At left, this main landing gear assembly from Air France Flight 447 is part of the debris field found almost two years after the jet crashed.

Modern jetliners just aren't supposed to fall out of the sky. It's simply not acceptable (it's not acceptable when smaller aircraft do it, either, by the way). Decades of refinement, engineering, development and lessons learned have produced an extremely safe worldwide air transportation system. That's one reason the disappearance of an Airbus A330 operating as Air France Flight 447 from over the Atlantic Ocean almost three years ago is serving as a wake-up call to operators and pilots alike.

The investigation into the flight's loss isn't complete, but we do know much more about what happened now that the all-important cockpit voice and flight data recorders have been recovered. The tale they tell has many chapters—about modern automation, old-fashioned complacency, cockpit resource management and pilot training. But the central question remains: How could a modern jetliner, in cruise flight, simply disappear?

WHAT HAPPENED?

It was a few minutes past 0200 Coordinated Universal Time (UTC) on June 1, 2009. The Airbus A330 was in cruise flight over the equatorial Atlantic Ocean at FL350, on a scheduled flight from Rio de Janeiro, Brazil, to Paris, France. Because this is a long flight—the great-circle distance between the two airports is 4941 nm—the captain left the cockpit and retired to a crew rest area at 0202. Minding the store in the cockpit were two first officers.

The widebody twin was flying in the Intertropical Convergence Zone, an area known for intense thunderstorms. That night was no different; at 0208, after studying the onboard weather radar, the first officers adjusted the jet's flight path 12 degrees to the left, presumably to miss the worst of the storms. Other flights in the area were making larger diversions.

Shortly, the Airbus entered the storms. Two minutes earlier, the cockpit had alerted the cabin crew to prepare for some turbulence. The crew also reduced the jet's speed, from 0.82 Mach to 0.80.

At 0210:05, the autopilot and auto-thrust disengaged. The pilot flying (PF) said, "I have the controls." The airplane began to roll to the right and the PF made a nose-up and left input. The stall warning sounded twice. Recorded parameters show a sharp decrease in airspeed, from about 275 KIAS to 60, displayed on the left primary flight display (PFD), followed a few moments later in the speed displayed on the integrated standby instrument system (ISIS), which incorporates attitude, airspeed and altitude information. The aircraft's flight control software went into alternate mode, removing various protections—like excessive pitch inputs.

Around 0210:16, the airplane's pitch attitude increased beyond 10 degrees and it started to climb. The PF made nose-down and left/right roll control inputs. Vertical speed, which had reached as high as a 7000 fpm climb, decreased to 700 fpm. Roll varied between 12 degrees right and 10 degrees left. The speed
displayed on the left side increased sharply to 215 KIAS. The airplane was then at an altitude of about 37,500 feet, with an angle of attack of around four degrees.

At 0210:51, the stall warning triggered again. Thrust levers were positioned in the takeoff/go-around detent and the PF maintained nose-up pitch inputs. The angle of attack, around six degrees at the triggering of the stall warning, continued to increase.

About 15 seconds later, airspeed displayed on the ISIS increased sharply toward 185 KIAS, making it consistent with the values displayed on the left-side PFD. The PF continued to make nose-up inputs. The airplane's altitude topped out at about 38,000 feet, its pitch attitude and angle of attack being 16 degrees.

At around 0211:45, the captain re-entered the cockpit. During the following seconds, all of the recorded speeds became invalid and the stall warning stopped. Altitude had decreased to about 35,000 feet, the angle of attack exceeded 40 degrees and the jet was descending at about 10,000 fpm. The airplane's pitch attitude never exceeded 15 degrees nose up, but roll oscillations continued, sometimes reaching a 40-degree bank. Engine speeds were close to 100 percent. The PF made control inputs to the left and nose-up stops, which lasted about 30 seconds.

At 0212:02, the PF said, “I have no more displays.” The pilot not flying (PNF) added, “We have no valid indications.” At that moment, the thrust levers had been placed in the idle detent and engine speed had dropped to around 55 percent. Some 15 seconds later, the PF made pitch-down inputs. As a result, the angle of attack decreased, the speeds became valid and the stall warning triggered again. This probably was the crew's last opportunity to recover and save the aircraft. At

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**Pitch Plus Power**

The great unanswered question about the loss of AFR447 is and always will be: How did an experienced crew flying for a major carrier lose control, enter a stall, fail to recognize it and maintain it during a descent from more than 38,000 feet and lasting almost four minutes? Without having been there, it's impossible to know.

One thing we do know, however: If the flightcrew had simply maintained pitch and power at or near their cruise-configuration norms until the ice-clogged pitot tubes cleared and the flight control system recognized valid airspeeds, the Airbus in all likelihood would have arrived in Paris safely later that day. If the crew had remembered a very simple formula — pitch plus power equals performance — no one would be studying their actions today, more than two years later. The FAA’s Instrument Flying Handbook (FAA-H-8083-15-1) spends a great deal of time emphasizing the fact that a given power setting and pitch will have specific results in speed and climb. Even a pre-solo student is taught the basics of the pitch/power/performance equation: He or she learns to use full power for climb, around 2300 rpm for cruise and to reduce to 1500 rpm on downwind.

More important, however, is that we all should know — within reasonable tolerances — what pitch and power values will result in desired airplane performance. For example, a Beech Bonanza flying at full power near sea level and with a five-degree nose-up pitch attitude will establish and maintain an approximate 750-fpm climb. The same airplane, in a clean configuration, at approximately 18 inches of manifold pressure and about 2.5 degrees nose-up will maintain altitude at roughly 90 KIAS. Each airplane type will have different numbers, but each will also perform basically the same each time, within the obvious variances produced by weight and atmospheric conditions.

If you don't know some basic pitch/power combinations for your airplane, now is a good time to go out, do some flying and write down the results of various pitch/power combinations. Depending on the kinds of operations in which you engage, you might want to establish values for initial climb, cruise climb, high-speed cruise, long-range cruise, en route descent, approach maneuvering and landing configurations. Put together a basic chart, like the one above, and fill in the blanks. Once it's complete, memorize it, tape it to the instrument panel or somehow figure out how to keep the results handy for when the magic soils the bed.
BEA’s Safety Recommendations

The BEA has issued 10 new safety recommendations as a result of its ongoing investigation into the loss of AFR447, in four broad categories:

OPERATIONS/TRAINING

The BEA’s “investigation brought to light weaknesses in the two copilots: the inappropriate inputs by the PF on the flight controls at high altitude were not noted by the PNF through an absence of effective surveillance of the flight path. The stall warning and the buffet were not identified either.”

The BEA recommends regulatory authorities “review the content of check and training programmes and make mandatory...specific and regular exercises dedicated to manual aircraft handling of approach to stall and stall recovery, including at high altitude.”

Further, the “investigation showed that an absence of training and practice for a crew consisting of two copilots does not guarantee a level of performance equivalent to a crew consisting of a Captain and a copilot when faced with a degraded situation.” The agency recommended “additional criteria for...relief Captain so as to ensure better task-sharing in case of relief crews.”

AIRPLANE CERTIFICATION

The BEA noted the AFR447 “crew never formally identified the stall situation. Information on angle of attack is not directly accessible to pilots.” Thus, regulatory authorities should “evaluate...requiring...an angle of attack indicator.”

FLIGHT RECORDERS

When considering the information available from flight and cockpit data recorders, the BEA noted “it is difficult to reconstruct the indications that were available to the crew on their instrument panel, especially the instructions given by the Flight Director....It is also impossible to see whether there have been any attempts to re-engage the autopilot.” Accordingly, two recommendations involve cockpit-mounted video recorders and rules guaranteeing their confidentiality.

Two additional recommendations would record both the flight director crossbar positions and data displayed on the right-side PFD, plus “evaluate recording of the air data and inertial parameters” used.

TRANSMITTING FLIGHT DATA/POSITION

Owing to the difficulties authorities encountered in finding the flight’s wreckage, the BEA recommended “triggering of data transmission to facilitate localisation as soon as an emergency situation is detected” and ELT activation “when an emergency situation is detected on board.”

0213:32, the PF indicated the jet was descending through 10,000 feet.

Recordings stopped at 0214:28 when the Airbus hit the water. The last recorded values were a vertical speed of -10,912 fpm and a ground-speed of 107 knots. The jet’s pitch attitude was 16.2 degrees nose-up, with a roll angle of 5.3 degrees left. All 216 passengers and 12 crewmembers were fatally injured.

DETAILS

What’s all that mean? According to the Bureau d’Enquêtes et d’Analyses pour la Sécurité de l’Aviation Civile (BEA), the French agency responsible for investigating aviation accidents, beginning at 0210:05 UTC and “likely following the obstruction of the Pitot probes in an ice crystal environment, the speed indications became erroneous and the automatic systems disconnected.”

The airplane’s flight path was not brought under control by the two copilots, who were rejoined shortly after by the Captain. The airplane went into a stall that lasted until the impact with the sea,” which occurred at 0214:28.

The BEA’s Third Interim Report on AFR447—the most recent one—which summarized the agency’s findings as of July 29, 2011, concluded blocked pitot tubes caused the A330’s flight control system to note erroneous airspeed data was being received, and disengage the autopilot and autothrottle systems, as it was designed to do. All of a sudden the crew—who had been mostly worried about circumnavigating thunderstorms—were asked to take over the tasks of maintaining altitude, speed and heading. They had years of experience doing exactly that—the least-experienced copilot had been flying since 2000—but couldn’t pull it off. Why?

As this article was being pre-
What About Airbus Automation?

The A330 uses a fly-by-wire system—the sidesticks are not physically connected to the flight controls. Instead, they are electronically linked to a computer, which determines the pilot’s intent and sends an appropriate signal to hydraulic mechanisms to move the control surfaces. The aircraft has three flight control primary computers and two flight control secondary ones; they do the calculations necessary to deflect the flight controls. Refer to the schematic at right.

The logic governing the computers is called control laws. In nominal operation, the A330 is in normal law. When monitoring triggers a fault, it may be replaced by degraded laws—alternate 1 or 2—or by direct law.

Normal law offers complete protection of the flight envelope: pitch and bank values are limited, based on expected load factor. In alternate law, fewer protections exist. In direct law, the sidesticks control the position of the various control surfaces directly. In alternate or direct law, angle-of-attack protections are no longer available.

The airspeed presented to the crew is the median value. When speeds from one of the three pitot tubes deviates too much from the other two, it is automatically rejected and the one presented is the average of the two remaining values. If the difference between these two remaining values becomes too great, they both are rejected and the control law changes to alternate 2. This is the control law in effect aboard AFR447 beginning at 0210:05 UTC and continuing to the end of the flight data recording.

pared, the BEA had made 10 safety recommendations to various certification and regulatory authorities, including the FAA. Additional recommendations are expected when the final report comes out, presently set for the first half of 2012. No one with even a casual familiarity with the AFR447 accident expects the BEA will not find major fault with the pilots.

LESSONS

Pilots have been known to joke about their understanding of cockpit automation, with phrases like, “Now what’s it doing?” or, “Yeah, it does that.” All of a sudden, it’s not funny any longer.

Air France, in a July 29, 2011, press release, said, “It is important to understand whether the technical environment, systems and alarms hindered the crew’s understanding of the situation.” Further, “It should be noted that the misleading stopping and starting of the stall warning alarm, contradicting the actual state of the aircraft, greatly contributed to the crew’s difficulty in analyzing the situation.”

There’s no question a stall warning system programmed to cease operation because the associated airspeed value is impossibly low needs some attention. And it’s disturbing that airspeed indications may have differed between the two PFDs and the ISIS. These characteristics certainly could have added to confusion in the cockpit. But automation isn’t going away, in part because we humans simply can’t fly accurately enough to meet RVSM standards for example, or fly optimal profiles in terminal airspace.

Regardless, at the end of the day, a well-qualified three-person crew failed to comprehend a relatively simple pitot-tube blockage, stalled the airplane and watched, confused, for almost four minutes as it descended to the ocean at approximately 10,000 fpm. Say what you may about the Airbus design philosophy and highly automated cockpits, but the AFR447 crew utterly failed to fly the airplane when it counted most.

The saddest thing? The crew really didn’t have to do anything: If they simply had maintained heading and attitude, letting airspeed fend for itself for the short time it took for the iced-up pitot tubes to clear themselves, nothing would have happened.

Which is the moral of this story. Regardless of how much automation is available and how well it’s working, we still have to fly the airplane at all times. Even when at high-altitude cruise with the autopilot minding the store, we must remain engaged with what the airplane is doing so we can take over if needed. When, not if, something breaks, we must remember to fly the airplane, even if all we have to work with is a throttle, a stick and some backup instrumentation.