HARVARD | BUSINESS | SCHOOL

9-320-104

REV: OCTOBER 12, 2020

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What Went Wrong with Boeing's 737 Max?

On March 9, 2019, Ethiopian Airlines Flight 302, flying the Boeing 737 Max, crashed shortly after taking off from Addis Ababa, Ethiopia, *en route* to Nairobi, Kenya. All of the 157 people on board, including a crew of seven and a security officer, were presumed to be dead.

At Boeing, the stunning and tragic news prompted some urgent decisions. Chairman and CEO Dennis A. Muilenburg, an engineer and 34-year Boeing executive, had devoted his career to the aviation industry and was passionate about flying and aircraft safety. Boeing had a great deal at stake in the success of the 737 Max, and under the leadership of Muilenburg's predecessor, CEO W. James McNerney, Jr., it had raced to get the Max into production in record time, in part by keeping the redesign of the 737 within the original 1968 Federal Aviation Administration (FAA) certification instead of treating it as a new airplane. That decision enabled Boeing to win orders over archrival Airbus's A320 for around 5,000 of the Max airplanes, of which more than 300 had already been delivered to customers.

Following the tragedy of Lion Air flight 610 in Indonesia the previous fall, flight 302 was the second crash of the Max in less than five months, leaving a total of 346 people dead. In the hours following the second crash, it was unknown whether there was a common factor underlying the two deadly accidents. Had Boeing's engineers placed too much blame for the first crash on Lion Air's inexperienced pilots? Should Boeing have grounded the Max immediately after the Lion Air crash? Should Boeing ground the model now? In the longer term, it was possible that the FAA would prohibit carriers from flying the Max—and even that the model would never fly again. How could Boeing regain the trust of regulators, airlines, and the public?

As chief executive, what was Muilenburg's responsibility as he prepared to meet with Boeing's executive committee and board to discuss the implications of the accidents? Should he offer to resign as CEO? Put out a personal expression of regret and apology? Or, should he leave the messaging to the public relations team? As news of the second crash spread, pressure was mounting for Muilenburg and Boeing to come up with a response.

Senior Fellow William W. George and Case Researcher Amram Migdal (Case Research & Writing Group) prepared this case. This case was developed from published sources. Funding for the development of this case was provided by Harvard Business School and not by the company. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

Boeing and the Rise of Commercial Aircraft Manufacturing[a]

Wheels Up: The Origins of Commercial Flight

In 1911, William E. Boeing, a lumber entrepreneur with a passion for aviation, bought a shipyard in Seattle, Washington, which would later become Boeing's first airplane factory. In 1916, Boeing completed and flew his company's first aircraft—the Model 1 seaplane. That year, Boeing incorporated the Pacific Aero Products Company, changing its name to Boeing Airline Company (Boeing) in 1917. Boeing would grow to be the world's largest producer of commercial and defense aircraft and a leading manufacturer of satellites and launch vehicles. (See **Exhibit 1** for a timeline of key company events.)

In the 1930s and 1940s, airframe and jet engine manufacturing remained primarily military technologies, while Boeing flew its first commercial airplane (the Model 247) in 1933. In 1958, Boeing delivered the first U.S.-made commercial jet airliner, the 156-seat 707, which had a range of about 4,000 miles and competed with the 269-passenger DC-8 from Boeing's largest U.S. rival, McDonnell Douglas. "Boeing was not the first company to produce a jet-powered airliner. But just as Ford's Model T popularized the automobile despite being a latecomer in the car world, the Boeing 707 would be the airplane to popularize jet travel," wrote one aerospace reporter.[1]

Cruising Altitude: Mid-Century Rivalry in a Maturing Market

In 1960, Boeing debuted the 727, launching a new generation of aircraft that traveled faster and at higher altitudes than earlier models. In the U.S., Boeing, Lockheed, and McDonnell Douglas dominated airframe manufacturing, holding as much as 80% of the market.[2] As short- to medium-range routes became increasingly busy, airline executives looked for higher-capacity, longer-range planes that could carry 250 to 300 passengers. In 1967, several European governments already in discussions to start Airbus Industries, a consortium to respond to continued U.S. dominance in the airframe market, announced plans for the A300 (300 passengers). That year, Boeing introduced the narrow, single-aisle 737, which offered fuel efficiency, range, and reliability. The 737 would go on to become the best-selling jet ever made. (By 2016, 2,000 of the aircraft were in the air at any given time, accounting for one of every three commercial flights; by 2018, 10,000 737s had been produced.)[3]

In 1969, Boeing debuted the 400-passenger, double-aisled, four-engine 747, which could fly 8,000 miles non-stop. The 747 took four years and $1.2 billion to create, requiring the construction of the world's largest factory, in Everett, Washington, just north of Seattle.[4] The 747's main competition was the A300, along with the McDonnell Douglas DC-10, which carried 220 passengers and had a range of 3,800 miles, and Lockheed's 400-passenger Tristar, which had a range of about 4,600 miles.

By 1972, commercial aircraft sales overtook military aircraft sales worldwide, by value—a shift in market dynamics.[5] The introduction of the hub-and-spoke routing structure further expanded the market for commercial aircraft. As airline traffic grew rapidly, so did competition among Airbus, Boeing, Lockheed, and McDonnell Douglas, as well as Bombardier, based in Canada, and the Brazilian Embraer. In the 1970s, Airbus pioneered so-called fly-by-wire planes, which relied on computer systems that controlled or helped pilots control a plane. Early the next decade, Lockheed suspended commercial aircraft production, unable to compete against its large rivals. For Boeing, military projects

[a] Information in this section draws from "Boeing History Chronology," Boeing website, https://www.boeing.com/resources/boeingdotcom/history/pdf/Boeing_Chronology.pdf, accessed April 2020, among other sources.

continued apace, and its reputation as one of the world's leading engineering companies rose with its participation in NASA's Space Shuttle program and the International Space Station (ISS) program.

In 1978, the U.S. government passed the Airline Deregulation Act, removing entry, price, and route restrictions and leading to a boom in lower fares and new routes. After deregulation, an influx of low-cost carriers gave rise to a point-to-point route system, unlike the hub-and-spoke model, increasing demand for smaller, more fuel-efficient planes. Low-cost carriers often limited their fleet of planes to one or two models. Some low-cost airlines established their own pilot training programs to produce enough pilots to meet growing demand, although aviation experts critiqued the quality of such programs, pinpointing pilot error as the leading cause of accidents.[6]

Charting the Boeing Flight Path into the 21st Century

With the end of the Cold War in the early 1990s, there was consolidation in commercial aviation, mimicking consolidation among U.S. and European defense contractors and a large drop in spending on military aircraft and equipment. The Gulf War further depressed air travel worldwide. In 1992, Boeing was worth $13 billion, yet by 1995, the aircraft industry was in its fourth consecutive year of declines in deliveries and revenues, the fourth such dip since the 1960s (**Exhibit 2** shows commercial airline deliveries for 1997–2018).[7] The year prior, in 1994, Boeing launched its first jetliner created with computer-assisted design, the twin-engine 777, which could transport 300 to 370 passengers. The 777 was also Boeing's first fly-by-wire airplane. Boeing "marshaled $5 billion and 10,000 employees—5,000 engineers and 5,000 machinists [. . .] to develop the 777," according to reports.[8]

In this period, Boeing was known as an engineering-first enterprise. "Boeing has always been less a business than an association of engineers devoted to building amazing flying machines," *Fortune* later wrote.[9] The *Atlantic* stated, "Its executives held patents, designed wings, spoke the language of engineering and safety as a mother tongue. Finance wasn't a primary language."[10] Therefore, it was no surprise in the late 1990s when Boeing renewed its focus on defense and adjacent sectors such as space and satellite technologies, marine craft, and transit and communications systems—even customer finance and asset management. In 1996, Boeing acquired the defense and aerospace businesses of Rockwell International, based in Seal Beach, California, for $3.2 billion.

In 1997, then-CEO Philip M. Condit led Boeing's acquisition of McDonnell Douglas, located in St. Louis, Missouri, in a $13 billion stock swap. Although the resulting company took the name Boeing, the merger left many McDonnell Douglas executives in high-ranking positions. From the standpoint of corporate culture, the merger represented "a move away from expensive, ground-breaking engineering and toward what some called a more cutthroat culture, devoted to keeping costs down and favoring upgrading older models at the expense of wholesale innovation," wrote one journalist.[11]

By 1998, Boeing's share of new aircraft orders was falling, with the balance of production coming from Airbus.[12] In 2000, Boeing continued to invest in technology to strengthen its diversified portfolio. That year, it purchased Jeppesen Sanderson, Inc., a global company headquartered in Denver, Colorado, for $1.5 billion. Jeppesen Sanderson provided flight information services such as "navigation data, computerized flight planning, aviation software products, aviation weather services, maintenance information, and pilot training systems and supplies," according to Boeing.[13] Also in 2000, Boeing bought the satellite manufacturing business of the Hughes Electronics Corporation for $3.75 billion, and partnered with Honeywell to continue both companies' contributions to U.S. technology efforts related to avionics, systems, and software for the ISS.[14]

In 2001, Boeing moved its headquarters from Seattle to Chicago, Illinois, in a deal that included more than $60 million in state and local tax incentives over 20 years.[15] This geographic distance—and the new executives' lack of technical expertise—alienated Boeing's engineers, who remained divided between military businesses in St. Louis, space-related units in Long Beach, and commercial aviation in Seattle.[16] ''We believe that having a headquarters separate from any of our businesses will help us grow," said Condit.[17] In 2002, Boeing combined the Hughes satellite operation, based in El Segundo, California, with other space- and defense-related units to create the Integrated Defense System, which generated $23 billion annually and was headquartered in St. Louis.[18] In 2003, Condit resigned one week after firing Boeing's CFO and another executive due to ethical misconduct.[19]

Cockpit Culture: Changes in Corporate Leadership

Following the merger with McDonnell Douglas, Boeing leadership's focus shifted. Share repurchases, employed sparingly throughout Boeing's history up to the merger, increased to more than $10 billion per year and eventually outpaced research and development (R&D) spending.[20] "When people say I changed the culture of Boeing, that was the intent, so that it's run like a business rather than a great engineering firm," said then-CEO Harry Stonecipher in 2004.[21] "It is a great engineering firm, but people invest in a company because they want to make money."[22] Stonecipher, a disciple of Jack Welch from his time at General Motors and General Electric, had led the merger from the McDonnell Douglas side and later came out of retirement to succeed Condit as CEO.[23]

However, in 2005, Stonecipher resigned following a personal scandal that violated Boeing's code of conduct. The Boeing board recruited McNerney (MBA 1975) from 3M, where he was chairman and CEO, to become Boeing's chairman, president, and CEO. Prior to 3M, McNerney had worked for 19 years at General Electric, where he was one of three finalists to be Jack Welch's successor. In choosing an outsider, Boeing passed over consummate engineer and head of the commercial airplanes division Alan Mulally, who had helped lead the successful 777 program and soon departed to become CEO of Ford Motor Company.

The 2010s signified both highs and lows for Boeing, with record commercial aircraft sales across the industry alongside some of the worst aircraft safety and design failures in the company's history. In 2010, Boeing successfully completed and handed over to NASA the on-orbit technologies needed for the ISS. That year also marked the debut of the third generation of 747 jets as well as a $1.7 billion contract with the FAA air traffic control system, called NextGen, following on Boeing's earlier acquisition of Jeppesen Sanderson and other investments in flight information services.

Turbulence Ahead: The 787 Dreamliner

Since the late 1980s, in contrast to Airbus's fly-by-wire planes, Boeing continued to design planes that ultimately depended on airmanship—the skill, experience, and instinct of pilots—to be safely operated. For decades, the A320 and the 737 competed for market dominance. Then, in 2010, Airbus came out with a new, more fuel-efficient version of the A320, called the New Engine Option (A320NEO), which flew longer ranges and carried more weight than its A320 predecessors or the 737.[24]

In 2011, Boeing came out with the 787 Dreamliner. The Dreamliner program had started design in 2004 and cost a total of more than $32 billion by the time the first plane shipped—taking twice as long and costing roughly 5.5 times as much as Boeing had initially estimated.[25] The new jet carried 280 passengers and promised airlines better fuel efficiency and performance for long-range flights; each unit cost nearly twice the initial anticipated estimates of $40 million per plane to produce and was priced at $250 million.[26] During development, to lower costs, Boeing hired contractors, leading to

quality issues, malfunctions, and delays that prompted buyers to cancel 60 of the 900 orders in hand at the end of 2008.[27] Even buyers that kept their orders sought compensation from Boeing, as delays kept them from meeting rising passenger demand.[28] Boeing executives blamed suppliers for the delays.

In 2013, a year after the Dreamliner was introduced, a problem surfaced: the batteries were overheating. In early 2013, Boeing grounded the worldwide fleet of 50 787s for three months.[29] One analyst wrote: "There was no contrition or soul-searching" on Boeing's part "about how the 787 could have gone this wrong."[30] Within two more years, though, the Dreamliner had 1,100 orders; despite the $250 million list price, customers were paying around $120 million per plane, on average, due to price reductions based on order specifications.[31]

By the end of 2013, Boeing proceeded to initiate development of its next model, the 777X, garnering orders for 259 units worth $95 billion, the most valuable commercial jet product launch ever at the time.[32] In addition, Dennis A. Muilenburg, who had been with Boeing since 1985 and started his career as an engineer and program manager, was promoted to vice chairman, president, and COO, sharing management of all Boeing's day-to-day operations with McNerney. Muilenburg had until then spent most of his career in Boeing's defense businesses, not commercial aviation, and most recently had been chief executive and president of Boeing Integrated Defense System.

Boeing Develops the 737 Max

In 2011, when American Airlines threatened to switch its fleet from Boeing to the A320NEO, Boeing put on a five-year rush production to quickly roll out an upgraded version of the 737, called the Max.[33] (See **Appendix** for an overview of aircraft manufacturing dynamics, including aircraft production cycles, drivers of industry competition, and information on regulations and pilot training.) According to reports, "Engineers were pushed to submit technical drawings and designs at roughly double the normal pace," and budget constraints led the Max program to hire employees away from other projects within the company.[34] "The timeline was extremely compressed," said one engineer, "It was go, go, go."[35] Boeing reportedly spent between $2 billion and $3 billion on the Max program.[36]

Aircraft Development and the FAA

New-aircraft certification by the FAA typically took five to nine years to complete, although manufacturers that modified already-certified model designs could apply for an amended type certificate, which took three to five years to complete.[37] Boeing sought an amended type certification for the Max, which meant that "the redesign had to lie within the original 1968 F.A.A. certification of the [737 aircraft] type and not be treated officially as a new airplane," reports stated.[38] Boeing's decision to seek the amended type certification meant the Max had to have the "same pilot type rating, same ground handling, same maintenance program, same flight simulators, same reliability" as previous 737 models, reports stated, in addition to the "same flying characteristics."[39] Airlines, too, wanted the new plane to maintain the same characteristics as previous 737 models in order to avoid the need to refresh spare parts inventories or renew pilot certifications via additional simulator training (at a cost of approximately $2,000 per pilot at Southwest Airlines, for example).[40]

In overseeing the 737 Max program, the FAA relied on engineers at Boeing to provide technical expertise and insight. Delegating more oversight responsibilities was supposed to make the FAA more efficient, given the agency's limited resources compared to the companies it regulated, and since 2005 the agency's rules had allowed airframe manufacturers to choose which engineers would be tasked with oversight responsibilities.[41] In 2009, the FAA created the Boeing Aviation Safety Oversight Office, dedicated specifically to oversight of Boeing and staffed primarily by Boeing personnel. In January

2012, Boeing officially applied for the amended type certification.[42] By 2016, the National Air Traffic Controllers Association, which represented FAA engineers, warned about the agency's "brain drain" and "inability to hire and retain qualified personnel," according to reports, which claimed that Boeing was allowed by the regulator to certify 96% of its own production.[43] In March 2017, the FAA granted amended certification for the 737 Max.[44]

The Maneuvering Characteristics Augmentation System (MCAS)

Like the A320NEO, the Max's more fuel-efficient engines were made by CFM International, the U.S.-French joint venture between General Electric and Safran. The CFM engines were about 40% wider and twice as heavy compared to previous 737 engines, necessitating a longer and heavier airframe and wider wingspan for the new plane.[45] However, due to the need to avoid FAA re-certification, the 737 Max could not be taller than its predecessors, leading to the need to mount the new engines further forward on the wings.[46] Later reporting revealed, "This alteration created a shift in the plane's center of gravity pronounced enough that it raised a red flag when the MAX was still just a model plane about the size of an eagle, running tests in a wind tunnel."[47] In 2015, once the Max was in early production, "test pilots discovered that the Max had unusual stall characteristics when the wing flaps were up and the engines were thrusting," another report later stated.[48]

Boeing's solution was to design a new software patch, rather than redesign any of the plane's aerodynamic features that could have risked the FAA's amended certification approval.[49] The fix was called the maneuvering characteristics augmentation system (MCAS), an automated solution intended to counter the possibility of a stall under certain conditions. Aircraft had two external sensors that monitored the angle between a plane's wings and oncoming airflow, or angle of attack (AoA). When this angle grew too large, it could create a stall and a rapid loss of altitude. To counter this eventuality, the MCAS activated when an aircraft's external sensors detected that the AoA had reached a critical point; the system then rapidly lowered the angle of the plane's nose to restore the AoA to a safe level.[50] The MCAS automatically pushed down the nose of the plane whenever AoA sensors detected a stall, "regardless of the [aircraft's] speed," said reports.[51] In theory, this adjustment would keep the plane at the proper altitude. The MCAS activated if just one of the aircraft's two AoA sensors reported issues, and did not require consensus between the sensors—a fact about which at least one Boeing engineer raised concerns, asking in December 2015 in an email to colleagues, "Are we vulnerable to single AOA sensor failures with the MCAS implementation or is there some checking that occurs?"[52]

Boeing made no mention of the MCAS in the flight manual nor did it alert airlines or pilots of the system's existence. A description of the MCAS for pilots could have qualified as enough of a change in flying experience that it would have required the Max to gain new FAA approvals and pilots to undergo additional simulator training hours. In fact, later reporting revealed, "Boeing managers told [Boeing employee Rick Ludtke] they even sold the plane to Southwest Airlines with a guarantee of a rebate of $1 million per plane if simulator training was required."[53] Boeing did not disclose the MCAS to the FAA, officials confirmed, and a description of the system was removed from the pilot's manual, meaning most pilots were unaware of the MCAS.[54] In general, the rushed pace of production caused concern among at least some Boeing employees working on the Max, one of whom wrote to the general manager of the Max program in June 2018 with concerns about the production process, stating, "Frankly right now all my internal warning bells are going off [. . .]. And for the first time in my life, I'm sorry to say that I'm hesitant about putting my family on a Boeing airplane."[55]

The Max Ships

In 2011, Southwest Airlines finalized a deal for 150 units of the 737 Max, becoming the first customer of the new plane (see **Exhibit 3** for Max orders and deliveries).[56] On January 29, 2016, the Max made its first flight. Three months later, Muilenburg took over as CEO, at a time when Boeing had lagged Airbus in aircraft orders for the past nine years.[57] In 2016, Boeing planes comprised 31.5% of the world's passenger jets, while Airbus had 27% market share and the remainder was split primarily between Bombardier and Embraer.[58] In August 2017, the first Max units were delivered to Southwest Airlines.

As 2018 began, Boeing retained its position as the largest manufacturer of commercial airplanes in the world.[59] It employed 140,000 people in 165 countries and had companywide earnings of $9 billion.[60] Of the $93.4 billion in revenue the company brought in, $56.8 billion was derived from the commercial airplane business, $21.1 billion from the defense, space, and security business, and about $15 billion from global services, Boeing capital, and other areas.[61] That year the company also increased share repurchases to $18 billion and increased dividends by 20%.[62] (See **Exhibit 4** for financial summary.)

Lion Air Background

In the 1990s, Indonesia began deregulating its airline industry as part of an effort to make air travel among the nation's many islands cheaper and more convenient. Following deregulation, Indonesia developed an international reputation for unsafe air travel, especially as many low-cost carriers emerged to compete against the national airline, Garuda. Inexperienced pilots rushed into the industry, but training lagged international standards. For example, an aviation expert wrote, "Normally two pilots train in a simulator at a time, with an instructor seated behind them—so, three in the box. I was told that in Indonesian simulators, there are sometimes seven in there: two pilots flying, one instructing and four others standing up and logging the time."[63] From 2003 to 2007, Indonesian airlines were 15 times more likely than the global average to have an accident.[64] In 2007, the U.S. and Europe prohibited Indonesian airlines from flying in their territories due to safety concerns.

By that time, Lion Air was among Indonesia's largest airlines. Rusdi Kirana, a Jakarta entrepreneur who had built a leading travel agency, founded Lion Air in 2000 by leasing a single, used Boeing 737.[65] Over five years, as domestic air travel in Indonesia tripled in volume, Lion Air outpaced competitors to become the market leader in domestic air travel, despite a poor record on safety and on-time performance.[66] The airline also became a significant Boeing customer. In 2005, the carrier ordered 60 Next-Generation 737-900ERs (extended range) jets from Boeing for nearly $4 billion, and by 2007 became the airplane manufacturer's biggest customer worldwide with an order for 40 more 737s.[67] In 2011, Lion Air placed the biggest order in the history of aircraft manufacturing to date, purchasing 230 new 737s from Boeing, including 201 of the then-new 737 Max jets for $22 billion.[68]

Lion Air often hired inexperienced pilots and trained them at its own pilot program at an airport west of Jakarta.[69] Each year, about 150 to 200 pilots-in-training, who were required to have graduated from high school, enrolled in the $60,000 program, which included six months of initial ground school followed by four to five months of flight training. By 2011, Lion Air "was responsible for 25 deaths, a larger number of injuries, five total hull losses and an unreported number of damaged airplanes," since its inception, according to an aviation expert.[70] The expert continued, "[. . .] all of Lion Air's accidents happened during takeoffs and landings and therefore at relatively low speed, either on runways or in their immediate obstacle-free vicinities. These were the brief interludes when the airplanes were being flown by hand."[71] Safety concerns grew so grave that Boeing eventually tried to intervene directly with Lion Air in order to improve pilot training and raise safety standards, but the airline resisted the

manufacturer's outreach.[72] In a 2018 *New York Times* article, a former employee accused the airline of tending to "spend the minimum on pilot training, salaries, management, everything."[73]

In July 2018, Boeing delivered the Lion Air 737 Max jet that would crash three months later.

The Lion Air Flight 610 Crash

On October 26, 2018, three days prior to the flight 610 accident, airspeed and altitude sensors in a Lion Air 737 Max malfunctioned. The sensors had two independent backups and alerted pilots and co-pilots whenever there was a mismatch between the three sensors. The October 26 errors caused no significant problems, and the crew reported them in the flight log. According to reports, "During intervals on the ground, the airline's technicians ran built-in tests, got coded responses and did plug-out plug-in reboot attempts of the mindless sort performed at automotive service centers."[74] The technicians replaced an exterior vane that informed the sensors, using a used part Lion Air had in stock from a secondhand supplier, then approved the airplane for its scheduled flight the next day.[75]

On October 28, 2018, the same 737 Max aircraft experienced a MCAS malfunction on its flight from Bali to Jakarta. Although the pilots recognized that the airspeed and altitude sensors were malfunctioning, they knew nothing of the MCAS and did not understand why the nose of the plane was repeatedly and automatically driving down.[76] However, they successfully managed the malfunctions and safely completed the flight. Logs showed that the pilots either did not accurately report the aircraft's safety issues, or the maintenance crews did not resolve them.[77]

A Short, Tragic Flight

On October 29, 2018, at 6:20 a.m., Lion Air flight 610 took off from Jakarta in good weather, *en route* to Pangkal Pinang in Indonesia's Bangka Belitung Islands. There were 189 passengers and crew onboard. Captain Bhavye Suneja, a 31-year-old Indian man trained at a small pilots' school in California, had started with Lion Air in 2011 and by October 2018 had significant experience in the cockpit, with more than 6,000 hours of flight time; his co-pilot was 41-year-old Harvino, who had a similar amount of flight experience.[78] Later analysis by an experienced pilot described the training of both men as "scripted, bounded by checklists and cockpit mandates and dependent on autopilots," with "rote knowledge of cockpit procedures as handed down from the big manufacturers."[79]

Shortly after takeoff, the Jakarta airport gave standard approval for Lion Air flight 610 to climb to 27,000 feet.[80] Reports described the subsequent events, based on investigations and expert analysis:

> Two and a half minutes after takeoff, as the airplane was climbing through 2,175 feet, it suddenly went into a violent 700-foot dive, rounding out of it at 1,475 feet and pulling into an uncertain climb. [. . .] Lion Air 610 climbed to 5,000 feet and stayed there shakily for an additional six minutes. Soon it was out over open water. At some point, Harvino declared the crew's intent to return to the Jakarta airport. Air-traffic control approved the return [. . .]. But nothing occurred as a result. The airplane kept flying away from the airport. [. . .] The airplane was flying unusually fast.[81]

After 11 minutes in the air, Suneja asked for confirmation of the airplane's altitude, reporting that the plane's indicators showed differing readings. The plane was not maintaining a steady altitude. Investigations later found that the 737 Max dove sharply 22 times, with the pilots evidently fighting to keep the plane level and aloft.[82] Twelve minutes after takeoff, Lion Air flight 610 crashed into the ocean about 39 miles from the Jakarta airport. "The preliminary data indicates a deep vertical dive rather than

any kind of belly landing. Compared with a typical airliner's descent rate of about 1,200 to 1,800 feet per minute, that data shows descent speeds quickly reaching 10,000 feet per minute and finally accelerating to 30,000 feet per minute, or 340 mph," wrote one aviation expert.[83]

After the Lion Air Crash

On October 29, 2018, when the stock market opened, Boeing's share price fell to $335.29, down from $359.27 on October 26; by November 1, it was back up to $363.07 (see **Exhibit 5**).[84] About 10 hours after the crash, at 4:22 p.m. in Jakarta, Boeing issued what appears to have been its first public statement, tweeting: "We are deeply saddened by the loss of Lion Air Flight JT 610. We express our concern for those on board, and extend heartfelt sympathies to their families and loved ones."[85] The tweet linked to a statement, which added, "Boeing stands ready to provide technical assistance to the accident investigation. In accordance with international protocol, all inquiries about aviation accident investigations must be directed to Indonesia's National Transportation Safety Committee (NTSC)."[86]

Within two days, Indonesia's NTSC had ordered and carried out emergency inspections on all of the 737 Max jets within the country.[87] None of the inspected aircraft were deemed not to be airworthy.[88] Edward Sirait, Lion Air's CEO, told the media, "[T]he fault reported on the jet's previous flight [. . .] had been fixed after instructions from Boeing before the plane took off again from Jakarta," in the words of later reports.[89] Both Indonesia's NTSC and the U.S. National Transportation Safety Board (NTSB) began investigations, with the Indonesian authorities taking the lead and NTSB inspectors assisting.[90] Boeing and CFM, the engine maker, provided technical advisers.

On November 6, 2018, Boeing issued a second statement regarding its provision of technical assistance and implicating "erroneous input" from one of the AoA sensors as part of the cause of the crash (see **Exhibit 6** for full statement).[91] The company stated that, as of November 6, it had issued an updated set of recommendations as part of its Operations Manual Bulletin (OMB) to inform pilots worldwide of the potential issues. Boeing did name the MCAS specifically but claimed that the Flight Crew Operation Manual contained information about the function and how to override it. The OMB was the first detailed description of the MCAS most pilots and airlines received.[92]

On November 13, 2018, Muilenburg said in a televised interview that Boeing planned to "fully cooperate" in the investigation.[93] That day, the FAA and Boeing announced that they would evaluate whether software or engineering design changes might be needed for the Max.[94] Two weeks later, on November 27, 2018, Boeing issued a statement on the preliminary report about the crash (see **Exhibit 7**).[95] In the statement, the company offered pilots and travelers "our assurance that the 737 Max is as safe as any airplane that has ever flown the skies."[96] At some point prior to the end of 2019, the FAA put a statement on its Airworthiness Certification page specifically about the 737 Max, explaining:

> The Boeing 737-8/9 Max design had minor changes to the 737 Next Generation (NG) design. For this reason, the FAA issued an Amended Type Certificate to the Max airplane, which was based on the Type Certificate of the 737NG. The FAA spent approximately five years certifying the Boeing 737 MAX. [. . .] During the certification process, FAA experts including chief scientists, engineers and flight test pilots, conducted in-flight testing of the flight control system, including the MCAS.[97]

The MCAS System Malfunction

Investigations eventually showed that the Lion Air accident likely involved mechanical failures that prompted the unnecessary activation of the MCAS.[98] The mechanical malfunction mimicked a

condition called runaway trim, in which the electric trim, which maintained aircraft attitude, lost control and prompted the plane to rapidly pitch upwards or downwards.[99] Although true cases of runaway trim could be dangerous, many pilots experienced at least one occurrence during their careers, and well-trained pilots understood the relatively simple steps to handle the situation.[100]

On flight 610, an AoA sensor malfunctioned and incorrectly reported to Suneja and Harvino that the plane was in danger of stalling, triggering the MCAS.[101] This forced the aircraft's nose downward in an attempt to adjust the AoA in response to the phantom stall signals from the faulty AoA sensor.[102] Rather than attempting a one-time correction, the MCAS was programmed to repeatedly adjust the aircraft until the proper AoA was restored. The MCAS would not have activated if the plane had been on autopilot, or if its wing flaps had been raised.[103]

The Possibility of Pilot Error

If they had known of the MCAS, the pilots could have disconnected it by shutting off the electric trim controls, which automatically managed the angle of the plane's nose.[104] According to an expert:

> Boeing convinced itself (and the F.A.A.) that there was no need to even introduce the MCAS to the airplane's future pilots. Boeing believed that in the worst case, a false positive would present as a mere runaway trim, a problem any pilot would know how to handle. The 737 features two prominent toggle switches on the center pedestal whose sole purpose is to deal with such an event [. . .]. There is not a 737 pilot in the world who is unaware of them. Boeing assumed that if necessary, 737 Max pilots would flip them much as previous generations of 737 pilots had. It would be at most a 30-second event.[105]

The pilots then could have manually adjusted the angle of the aircraft's nose—regardless of the erroneous reporting from the AoA sensor—and counteracted the unneeded MCAS corrections.[106] This seems to have been the successful tactic employed by the crew of the same airplane on the Bali–Jakarta flight the day before the crash. However, on flight 610, "The MCAS was fast and relentless. Suneja could have disabled it at any time with the flip of the two trim cutout switches, but this apparently never came to mind," according to later reports.[107] When the broken sensor did not respond to the MCAS's adjustments and instead continued to report a phantom potential stall, the MCAS never stopped driving the plane's nose downward.[108]

Following the Lion Air 610 crash, Boeing conceded that it had anticipated that pilots would know how to correct the issue in the case of an MCAS malfunction.[109] It later released an overview of the MCAS and detailed how pilots should respond in the event of a sensor error. Investigators also noted that more than 30 pages disappeared from the Lion Air flight maintenance log following the difficulties on the two flights proceeding flight 610.[110] Pilots who subsequently underwent simulations of the crash suggested that many of the cockpit's emergency response systems, in tandem with the MCAS activation, may have inhibited the pilots' ability to respond to the MCAS malfunction in time.[111]

The Ethiopian Airlines Flight 302 Crash

On March 9, 2019, at 8:38 a.m., Ethiopian Airlines flight 302—another Boeing 737 Max—took off from Addis Ababa, Ethiopia, *en route* to Nairobi, Kenya, with 157 people on board.[112] Yared Getachew, a 29-year-old graduate from Ethiopia Airlines' own pilots' academy with 10 years and 8,122 hours of flight experience, was the captain; a recent graduate of the same program, 25-year-old Ahmed Nur Mohammod Nur, who had logged just 361 hours of flight time, was co-pilot.[113] According to reports:

> Both men were aware of the Lion Air tragedy. They had been briefed on the MCAS system and knew the basics: that it provided repetitive 10-second bursts of nose-down trim, that it could be held at bay through vigorous use of the control yoke thumb switches to counter-trim, that it would not activate if the flaps were down or the autopilot was on, that it could be deactivated by shutting off the electric trim through use of the now-famous cutout switches on the center pedestal and that afterward the airplane could be trimmed using the manual trim wheel.[114]

Immediately after takeoff, the pilot-side AoA sensor began sending erroneous signals, just as it had on Lion Air flight 610.[115] About one minute into the flight, at an altitude of 1,000 feet, Getachew and Nur engaged autopilot, but then disengaged it after receiving clearance from ground control to ascend to cruising altitude.[116] Over the next few minutes, the pilots battled the MCAS as it repeatedly tried to point the plane's nose toward the ground in response to mis-readings from the AoA sensor.[117] In addition to the haywire system and rogue software, the pilots made a number of errors in the confusion—not least of which was forgetting to reduce the plane's throttle from its full-speed takeoff mode. The pilots also attempted four times to re-engage the autopilot, but the pressure on the control throttle caused by the MCAS's nose-down maneuvering and Getachew's manual efforts to counteract it prevented the autopilot from coming back online (autopilot is designed not to be able to engage when the plane senses such problems in the cockpit).[118] After just six minutes in the air, the plane crashed about 32 miles west of Addis Ababa, killing all 157 people on board.[119]

How to Address the Tragedy?

By March 9, 2019, Boeing had delivered more than 300 of the model 737 Max jets to airlines worldwide.[120] With news of the second crash and 346 lives lost due to Max crashes over the course of a few months, Boeing faced a number of pressing decisions. From a safety perspective, Muilenburg and Boeing's leadership had to quickly determine whether the two crashes shared an underlying cause and how best to respond. Should Max jets worldwide be grounded? Would airline customers and regulators take matters into their own hands and stop flying their Max fleets? From a business perspective, the chief executive would have to confront airline customers that might demand to cancel orders or that Boeing compensate them for planes that had already been delivered. What responses would be necessary to keep customers happy and prevent Boeing from suffering a significant financial setback from its investment in the 737 Max? Finally, what could Muilenburg and Boeing do to address the tragedy and help retain the trust of passengers and the public?

Exhibit 1 Boeing Key Events, 1997 to 2019

Year	Event
February 1997	Philip M. Condit became CEO
August 1997	Boeing acquired McDonnell Douglas in $13 billion stock swap
January/August 2000	Boeing acquired Jeppesen Sanderson, Inc., for $1.5 billion and Hughes Electronics Corporation for $3.75 billion
June 2000	Lion Air was founded by Rusdi Kirana
September 2001	Boeing moved its headquarters from Seattle to Chicago
December 2003	Condit resigned and Harry Stonecipher became CEO
April 2004	Boeing began the 787 Dreamliner program
March 2005	Stonecipher resigned
May 2005	Lion Air ordered 60 737-900ER units from Boeing
June 2005	W. James McNerney, Jr., became CEO
February 2006	Boeing produced its 5,000th 737, making it the most-produced commercial jet ever
August 2007	Lion Air ordered 40 737 units from Boeing, becoming Boeing's biggest customer
August 2011	Boeing initiated the 737 Max program
September 2011	Boeing brought out the 787 Dreamliner
November 2011	Lion Air ordered 230 737 units from Boeing, including 201 737 Max units
January 2012	Boeing applied for FAA amended type certification for the 737 Max
January–March 2013	Dreamliner batteries began overheating and Boeing grounded Dreamliners
November 2013	Boeing initiated development of the 777X, taking record orders
May 2014	Boeing took its 2,000th order for the 737 Max
September 2014	Ethiopian Airlines ordered three 737 Max units
2015	Boeing test pilots noted potential safety issues related to the 737 Max design, first raised during simulations in 2012; Boeing decided to create the MCAS as a solution
June 2015	Dennis A. Muilenburg succeeded McNerney as CEO
January 2016	The first 737 Max flight took place
March 2017	The FAA granted Boeing amended type certification for the 737 Max
August 2017	The first 737 Max units were delivered (to Southwest Airlines)
July 2018	Boeing delivered the 737 Max unit to Lion Air that would be flown on flight 610
October 29, 2018	Lion Air flight 610 crashed
November 6, 2018	Boeing issued an updated Operations Manual Bulletin about potential issues
November 27, 2018	Boeing issued an initial report on the Lion Air crash
March 9, 2019	Ethiopian Airlines flight 302 crashed

Source: Compiled by casewriter.

Exhibit 2 Commercial Aircraft Deliveries, by Manufacturer and Year, 1997–2018

Year	Boeing	Airbus	Bombardier	Embraer	Other	Total
1997	375	182	60	33	27	677
1998	564	229	75	60	22	950
1999	620	294	82	97	38	1,131
2000	492	311	99	160	48	1,110
2001	527	325	147	161	39	1,199
2002	381	303	185	129	8	1,006
2003	281	305	222	92	11	911
2004	285	320	175	147	8	935
2005	290	378	99	138	4	909
2006	398	434	79	129	1	1,041
2007	441	453	60	169	0	1,123
2008	375	483	61	198	0	1,117
2009	481	498	59	139	0	1,177
2010	462	510	34	97	0	1,103
2011	477	534	47	108	5	1,171
2012	601	588	14	106	8	1,317
2013	648	624	26	90	28	1,416
2014	723	629	59	92	26	1,529
2015	762	635	44	101	21	1,563
2016	748	688	53	108	20	1,617
2017	763	718	43	101	27	1,652
2018	806	800	33	90	35	1,764
Total	**11,500**	**10,243**	**1,756**	**2,545**	**376**	**26,420**

Source: Compiled by casewriter from company annual reports and "Number of Jets Added to the Global Aircraft Fleet from 1997 to 2015 by Manufacturer (in units)," 2019, via Statista, accessed May 2020.

Exhibit 3 737 Max Orders and Deliveries, January 1, 2011 to March 9, 2019

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Orders										
Southwest Airlines	149	0	50	0	0	0	40	40	0	279
Flydubai	0	0	75	0	0	0	176	0	0	251
Lion Air	0	201	0	0	0	0	50	0	0	251
VietJet Air	0	0	0	0	0	100	0	100	0	200
United Airlines	0	99	0	0	1	61	0	24	0	185
Others	0	524	496	822	385	304	397	494	8	3,430
Total Orders	149	824	621	822	386	465	663	658	8	4,596

Exhibit 3 (continued) 737 Max Orders and Deliveries, January 1, 2011 to March 9, 2019

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Deliveries										
Southwest Airlines	0	0	0	0	0	0	13	18	0	31
Flydubai	0	0	0	0	0	0	6	7	1	14
Lion Air	0	0	0	0	0	0	8	6	0	14
VietJet Air	0	0	0	0	0	0	0	0	0	0
United Airlines	0	0	0	0	0	0	0	10	4	14
Others	0	0	0	0	0	0	60	233	51	344
Total Deliveries	0	0	0	0	0	0	74	256	56	386

Source: Compiled from Boeing, "Orders and Deliveries," https://bit.ly/2M4Z7oh, accessed May 2020.

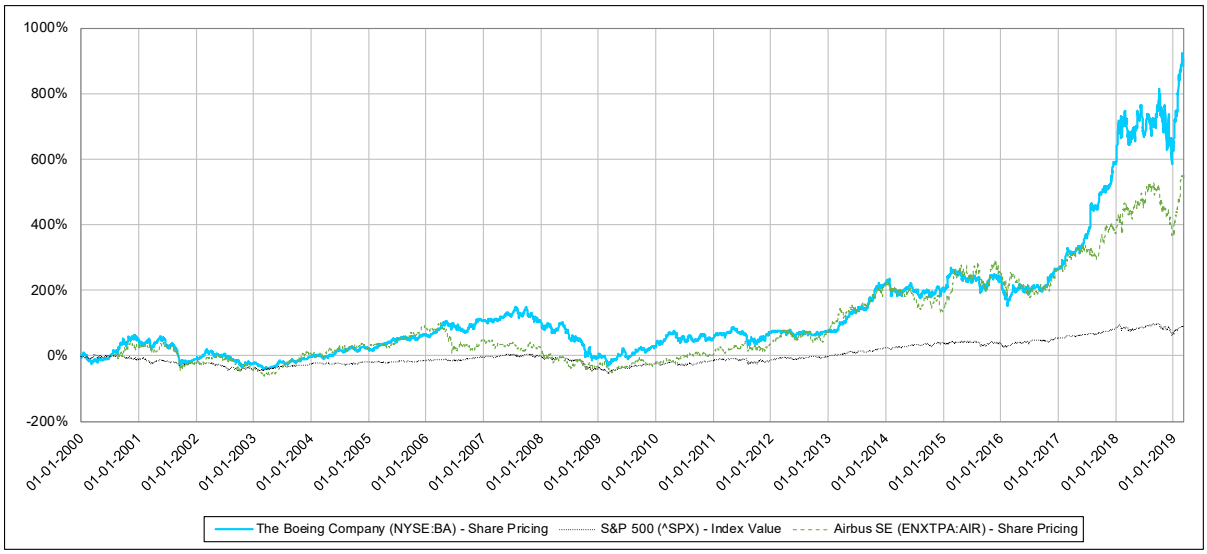
Exhibit 4 Key Financials, 2016–2018 ($ millions)

	2016	2017	2018
Total Current Assets	85,194	87,830	102,229
Total Assets	112,362	117,359	133,625
Total Current Liabilities	74,648	81,590	97,312
Total Liabilities	110,649	116,949	141,925
Total Equity	1,713	410	(8,300)
Total Liabilities And Equity	112,362	117,359	133,625
Total Revenue	93,496	94,005	101,127
Gross Profit	14,470	17,393	19,637
Other Operating Exp., Total	7,482	7,280	7,794
Operating Income	6,988	10,113	11,843
EBT Excl. Unusual Items	7,115	10,199	11,579
EBT Incl. Unusual Items	5,783	10,107	11,604
Earnings from Cont. Ops.	5,034	8,458	10,460
Net Income	5,034	8,458	10,460
EBITDA	8,877	12,160	13,957
EBIT	6,988	10,113	11,843
Diluted EPS	$7.83	$13.85	$17.85
Issuance of Common Stock	321	311	81
Repurchase of Common Stock	(7,094)	(9,368)	(9,257)

Source: Compiled from Capital IQ, Inc., a division of Standard & Poor's.

Note: Balance sheet figures are stated as of December 31. Income statement and cash flow figures are for the 12 months ended December 31.

Exhibit 5 Boeing and Airbus Share Price, S&P 500 Index, 2000–2019



Source: Chart Builder, Capital IQ, Inc., a division of Standard & Poor's.

Exhibit 6 Boeing Statement, November 6, 2018

Boeing is providing support and technical assistance to the Indonesian National Transportation Safety Committee and other government authorities responsible for the investigation into Lion Air flight 610.

The Indonesian National Transportation Safety Committee has indicated that Lion Air flight 610 experienced erroneous input from one of its AOA (Angle of Attack) sensors.

Whenever appropriate, Boeing, as part of its usual processes, issues bulletins or makes recommendations regarding the operation of its aircraft.

On November 6, 2018, Boeing issued an Operations Manual Bulletin (OMB) directing operators to existing flight crew procedures to address circumstances where there is erroneous input from an AOA sensor.

The investigation into Lion Air flight 610 is ongoing and Boeing continues to cooperate fully and provide technical assistance at the request and under the direction of government authorities investigating the accident.

Source: Boeing media statement, "Boeing Statement on Operations Manual Bulletin," issued October 29, 2018, apparently updated at least as of November 6, 2018, https://bit.ly/3dbPNuE, accessed February 2020.

Exhibit 7 Full Boeing Statement on Lion Air Flight 610 Preliminary Report, November 27, 2018

The Boeing Company is deeply saddened by the loss of Lion Air Flight 610. We extend our heartfelt condolences and sympathies to the families and loved ones of those onboard.

Safety is a core value for everyone at Boeing and the safety of our airplanes, our customers' passengers and their crews is always our top priority. As our customers and their passengers continue to fly the 737 Max to hundreds of destinations around the world every day, they have our assurance that the 737 Max is as safe as any airplane that has ever flown the skies.

Boeing appreciates Indonesia's National Transportation Safety Committee (NTSC) for its ongoing efforts to investigate the causes of the accident. Boeing is taking every measure to fully understand all aspects of this accident, working closely with the U.S. National Transportation Safety Board as technical advisors to support the NTSC as the investigation continues.

Earlier today, the NTSC released its preliminary accident investigation report. The report provides detailed accounts of Flight 610 and of the immediately preceding flight of the same aircraft. The report explains that the maintenance logs for the accident aircraft recorded problems related to airspeed and altitude on each of the four flights that occurred over the three days prior to Flight 610. The logs indicate that various maintenance procedures were performed, but issues related to airspeed and altitude continued on each successive flight. The logs indicate that, among other procedures, on Oct. 27, two days prior to the incident flight, one of the airplane's Angle of Attack (AOA) sensors was replaced.

On Oct. 28, before the flight immediately prior to Flight 610, the pilot in command and the maintenance engineer discussed the maintenance that had been performed on the aircraft. The engineer informed the pilot that the AOA sensor had been replaced and tested. The report does not include records as to the installation or calibration of the new sensor, nor does the report indicate whether the sensor was new or refurbished. Although the report states that the pilot was satisfied by the information relayed by the engineer that the AOA sensor had been replaced and tested, on the subsequent flight the pilots again experienced problems with erroneous airspeed data, and also experienced automatic nose down trim.

The report states that the flight crew of the Oct. 28 flight turned off the stabilizer trim switches within minutes of experiencing the automatic nose down trim, and continued with manual trim through the end of the flight. The report further notes that the pilot performed three non-normal checklist procedures, including the runaway stabilizer non-normal checklist, which is a memory item prescribed by the 737 Max Flight Crew Operations Manual, and reaffirmed in Boeing Flight Crew Operations Manual Bulletin TBC-19 and FAA Emergency Airworthiness Directive (AD) Number 2018-23-51, as the appropriate procedure to address unintended horizontal stabilizer movement, regardless of source.

The report indicates that the remainder of the Oct. 28 flight was uneventful and that the flight continued to its destination. The report also states that, after landing, the pilot reported some of the experienced issues both on the aircraft maintenance log and to engineering. The report states that the pilot ran the runaway stabilizer non-normal check list, but it does not state that he communicated that fact in the maintenance documentation following that flight.

The following day, Oct. 29, shortly after taking off, the pilots experienced issues with altitude and airspeed data that the pilots had previously experienced on the earlier flights, due to erroneous AOA data. Data from the flight data recorder summarized in the report also makes clear that, as on the previous flight, the airplane experienced automatic nose down trim. In response, the flight crew repeatedly commanded nose up trim. This sequence repeated for the remainder of the flight, during which the flight crew was able to maintain control of the airplane for approximately ten minutes. Unlike as is stated with respect to the prior flight, the report does not state whether the pilots performed the runaway stabilizer procedure or cut out the stabilizer trim switches. In accordance with international protocol, all inquiries about the ongoing accident investigation must be directed to the NTSC.

Source: Boeing media statement, "Boeing Statement on Lion Air Flight 610 Preliminary Report," issued November 27, 2018, https://boeing.mediaroom.com/news-releases-statements?item=130336, accessed February 2020.

Appendix: Aircraft Manufacturing Dynamics

Aircraft Production and Airlines

Major global airlines, many of which were headquartered in the U.S., purchased most new aircraft. Demand was driven by airline profitability and consumer air-travel demand forecasts, as well as the age of existing fleets. New-model development involved long-term cycles that required significant R&D and capital expenditures. It took an average of four to eight years to design a new aircraft. Following design, aircraft makers then manufactured aircraft in sections, transported the sections to a single facility, undertook final assembly, and finally proceeded with trial flights. The average lifespan of a commercial plane was 20 years. The desire to reduce operating and fuel costs, coupled with emissions and other environmental regulations, also influenced demand. Due to the length of production cycles, airlines typically ordered planes several years ahead of anticipated use. Most airlines stayed with the same manufacturer once they began building up their fleets, as switching costs were high due to the need to change equipment, parts, flight simulators, and training curriculums.

Airlines could buy planes directly from manufacturers, but around half of planes were leased via intermediaries such as the International Lease Finance Corporation (ILFC). Leasing offered airlines shorter commitments and greater flexibility to adjust the number and type of aircraft in their fleets. Airlines and leasing companies regularly paid different prices from one another, even for the same model, and discounts and price concessions were common. Whether buyers were airlines or leasing companies, they typically paid 1% to 2% of total contract value up front, then made scheduled payments throughout construction; around 20% to 25% of the total cost was paid in the last two years, with a final payment upon delivery.

Engines

Engine makers also faced long, expensive production cycles and historically looked to enter into exclusive contracts with aircraft manufacturers, aiming to become the sole provider of engines for specific aircraft models to avoid steep price wars. The engine price (20% of total aircraft cost), while not the only consideration, was often a deciding factor for airlines choosing to purchase new aircraft. Typically, airframe makers such as Boeing asked at least two different manufacturers to develop engines for each new airframe to ensure competitive prices and advanced technology; airlines could then negotiate separately with engine suppliers. Engine manufacturers offered heavy discounts in order to lock in long-term business for replacement parts, repairs, and maintenance.

Airframe and Engine Maintenance

Airlines, airframe and engine manufacturers, and regulators worked together to establish proper procedures for scheduled maintenance. Through the 1970s, airlines typically operated their own maintenance facilities. After a purchase, maintenance, repair, and overhaul (MRO) work—which represented some 10% to 45% of an airline's annual operating expenses—was typically performed by the airlines themselves or outsourced to MRO specialist firms. After U.S. deregulation, cash-strapped airlines began outsourcing maintenance, and by the 1980s, several manufacturers identified an opportunity to increase revenue by taking on MRO work. However, some large airlines still performed their own maintenance in-house, or in conjunction with other airlines. Over a 20-year lifespan, an engine might need repair or heavy maintenance some eight times, and the cost of maintenance over the life of an engine could exceed the aircraft's initial purchase price.

Regulation

Each model of aircraft had to be approved by regulators, such as the FAA in the U.S. and the International Civil Aviation Organization. FAA certification included review of proposed designs, ground and flight tests, an evaluation of required maintenance and operational suitability for the airplane to begin service, and coordination between aviation regulators in different jurisdictions. Since 2005, the FAA, which employed about 1,300 engineers, inspectors, test pilots, and other professionals, had been authorized to delegate some of its oversight responsibilities to qualified organizations, including the airframe and engine manufacturers themselves. However, the FAA was required to maintain strict oversight, and manufacturers could not self-certify their aircraft. New-aircraft certification took five to nine years to complete and was valued at $25 to $50 million. When manufacturers wished to modify an already-certified model design, the FAA could issue an amended type certificate; amended type certification took three to five years to complete.

Pilot Training

An FAA Airline Transport Pilot certificate required pilots to be at least 23 years old; to obtain medical certification; to already have a commercial pilot's license with an instrument rating (meaning the pilot was certified in the multiple instrument skills needed to safely fly in inclement weather); and to have at least 1,500 hours of recorded flight time, including at least 50 hours flying a multi-engine plane. Most large commercial airlines required pilots to hold bachelor's degrees. Pilot training took place in flight schools or certified aviation college programs or academies. Many commercial airline pilots received their training in the military, prior to obtaining commercial licenses. Other airline pilots logged their hours by working as agricultural pilots (crop dusters), bush pilots, flight instructors, or unscheduled charter pilots. Some low-cost carriers and regional airlines around the world employed commercial airline pilots with far less training, simulator experience, and flight time—these ill-trained and inexperienced pilots depended on cockpit automation and "a rote approach to flying," wrote one expert. By the 2010s, there were about 300,000 airline pilots worldwide.

Source: William Spitz, Richard Golaszewski, Frank Berardino, and Jesse Johnson, *Development Cycle Time Simulation for Civil Aircraft* (Hampton, VA: Langley Research Center and National Aeronautics and Space Administration, January, 2001), p. 1-1, https://bit.ly/2Tr8xi4; William Langewiesche, "What Really Brought Down the Boeing 737 Max?" *New York Times Magazine*, September 18, 2019, updated January 21, 2020, https://nyti.ms/2zWGLTE; Nicola Clark, "Woes of Aircraft Leasing Companies Could Mean Higher Ticket Prices," *New York Times*, October 5, 2009, https://nyti.ms/3bT5Z2B and Leslie Wayne, "The Real Owner of All These Planes," *New York Times*, May 10, 2007, https://nyti.ms/3gcki5R; Daniel Michaels, "The Secret Price of a Jet Airliner," *Wall Street Journal*, July 9, 2012, https://on.wsj.com/36iJkvr; Rick Tauber, "Boeing Co," Morningstar Corporate Credit Research, September 16, 2016, pp. 2–3, accessed March 2017; "Gearing up for a fight," *Economist*, January 25, 2014, https://econ.st/2LLXJHd; "New Engines, More Problems," Industry Insights, Boyden, https://bit.ly/36kEo9o; Advisory Circular, "Maintenance Review Boards, Maintenance Type Boards, and OEM/TCH Recommended Maintenance Procedures," U.S. Department of Transportation, Federal Aviation Administration, August 27, 2012, p. 5, https://bit.ly/2TqWRvU; Brandon Battles, "Maintenance Costs: Significant but Tricky," Aviation Pros, April 1, 2003, https://bit.ly/2zVTZjG; Pravin Vazirani, "Everything MRO: Putting Maintenance, Repair, and Overhaul on Blast," Chetu, Inc., https://bit.ly/3cU0zWn; John Walton, "Where are all the unused planes right now?" BBC, April 15, 2020, https://bbc.in/3cU0AJV; Federal Aviation Administration, "Airworthiness Certification," https://bit.ly/2Zo0SEY; Natalie Kitroeff, David Gelles, and Jack Nicas, "The Roots of Boeing's 737 Max Crisis: A Regulator Relaxes Its Oversight," *New York Times*, July 27, 2019, https://nyti.ms/2Tpv8f1; Dan Johnson, "The cost of certification," *General Aviation News*, September 9, 2012, https://bit.ly/2Xg312V; Sarina Houston, "How to Become an Airline Pilot," The Balance Careers website, updated September 1, 2019, https://bit.ly/3gaa2uU; Sarina Houston, "More Ways for Pilots to Build Flight Time," The Balance Careers website, updated November 20, 2019, https://bit.ly/2TqTFjT; all accessed April 2020 unless otherwise noted.

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