Mystery over the Atlantic: the tragic fate of Air France Flight 447

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Introduction

At 2:02 a.m., on a routine flight from Rio de Janeiro, Brazil, to Paris, France, the captain of Air France 447 (AF447) left the flight deck to take a nap. Within 15 min, everyone aboard the plane will be dead. For more than two years, the disappearance of AF447 over the mid-Atlantic in the early hours of June 1, 2009, remained one of aviation's greatest mysteries. How could an Airbus A330, a technologically state-of-the art airliner, simply vanish?

With the wreckage and flight data recorders lost beneath 2 miles of ocean, experts were forced to speculate using the only data available: a cryptic set of communications beamed automatically from the aircraft to the airline's maintenance center in France. The data implied that the plane had experienced a technical problem – the icing up of airspeed sensors – which in conjunction with severe weather (see Figure E1) led to a complex "error chain" that ended in a crash and the loss of 228 lives.

The matter might have rested there, were it not for the remarkable recovery of AF447's black boxes two years later in 2011. Upon the analysis of their contents, the French accident investigation authority, the *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation* (BEA), released a report that, to a considerable extent, verified the initial suppositions. An even fuller picture emerged with the publication of a book in French entitled *Erreurs de Pilotage* (REF) (Volume 5), by Pilot and Aviation Writer Jean-Pierre Otelli, which included the full transcript of the pilots' conversation.

We now understand that, indeed, AF447 passed into clouds associated with a large system of thunderstorms, its speed sensors became iced over and the autopilot disengaged. In the ensuing confusion, the pilots lost control of the airplane because they reacted incorrectly to the loss of instrumentation and then seemed unable to comprehend the nature of the problems they had caused. Neither weather nor malfunction doomed AF447, nor a complex chain of technical errors, but a simple but persistent mistake on the part of one of the pilots.

Human errors, of course, are never made in a vacuum. Pilots are part of a complex system that can either increase or reduce the probability that they will make a mistake. After this accident, the million-dollar question was whether training, instrumentation and cockpit procedures could be modified all around the world so that no one would ever make this mistake again – or whether the inclusion of the human element will always entail the possibility of a catastrophic outcome. After all, the men who flew AF447 were three highly trained pilots flying for one of the most prestigious fleets in the world. If they could fly a perfectly good plane into the ocean, then what airline could plausibly say, "Our pilots would never make that mistake"?

Dedication: this case work is to honor the memory of all those who lost their lives aboard Air France 447. It is dedicated to three Irish women – Jane Deasy, Aisling Butler and Eithne Walls. You inspire us through your memory.

Synopsis of the final minutes of Air France 447

Here is a synopsis of what occurred during the course of the doomed airliner's final few minutes:

- At 1 h and 36 min into the flight, the airplane entered the outer extremities of a tropical storm system. Unlike other planes' crews flying through the region, AF447's flight crew did not change the route to avoid the worst of the storms. The outside temperature was

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much warmer than the forecast, preventing the still fuel-heavy aircraft from flying higher to avoid the effects of the weather. Instead, they proceeded through a layer of clouds (see Figure E1).

- At 1 h, 51 min into the flight, the cockpit became illuminated by a strange electrical phenomenon. The Co-pilot in the right-hand seat, the more inexperienced 32-year-old named Pierre-Cédric Bonin, asked, “What’s that?” The Captain, Marc Dubois, a veteran with more than 11,000 h of flight time, told him it is St Elmo’s fire, often found with thunderstorms at these latitudes. St Elmo’s fire is a weather phenomenon in which luminous plasma is created by a coronal discharge from a sharp or pointed object in a strong electric field in the atmosphere (such as those generated by thunderstorms).
- At approximately 2 a.m., the other Co-pilot, David Robert, returned to the cockpit after a rest break. At 37, Robert was both older and more experienced than Bonin, with more than double his colleague’s total flight hours. The captain got up and gave him the left-hand seat. Despite the gap in seniority and experience, Dubois left Bonin in charge of the controls.

At 2:02 a.m., the captain left the flight deck to take a nap. Within 15 min, the plane crashed into the Atlantic Ocean.

Crew biographies

Captain Marc Dubois joined Air France in February 1988 and had 10,988 flying hours, of which 6,258 were as Captain, including 1,700 h on the Airbus A330; he had carried out 16 rotations in the South America sector since he arrived in the A330/A340 division in 2007.

First Officer No. 1: First Officer David Robert, the 37-year-old Co-pilot in the left seat, had joined Air France in July 1998 and had 6,547 flying hours, of which 4,479 h were on the Airbus A330; he had carried out 39 rotations in the South American sector since he arrived in the A330/A340 division in 2002. Robert had graduated from *École Nationale de l’Aviation Civile*, one of the elite *Grandes Écoles*, and had transitioned from a Pilot to a management job at the airline’s operations center. He served as a Pilot on this flight to maintain his flying credentials.

First Officer No. 2: First Officer Pierre-Cédric Bonin (PF-Pilot Flying), the 32-year-old Co-pilot in the right seat, had joined Air France in October 2003 and had 2,936 flight hours, of which 807 h were on the Airbus A330; he had carried out five rotations in the South American sector since arriving in the A330/A340 division in 2008.

The cockpit voice recording – the final 10 min of AF447

The following transcript was translated from the original French (Otelli, 2011) and is presented verbatim:

> 02:03:44 (Bonin): The inter-tropical convergence […] look, we’re in it, between “Salpu” and “Tasil” [Salpu and Tasil are two air-traffic-position reporting points] And then, look, we’re right in it […].

The inter-tropical convergence is an area of consistently severe weather near the equator. As is often the case, it has spawned a string of very large thunderstorms, some of which stretch into the stratosphere. Unlike some of the other plane’s crews flying in the region this evening, the crew of AF447 had not studied the pattern of storms and requested a divergence around the area of most intense activity (The last transmission point can be seen in Figure E2) (Otelli, 2011):

> 02:05:55 (Robert): Yes, let’s call them in the back, to let them know […].

Robert pushed the call button to alert the flight attendants that they would be traveling through some turbulence:

> 02:05:59 (flight attendant, heard on the intercom) Yes? Marilyn.
>
> 02:06:04 (Bonin): Yes, Marilyn, it’s Pierre up front […]. Listen, in 2 minutes, we’re going to be getting into an area where things are going to be moving around a little bit more than now. You’ll want to take care.

02:06:13 (flight attendant): Okay, we should sit down then?

02:06:15 (Bonin): Well, I think that's not a bad idea. Give your friends a heads-up.

02:06:18 (flight attendant): Yeah, okay, I'll tell the others in the back. Thanks a lot.

02:06:19 (Bonin): I'll call you back as soon as we're out of it.

02:06:20 (flight attendant): Okay.

The two co-pilots discussed the unusually elevated external temperature, which had prevented them from climbing to their desired altitude and expressed happiness that they were flying an Airbus 330, which had better performance at altitude than an Airbus 340:

02:06:50 (Bonin): Let's go for the anti-icing system. It's better than nothing.

Because they were flying through clouds, the pilots turned on the anti-icing system to try to keep ice off the flight surfaces; ice reduces the plane's aerodynamic efficiency, weighs it down, and in extreme cases, can cause a crash:

02:07:00 (Bonin): We seem to be at the end of the cloud layer, it might be okay.

In the meantime, Robert was examining the radar system and found that it had not been set up in the correct mode. Changing the settings, he scrutinized the radar map and realized that they were headed directly toward an area of intense activity (see the thunderstorm from Figure E1):

02:08:03 (Robert): You can possibly pull it a little to the left.

02:08:05 (Bonin): Sorry, what?

02:08:07 (Robert): You can possibly pull it a little to the left. We're agreed that we're in manual, yeah?

Bonin wordlessly banked the plane to the left. Suddenly, a strange aroma, like an electrical transformer, flooded the cockpit and the temperature suddenly increased. At first, the younger pilot thought that something was wrong with the air-conditioning system, but Robert assured him that the effect was from the severe weather in the vicinity.

Bonin seemed ill at ease. Then the sound of slipstream (a region behind an airplane in which a wake (typically air) is moving at velocities comparable to the moving object) suddenly became louder. This, presumably, was due to the accumulation of ice crystals on the exterior of the fuselage. Bonin announced that he was going to reduce the speed of the aircraft and asked Robert if he should turn on a feature that would prevent the jet engines from flaming out in the event of severe icing (Wise, 2011).

Just then, an alarm sounded for 2.2s, indicating that the autopilot was disconnecting. The was caused by the icing over of the plane's pitot tubes (see Figure E3), externally mounted sensors that determine air speed, had iced over, so human pilots would have to fly the plane by hand.

At this point, the plane had suffered no mechanical malfunction. Aside from the loss of airspeed indication, everything was working perfectly. Otelli (2011) reported that many airline pilots (and, indeed, himself) subsequently flew a simulation of the flight from this point and were able to do so without any trouble. But neither Bonin nor Roberts had ever received training in how to deal with an unreliable airspeed indicator at cruise altitude or in flying the airplane by hand under such conditions:

02:10:06 (Bonin): I have the controls.

02:10:07 (Robert): Okay.

Perhaps spooked by everything that had unfolded over the past few minutes – the turbulence, the strange electrical phenomena, his colleague's failure to route around the potentially dangerous storm – Bonin reacted irrationally. He pulled back on the side stick to put the airplane into a steep climb (see Plate E1 for the layout of an Airbus cockpit), despite having recently discussed the fact that the plane could not safely ascend due to the unusually high external temperature.

Bonin's behavior was difficult for professional aviators to understand:

"If he's going straight and level and he's got no airspeed, I don't know why he'd pull back," says Chris Nutter, an Airline Pilot and Flight Instructor. (Otelli, 2011).

> "The logical thing to do would be to cross-check" – that is, compare the pilot's airspeed indicator with the co-pilot's and with other instrument readings, such as groundspeed, altitude, engine settings, and rate of climb. (Otelli, 2011).
>
> In such a situation, "we go through an iterative assessment and evaluation process," Nutter explains, before engaging in any manipulation of the controls. "Apparently that didn't happen." (Otelli, 2011).

Almost as soon as Bonin pulled up into a climb, the plane's computer reacted. A warning chime alerted the cockpit to the fact that they were leaving their programmed altitude. Then the stall warning sounded. This was a synthesized human voice that repeatedly called out, "Stall!" in English, followed by a loud and intentionally annoying sound called a "cricket."

A stall (see Figure E4) is a potentially dangerous situation that can result from flying too slowly. At a critical speed, a wing suddenly becomes much less effective at generating lift, and a plane can plunge precipitously. All pilots are trained to push the controls forward when they are at risk of a stall, so the plane will dive and gain speed (Wise, 2011).

The Airbus's stall alarm was designed to be impossible to ignore. Yet for the duration of the flight, none of the pilots mentioned it or acknowledged the possibility that the plane had indeed stalled – even though the word "Stall!" blared through the cockpit 75 times.

Throughout, Bonin kept pulling back on the stick, the exact opposite of what he ought to have done to recover from the stall:

> 02:10:07 (Robert): What's this?
>
> 02:10:15 (Bonin): There's no good […] there's no good speed indication.
>
> 02:10:16 (Robert): We've lost the, the, the speeds, then?

The plane soon was climbing at a blistering rate of 7,000 feet per minute. While it was gaining altitude, it was losing speed, until it was crawling along at only 93 knots, a speed more typical of a small single-engine aircraft than a large jet airliner. Robert noticed Bonin's error and tried to correct him:

> 02:10:27 (Robert): Pay attention to your speed. Pay attention to your speed.

He was probably referring to the plane's vertical speed. They were still climbing:

> 02:10:28 (Bonin): Okay, okay, I'm descending.
>
> 02:10:30 (Robert): Stabilize […].
>
> 02:10:31 (Bonin): Yeah.
>
> 02:10:31 (Robert): Descend […] It says we're going up […] It says we're going up, so descend.
>
> 02:10:35 (Bonin): Okay.

Thanks to the effects of the anti-icing system, one of the pitot tubes began to work again. The cockpit displays again showed valid speed information:

> 02:10:36 (Robert): Descend!
>
> 02:10:37 (Bonin): Here we go, we're descending.
>
> 02:10:38 (Robert): Gently!

Bonin eased the back pressure on the stick, and the plane gained speed as its climb became shallower. It accelerated to 223 knots. The stall warning fell silent. For a moment, the co-pilots were in control of the airplane:

> 02:10:41(Bonin): We're […] yeah, we're in a climb.

Yet, still, Bonin did not lower the nose. Recognizing the urgency of the situation, Robert pushed a button to summon the captain:

> 02:10:49 (Robert): Damn it, where is he? Damn it, is he coming or not?

The plane then reached its maximum altitude of 38,000 feet. With engines at full power, the nose pitched upward at an angle of 18 degrees, it moved horizontally for an instant and then began to sink back toward the ocean:

> 02:11:21 (Robert): We still have the engines! What the hell is happening? I don't understand what's happening.

Unlike the control yokes of a Boeing jetliner (see Plate E2), the side sticks on an Airbus are "asynchronous," that is, they move independently. "If the person in the right seat is pulling back on the joystick, the person in the left seat doesn't feel it," says Dr David Esser, a Professor of Aeronautical Science at Embry-Riddle Aeronautical University (Otelli, 2011; Wise, 2011).

"Their stick doesn't move just because the other one does, unlike the old-fashioned mechanical systems like you find in small planes, where if you turn one, the [other] one turns the same way." Robert had no idea that, despite their conversation about descending, Bonin had continued to pull back on the side stick (Otelli, 2011; Wise, 2011).

The men were utterly failing to engage in an important process known as crew resource management. They were failing, essentially, to cooperate. It was not clear to either one of them who was responsible for what and who was doing what. This was a natural result of having two co-pilots flying the plane:

> "When you have a captain and a first officer in the cockpit, it's clear who's in charge," Nutter explains. "The captain has command authority. He's legally responsible for the safety of the flight. When you put two first officers up front, it changes things. You don't have the sort of traditional discipline imposed on the flight deck when you have a captain." (Otelli, 2011)

The vertical speed toward the ocean accelerated. If Bonin let go of the controls, the nose would have fallen, and the plane would have regained forward speed. But because he was still holding the stick all the way back, the nose remained high and the plane had barely enough forward speed for the controls to be effective. As turbulence continued to buffet the plane, it was nearly impossible to keep the wings level:

> 02:11:32 (Bonin): Damn it, I don't have control of the plane, I don't have control of the plane at all!
>
> 02:11:37 (Robert): Left seat taking control!

At last, the more senior of the pilots (and the one who seemed to have a somewhat better grasp of the situation) took control of the airplane. Unfortunately, he, too, seemed unaware of the fact that the plane was stalled, and he also pulled back on the stick. Although the plane's nose was pitched up, it was descending at a 40-degree angle. The stall warning continued to sound. Bonin soon after took back the controls.

A minute and a half after the crisis begins, the captain returned to the cockpit. The stall warning continued to blare:

> 02:11:43 (Captain): What the hell are you doing?
>
> 02:11:45 (Bonin): We've lost control of the plane!
>
> 02:11:47 (Robert): We've totally lost control of the plane. We don't understand at all […] We've tried everything.

By now the plane returned to its initial altitude but was falling fast. With its nose pitched 15 degrees up, and a forward speed of 100 knots, it was descending at a rate of 10,000 feet per minute, at an angle of 41.5 degrees. It maintained this attitude with a little variation all the way to the sea. Though the pitot tubes were now fully functional, the forward airspeed was so low – below 60 knots – that the angle of attack inputs were no longer accepted as valid, and the stall warning horn temporarily stopped. This may have given the pilots the impression that their situation was improving, when in fact it signaled just the reverse.

Another revelation of the Otelli's (2011) transcript was that the captain of the flight made no attempt to physically take control of the airplane. Had Dubois done so, he almost certainly would have understood, as a pilot with many hours flying light airplanes, the insanity of pulling back on the controls while stalled. But instead, he took a seat behind the other two pilots. This, experts say, was not so hard to understand:

> "They were probably experiencing some pretty wild gyrations," Esser says. "In a condition like that, he might not necessarily want to make the situation worse by having one of the crew members actually disengage and stand up. He was probably in a better position to observe and give his commands from the seat behind." (Otelli, 2011)

But from his seat, Dubois was unable to infer from the instrument displays in front of him why the plane was behaving as it was. The critical missing piece of information: the fact that someone was holding the controls all the way back for virtually the entire time. No one had told Dubois, and he did not think to ask:

02:12:14 (Robert): What do you think? What do you think? What should we do?

02:12:15 (Captain): Well, I don't know!

As the stall warning continued to blare, the three pilots discussed the situation with no hint of understanding the nature of their problem. No one mentioned the word "stall." As the plane was buffeted by turbulence, the captain urged Bonin to level the wings – advice that did nothing to address their main problem. The men briefly discussed, incredibly, whether they were in fact climbing or descending, before agreeing that they were indeed descending. As the plane approached 10,000 feet, Robert tried to take back the controls, and pushed forward on the stick, but the plane was in "dual input" mode, so the system averaged his inputs with those of Bonin, who continued to pull back. The nose continued to remain high:

02:13:40 (Robert): Climb […] climb[…] climb[…] climb […]

02:13:40 (Bonin): But I've had the stick back the whole time!

At last, Bonin told the others the crucial fact whose import he had so grievously failed to understand himself:

02:13:42 (Captain): No, no, no […] Don't climb […] no, no!

02:13:43 (Robert): Descend, then […] Give me the controls […] Give me the controls!

Bonin yielded the controls, and Robert finally put the nose down. The plane began to regain speed. But it was still descending at a precipitous angle. As they neared 2,000 feet, the aircraft's sensors detected the fast-approaching surface of the ocean and triggered a new alarm. There was no time left to build up speed by pushing the plane's nose forward into a dive. At any rate, without warning his colleagues, Bonin once again took back the controls and pulled his side stick all the way back:

02:14:23 (Robert): Damn it, we're going to crash […] This can't be happening!

02:14:25 (Bonin): But what's happening?

02:14:27 (Captain): Ten degrees of pitch […]

Exactly 1.4s later, the cockpit voice recorder stopped, and AF447 crashed into the Atlantic Ocean.

Aftermath of Air France 447

On July 5, 2012, the BEA released its final report on the accident. This confirmed the findings of the preliminary reports and provided additional details and recommendations to improve safety. According to the final report (BEA, 2012), the accident resulted from the following succession of major events:

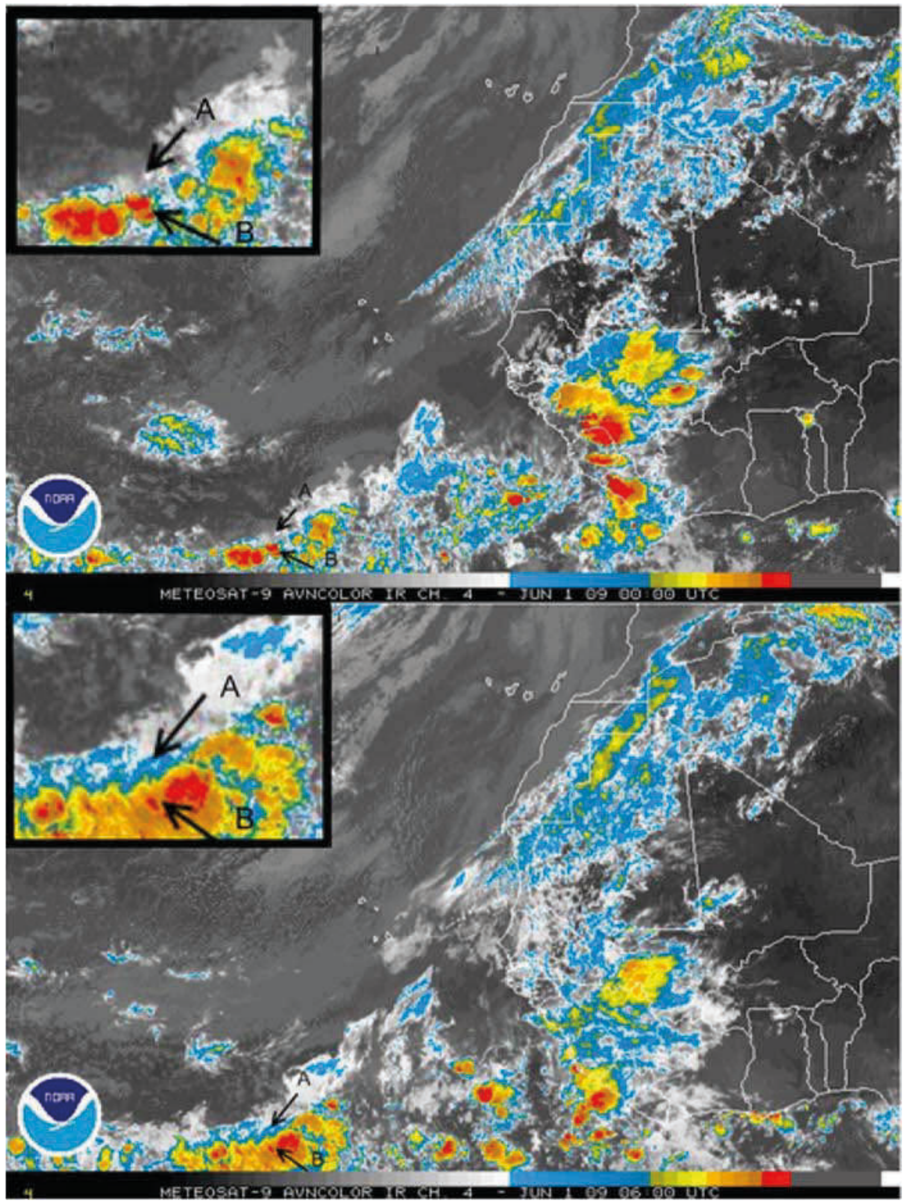
1. temporary inconsistency between the measured speeds, occurring likely because of the obstruction of the pitot tubes by ice crystals, causing the autopilot disconnection and reconfiguration to alternate law;
2. the crew made inappropriate control inputs that destabilized the flight path;
3. the crew failed to follow appropriate procedure for the loss of displayed airspeed information;
4. the crew were late in identifying and correcting the deviation from the flight path;
5. the crew lacked understanding of the approach to stall; and
6. the crew failed to recognize that the aircraft had stalled and consequently did not make inputs that would have made it possible to recover from the stall.

These events resulted from the following major factors in combination:

1. feedback mechanisms on the part of those involved made it impossible to identify and remedy the repeated non-application of the procedure for inconsistent airspeed, and to ensure that crews were trained in icing of the pitot probes and its consequences;
2. the crew lacked practical training in manually handling the aircraft both at high altitude and in the event of anomalies of speed indication;
3. the two co-pilots' task sharing was weakened both by incomprehension of the situation at the time of autopilot disconnection, and by poor management of the "startle effect," leaving them in an emotionally charged situation;
4. the cockpit lacked a clear display of the inconsistencies in airspeed readings identified by the flight computers; and
5. the crew did not respond to the stall warning, whether due to a failure to identify the aural warning, to the transience of the stall warnings that could have been considered spurious, to the absence of any visual information that could confirm that the aircraft was approaching stall after losing the characteristic speeds, to confusing stall-related buffet for overspeed-related buffet, to the indications by the flight director that might have confirmed the crew's mistaken view of their actions, or to difficulty in identifying and understanding the implications of the switch to alternate law, which does not protect the angle of attack.

Exhibit 1

Figure E1 Storm activity on the night of June 9, 2009



Source: Public Domain available at: https://commons.wikimedia.org/wiki/File:NESDIS_Atlantic_Ocean_1_June_0000-0600.png

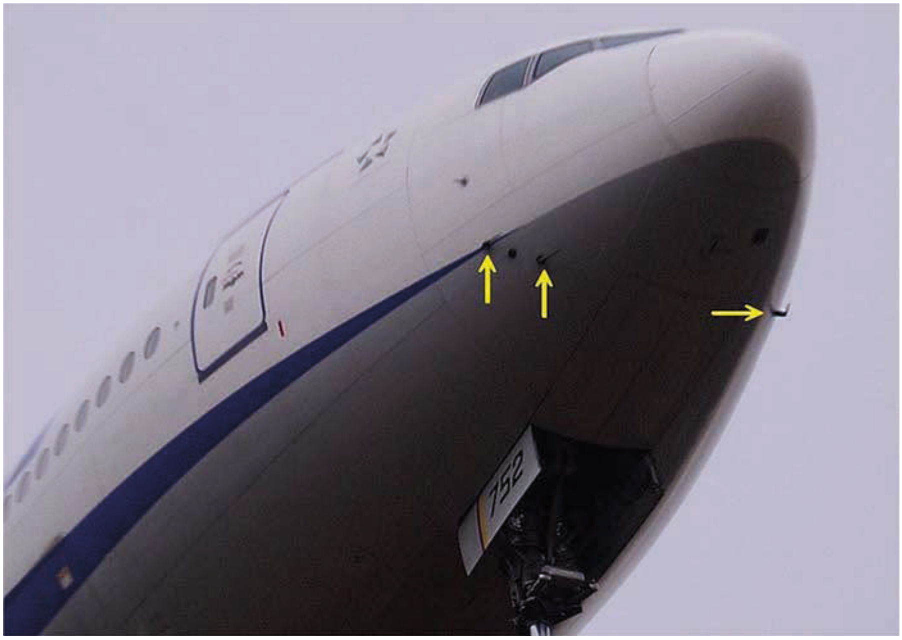
Exhibit 2

Figure E2 Air France 447 Flight path

Source: Public Domain available at: https://commons.wikimedia.org/wiki/File:Air_France_Flight_447_path.svg

Exhibit 3

Figure E3 Pitot tube location



Source: Public Domain available at: https://commons.wikimedia.org/wiki/File:B777-381_JA8752_nose_Pitot_tube_ja.jpg

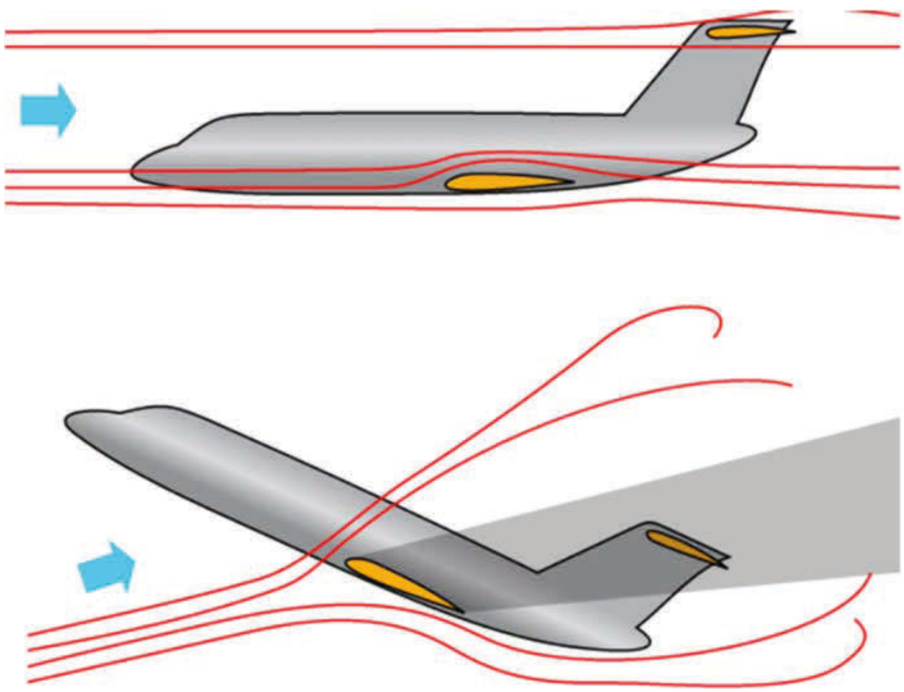
Exhibit 4

Plate E1 Airbus A330 cockpit layout (note the "side sticks")

Source: The file is licensed under the Creative Commons Attribution 2.0 Generic license and available at: https://commons.wikimedia.org/wiki/File:Airbus_A320_Glass_Cockpit.jpg

Exhibit 5

Figure E4 From top: a plane in normal flight; a plane in a stall



Source: The file is licensed under the Creative Commons Attribution 2.0 Generic license and available at: https://commons.wikimedia.org/wiki/File:Deep_stall.svg

Exhibit 6

Plate E2 Boeing cockpit layout (note the large flying "yokes")

Source: The file is licensed under the Creative Commons Attribution 2.0 Generic license and available at: https://commons.wikimedia.org/wiki/File:Boeing_757-300_Cockpit.JPG

Exhibit 7

Figure E5 Approximate flight path of Air France 447

Notes: The solid red line shows the actual route. The dashed line indicates the planned route beginning with the position of the last transmission heard
Source: Courtesy of Oona Räisänen, available in the public domain at: https://commons.wikimedia.org/wiki/File:AF_447_path-notext.svg

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Teaching notes

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Case synopsis

On June 9, 2009, on a routine flight from Rio de Janeiro to Paris, Air France 447 (AF 447), carrying 220 people crashed in the mid-Atlantic Ocean. Drawing from various first-hand accounts (cockpit voice recorder) and secondary evidence (news reports and online sources) of the tragedy, the case provides a detailed account of the key events that took place leading up to the accident. The case describes how the pilots on AF447 were confronted with a scenario they had not faced before, and through the confusion made a series of errors. Through many of the quotes in the text, readers gain an understanding of the impressions and perceptions of the pilots, including how they felt about many of the critical decisions and incidents during the last minutes of the flight. The case concludes by highlighting the main findings of the BEA report.

Teaching objectives

This case has two primary purposes. First, it allows students to examine how cognitive bias can affect decision making in stressful situations. Students explore why individuals make flawed choices. They learn about how managers shape the context and the process through which teams make decisions. For instance, automation can create a climate in which people then struggle to cope with the unexpected when it happens. Students examine why individuals make these systematic errors in judgment. The case demonstrates that leaders need to be aware of the traps that individuals and teams encounter when they make decisions in crisis situations, and it enables students to discuss the strategies that leaders can employ to avoid these traps. Second, the case provides an opportunity to examine a catastrophic failure in detail. Students discover that it can be nearly impossible to identify a single factor that caused the failure. Instead, they learn how to apply multiple theoretical perspectives to examine a serious organizational breakdown. They become familiar with important concepts from behavioral decision theory, such as complex systems theory and how it interacts with cognitive bias.

Research methods

The technical report released by the French Aviation Authority (BEA, 2012) along with the primary flight cockpit voice recorder data (Otelli, 2011) were used as the basis for this case. Other available public data such as news reports were used to round out the synopsis of the case study.

Suggested teaching plan

When the author teaches this case, the students are required to read the case as pre-reading before class. Various media (see supplemental media below) are made available to students before class. This case is best explored over a 90-min session but could be expanded to take up one three-hour session. The author has used this case format in an undergraduate senior capstone organizational behavior seminar and in an MBA Leadership and Organizational Change class. It works particularly well in the MBA class, as students with work experience can see the links between the mistakes the pilots made and their workplaces. Thus, the overall structure of the teaching plan looks as follows:

90-minute session:

1. Introduction of the topic and objectives of the case (5 min).
2. Short discussion of the case with multi-media accompaniment (10 min).
3. Discussion of Question 1 (15 min).

4. Discussion of Question 2 (30 min):
   - Of course, the instructor may decide to add more sections on further phenomena – status quo effects, overconfidence, risk attitude, etc. — of decision making here and come back to the case later. This is the perfect place to shorten or extend the discussion as necessary.
5. Discussion of Question 3 (25 min).
6. Closing of the case and recommendations for the workplace (5 min).

Supplemental media

These media can be assigned pre- or post-class. The author will use clips during class to help introduce the case. The CBS report is useful for this. Children of Magenta is useful in an MBA setting:

- CBS Report on Air France 447 (July 9, 2012) – Airbus Cockpit Controls, available at: www.youtube.com/watch?v=kERSSRJant0
- Lost – The Mystery of Flight 447, available at: www.youtube.com/watch?feature=player_detailpage&v=6QsCkm3c200
- Fatal Flight 447 – Chaos in the Cockpit, available at: www.youtube.com/watch?v=XAom93qwoN0
- Children of Magenta (1997 AA presentation about the Levels of Flight Deck Automation and how to keep out of trouble): www.youtube.com/watch?time_continue=78&v=pN41LvuSz10

Supplemental readings that may aide the instructor

- For in-class experiments on diagnosis bias, see Ariely, D. (2008), *Predictably Irrational: The Hidden Forces that Shape our Decisions*, HarperCollins, New York, NY; and Brafman, O. and Brafman, R. (2009), *Sway: The Irresistible Pull of Irrational Behaviour*, Virgin Books, London.
- For a classic example of an analysis of organizational decision-making through different conceptual lenses, see Allison, G. (1971), *Essence of Decision: Explaining the Cuban Missile Crisis*, Little Brown, Boston, MA.
- For an insightful multi-level analysis of a failure, see Snook, S. (2000), *Friendly Fire: The Accidental Shootdown of US Black Hawks over Northern Iraq*, Princeton University Press, Princeton, NJ.
- For more on cognitive bias research, see Kahneman, D., Slovic, P. and Tversky, A. (1982), *Judgment under Uncertainty: Heuristics and Biases*, Cambridge University Press, New York, NY; Bazerman, M. (1998), *Judgment in Managerial Decision Making*, John Wiley & Sons, New York; Russo, J.E. and Schoemaker, P. (1989), *Decision Traps: The Ten Barriers to Brilliant Decision Making and How to Overcome Them*, Fireside, New York, NY.
- For more on overconfidence bias, see Lichtenstein, S., Fischhoff, B. and Phillips, L. (1982), "Calibration of probabilities: the state of the art to 1980", Kahneman, D., Slovic, P. and Tversky, A. (Eds), *Judgment under Uncertainty: Heuristics and Biases*, Cambridge University Press, New York, NY; In addition, see Arkes, H. and Hammond, K. (1986), *Judgment and Decision-Making: An Interdisciplinary Reader*, Cambridge University Press, New York, NY; Russo, J. and Schoemaker, P. (2002), *Winning Decisions: Getting it Right the First Time*, Currency Doubleday, New York, NY.
- For more on the sunk cost effect, see Staw, B. and Ross, J. (1989), "Understanding behavior in escalation situations", *Science*, Vol. 246, pp. 216-20. In addition, see: Arkes, H. and Blumer, C. (1985), "The psychology of sunk cost", *Organizational Behavior and Human Decision Processes*, Vol. 35 (March), pp. 124-40; Brockner, J. (1992), "The escalation of commitment to a failing course of action", *Academy of Management Review*, Vol. 17, March, pp. 39-61.

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Suggested discussion questions

These are the questions the author uses. It would be completely acceptable to break down Question 2 into more direct questions, but a broad approach to question two has worked well:

Question 1. Why did this tragedy occur? What is the root cause of this disaster?

Question 2. What were the most significant flawed decisions made by the pilots of AF447? Why did the pilots fail react appropriately to the challenges that they faced?

Question 3. What are the lessons from this case for general managers in organizations?

Analysis of answers to discussion questions

Question 1. Why did this tragedy occur? What is the root cause of this disaster?

During the discussion of Question 1, students will often point to several surface level causes: the weather on the night of the accident, the odd instrument readings and the inexperience of Bonin – citing his apparent nervousness from the flight deck recordings. The instructor can guide the conversation away from a sole explanation and explore the examination of the 2009 Air France tragedy in a way that does not try to pinpoint a single cause of the catastrophe; in fact, the contention here is that the search for a single root cause is counterproductive in the case of catastrophic failures. Instead, this discussion examines the incident at the individual and group level of analysis. The two levels of analysis are not simply alternative lenses for interpreting the tragic events of June 1, 2009. Instead, factors at each level – individual, group, reinforce and interrelate with one another. As such, these factors serve as complementary and mutually reinforcing explanations of the tragedy. This is a nice set-up for the behavioral decision theory discussion that will arise in Question 2.

Question 2. What were the most significant flawed decisions made by the pilots of AF447? Why did the pilots fail react appropriately to the challenges that they faced?

For Question 2, the author leans heavily on behavioral decision theory, complex systems and reliance on technology with nods to alarm fatigue and social redundancy. Behavioral decision theory argues that individuals exhibit systematic cognitive biases when they make choices. The evidence in this case suggests that several cognitive biases may have impaired the pilots' judgment. Students will generally have a rudimentary knowledge of cognitive biases and their answers here will be general and vague – inexperience, confusion, and stress all have come up in classroom situations.

Once the instructor feels like the students do not have any additional insights, it is an appropriate time to direct the conversation toward some interesting areas of decision making and cognitive bias. Instructors could use the following prompts as a way to explore further discussion in the class. The author has used the following areas as rich areas for discussion and conversation.

Decision making

The following three sections can be composed as a combination of mini lectures and discussion points, experiments or illustrations. As the literature in this field is widely available and quickly growing, the author will give brief definitions of the phenomena involved and point toward a few examples. Further ideas on covering these phenomena can be taken from the works listed in the supplemental readings section at the beginning of this teaching note.

Cognitive bias

Behavioral decision theory contends that individual decision makers, operating under the condition of bounded rationality, tended to exhibit certain systematic biases when they make choices. The evidence in the case suggests some elements of three such biases were present – overconfidence bias, the recency effect and diagnosis bias – as characterized by the decision-making by the pilots during the Air France tragedy.

Overconfidence bias

- Research has shown that people from a wide variety of professions tend to exhibit overconfidence about their judgments and choices.
- Dubois and Robert were very accomplished Pilots. They had every reason to believe that they could overcome challenging obstacles should they arise in on any of their flights.
- Dubois, in particular, had a tremendous record of successful flights on the A330. He had flown in this particular region 16 times.
- They were flying one of the safest, most technologically advanced and modern passenger airliners in the world – the Airbus A330, over a region of airspace they had all traversed several times.
- From the flight recorder, at 02:14:23, Robert: "Damn it, we're going to crash […] This can't be happening!" 02:14:25, Bonin: "But what's happening?" The pilots can't believe that this modern Airbus A330 might actually crash.

Recency effect

- Research has shown that individuals tend to over-emphasize information and evidence that is readily available when making judgments and choices. One form of this availability bias occurs when people place too much emphasis on recent events, rather than examining a complete sample of past episodes, when estimating the probability that a particular event might occur in the future.
- At 02:10:06, Bonin states "I have the controls." This is the moment the plane's pitot tubes have frozen and the autopilot disengages. From this point on the plane will have to be flown by humans.

- Perhaps spooked by everything that has unfolded over the past few minutes – the turbulence, the strange electrical phenomena, his colleague's failure to route around the potentially dangerous storm – Bonin reacted irrationally. He pulled back on the side stick to put the airplane into a steep climb.
- At this point the instructor could show Plate E1 from the case – the Airbus A330 Cockpit. Given the A330s controls work asynchronously, Robert would not have been aware that Bonin has put the airplane into a steep climb. Later, this point ties in nicely to the technological flaws present in the Airbus cockpit.
- Indeed, Bonin's behavior is difficult for professional aviators to understand. "If he's going straight and level and he's got no airspeed, I don't know why he'd pull back," says Chris Nutter, an Airline Pilot and Flight Instructor (Otelli, 2011).
- In typical scenarios, where some manipulation of the aircraft is needed, pilots are supposed to go through iterative assessments and evaluation processes before altering the pitch or movement of the aircraft (Otelli, 2011).
- As soon as Bonin pulls the plane into the climb, the aircraft's computer reacts with a warning that the airplane is entering a stall – see Figure E5 in the case. All pilots are trained to push the controls forward in a stall situation so the plane will dive and gain speed. Bonin held the stick back the entire time.

Diagnosis bias

1. The term "diagnosis bias" refers to the tendency to label people, things and ideas based on our very first opinion of them. It describes our inability to change these judgments once we have made them and to discard evidence that suggests we reconsider our initial judgments.
2. The instructor can use two simple examples to explain this phenomenon to students:
    - A study on NBA players revealed that the number one variable explaining performance was the order in the draft selection. Comparing two players with the same qualities in terms of toughness, scoring or quickness, the one selected earlier in the draft got more playing time, was less likely to be traded to another club, and had a longer career.
    - After being given a short bio on a new instructor, students were asked to characterize the instructor after a teaching session. Students who had been told that the instructor was considered a "rather cold person" described him as "self-centered, formal, unsociable, unpopular, irritable, humorless, and ruthless." When the instructor was introduced as "a rather warm person," they described him as "considerate of others, informal, sociable, popular, good natured, humorous, and humane. Again, to give participants a first-hand, live experience, of the tendency to attribute value, the instructor may want to incorporate an experiment in the session – see Ariely. (2008) and Brafman, and Brafman (2009).
3. Immediately after the stall warning, the two co-pilots seem to focus on their speed reading rather than focusing on the pitch of the airplane. From 02:10:07, Robert: "What's this?" 02:10:15, Bonin: "There's no good […] there's no good speed indication." 02:10:16, Robert: "We've lost the, the, the speeds, then?" 02:10:27, Robert: "Pay attention to your speed. Pay attention to your speed."
4. At this point, thanks to the effects of the anti-icing system, one of the pitot tubes began to work again. The cockpit displays again showed valid speed information. At 02:10:31, Robert: Descend […] It says we're going up […] It says we're going up, so descend. 02:10:35, Bonin: Okay. 02:10:36, Robert: Descend! 02:10:37, Bonin: Here we go, we're descending. 02:10:38, Robert: Gently!
5. As described in the case, Bonin eased the back pressure on the stick, and the plane gained speed as its climb became shallower. It accelerated to 223 knots. The stall warning fell silent. It was at this moment, the pilots were in control of the airplane. Once again here, at 02:10:41, Bonin: "We're […] yeah, we're in a climb." However, Bonin did not lower the nose as he

should have. Recognizing the urgency of the situation, Robert pushed a button to summon the captain. Robert is completely oblivious to Bonin's behavior at this point.

6. It is at this point the plane reaches its highest altitude (38,000 feet), and then begins to fall toward the ocean as it is completely stalled. The problem has yet to be diagnosed properly by either pilot. The men were utterly failing to engage in an important process known as crew resource management (CRM). They were failing, essentially, to cooperate. It was not clear to either one of them who was responsible for what and who was doing what. This was a natural result of having two co-pilots flying the plane. When the captain returns to the flight deck, the pilots state at 02:11:45, Bonin: "We've lost control of the plane!" 02:11:47, Robert: "We've totally lost control of the plane. We don't understand at all […] We've tried everything."
7. At this point, the instructor could also show the layout of a Boeing cockpit in Plate E2 from the case, and point out unlike the control yokes of a Boeing jetliner the side sticks on an Airbus are "asynchronous," that is, they move independently. If the person in the right seat is pulling back on the joystick, the person in the left seat does not feel it (Figure E4).

Complex systems

After discussing the possible cognitive biases that may have been at play on the night of the disaster, instructors can move the discussion to a complementary force at play – complex systems.

The theory

Complex systems theory suggests that certain attributes of the human, physical and technological systems employed during the AF447 flight enhanced the risk of catastrophic failure. According to this conceptual framework, we cannot identify a single root cause of the tragedy, but rather must examine whether a series of interconnected breakdowns led to catastrophe. For example, one might ask: How did human errors, group procedures, equipment failures, and the unexpected storm interact to enhance the risk of a tragic outcome?

1. Complex systems have two attributes in an organizational system – complex interactions and tight coupling. They both increase the risk of catastrophe happening:
   - Complex interactions: do different elements of the system interact in ways that are unexpected and difficult to perceive or comprehend in advance?
   - Tight coupling: are different elements of the system closely linked, such that a breakdown in one subsystem can trigger problems in a series of other areas?

Complex interactions

The pilots, for example, encountered a series of interconnected problems on the night of the tragedy:

- Large thunderstorms on route.
- The captain leaving two co-pilots in charge that were both less experienced.
- The two pilots remaining were both co-pilots, leaving a situation where who was actually in charge being a factor.
- Rare weather phenomena that caused ice crystals to form on the aircraft.
- Pitot tubes freezing thus shutting off the auto pilot.
- The technological layout of the Airbus cockpit.
- The pilots not following stall recovery procedure. The pilots assumed that they were in a stall. This assumption proved to be incorrect as Bonin was pulling back on the stick – this was the actual reason they eventually entered a stall.
- The captain was not notified of the problems they were having on the flight deck immediately.

Tight coupling

1. Tightly coupled systems have four characteristics:
   - Time-dependent processes.
   - Rigid sequence of activities.
   - One dominant path to achieving a goal.
   - Very little slack.
2. Time dependence:
   - The crew had mere minutes to recover from the emergency, once the aircraft actually enters the stall. Everything takes place within a short 15-min period.
3. Rigid sequence of activities:
   - The flight operated according to a scripted route and flight routine. This was also exacerbated by being midway over the Atlantic Ocean out of reach by any airport to land at.
   - The storm was large enough that it would have been problematic to go around it.
4. One dominant path to achieving a goal:
   - The goal in this emergency was to keep the plane flying safely. In this type of "stall" situation (where no airspeed reading is available) pilots are trained to keep the airplane flying safely by using the correct pitch (pointing the nose down) and the appropriate power (engine) settings (BEA, 2012). In this case, what is most fascinating is that Bonin does the exact opposite of that training by continuing to pitch the nose of the airplane up reinforcing and worsening the stall.
5. Very little slack:
   - The margin for error when the emergency starts is very small. There is no safety net over the ocean, and only the pilots can solve the problem they face. This is not a simulator after all.

Potentially flawed technology

In the final part of the discussion of question two, the author explores in more detail whether the tragedy was impacted by the layout of the airbus cockpit, along with the concept of social redundancy.

Cockpit design and social redundancy

1. We could point to the (arguably) flawed design of the Airbus cockpit. Surely, a better design could have prevented Bonin from pulling back on the control stick without Robert knowing. All Airbus aircraft are configured in this manner.
2. Adding redundancy to a system may not always reduce the risk of an accident. Yale Sociologist Charles Perrow argued that redundancies can actually increase the interactive complexity of a system.
3. Redundant mechanisms designed to enhance safety may lead to compensatory behavior on the part of system operators, i.e., individuals may take more risks if they know that a failsafe mechanism exists (e.g. the students could be reminded of their economics classes – the principle of moral hazard suggests, e.g., that individuals may engage in riskier behaviors if they have purchased insurance).
4. In the case of the Airbus A330, which many pilots refer to as uncrashable because the advanced computer systems simply will not allow that to happen, this could have played a role. A study on how anti-lock braking systems affected the behavior of taxi drivers in Munich, Germany. They found that drivers with anti-lock braking systems drove at a higher speed, engaged in rapid deceleration more frequently, made sharper turns and followed other cars more closely in more risk-taking behavior.

5. Could compensatory behavior have taken place on AF447? Recall from the case the stall alarm blares 75 times, however, the pilots never once mention the stall. Why? These pilots are accustomed to the presence of layers of technological backup systems, and the fact that the captain was responsible for checking the work of the co-pilots, this may have contributed to risk-taking behaviors, as he was on a rest break during the critical time.

6. In this way, the cockpit maintained social redundancy. Harvard Business School Professor Scott Snook calls it the "fallacy of social redundancy." Snook undertook a study of a 1994 friendly fire incident in the no-fly zone over Northern Iraq. He questioned why controllers aboard an Air Force AWACS plane did not warn US fighter jets that that they were near US helicopters on a humanitarian mission to the Kurdish people. He wrote:

> After examining the group dynamics at play in the shootdown, I am ready to propose a "fallacy of social redundancy." Two controllers may not be better than one. Four leaders may be worse than two […] Perhaps one of the reasons teams should be slightly smaller than absolutely necessary is because redundancy in social systems can lead to a diffusion of responsibility and a tendency for inaction […] Sometimes, when everyone is responsible, no one is.

7. The diffusion of responsibility (CRM) may have played a key role on the AF447. During the emergency, who was actually in charge? During the British Petroleum (BP) disaster in the Gulf of Mexico in 2010, multiple companies worked to drill the Macondo well. BP designed the well and oversaw the work. Transocean personnel operated the rig. Halliburton performed the cement job. Other contractors contributed as well. While BP bore the ultimate responsibility for the accident, because so many other companies were involved, excessive risk taking took place that contributed to that disaster. In the same way, aboard AF447, the captain bore ultimate responsibility for the flying of the aircraft; however, the presence of two co-pilots, equal in rank, may have led to excessive risk-taking or detrimental lack of adequate and appropriate communication – when everyone is responsible, no one is.

Alarm fatigue

- The instructor could tie the stall alarm point from above to a quick comment on alarm fatigue. Healthcare researchers have found problems with alarms embedded in the monitoring systems of intensive care units. Health care workers become immune to the alarms because they go off so frequently (researchers call it "alarm fatigue.") Alarms do not represent "special" occurrences that grab one's attention; they become quite regular occurrences. Eventually, workers may have a tough time separating the signals of a potential catastrophe from the noise.
- Organizations need to build redundancy into their technical systems while remaining alert for compensatory behavior that may occur. Organizations also need to be sensitive to "alarm fatigue" as well as the potentially detrimental impact of false alarms.

Question 3. What are the lessons from this case for general managers in organizations?

Instructors can begin this part of the discussion by putting students in small groups and soliciting commentary that probes recommendations for general managers. The author has asked students to think about what they might take away and use in their internships and work. After this, instructors could tie together the student made recommendations with these key take away points.

1. Examining catastrophic failures:
   - When accidents happen, or organizations fail, we often engage in an elusive search for the key factor that caused the catastrophe. At times, we pit competing theories against one another, and we try to build a case for why one theory explains what happened more effectively than other hypotheses.
   - The Air France case discussion provides an opportunity to present a multi-level framework for examining an organizational decision-making failure. Rather than pitting theories against one another, this conceptual framework integrates different perspectives to explain why tragic events occurred.

- In his book on the 1994 friendly fire incident in Northern Iraq, Scott Snook makes a strong case for employing multi-level analysis to examine complex organizational failures. He wrote, "I am more convinced than ever that we cannot fully capture the richness of such complex incidents by limiting ourselves to any one or even a series of isolated, within-level accounts […] [We must] capture the dynamic, integrated nature of organizational reality."

2. The importance of clear communication, CRM and automation:
   - In this case, we see pilots fail to communicate as they are trained to do using CRM.
   - CRM complements the technical skills of flight crews for safely operating an aircraft by focusing on training, cognitive and interpersonal skills. Therefore, crews are trained on gaining and maintaining situational awareness, problem solving, decision making, as well as communication.
   - An important objective of CRM training is ensuring that junior crew members develop assertiveness in communication to enable them to speak up in the hierarchical team structure of flight crews. CRM is by now an integral and mandatory part of training for pilots but also for cabin crews and maintenance staff.
   - Ironically, in the aftermath of the deadliest aviation disaster of the twentieth century (the 1979 Tenerife accident where a Royal Dutch KLM 747 crashed into a Pan American 747 on the runway), the National Transportation Safety Board (recognized the need for action. Together with NASA and the Federal Aviation Authority, a joint research effort was initiated to improve flight crew cooperation and error management. This led to the development of the concept of CRM that we know about today.
   - In the aftermath of the 2009 tragedy, Air France agreed that their CRM training procedures needed updating in light of the tragedy and the interplay between CRM and the heavy automation present in their Airbus aircraft. In 1979, at the time of the Tenerife accident, automation was not as much of a concern as pilots did not rely on computers as much to fly their airplanes.
3. Stifling constructive dissent:
   - When teams operate in a climate of high psychological safety, individuals are more likely to express dissenting views. Several conditions serve to diminish psychological safety, and thereby diminish constructive dissent in groups and organizations.
   - In particular, this case demonstrates the impact that inexperience in a crisis situation, lack of leadership, lack of adherence to training procedures and a lack of clear lines of authority can have on the likelihood that team members will express dissent. Other factors that may inhibit dissent within management teams include high levels of group cohesion, demographic homogeneity, and a culture of solving problems through deference to experts.
4. Learning from failures:
   - Managers should try to learn from others' mistakes and failures. However, we need to be aware of the typical attributions that individuals make when success and failure occurs.
   - Research shows that individuals often attribute their own failures to external factors, while they argue that personal characteristics and mistakes cause others' failures. Attributing a catastrophe to the flawed decisions of others can become a convenient argument for those who want to attempt a similar course of action.
   - By concluding that human error caused others to fail, ambitious and self-confident managers can convince themselves that they will learn from those mistakes and succeed where others did not.
   - One could argue that if you can convince yourself that the people on Air France 447 died because of a string of injudicious errors and that you are too clever to repeat those same errors, it makes it easier for accidents like this to happen again. The students seem to resonate with this point in the closing comments.

5. Understanding human behavior:
   - It is important to understand human beings and the existence of our instinctive interpretations of situations, decision making, cognitive biases and automatic action patterns – a reality that decision makers should know more about in order to identify them in themselves and others.
6. Building resilience in performance.

As a closing point, the author uses Weick and Sutcliffe’s work to identify the following five dimensions of reliability in performance:

1. Preoccupation with failure: people need to be alert to early warning signs and always imagining potential failure scenarios.
2. Reluctance to simplify: people cannot be quick to accept simple explanations for anomalies, but instead must probe for a deeper understanding.
3. Sensitivity to operations: people must recognize and try to better understand how different elements of an organizational system interact.
4. Commitment to resilience: the organization must have the ability to not simply prevent failures, but also to recover quickly from them. That resilience requires strong learning capabilities.
5. Deference to expertise: senior managers must recognize when lower-level employees have the relevant knowledge and expertise to address a problem and they must make them feel comfortable expressing concerns.

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Further reading

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Abstract

Theoretical basis – *This case has two primary purposes. First, it allows students to examine how cognitive bias can affect decision making in stressful situations. Students explore why individuals make flawed choices. They learn about how managers shape the context and the process through which teams make decisions. For instance, automation can create a climate in which people then struggle to cope with the unexpected when it happens. Students examine why individuals make these systematic errors in judgment. The case demonstrates that leaders need to be aware of the traps that individuals and teams encounter when they make decisions in crisis situations, and it enables students to discuss the strategies that leaders can employ to avoid these traps. Second, the case provides an opportunity to examine a catastrophic failure in detail. Students discover that it can be nearly impossible to identify a single factor that caused the failure. Instead, they learn how to apply multiple theoretical perspectives to examine a serious organizational breakdown. They become familiar with important concepts from behavioral decision theory, such as complex systems theory and how it interacts with cognitive bias.*

Research methodology – *The technical report released by the French Aviation Authority along with the primary flight cockpit voice recorder data were used as the basis for this case. Other available public data such as news reports were used to round out the case study.*

Case overview/synopsis – *On June 9, 2009, on a routine flight from Rio de Janeiro to Paris, Air France 447 (AF 447), carrying 220 people crashed in the mid-Atlantic Ocean. Drawing from various first-hand accounts (cockpit voice recorder) and secondary evidence of the tragedy, the case provides a detailed account of the key events that took place leading up to the accident. The case describes how the pilots on AF447 were confronted with a scenario they had not faced before, and through the confusion made a series of errors. Through many of the quotes in the text, readers gain an understanding of the impressions and perceptions of the pilots, including how they felt about many of the critical decisions and incidents during the last minutes of the flight. The case concludes by highlighting the main findings of the BEA report.*

Complexity academic level – *This case study is appropriate for undergraduate students studying organizational behavior. It is also appropriate for MBA-level leadership and behavior classes.*

Keywords *Decision making, Aviation case study, Critical incident case, Disaster, Air France 447, Cognitive bias, Organizational behaviour, Complex systems*