures," the report said. "The bus tie relay, which was designed to automatically connect the two main electrical systems in the case of generator failure, did not operate. An optional generator control unit modification to prevent unalerted low-voltage conditions had not been incorporated."

Fuel Starvation Prompts Engine Shutdown Over English Channel

Piper PA-34-220T Seneca III. No damage. No injuries.

The airplane was being flown on a public transport flight across the English Channel from England to France when the right engine stopped producing power and ran roughly. Gauges indicated that the right fuel tank was empty, that fuel pressure for the right engine was zero and that the left fuel tank contained 10 gallons (38 liters) of fuel.

The captain shut down and feathered the right engine and diverted the airplane to a nearby airport, where she conducted a landing. Maintenance checks determined that fuel starvation had caused the problem.

An investigation found that the day before the flight, the captain had calculated the amount of fuel required for the flight and that the fueling organization was asked to add about 26 gallons (100 liters) of fuel to the tanks.

"However, the fax machine at the refueling point had run out of toner," the report said. "The fax request did not print, with the result that the refueling organization was unaware that the aircraft required refueling, and it was not refueled."

When the captain conducted the preflight inspection, she could not see fuel in the fuel tanks, "but given the reduced amount to be carried, she was not concerned." The fuel gauges indicated less fuel in each fuel tank than she expected, but "she doubted the accuracy of light aircraft fuel gauges," the report said.

After the incident, the operator reviewed company operating procedures for refueling and in-flight fuel management, the captain received additional training, and the refueling organization began indicating on the fuel-order form how much fuel was loaded into each fuel tank.

Skyvan Strikes Canal Bank During Emergency Landing

Short Brothers SC.7 Skyvan. Substantial damage. Two fatalities, five serious injuries.

Visual meteorological conditions prevailed for the late morning takeoff of the charter passenger and cargo airplane from an airport in Guyana. About one minute after takeoff, when the airplane was at 200 feet to 300 feet, the pilot declared an emergency and said that he intended to land the airplane in a sugar cane field. During the landing, the airplane struck a canal bank near the field.

A preliminary investigation revealed that the right engine was not developing power when the airplane struck the ground. The investigation was continuing.

Airplane Slides Across Icy Ramp Into Concrete Wall

Gates Learjet 35A. Substantial damage. No injuries.

Visual meteorological conditions prevailed for the landing at an airport in the United

States. After landing, the flight crew taxied the airplane off the runway without difficulty, but as the airplane was turned onto the ramp, it slid on a layer of ice.

The brakes were ineffective, and the crew shut down the engines. Nevertheless, because of the downward slope of the ramp area and the wind, which was from 300 degrees at 16 knots, with gusts to 27 knots, the airplane accelerated on the ramp and struck a concrete retaining wall.

An inspection of the area about 90 minutes after the accident found that the layer of ice on the ramp was about one inch (2.5 centimeters) thick.

Tire Fails During Takeoff

Rockwell Commander 690A.
Substantial damage. No injuries.

Visual meteorological conditions prevailed and an instrument flight rules flight plan was filed for the flight from an airport in the United States. During the takeoff roll, about 1,250 feet (381 meters) from the departure end of the runway, the left-main landing gear tire failed. The airplane veered off the runway to the left and stopped in a field.

Landing Gear Fails to Retract, Collapses During Landing

Beech Super King Air 200.
Minor damage. No injuries.

After takeoff from an airport in England, the pilot conducted the usual after-takeoff actions, including moving the landing-gear selector lever to retract the landing gear. After controllers in the air traffic control tower told him that the landing gear was extended, he observed that the selector handle was in the "UP" position and that the "gear unsafe" warning light was illuminated. A visual check confirmed that both main landing gears were extended.

The pilot said that he selected the landing-gear selector lever "DOWN" to recycle the landing gear; subsequently, he was unable to move the lever to the "UP" position. After flying the airplane past the airport control tower, controllers said that the landing gear appeared to be extended, and the pilot decided to land the airplane.

"On landing, the aircraft rolled straight along the runway for a while before it veered to the left and stopped," the accident report said. "Realizing that the landing gear had collapsed, the pilot shut down the engines, switched off the electrical master switch and activated the fuel firewall shutoff valves before evacuating the aircraft, together with the other occupants, through the main entry door."

An examination of the airplane revealed that, although all three landing gears had collapsed, the nose landing gear had remained extended sufficiently to keep the propellers from scraping the ground.

The report said that an electrical problem apparently prevented the landing gear from being completely retracted and that additional tests of the landing gear were planned.

The report also said that the pilot did not follow the correct procedures when he observed the "GEAR UNSAFE" warning light and the absence of three green lights that would have indicated that the landing gear was fully extended.

"The correct procedure when faced with this eventuality was to select the landing gear down again, and, if 'three greens' were not obtained, to isolate the landing gear [circuit breaker] before activating the emergency [landing-]gear extension manual-crank mechanism, until they were obtained," the report said.

Replica of Lindbergh's Plane Destroyed at Air Show

Ryan M1/M2 NYP.
Destroyed. One fatality.

The airplane, a replica of the one in which Charles Lindbergh made the first trans-Atlantic crossing in 1927, was being flown in an air show in England. Soon after the pilot began a series of gentle maneuvers to display the airplane in flight, the right wing "suffered a major structural failure," the accident report said.

As the pilot conducted a level right turn, the right wing leading edge rolled backward and the right wing folded up toward the fuselage. The airplane entered a right spin and struck a building in an industrial area near the airport.

The report said that the wing failure resulted from "the failure in fatigue of a combined right-[main] landing gear and wing-strut support fitting."

Airplane Flips During Attempted Go-around in Strong Winds

De Havilland DHC-6 Twin Otter. Substantial damage. Minor injuries.

Visual meteorological conditions prevailed for the approach to land on a gravel runway in Antarctica. Before the landing, snow had been cleared from the runway, and because of a thaw, the surface was softer than usual.

Winds in the area are influenced by surrounding mountains. As the pilot prepared for the approach to Runway 36, the runway anemometer indicated that winds were from 360 degrees at 10 knots; another anemometer, located on a hill to the east, indicated that winds were from 070 degrees at 20 knots.

"The pilot was familiar with this type of condition and decided to make an approach to Runway 36 using 20 [degrees] to 25 degrees of flap," the accident report said.

After the airplane touched down, the pilot had difficulty maintaining directional control and conducted a go-around. The pilot observed the sea surface, determined that the wind was from the east and conducted an approach to Runway 18. The airplane touched down about 200 meters (656 feet) past the runway threshold, and the pilot applied brakes, full right rudder and full left aileron. He used little or no reverse thrust because he wanted to be prepared to conduct another go-around, if necessary. As the airplane veered to the left, the pilot at first used nosewheel steering to assist with directional control and then decided to conduct a go-around. The airplane veered farther to the left, the nosewheel separated, and the airplane flipped over.

The accident report said, "The pilot's relative lack of recent experience on the aircraft type and his decision not to use full reverse thrust on landing (in the event that a go-around was necessary) were considered by both the pilot and his chief pilot as two of the main causal factors."

After the accident, the operator reviewed currency requirements, crosswind landing techniques and local wind effects.

Loss of Control Follows Landing on Down-sloping Runway

Ayres Turbo-Thrush S2R-T15. Minor damage. No injuries.

The airplane was one of two aircraft being flown in a fire fighting operation on a plantation in Swaziland. Pilots of both airplanes were landing at a nearby airport to take on loads of water and foam. Because of the favorable wind direction and overshoot options, both airplanes were being operated on a runway with a steep downward slope.

As the accident pilot prepared to land his airplane, he selected reverse pitch to help reduce airspeed. The report said that, because of the reduced airflow over the rudder and the right-crosswind component, the pilot experienced a loss of control of the airplane, which departed the runway to the right, "bounced through a drainage ditch" and stopped on a pile of rocks.

Passenger Injured While Hand-swinging Propeller

Aeronca 11AC Chief. No damage. One minor injury.

The airplane was being prepared for a flight from an airport in England. The passenger assisted with the standard starting procedure by hand-swinging the propeller. After the second swing, the engine "coughed and kicked back" and the metal trailing edge of the propeller blade struck the passenger's right hand, breaking a bone and causing a deep cut, the accident report said.

"On a previous day, the [passenger] had spent almost two hours swinging the propeller without managing to start the engine," the report said.

"On this occasion, he swung the propeller without expecting the engine to fire and was caught off guard when it did and the propeller kicked back."

ROTORCRAFT

External Load Strikes, Severs Tail Rotor

Hughes 369F.
Substantial damage. No injuries.

Visual meteorological conditions prevailed for the late afternoon external-load operation in the United States. The accident flight was the last flight of the day, and a load consisting of four ladders had been placed in a cargo net and attached to the helicopter's long line.

After takeoff, as the helicopter accelerated, the pilot heard a bang and felt the helicopter pitch forward and roll left. The pilot conducted an autorotation and landed the helicopter in a riverbed.

A preliminary inspection revealed that one of the ladders had shifted during takeoff and had struck the tail rotor, which separated from the helicopter. The helicopter then struck terrain.

Helicopter Strikes Power Lines During Photographic Flight

Aerospatiale AS 350B.
Minor damage. No injuries.

The helicopter was being flown on a photographic flight in Scotland, with passengers filming marine traffic on two bodies of water. As the pilot flew the helicopter in a descent to 200 feet above ground level, he conducted 1 1/4 turns to the right, then turned the helicopter left and observed power lines about 65 meters (213 feet) ahead. He applied aft cyclic to fly the helicopter over the power lines. After the cameraman told him that the helicopter might have struck the wires, the pilot conducted a landing in a nearby field, where examination of the helicopter showed that both tail-rotor blades and the lower vertical fin had sustained wire-strike damage but were intact. One power line was severed.

After the accident, orange reflective devices were installed on the power lines to increase visibility.

The pilot said that the accident had occurred because the filming operation had distracted him from his flight duties.

R22 Strikes Terrain During Mustering Flight

Robinson R22.
Substantial damage. Two fatalities.

The helicopter was one of two aircraft being flown in a livestock-mustering operation in Australia. After the pilot of the other helicopter had heard no radio transmissions from the accident helicopter for about 15 minutes, he began a search for the helicopter and found the wreckage.

A preliminary investigation revealed that the helicopter had struck the ground heavily with little forward speed and that, at the time of impact, the main-rotor blades were rotating at low speed, the tail rotor was rotating at high speed, and the engine was operating at high power. The clutch shaft apparently failed before the impact.

A preliminary report said that the crashworthiness of the helicopter seats had been compromised by equipment that had been stored under the seats.

The investigation was continuing.■

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