INTRODUCTION

Existential Crisis

"Alaska Flight 1282, Declaring an Emergency."

DAVID CALHOUN AND BRIAN WEST, the chief executive officer (CEO) and the chief financial officer (CFO) of The Boeing Company, were upbeat. It was November 2, 2022, and Boeing held its first investors day briefing since 2018.

The intervening years had presented existential threats to Boeing. First, the 737 MAX ("737" or "MAX") suffered two crashes five months apart in October 2018 and March 2019. Regulators across the globe grounded the airplane. It would be twenty-one months before the Federal Aviation Administration (FAA) recertified the MAX for a return to service. Boeing had billions of dollars tied up in 450 MAXs that had been built and stored before production was suspended during the grounding. Bringing these airplanes into compliance with the necessary fixes and software updates, and simply "waking" the planes up from being stored so long, took weeks per airplane. Boeing wrote off more than $5 billion dollars for costs and customer compensation. The 737 is the company's biggest money-maker. In any given normal year, 737 sales account for between 80 and 85 percent of Boeing's orders.

In March 2020, just two months after becoming CEO, Calhoun was hit with another existential crisis: the new, mysterious deadly disease called COVID-19 became a global pandemic. Airlines worldwide slashed service by up to 90 percent. West had to raise an additional $25 billion to carry Boeing through the grounding and the pandemic. The additional debt nearly doubled Boeing's long-term debt to more than $50 billion. Boeing's credit rating was reduced, which made borrowing more expensive. Boeing's deliveries of widebody planes ground to a halt. It would be two years before the pandemic was under control, after millions died.

The pandemic was not Boeing's only problem in 2020. In October of that year, production flaws in the company's 787 model were discovered during inspections. Paper-thin gaps were found between fuselage barrel sections. Deliveries were suspended for twenty months. Reworking the 787s to shim these gaps and to fix other problems discovered during the inspections would take three to four months per airplane. Boeing built 110 787s that were stored during the delivery suspension. For the first time in the 787's program, the company took a billion-dollar-plus write-off as costs and customer compensation mounted.

The FAA revoked Boeing's ability to certify each 737 and 787 as airworthy, a step required before any aircraft could be delivered to a customer. This "ticketing authority" was assumed by the FAA, which had to staff up to perform its duties, adding another step to the certification process and causing public embarrassment for the company. There was no telling when, or even if, the FAA would return ticketing authority to Boeing.

Certification of the 737-7 and 737-10 MAXs was stalled once the MAX was grounded because of the lengthy time needed to make design fixes, validate them, and implement them. The MAX 7 was already in flight testing, which ground to a halt. The MAX 10's first test airplane rolled out of the factory during the grounding and straight to a parking place while all the work required by the FAA was underway. (Unknown at the time: neither derivative would be certified during the next six years.)

The grounding, inspections, discovery of new technical problems, and the scandal surrounding the FAA's assumption of the certification process of the MAX caused one delay after another. Boeing and the FAA were embarrassed by the revelations that emerged from multiple investigations. Certification of the giant 777X had been in process when the MAX crashes happened. After the accidents, the FAA began a review that involved looking at every step Boeing had undertaken on the plane's production and certification steps to date. The negative halo effect of this oversight indefinitely stalled certification of the 777X. Boeing estimated at the time that certification would happen in 2024, nearly five years after it had been expected. Even this would prove optimistic.

On top of these issues, the company's defense and space programs were running years late and up to billions of dollars over budget.

But by investors day in late 2022, Calhoun and West were sufficiently confident that the end of the company's trials and tribulations was in sight. The inventories of the stored MAXs and 787s should be cleared by the end of 2024, they said. Profits and positive cash flow would return as the inventory airplanes, with concurrent increases in production of the 737 and 787 lines, were delivered. The executives predicted that by the end of 2025, the production rate for the 737 would return to fifty per month (still below the pre-grounding rate of fifty-two per month). Boeing was already alerting its supply chain that higher production rates were imminent. The 787's production rate, reduced to a mere 0.5 per month during the delivery pause, would be back to five per month by the end of 2023 and ten a month by the end of 2025. This was well below the pre-pandemic peak of fourteen per month, but nevertheless a healthy rate for a widebody airplane.

Calhoun and West told aerospace analysts that November 2 that by

2025/2026, free cash flow should reach $10 billion a year. The analysts, more concerned about near-term shareholder value than long-term company health, were pleased. More pleasing was Calhoun's announcement that Boeing would not "introduce" a new airplane until the middle of the 2030s. Technology, he said, would not be ready before then to produce the 20 to 30 percent improvement in cash operating costs the airlines needed to justify a new airplane.

The analysts loved hearing this. A new airplane meant a jump in spending for research and development (R&D). A jump in R&D spending meant less money for stock buybacks and dividends, i.e., shareholder value. Boeing's stock price jumped on November 3, 2022. Within a week, it was up 18 percent and climbed further as the year ended.

For Boeing, the year 2023 was not without hiccups. Production ramp-up for the 737 was falling behind plan, and meeting announced production rates was a struggle for the company. The supply chain still hadn't recovered from the pandemic; shipping parts was also falling behind schedule. Quality was a problem. After Boeing laid off thousands of workers during the grounding and the pandemic, thousands of new people were hired. Training and a learning curve were necessary for an efficient assembly process. Mistakes happened. Boeing was plagued by poor quality products, which it calls "quality escapes." Planes were rolled out of the factory with missing parts because the supply chain couldn't deliver on time. While this "traveled work" is normal (and happens at Airbus and other manufacturers), it's annoying and inefficient. If severe enough, it causes delivery delays.

Despite these setbacks, Boeing's stock price continued to climb. By the end of 2023, the price was more than $250 a share. This was well below the $440 a share before the March 2019 grounding of the MAX fleet but well above the five-year low of $95 per share at the start of the pandemic in March 2020.

Thus, as 2023 shifted into 2024, there was nothing but optimism at Boeing that its main troubles were behind it.

Then, on January 5, 2024, at 5:06 p.m., Alaska Airlines flight 1282 took off from Portland, Oregon, for Ontario, California. There were 177 passengers and crew aboard the ten-week-old 737-9 MAX. There were only seven empty seats on the flight. Two of these seats were 26A and 26B.

Six minutes later, the plane was passing 14,830 feet on climb-out when the cabin pressure dropped from 14 pounds per square inch (PSI) to 11.64 PSI. The plane was flying at 271 knots. In the cockpit, a warning light flashed that the cabin-pressure equivalent was now greater than 10,000 feet, the altitude considered safe for humans. Within seconds, the cabin pressurization went to zero. The cabin completely depressurized. The cockpit door blew off its hinges, oxygen masks deployed, the shirt of a teenager in seat 25A was ripped off, and his mother in 25B grabbed her son and held him to prevent him from being sucked out a hole in the fuselage next to seat 26A. Had this seat been occupied, this passenger probably would have been sucked out despite being buckled in with a seat belt.

"Alaska 1282, declaring an emergency," the co-pilot radioed. The pilots landed at Portland at 5:26 p.m., fourteen minutes after the depressurization. There were no fatalities and only minor injuries. There was damage throughout the cabin. It was a terrifying experience, but the passengers and crew were lucky. It could have been far worse.

A part of the fuselage had separated from the airplane. It was a "door plug" that fit into an opening designed to be an emergency exit for the high-density version of the MAX 9. Alaska Airlines, United Airlines, and others that configured their cabins for a lower density didn't need this emergency exit, so instead of a removable door to allow emergency egress, a plug is installed. The plug reduces weight (63 pounds vs. 150 pounds for an emergency door) and eliminates the need for some structural components, which saves fuel. Without the emergency exit, seat pitch didn't have to be expanded to allow unimpeded egress in the event of an evacuation.

It was sheer luck that nobody was seated in 26A or 26B and astounding luck that the mom was able to hold onto her son in seat 25A. Flight attendants in the forward cabin didn't know what had happened, only that the cabin depressurized. Communications between the cockpit and the flight attendants were severed due to cabin and cockpit damage. At 16,000 feet, the peak altitude of the event, the differential between the cabin air and outside atmosphere was far less than what it would have been had the event occurred at cruising altitude. At 16,000 feet, passengers were still buckled in. Had the event occurred at cruising altitude, passengers might have been moving about the cabin, flight attendants could have been serving food and beverages, and seat belts might have been loosened. Anyone standing in the cabin or sitting with a loosened seat belt could have been sucked out of the airplane. The explosive decompression at that altitude may have been too much for the airplane to withstand; the plane could have come apart, killing all aboard.

When the door plug separated from the fuselage, it missed hitting any other part of the airplane. Had it hit the horizontal or vertical tail, the structural damage could have made the plane uncontrollable. The plane could have crashed, with deaths—perhaps to all aboard—likely.

The pilots reacted as they were trained. The air traffic control recordings available on YouTube reflect a calm response to the emergency. The co-pilot, handling the radio, was communicating through her oxygen mask, which distorted her voice somewhat. This led some misogynists to claim that the female pilot was rattled and unqualified to be in the cockpit and that she was there only because of diversity policies. The claims were nonsense, of course. The co-pilot had 8,300 hours of experience, including

1,500 in the MAX. (The captain had 12,700 hours of experience, including 6,500 in the MAX.)

After the flight landed, all anyone knew was that the door plug had separated from the airplane. Within hours, Alaska Airlines grounded its MAX 9 fleet of sixty-five aircraft.[1] United, which had seventy-nine MAX 9s, followed suit the next morning. The FAA officially grounded the 171 MAX 9s flying in the United States shortly after United's action. Foreign operators of the MAX 9 with the door plug instituted groundings of their own.

Within days, the "why it happened" narrative began to emerge. Boeing was responsible for yet another quality escape when assembling the Alaska Airlines airplane—one that could have been fatal. The FAA descended on Boeing with new factory inspections. It capped production rates and blocked the establishment of an entirely new 737 North Line at the company's Everett, Washington, factory. The FAA rejected Boeing's first inspection-and-repair process and kept the MAX 9 grounding order in effect for three weeks while Boeing revised the process and completed inspection of at least forty aircraft.

The company's stock price plunged from 2023's close of $261 to $217 (17 percent) when Boeing's culpability became clear. Certification of the MAX 7, expected to occur early in 2024, was put off again, this time by at least nine months if not longer. Southwest Airlines, the principal customer for the 737-7, took the airplane out of its scheduling plans for 2024. Certification of the MAX 10, which Boeing hoped would take place in early 2025, was to be delayed, probably by a year. United took the MAX 10 out of its scheduling plan indefinitely.

A new crisis was underway for Boeing. Another crisis in confidence began.

Once considered the gold standard in aerospace engineering and production efficiency, many wondered how Boeing had experienced such a precipitous fall from grace. The company once commanded about 60 percent of the global airliner market. Today it's about 40 percent and falling. Again, how did this happen?

The Rise and Fall of Boeing examines how the company became a poster child for inefficiency and quality escapes. Many of the events leading to Boeing's fall were self-inflicted wounds; the oft-repeated accusation that illegal subsidies to Airbus were to blame is untrue. *Rise and Fall* tells the story.

Can Boeing recover and become a leader in the sector once again? *Rise and Fall* explores this question.

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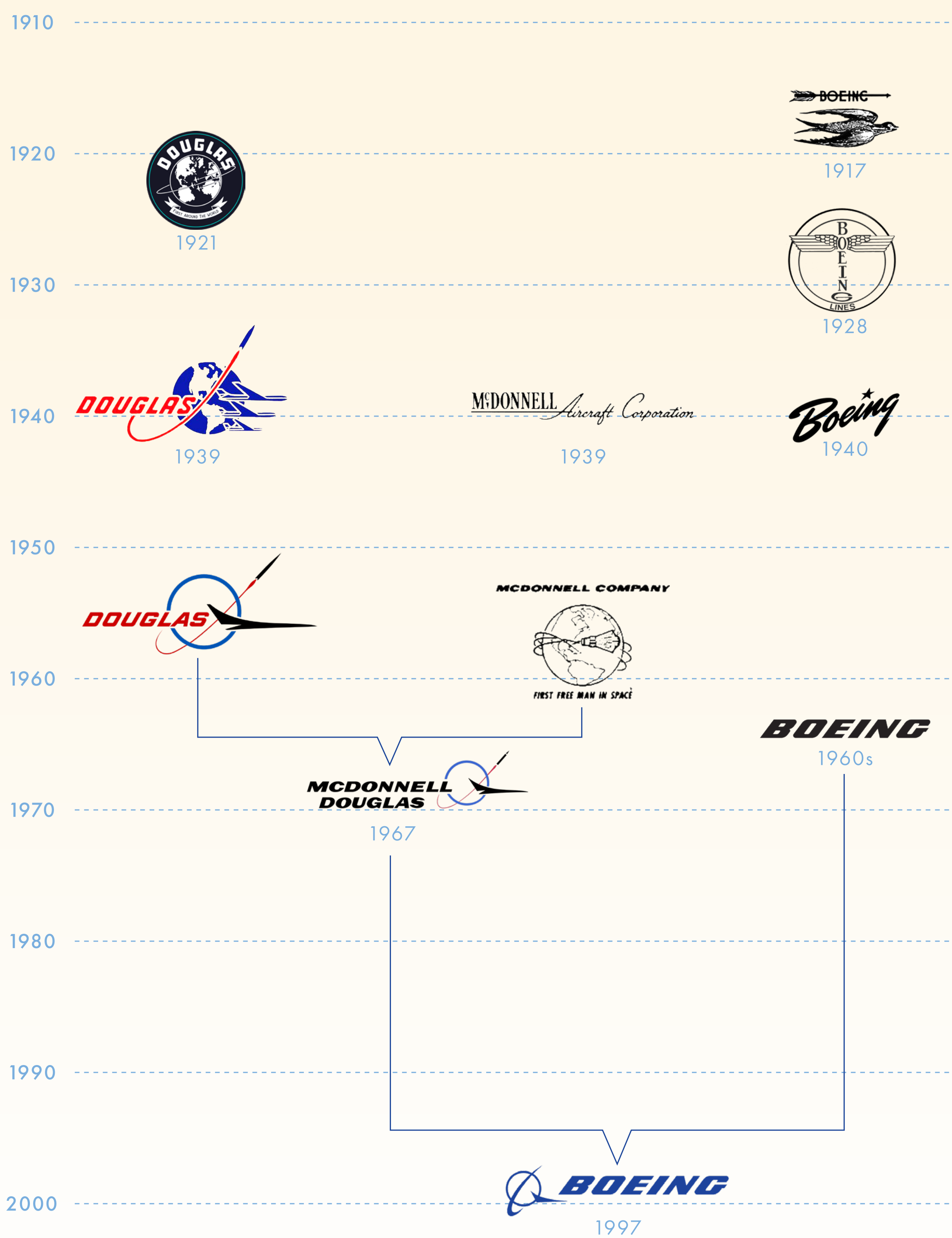
1. The smaller, standard 737-8 MAX doesn't have the emergency exit or door plug, so it was not affected.

PART 1

THE RISE



Credit: Guilhem Renier

Figure 1. Boeing's first airplane was the biplane B & W Model 1 seaplane. This is a replica. Museum of Flight photo.

1

Humble Beginnings

The First Modern Airliner—and a Tactical Mistake

THE BOEING COMPANY WAS FOUNDED IN 1916 in Seattle by William Boeing. Bill Boeing made his fortune logging in the Pacific Northwest. Bitten by the emerging aviation bug, the first Boeing airplane, the Model 1, was a single-seat biplane (a fixed-wing aircraft that has two wings, one situated above the other) also known as the B & W Seaplane. The "W" stood for co-designer George C. Westervelt. Only two were built. The airplane was offered to the U.S. Navy, which declined the offer. The two airplanes were sold to buyers in New Zealand, where they were first deployed at a flying school. Later, they were used to carry mail. A replica of the Model 1 hangs in the Museum of Flight at Boeing Field in south Seattle.

Through the 1920s, passenger air service began to take hold in Europe and the United States. Small, single-engine airplanes were built, including Boeing's Model 40. About eighty of these biplanes were sold. The pilots of Model 40s worked in an open cockpit. Four passengers were carried in the plane's closed cabin. In 1927, Boeing introduced the tri-motor Model 80, also a biplane. Twelve passengers were carried in the cabin, and Model 80

Figure 2. Boeing's Model 247 was considered the first modern airliner in the early days of aviation. Museum of Flight photo.

Figure 3. Douglas responded to a request from TWA for an airplane to compete with the Boeing 247. Credit: Getty.

pilots worked—finally—in a cabin-accessible closed cockpit. Only sixteen Model 80s were built; one survives at the Museum of Flight.

The Ford Motor Company built 199 TriMotors, a metal airplane introduced in 1926. A carbon copy of the Fokker TriMotor, a wooden airplane introduced in 1925, legend has it that Henry Ford took measurements of a Fokker overnighting in Detroit to design the Ford TriMotor. The Fokker plane carried twelve passengers. Its wooden construction proved to be its fatal flaw. A wing spar on a TriMotor operated by Transcontinental & Western Airlines, the forerunner of Trans World Airlines (TWA), rotted through and the plane crashed, killing Notre Dame's famous football coach, Knute Rockne. The crash led manufacturers to produce only all-metal airplanes.

While single-engine biplanes and planes produced from old designs plodded around the U.S. and the world, Boeing took the plunge and created the first "modern" airplane, the Model 247. The 247 was the first passenger aircraft that was a low-wing monoplane. It was metal, it was a twin-engine design, and it carried ten passengers. The 247's wing spar—metal, after the Fokker crash—ran right through the cabin. A step was needed for passengers to climb over it. For its day, it was aerodynamically clean. There were no stringers on the wings, and its design was sleek compared with the clunky aircraft from Boeing, Ford, Fokker, and others that preceded it. For the day, it was also fast.

The 247's first flight was in February 1933. Airlines loved the plane. There was only one problem: Boeing couldn't sell it to any airline but United. Boeing had become part of a consortium that owned Pratt & Whitney and United, which had been given exclusive purchase rights to the first sixty 247s. This prompted United competitor TWA to issue a request for proposals (RFP) to other manufacturers to design and build

Figure 4. Boeing designed the B-17 bomber for the U.S. Army Air Corp (later the U. S. Army Air Force). Credit: Getty.

Figure 5. Boeing followed the B-17 with the civilian B-307 Stratoliner, using the engines, wings and tail. Credit: Getty.

a plane to rival the 247. Among those responding was the small-sized Douglas Aircraft Company.

Douglas designed the DC-1 prototype, which begot the DC-2 model. The DC-2 carried four more passengers than the 247 and had more powerful engines, greater range, and was faster. Perhaps more importantly, it was available to purchase.

In response to TWA's RFP, the Lockheed Corporation designed the Model 10, also known as the Electra, in 1934. Another ten-passenger airplane, it was faster than the DC-2. The Electra entered service in 1935; the DC-2 came on the scene in 1934. Sales were respectable for the era: 149 for the Electra and 198 for the DC-2. Sales for Boeing's pioneering 247 stopped at 75. It wouldn't be the last time Boeing's industry-leading designs came up short in sales competition.

While Boeing worked to fill United's order for those sixty 247s, Douglas sold to all comers. Boeing made history with the "first modern airliner," but it made a huge strategic mistake by blocking out the first sixty sales for United. Douglas quickly became the number one commercial-airliner producer. American Airlines wanted an improved DC-2. Douglas designed the even better, twenty-one-passenger DC-3, the iconic airplane that, thanks to demand for the model in World War II, saw more than 10,000 built. Boeing was for all practical purposes put out of the commercial aviation business because of its miscue on the 247 sales. The company later built the long-range B-314 Clipper, a large flying boat for Pan American Airways (Pan Am). Only a dozen of these models were built, however, before World War II made flying boats obsolete.

Boeing's engineering prowess was on display with its next civil airliner. The company attempted to leapfrog to the next level with the B-307

Figure 6. The Boeing B-29 was designed for the long distances over the Pacific Ocean. It's most famous for dropping the world's only atomic bombs on Japan to end World War II. Credit: Getty.

Figure 7. During the latter part of World War II, Boeing developed the C-97 freighter based on the B-29. Post-war, the C-97 was turned into the B-377 Stratocruiser. The similarities with the B-29 are obvious. The Stratocruiser was not successful as an airliner. Credit: Getty.

Stratoliner. Based on the early B-17 bomber, the Stratoliner used the wings, tail, and engines from that airplane. The cigar-shaped fuselage could seat thirty-three passengers, which was huge for the era. The B-307 was the first airliner to offer pressurization. It was highly advanced for its day. Pan Am bought five and TWA bought four. TWA's principal owner, Howard Hughes, bought one. Only ten were built. The B-307 had a range of only 1,750 miles, eliminating it from use for transoceanic service, something the B-314 provided. Sales prospects for the B-307 were hurt when a prototype Stratoliner crashed during a demonstration flight for KLM Royal Dutch Airlines, which had personnel on board. Demonstrating how the airplane would fly with two engines feathered on the same side, the pilot lost control. An investigation of the incident concluded that the plane's vertical tail was too small to provide directional stability with two engines out on one side. The Stratoliner finally entered service with Pan Am on July 4, 1940. World War II was already underway, however, and the Stratoliner would soon be eclipsed.

While Boeing pursued the Stratoliner, Douglas designed the DC-4E (the "E" was for "Experimental"). This four-engine airplane, unlike the tail-dragging Boeing, sat on a tricycle gear. It had a triple tail to fit in low-rise hangars and forty-two passenger seats. It was also pressurized. The prototype was the only DC-4E built, and it was, in 1938, considered too big by the airlines. Also, the many systems innovations on this experimental aircraft were thought to be too complex by the airlines. Nevertheless, the DC-4E proved to be useful in that it led to the simpler DC-4 that went into production at the start of World War II as the C-54. This became the staple of long-haul cargo and VIP transport during the war, and the first four-engine airplane to carry passengers after the global conflict. The DC-4 became the forerunner of the highly successful DC-6 and the less successful but still useful DC-7.

Lockheed also pursued a four-engine, pressurized airplane, the Constellation (also known as the Connie). With its shark-like fuselage and triple tail, the Connie entered service with the military in 1943 as the C-69. It, too, migrated to the airlines after the war.

That the Stratoliner was based on the B-17 illustrated Boeing's shifting emphasis to military development. Boeing's B-17 was succeeded by the B-29 Stratofortress. With pressurization and very powerful if temperamental piston engines, the B-29 had long range for use across the Pacific to bomb Japan. It cruised at high altitudes.

Once more using a bomber as a base, Boeing developed the B-367 cargo airplane. The baseline B-29 model was used as a foundation: wings, engines, tail, and lower fuselage. Another fuselage was placed on top, creating the so-called "double bubble." The military designation for the B-367 was the C-97, which first flew in late 1944. After the war, William Allen, who succeeded Bill Boeing as CEO, decided that Boeing needed a product to herald the company's return to commercial aviation. He ordered the development of a civilian version of the C-97. Identical to the cargo airplane except for a taller tail, the B-377 Stratocruiser ("Strat") was launched.

The B-377 was an ungainly looking airplane. Its blunt round nose made it look like it was pushing, not gliding, through the air. Its powerful engines were cranky. Failures were frequent, and it wasn't unknown for the vibration from a failed engine to rip it from the wing. The plane's exposed flat firewall made it difficult to stay airborne. At least one or two crashes were thought to be caused by the increased drag of such a failure. The B-377's operating costs were far higher than those of the competing DC-6s and Constellations. (The DC-7 would come a few years later.)

The B-377 Stratocruiser was huge by the standards of the day. It could carry up to eighty-three passengers, more than all other airplanes until well after it entered service in 1947. The Strat had a lower-deck lounge that gave it a panache not seen on any other post-war airplane and which wouldn't be seen until the advent of the Boeing 747 design, with its upper-deck lounge, in the mid-1960s. The B-377 had more range than the DC-4s, DC-6s, and Connies of 1947–1952. But it was its lounge that gave it romance.

Pan Am ordered twenty Strats for its transatlantic and Hawaiian services. Northwest Orient Airlines, United, American Overseas Airlines (AOA), and British Overseas Airways Corporation (BOAC) placed orders. So did Scandinavia's SAS, but it canceled before taking delivery. United sold its small Stratocruiser fleet to BOAC in 1954 after only four years in service. AOA's B-377 fleet went to Pan Am in a merger. Trans Ocean Airlines, a successful charter carrier, bought a fleet of Stratocruisers as they were retired from mainline carriers. Trans Ocean promptly went bankrupt after acquiring the costly, temperamental airplanes.

Only fifty-six Stratocruisers were built, including the prototype. But Boeing built 888 KC-97s, ensuring financial success for the company's combined civilian-military program and further cementing its long history of cross-overs between its military and commercial divisions. The Stratocruiser, operational dog that it was, served its purpose. It kept Boeing in the commercial aviation market. Even as the aircraft struggled in service, Boeing was designing a commercial jet, code-named the 367-80 to hide its studies. Recall that the original C-97 had the internal designation B-367. The -80 suffix was said to represent the 80th design iteration of the jet. Indeed, some early drawings illustrated a C-97 fuselage with swept wings and podded-engine clusters.

With developments in Europe bringing jet-powered airliners forward and its own experience with the B-47 and B-52, Boeing naturally turned to the development of a jet-powered airliner. The jet age was about to dawn in the United States.

2

The First Jet Age

"It was a big, hairy-chested airplane."

—D. P. DAVIES, CHIEF TEST PILOT FOR THE UK'S CIVIL AVIATION AUTHORITY

THE RISE OF THE BOEING COMPANY in commercial aviation began with the jet age. The company's 707 model entered service in October 1958. Boeing would hold the top spot in the industry for nearly fifty years, eclipsing Douglas in the jet age as the number one producer of airliners. Lockheed, which had shared dominance in the piston era, took a pass on offering a jet and instead chose to design a second Electra model (see Chapter 1), this one a four-engine turboprop. But for all of Boeing's innovation in the field of jets (which began with the jet-powered B-47 and B-52 bombers), European aircraft manufacturers initially were the leaders in the commercial jet age. The Soviet Union's Tupolev designed the twin-engine TU-104 jet, which entered service in 1956.

During World War II, Britain's airplane industry concentrated its efforts on fighters and bombers. While America's industry pursued fighter and bomber development, it also developed transports and cargo airplanes. Thus, after the war, Britain converted World War II bombers—notably the Lancaster—to civil airliners. The fuselages of these planes were cramped and, because they were "tail draggers," passengers had to climb uphill to reach their seats. These planes were hardly the ideal solution to postwar travel. The Americans had the tricycle-gear DC-4 and the Lockheed L-049 Constellation, followed by the later-improved DC-6, DC-7, and multiple Constellation models. Boeing had the unsuccessful Stratocruiser (see Chapter 1).

Some debate exists over who developed the first jet engine. Britain's Frank Whittle developed a jet engine concept in 1929, obtaining a patent a short time later. The Royal Air Force (RAF) had no interest in the engine initially, and the design languished on paper. It wasn't until 1936 that the RAF showed interest and Whittle's engine approached the prototype stage.

In Germany, jet engine development was underway more or less on a similar timetable. Hans Von Ohain, an engineer at the airplane manufacturer Heinkel, filed for a patent for an engine in 1935 after reviewing Whittle's early work, and Spain's Virgilio Leret Ruiz filed his own engine patent in 1935. None of the engines were produced when World War II began on September 1, 1939. But with the Allies regularly overwhelming the Luftwaffe, the world's first operational jet airplane, the Messerschmidt Me-262 fighter, entered service in April 1944. Faster than the fastest Allied fighter, Luftwaffe Me-262 pilots shot down more than 500 fighters and B-17 bombers by war's end.

The Germans designed other jet-powered warplanes, but none reached production. And it's here that Boeing got its jump over Douglas and all other U.S. aerospace companies. Boeing engineers were part of a U.S. postwar contingent that swept up German war records, including secret plans for new weapons, submarines, and airplanes. Germany's swept-wing concepts and design papers made their way back to Boeing in Seattle. This research became the basis for the world's first all-jet bomber, the Boeing B-47. A follow-on design, the B-52, came a few years later. The first B-52 flight was in 1952, and the plane entered service in 1955. The B-52 proved to be so robust that it is still in service today.

B-47s and B-52s needed aerial-refueling tankers to fulfill their intended missions. The piston-powered Boeing KC-97, itself a basic derivative of the famed Boeing B-29, was too slow to accomplish this task. The jet bombers had to slow down to speeds barely above stall at the refueling altitudes. Even after the U.S. Air Force added jet engines to supplement piston power, the KC-97s clearly had to be replaced.

The Air Force ran a jet tanker competition. Forgotten to history, Lockheed won with a design that embedded four engines—two on either side of the aircraft—next to the fuselage. Named the Constellation II, after the C-69 military and L-049 civilian Constellation models, the L-193-44 (as the internal designation was named) beat out Boeing's tanker concept. The reason why is lost to history.

Boeing's tanker design had four engines in pylons across the aircraft's wings, similar its B-47 and B-52 models. The plane, called the C-135/KC-135, was ready to fly. Boeing had a close relationship with General Curtis LeMay, the first commander of the new Strategic Air Command (SAC), in no small part because the company's B-47s and B-52s were becoming the mainstays of SAC and its KC-97s were refueling them. With the L-193-44 still a paper concept, LeMay turned to Boeing for the KC-135. Once Boeing was in the door, Lockheed was out, and it never produced the L-193-44, either in military or civilian form.

Boeing's prototype 707 first flew in 1954. As early as this was, however, the Brits hit the skies first with jet power for an airliner.

The British-designed Vickers Viscount first flew in July 1948, three years after the end of the war in Europe. The Viscount was designed around jet-prop engines. The plane was small, seating just forty-four passengers in its original version and up to eighty in its subsequent stretched Viscount 810 model. The plane's range was a mere 1,400 statute miles—plenty for intra-European routes but well short of the vast distances of planes operating in the United States. Capital Airlines and Northeast Airlines were the original operators of Viscounts in the U.S. The systems of these airlines were largely confined to areas east of the Mississippi River and up and down the East Coast, respectively. Continental Airlines ordered a small number of the largest model 810, but its system ended in Chicago and Texas. Still, the Viscounts, with their oversized passenger windows, nearly vibration-free flight experience, and relatively quiet engines were a big hit with airlines and passengers alike. The Viscount was easily the most successful of all British airliners, with 445 built during a fifteen-year production run ending in 1963.

Figure 8. Lockheed proposed a jet tanker for the U.S. Air Force with the internal name L-193. Jets were buried next to the plane's fuselage. A commercial version called the Constellation II was floated. Neither went into production. Credit: Lockheed.

Figure 9. The de Havilland Company of England designed the first commercial jet airliner, the Comet. It first flew in 1949 and entered service in 1952. The Boeing 707 prototype did not fly until 1954. Credit: Getty.

As successful as the Viscount was, Britain placed its commercial airliner bet and prestige on the de Havilland Comet jetliner. The first flight of this aircraft followed the Viscount by a year almost to the day. The Comet entered into service nearly three years later. Like the Viscount, the Comet was too small. It, too, carried a little more than forty passengers, and, like the Viscount, its range was too short, just 1,750 miles. This shortcoming was a function of the fact that the engines were new and had a thrust of only 5,000 lbs. The plane's wings were small, limiting fuel capacity. The Comet I, as the initial model became known, only had a cruising speed of 400 knots, or about 450 m.p.h. In 1952, the skies were dominated by DC-6s, Constellations, Stratocruisers, and converted British bombers that plodded along at 300 m.p.h. on a good day. The slower DC-4s and oldest Connies cruised closer to 200 m.p.h.

BOAC was the launch customer for the Comet. It placed the airplane on routes to the Middle East, South Africa, and, eventually, Singapore. The plane's short range meant frequent stops on the longest routes. But the

Comet still beat the piston airliners to its destination by hours and sometimes by days. As much as passengers liked the Viscount, they liked the Comet even more. While the Viscount's Rolls-Royce (RR) engines were much quieter and virtually free of vibration compared with piston engines, the Comet's Ghost jet engines were quieter and had less vibration. The Viscount could cruise above 20,000 feet. The Comet could cruise up to 40,000 feet, well above all but the most extreme weather.

In October 1952, a mere five months after entry into service (EIS), a BOAC Comet crashed on takeoff in Rome. Everyone on board survived. The following March, a Canadian Pacific Airlines Comet on a delivery flight from the UK to Canada crashed following a fueling and rest stop in Karachi, Pakistan. Five crew members and six passengers died. In each case, pilot error was found to be responsible. The plane's over-rotating on takeoff was found to have caused a loss of lift, contributing to the crashes. Leading-edge wing modifications were adopted to prevent this from happening again.

Two months after the Canadian accident, a BOAC Comet crashed in Calcutta, India, shortly after takeoff into a major thunderstorm. Observers saw the Comet, wingless, falling from the sky, indicating a structural failure. Investigators concluded that the airplane was stressed beyond design limits. All forty-three people on board died.

De Havilland made history with its breakthrough technology. But its ground-breaking airplane was destined for tragedy. The company, through no fault of its own, pushed the scientific envelope farther than the known science at the time. In 1954, two BOAC Comets blew apart over the Mediterranean Sea at high altitudes. At the time, before the advent of flight data, cockpit voice recorders, and widespread radar coverage, the causes of the two events were hypothesized to be sabotage or perhaps blades thrown from the engines buried next to each other in the wing roots.

The weather for each BOAC accident was clear and radio communication during each flight was routine. There was no obvious reason for the airplanes to come apart at or near cruising altitudes. The British industry regulator, the Air Regulation Board (ARB), grounded the airplanes until more information could be gathered. The wreckage of the planes lay deep on the Mediterranean's seabed. A massive recovery effort was launched. Bodies floating on the surface of the water showed signs of blunt-force trauma consistent with catastrophic depressurization, which could possibly be explained by sabotage or uncontained engine failure. The two airplanes had logged low flying hours and a low number of cycles (each cycle is a takeoff and landing). Surely, many thought, the planes didn't simply blow apart on their own. But after recovering enough wreckage for examination, investigators believed that was precisely what happened. Signs of metal fatigue along the aircraft's navigation windows on top of the fuselage were unmistakable. De Havilland and the British government took a BOAC Comet with similar flight time, dunked it into a giant water tank, and rapidly pressurized and depressurized the cabin, simulating flights from takeoff-to-altitude-to-descent and landing. Eventually, the structure of the cabin and the navigation windows failed. Without a doubt, the Comet's fatal flaw was metal fatigue. Even though de Havilland used state-of-the art testing processes for the time, unknowingly, it didn't go far enough.

While the Comet drama was unfolding, Boeing was developing the four-engine, swept-wing jets that would become the U.S. Air Force's aerial-refueling tanker and its all-cargo sibling, the KC-135/C-135, along with a commercial airliner that would become the 707. Douglas, meanwhile, began design on the 707's rival, the DC-8. Boeing wanted to use the tanker tooling for the 707 to save costs. The tanker's fuselage was wide enough to accommodate five passengers abreast in the coach section. Douglas, with no such restriction, designed its cabin for six abreast, a requirement from customer United Airlines. When the two commercial jet programs were launched, Boeing initially jumped to the lead. In a scenario reminiscent of Boeing's lead with the 247, which went on to be overtaken by the DC-2 and DC-3, the company refused to widen the 707's fuselage for six-abreast seating. Douglas's orders soon surged ahead. Fearing a repeat of the piston-era rivalry, Boeing made the costly decision to widen the 707's cabin with the associated new tooling. With an EIS advantage of one year, airlines flocked to Boeing, which never looked back—at Douglas. But arrogance, poor decisions, and complacency would one day relegate Boeing to a distant second to a different rival.

The aviation industry learns lessons from every accident. The Comet tragedies were no exception, and the lessons learned benefitted commercial aviation. Boeing, Douglas, and every other jet airliner manufacturer learned more about metal fatigue in high altitude, high pressurization operating environments from the Comet accidents and investigations. Thicker skin was selected, and stringers or stoppers were designed into the fuselages to prevent cabin tears from ripping to the point of destruction. For the most part, the industry succeeded. Although metal fatigue in various forms and in various components, structures, or engines would bring airplanes down in the coming decades, nothing along the lines of the Comet accidents would plague the industry again.[2]

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2. The closest incident happened on Aloha Airlines flight 243 in 1988 when the upper half of the forward fuselage of an aging Boeing 737-200 ripped off while the plane was cruising at 24,000 feet. Fatigue was found to be the culprit, but the fact that the plane operated in a very high-cycle, corrosive salt-air environment in Hawaii, combined with the bonding method used on planes at the time, was to blame for the fatigue—not a design flaw, per se, by Boeing.

Figure 10. The United States Post Office issued an airmail stamp in July 31, 1958, with the image of a jet aircraft strongly resembling the Boeing 707. Public domain.

By the time de Havilland redesigned the Comet, naming it the Comet IV, Britain's industry lead had vanished. (Production of the Comet II had been halted, with modified airplanes going to the Royal Air Force instead of to airlines, and only one Comet III had been produced.) BOAC inaugurated trans-Atlantic service with the Comet IV in October 1958, only a few weeks ahead of Pan Am's new jet service with the Boeing 707. The introduction into service of the Douglas DC-8 would follow in September 1959. Sud Aviation's Caravelle, a twin-engine jet airliner, entered service in April 1959, following a four-year flight-testing program. The Caravelle used the nose/cockpit section of the Comet. The Caravelle was a short-to-medium range transport in a different category than the medium-to-long-range Comet, the 707, and the DC-8.

In the end, de Havilland only produced 114 Comets. Boeing produced more than 1,000 707s/720s. Douglas built 555 DC-8s. Sud Aviation sold 282 Caravelles. After the successful Vickers Viscount, no other British-produced airliner came close to the Viscount's sales success.[3]

A FAMILY OF AIRPLANES

A key factor in Boeing's march to leadership in the jet age was a decision to offer a variety of versions of the 707 in a bid to win orders.

To win over Braniff International Airways, which had hot-and-high air-

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3. The British Aircraft Corporation's BAC-111, the first twin-engine jet of the 1960s, which came ahead of the Douglas DC-9 and the Boeing 737-100/200, saw only 244 sales. The DC-9-10 through the plane's Series 50 won nearly 1,000 sales; the 737-100/200 saw more than 1,000 sales. De Havilland designed a plane called the tri-jet Trident but, like so many British jets, it was too small and had too short a range. Only 117 Tridents were sold under the Hawker Siddeley brand, into which de Havilland was forcibly merged by the UK government. The Trident beat the Boeing 727 into the air and into airline service, but sales of the more flexible 727, which shared commonality with the 707/720, reached 1,832. The British Aerospace regional jet, initially branded as the BAe 146 and later the Avro RJ, saw 394 sales, the most successful of the British jets, despite being a miserable airplane for passenger experience and initially equipped with balky Lycoming jet engines.

ports in South America to serve, Boeing offered a hot-rod version, the 707-227, with more-powerful engines. Only five were built. To win the business of Qantas Airways, the flag carrier of Australia and a long way from everywhere, Boeing shortened the 707's fuselage while keeping its standard wing and engine designs to produce another hot-rod, long-haul version, the 707-138B. BOAC needed RR engines to "buy British," so Boeing offered this, too, in the 707-420.

When United wanted a medium-haul jet in 1960, Boeing offered the 707-020 with a shorter fuselage (which was still slightly longer than the Qantas model). United didn't want to call it the 707, so Boeing named it the 720. Eastern Airlines, Northwest Airlines, Aer Lingus, and several other carriers ordered the 720 and its fan-jet version, the 720B. Douglas stubbornly resisted making these specialized versions, although it did offer a RR-powered model for Trans-Canada Airlines (after all, it was a British Crown country). No shorter fuselages. No hot-rod versions.

In December 1960, Boeing launched the 727. The 727 was designed for short- and medium-range routes and was intended to replace the Constellations, DC-6s, and DC-7s that were displaced by jets for long-haul routes and to replace the Viscounts and turboprop Lockheed Electra for short-to-medium routes. The 727, with its three engines and wing design that made it possible to land at airports serviceable to propeller airplanes but not four-engine jets, was an engineering marvel. Its commonality with the 707/720 made the decisions by airlines to stick with Boeing easy.

Douglas responded with the DC-9, a twin-jet designed for short-to-medium, small-airport service. The DC-9 wasn't as versatile as the 727, however, and it didn't have the commonality with Douglas's DC-8 the way the 727 did with Boeing's 707.

Eventually, Douglas created the DC-8 Super 60 series. The -61 could seat up to 250 passengers. The -62 had a slight stretch over the standard DC-8, and better engines and aerodynamic cleanup gave it superior range. The DC-8-62 was an "ultra long-haul" airplane with a range of some 6,000 miles. The -63 combined the capacity of the -61 with the improvements of the -62. Even so, DC-8 production ended with 555 sales. Boeing sold more than 1,000 707/720s. There were ninety-three military models that came off the commercial 707 line. More than sixty C-135 Transports and more than 700 KC-135s were built.

EARLY DEFECTS OF THE *707* AND THE DC-8

As the story of the de Havilland Comet showed, the transition from prop planes to jets was difficult. Boeing, Douglas, and Convair—the third U.S. airliner manufacturer of the day—suffered early, fatal crashes. Some occurred during training flights (this was before simulators became widely avail-

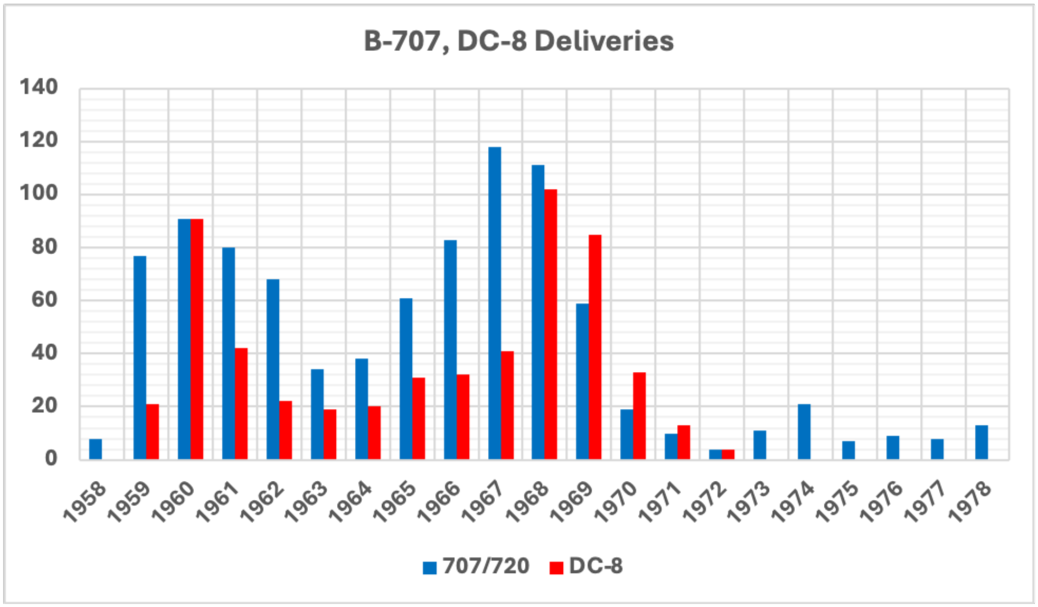

Figure 11. Douglas Aircraft Company dominated the piston airliner era, with Boeing a very distant third (after Lockheed's second place). But in the jet age, Boeing leapt to a big lead and didn't give it up for forty years. Credit: Company data. Chart by Scott Hamilton.

able for jets). Others occurred for weather-related reasons. Some occurred due to pilot error. Jets are unforgiving, especially for pilots transitioning from pistons to jets, and mistakes that might be correctable in prop models quickly spun out of control in jets. The DC-8's defects were related to power units that caused a loss of control. The 707 had larger issues.

Boeing's 707 drew scrutiny from Britain's regulator, the Air Registration Board (ARB). The original tail on the 707 was shorter than people might remember today. The ARB was concerned that in an engine-out situation, the 707's rudder in its short tail was insufficient to give pilots enough control over the aircraft.

D. P. Davies, the ARB's Chief Test Pilot, explained these concerns in a speech before the Royal Aeronautical Society on September 16, 2017. Davies recalled his battle with the ARB and his boss, Sir Robert Hardingham, over the certification of the Boeing 707, a plane that had major stalling problems. In a lecture, Davies was asked, "Why do the Americans build better airplanes than we [the Brits] do?" Davies replied, "I can give you one reason. When you build an airplane, your own pilots fly it and they tell you whether it's good, bad, or indifferent. They might even tell you you've got a bloody great snag on it. You can have big problems. In the States, the difference is the attitude of the chief designer. In America, a chief designer listens to his pilots. If they say, 'holy smoke, you've got a snag, you'll never get away with it, you've got to fix it[,]' . . . they fix it. It doesn't matter what it costs or the delay. They fix it there and then. They would work like mad. They'd put a new wing on. They'd do anything to fix it. In the UK, the chief designer says, 'oh, I've got a big problem.' When he's asked what he's going to do about it, he says, 'oh, I don't know.' They're hoping the problem will quietly go away. But it doesn't go away." Then, Davies said, the pressure campaign starts to accept the airplane.

"The Boeing 707 really was one of the leaders in big transport airplanes for its day. The first 707 bought by BOAC was one of the Intercontinentals, the 707-436 [with RR engines]. It was a big, hairy-chested airplane. But it was unreasonably demanding to fly. The primary flight controls were fundamentally manual . . . supported by power spoilers for roll and a boosted rudder. But the airplane was very heavy to fly on all axes and lacked precision over small angles," he said.

"The flight trials at Boeing Field went reasonably well in a lot of areas. The stall qualities were immaculate. But it became clear there were large problems in directional stability and control. Fundamentally, the fin [vertical tail] was too small. This led to all the problems associated with it—divergent Dutch roll, violent rolls following engine failure, and high minimum-control speeds. It was compounded by high foot forces (180 pounds) in engine-out conditions and extremely high foot forces (220 pounds) in two engine-out conditions. It was all made worse by the unachievably low minimum-control speeds on takeoff and go around." Davies said that Boeing's 747 required a foot force of 70 lbs.

Davies continued: "I was appalled when I finished flying the airplane. It didn't take any wit on my part to turn the aircraft down [for certification] on all these grounds. The unfortunate circumstances were that the machine was already FAA-certificated and the FAA test pilot had not been supported by Washington in his attempt to reject the airplane. The machine was literally potentially dangerous in the event of engine failure, particularly at the speeds quoted in the FAA flight manual. Boeing simply couldn't believe that we were turning the airplane down. In an attempt to limit the damage to their reputation and knowing in their hearts that the machine was much too demanding, they promised a fix within twelve months if we would accept the airplane temporarily.

"Having been caught before by promises not kept, and truly fearful of an airline pilot failing to control the machine in the event of engine failure on takeoff, I said no, and I came home. It caused an awful fuss. BOAC were furious. The BALPA[4] and the airline pilots in general were all with me. My chairman at the time, Lord Brabazon, who I heard later from his wife, quote, loved to fight, unquote, stuck with me, and together we persuaded the then-permanent secretary of the ministry to refuse the machine's certification. Some months later, I was recalled to Seattle to fly the improved model. The

4. British Air Line Pilots' Association.