# Creating the Modern Airliner: U.S. Government and Business, 1918-2014

From the very beginning of the airline industry in the United States, the federal government has worked closely with industry in developing the aircraft, equipment, and the infrastructure necessary to create and foster a rational, coherent system of passenger air travel. That assistance was critical for in the years before the creation of technologically efficient aircraft and well developed infrastructure, private attempts to operate airlines all failed. The world's first airline, the St. Petersburg – Tampa Air Boat Line, carried regularly scheduled paying passengers across Tampa Bay, Florida, as early as the first three months of 1914. It lasted as long as the subsidy from the city of St. Petersburg lasted. Other attempts quickly failed because of the high operating costs and low productivity of early, World War I vintage aircraft. The only airline to fly for more than a few months was Aeromarine Airways, which operated from 1920 through 1924 carrying passengers and cargo from the Great Lakes into Canada and from Florida to the Bahamas. It survived as long as it did, not because of its superior equipment of modified Navy flying boats, but because the American's public's desire to get a drink during the era of Prohibition, for a time, overcame the reluctance to purchase an expensive ticket to fly.[1]

Between 1918 and 1927, the U.S. Post Office laid the foundation for the American airline industry by creating and maintaining the nation's air routes, proving to a skeptical aviation community, that routine long distance air commerce was not only possible but practical and was a worthy place for capital investment. By 1924, air mail was consistently crossing the country in fewer than 24 hours over routes developed in cooperation with the Department of Commerce, which developed a sophisticated system of lighting and other navigational aids. By 1926, the Post Office willingly turned over the delivery of the mail to contractors – the airlines.[2]

But what of the aircraft? What is less known in American aviation history is the important role government played in the actual development of many of the aircraft that have made air transportation the most popular means of long distance travel. Without safe and efficient aircraft, no airline can survive. With the explicit cooperation of the National Advisory Committee on Aeronautics (N.A.C.A.), and later NASA, as well as other agencies and departments, the government took a direct role in the discovery, distribution, and implementation of new aviation technologies that would revolutionize air transportation. The stringent requirements of the military in particular have produced rapid improvements in the performance and efficiency of commercial airliners.

During the early 1920s, numerous airlines emerged and quickly died because the existing aircraft were so inefficient. Based on World War I vintage technology, these wooden-framed, fabric covered biplanes were unreliable, slow, and uncomfortable with high operating costs. Engines were usually heavy water-cooled Liberty V-12s, which were equipped with bulky radiators and untrustworthy water pumps and hoses. Engine failures were an ever-present problem.

Operating from its first aircraft carrier, the U.S.S. Langley, the U.S. Navy was keenly aware of the inherent limitations of water-cooled engines. While engine failures over land were usually just a nuisance, engine failures over the ocean often were catastrophic to aircraft and crew.

During the 1920s, the U.S. Navy became interested in the air-cooled radial engines produced by the tiny Lawrance Aero-Engine Corporation of New York City. The Lawrance J series of engines seemed ideal, as they had no troublesome radiators, water pumps, or vulnerable cooling lines.

Wishing to find a large company with enough resources to produce and develop this engine, the Navy threatened and cajoled Fred Rentschler, then president of the Wright Aeronautical Company, into purchasing the Lawrance Company in 1923. By 1924, the Wright J-3 and J-4 engines, better known as the Whirlwind engines, were in service. Incorporating Englishman Samuel D. Heron's revolutionary sodium-cooled valves, which virtually eliminated the chronic problem of burned exhaust valves, the improved J-5 series was the first to offer power and great dependability. This power plant, the world's first truly reliable aero-engine, made possible Charles Lindbergh's non-stop flight from New York to Paris in 33 1/2 hours with no problems and was soon the engine of choice for most long-distance flights. More important in the context of this discussion, the Whirlwind quickly became the preferred engine on a new generation of airliners, specifically, the Fokker F.VII/3m series and its derivatives, and the classic Ford 4-AT Tri-Motor. Borrowing heavily from the Fokker’s design and Junkers’ corrugated duralumin construction, the Ford Tri-Motor helped convince the traveling public in the U.S. that safe, reliable - albeit loud - air travel was now a possibility.

As good as the Whirlwind was, its 220 horsepower was insufficient if larger, more capable aircraft were to be developed. In 1924, Rentschler left Wright and formed the Pratt & Whitney Company in 1925, assuming the name of an idle tool factory in Hartford, Connecticut and began the development of a new, higher horse-powered engine. Incorporating numerous changes, the new Wasp engine could generate 400 horsepower.[3] From Seattle, Washington, Phil Johnson of the Boeing Airplane Company was interested in bidding on the last air route, the potentially profitable CAM-18 from Chicago to San Francisco. To win the contract he felt he needed an aircraft superior to any then in existence. Key to this was the Wasp engine. Pratt & Whitney was building its Wasps for a series of Boeing fighters for the Navy which peaked

Boeing's interest in the engine for a civilian use. The result was the Model 40A biplane. This aircraft allowed the new Boeing Air Transport to underbid Western Air Express by 50 percent yet fly profitably once B.A.T. opened its service in the summer of 1927. Clearly by this time the air-cooled radial engine, which had been developed specifically for the needs of the U.S. Navy, was now the engine of choice for the nation's airlines.[4]

The late 1920s was a remarkable time in the history of the development of aircraft technology when the technology necessary for the creation of a new generation of aircraft began to coalesce.

Even before World War I, in efforts to streamline aircraft designs and to reduce the drag resulting from the external wire bracing of the wings of traditional wood and fabric aircraft, German designers, particularly Dr. Hugo Junkers, pioneered the internally supported, cantilevered monoplane. Aircraft produced by Junkers and other farsighted designers who followed his lead, were very successful because of the relative efficiency of their clean and strong wings. Junkers also was a pioneer in the use of metal in aircraft construction because of its strength, durability, and predictability. Steel and iron was too heavy and aluminum too weak. The solution came from the German chemical and metallurgical industry.[5]

In 1903, at the same time that the Wright brothers were completing their first powered aircraft, German metallurgist Alfred Wilm, patented a method to strengthen aluminum-copper alloys by heating and cooling methods. That year, the German War Munitions Factory assumed control of his work in order to find an aluminum alloy as strong as brass. Wilm had developed a strong alloy by adding copper and manganese to aluminum. Unfortunately, it lacked hardness. Wilm added a small amount of magnesium to the mix and rolled a thin sheet of the new metal, after annealing it in a salt bath. Wilm and his assistant tested the strength of the new alloy and were mildly disappointed in the results. Leaving the material over the weekend, Wilm retested the material a week later and was astounded to discover that it was considerably harder while its strength had also improved. Unlike iron alloys, Wilm discovered that aluminum alloys strengthened with age – in this case four days.[6] By 1911, Wilm was able to patent the new alloy and negotiated with the Durener Metalwerke for production rights. The new alloy was named after a contraction of the company's name and that of aluminum thus becoming "duralumin" or later simply "dural."[7]

Junkers quickly turned to this new, strong, lightweight metal alloy to build all of his subsequent aircraft. His Junkers armored attack aircraft fought successfully in the latter stages of World War I but, of far greater significance, his line of commercial all-metal dural transports made him famous. Using duralumin, Junkers corrugated the sheet metal to provide linear strength, using this on his highly efficient F.13 single-engine monoplane.[8] Junkers' research and that of countless other leading designers and aerodynamicists from Europe was dutifully and carefully gathered by the N.A.C.A. and translated into English for use by the budding American aviation industry. Subsequent designs led the industry through the 1920s and inspired many other, copycat designs, including the famous Ford Tri-Motor of 1926.[9]

As John Anderson states and Eric Schatzberg reluctantly agrees, metal aircraft construction was not widely adopted until the late 1920s.

Why? Schwartzberg argues that that is because the acolytes of metal, with the backing of the military, navy, and federal government in the United States, pushed long and hard to overcome the problems of metal, deliberately ignoring the early failures of metal design while deliberately ignoring the advantages of wood because of the so-called progressive ideology of metal.[10] Anderson has a much simpler and rational explanation: designers are inherently conservative. They are not prone to making rash decisions and much prefer using what it known rather than what is not known. They prefer evolution to revolution because they are keenly aware of the often fatal consequences for failure.[11]

This conservative approach produced a string of excellent, evolutionary aircraft during the 1920s. While the National Advisory Committee for Aeronautics (N.A.C.A.), the predecessor to NASA, was actively researching metal and advocating its eventual use most designers were leery of the material. Indeed, for a while in the N.A.C.A. and in the British Ministry of Aviation, designers were directly discouraged from using duralumin. Some of this was the fear of the unknown and the conservatism of tradition – bound bureaucrats, but it was more a reflection on a potentially fatal flaw in duralumin – corrosion.

Pure aluminum is a remarkable metal in that it does not corrode. Unfortunately aluminum alloys, especially duralumin and its imitators are highly subject to corrosion.[12] This unfortunate fact was not fully understood when Junkers' first series of popular duralumin aircraft entered the market. The Junker F.13, sold in the United States as the Junkers Larson JL-6, was initially sold to the United States Post Office for service on its air mail routes. The aircraft quickly developed an unfavorable reputation especially once intercrystalline corrosion was discovered throughout its structure.[13] Tests on the Junkers and other similar designs revealed that duralumin was highly susceptible to internal corrosion. The lifespan of such an aircraft was less than four years.[14]

Designers wisely stayed away from duralumin until a solution was found in the late 1920s. In 1927 in Great Britain, G.D. Bengough and H. Sutton of the National Physical Laboratory developed a technique of anodizing alloys with a protective oxide coating.[15] While successful, and used on the world's first modern airliner, the Boeing 247 of 1933, it produced an unattractive, uneven finish. Many passengers thought the aircraft they were traveling on had been in numerous accidents as the metal sheets did not match in color.[16] A better solution was found through the collective efforts of the N.A.C.A. and Alcoa.

In 1927, Edward H. Dix of Alcoa patented a method of binding corrosion-proof pure aluminum to sheets of duralumin. This resulted in a beautifully finished, highly corrosion-resistant alloy. This process of applying an aluminum cladding to sheets of alloy was made under the trademark of "Alclad."[17] This coupled with Alcoa's efforts to emulate German duralumin with an alloy of its own, at the insistence of the U.S. Navy, resulted in the first practical corrosion-resistant aluminum alloy for aircraft use - Alcoa 17ST.[18]

While the advantages of all-metal, cantilevered construction were known for some time, the problems of airframe weight remained a limiting factor. The advent light-weight, high-powered radial engines partially solved the weight problems, but the final step towards making all-metal construction truly the technology of choice came with the incorporation of stressed skin, semi-monocoque construction. This produced a very strong, yet lightweight fuselage, with large usable interior volume for payload as well as a corresponding rounded, lower drag cross section. Monocoque (or single shell construction), originated in boat building and was quickly introduced to aircraft designs by Ruschonnet of Switzerland and others before World War I.[19] Because of a lack of high quality spruce, the German aviation industry used inexpensive plywood sheets formed around molds and designed to carry the stress of the airframe. This technology was used in the successful line of Albatros and Pfalz fighters and Roland light bombers.

The leading advocate of stressed skin monocoque construction and of all-metal design in the United States was John J. "Jack" Northrop, one of the truly great designers in history. One of the so-called acolytes of metal construction, Northrop actually stayed with plywood until the duralumin corrosion problem was solved. He designed many sleek, fast, efficient aircraft in the late 1920s but none more significant than the classic Lockheed Vega. The Vega quickly became the high-speed aircraft of choice for racers, record-setters, explorers and the like. Made of plywood with a monocoque fuselage and a fully cantilevered wing, this aircraft carried Wiley Post around-the-world twice in his “Winnie Mae” in 1931 and 1933, and Amelia Earhart across the Atlantic in 1932. He left Lockheed and joined William Boeing’s new holding company, United Aircraft and Transport Corporation, briefly at the end of the decade before he left to form his own company to build his first all-metal civil transport, the Northrop Alpha. His brief tenure with Boeing was long enough to convince the company of the superiority of all-metal construction.[20]

Of great importance the N.A.C.A. at this time had developed the first practical engine cowling for radial engines. This dramatically reduced the frontal drag of the engine while improving the cooling. The result was dramatically increased power and reliability at little additional cost in weight. Interestingly, the N.A.C.A. cowling only worked in conjunction with rounded monocoque fuselages. The first aircraft fitted with this cowling was a Lockheed Vega which experienced a 20 mile per hour increase in its top speed solely due to the lower drag device.

Furthermore, N.A.C.A. research on multiple-engined aircraft revealed that the most efficient placement of an engine was significantly in front of the leading edge of the wing. This improved the performance of the aircraft by reducing the interference of the propeller wash with the airflow. These new technologies, as well as airfoils selected from a detailed published list of N.A.C.A. airfoil shapes, were used together of the Boeing 247, the world’s first modern airliner.

Unknown to most, the Boeing 247 was the direct result of action taken by the Post Office. In February 1931, Postmaster General Walter Folger Brown, who had just transformed the nation's airline industry through his firm but far-sighted management with the judicious use of financial incentives to promote industry efficiency, brought the nation's aviation leaders to Washington for a conference. Concerned that independent passenger-only airlines flying fast single-engined Lockheed Vegas and other equipment were outpacing the air mail carriers, Brown demanded that they develop a new series of high-speed airliners to carry both mail and passengers.[21]

Phillip Johnson of Boeing responded. Under development for the U.S. Army Air Corps was the revolutionary Boeing B-9 bomber. This aircraft was all-metal, powered by two air-cooled engines and possessed a fully cantilevered wing and a monocoque fuselage. This was to be the world's first modern bomber, and was capable of speeds up to 200 miles per hour, as fast as contemporary high-speed fighters.

Immediately after the conclusion of the conference, the Boeing Airplane Company began a competition to develop a commercial mailplane based on the revolutionary design characteristics of the B-9. Originally intended as a high-speed mailplane that could carry eight passengers as well as a 2000-pound mail load, the design evolved into the all-metal, mid-wing cantilevered monoplane, twin-engine, ten-seat Model 247 with retractable landing gear - the world's first modern airliner - which was to enter service two years later, in 1933. This aircraft was destined to change the face of commercial aviation. With its cruising speed of 160 miles per hour, the 247 was 60 percent faster than the Ford Tri-Motors it replaced and did so with 20 percent less horsepower. Most importantly, it was deliberately designed to take advantage of the incentives provided by the Post Office's variable payment scheme. Thus the Post Office was directly responsible for inspiring the creation of an entirely new generation of commercial aircraft, the design of which has changed little in the past 60 years.[22]

According to historian Richard Smith, 1934 was an “Annus Mirabilis” in airliner design. Despite its ground-breaking technologies, the 247 was quickly supplanted by the superior Douglas DC-2 and, by the following year, the immortal DC-3 – widely considered to be the first aircraft capable of making money without a the need for a subsidy. The DC-2 and -3 were all metal monocoque designs with cantilevered wings, retractable landing gear and variable-pitch propellers like the Boeing 247. With Jack Northrop’s help, they also were among the first airliners fitted with flaps to reduce landing and take-off speeds and featured Northrop’s classic multicellular wing design. These features made the Douglases efficient and immensely strong. Interestingly enough, when American Airlines president C.R. Smith approached Douglas with a proposal for a sleeper version of the DC-2, he approached the government for a loan through the Reconstruction Finance Corporation that paid for what would become the Douglas Sleeper Transport, and later the DC-3.[23]

In Connecticut, famed aviation pioneer Igor Sikorsky, a Russian émigré who came to the United States in 1920, produced his outstanding S-42 flying boat for Pan American Airways. Sikorsky had always been an advocate for large commercial aircraft since his days in Imperial Russia where he designed and built the Grand, the world’s first four-engined aircraft, and most significantly, his Ilya Mourometz series of long range bombers. Despite its size and less than aerodynamic flying boat hull, this remarkable four-engined airliner was as efficient as the DC-3 and, with its exceptional long range, enabled Pan Am to secure the Latin American market while make pioneering survey flights across both oceans.[24]

In an attempt to regain its market share and leap ahead of its competition, Boeing, under the leadership of Clare Egtvedt, again turned to technologies pioneered by the government to produce a radical new airliner – the Boeing 307. As early as 1933, Boeing had been working closely and secretly with the U.S. Army Air Corps in developing a new generation of long-range heavy bombers. Designated "Project A" by the Air Corps, this new bomber featured a huge wing and was powered by a four Pratt & Whitney R-1830, 1000 horsepower engines. Although only one was built, the XB-15 showed Boeing that the Air Corps was interested in large four-engined designs. Armed with this knowledge, Boeing responded to an Army circular for a new "multi-engined" bomber with its Model 299 in the summer of 1935. This aircraft would become the famous B-17 Flying Fortress.[25]

The Army Air Corps, through its research establishment at Wright Field, was constantly pushing the limits of aircraft technology to develop increasingly more capable aircraft. While the Air Corps was building its mission around the long-range, four-engined heavy bomber (which would ultimately lead to their organizational independence as the U.S. Air Force) it began to look for ways to improve its latest bombers. In 1936, the Air Corps contracted with Lockheed to build an experimental aircraft equipped with a pressurized fuselage that would allow comfortable operations for a flight crew at high altitudes. The result of this effort was the Lockheed XC-35, which was based on the Model 10 airliner but incorporated a new fuselage with a circular cross section and heavily reinforced. After much testing, the XC-35 validated the concept of a pressure cabin, the lessons of which were immediately applied in what would become the Boeing B-29.[26]

For Boeing, their experience with the B-17 and the lessons learned from the XC-35 that were disseminated throughout the industry, made possible their next airliner. For the airlines, greater speed means greater efficiency and ultimately, greater profits. An airliner that could fly in the stratosphere - above most of the bad weather - could fly faster than unpressurized aircraft and, as an added benefit, far more smoothly. Such an airliner would benefit airline and passenger alike with greater productivity and greater comfort – particularly much less chance of airsickness, which was an unmentioned problem that plagued conventional airliners.

Using the wings, engines, and tail of a B-17C, Boeing developed a wide, pressurized fuselage that could carry 33 people in great comfort and speed. Cruising at 220 miles per hour at 25,000 feet along the routes of Transcontinental and Western Air (TWA), the Boeing 307 cut transcontinental travel time from New York to Los Angeles from 18 hours to fewer than 14 hours when it entered service in 1940. Much more would have been heard from this remarkable aircraft were it not for World War II and the temporary suspension of most of civilian air travel.[27]

The lessons learned in the development of the experimental XB-15 were not wasted. In 1935 when Pan American Airways approached Boeing for the design and production of a new seaplane with greater range and payload to carry U.S. Air Mail than its classic Martin M-130 flying boats – the immortal "China Clipper" – Boeing resurrected the XB-15 and incorporated its massive wing and engine nacelles and placed it on a new flying boat hull. The result was the greatest of the pre-war flying boats, capable of traversing the Atlantic and Pacific with ease and extraordinary comfort. In fact, it was the Boeing 314 that pioneered regularly scheduled aircraft passenger service across the Atlantic in 1939.[28] Clearly, at least in the case of the 307 and 314, the technology flow between the military and civilian aviation industry could be in both directions.

World War II saw the rapid development of sophisticated passenger transport aircraft, particularly the Douglas and Lockheed series of four-engined transports.  The government's massive investment in building concrete runways around the world to support the war effort had a most beneficial effect on the airline industry in the immediate post-war years as these more efficient landplanes could now fly safely across the oceans and around the world.  Airlines were no longer dependent upon flying boats for long-distance, overwater flights.  Subsequent developments in navigation aids and instrument landing systems revolutionized the industry, increasing safety and permitting aircraft to fly more safely at night and in bad weather.

While the government's investment in the post-war generation of piston-engined airliners was not as great, these classic DC-6's, -7's and Lockheed Constellations and Super Constellations were pressurized and benefited from engines derived from military applications, particularly the Pratt & Whitney R-2800 and the Wright R-3350, which powered numerous fighter and bomber types.  Of note, the graceful Constellation used a wing in identical planform to that of the Lockheed P-38 Lightning fighter of World War II fame.[29]

At the end of the Second World War, America and its Allies emerged triumphant. Its secure geographic position between two oceans, which prompted the development of long-range aircraft, also ensured that the nation emerged relatively unscathed with a huge economy that allowed for massive concurrent commercial and military investment.  No other country had that luxury.  During the succeeding postwar years, and especially in the 1950s, the United States was able to use its unmatched resources to take a dominant position in commercial aircraft design that would last for several decades.

The advent of the jet age in commercial air transportation could not have been possible without government support. Jet technology was one field where the United States was lacking.

In August 1939, the German Heinkel He 178 became the first jet-powered aircraft to fly, powered by an engine developed by Dr. Hans von Ohain. Two years later the Gloster E28/39 became the first British jet aircraft to fly. Sir Frank Whittle and been working on jet propulsion since the early 1930s and had actually run a jet engine in static tests in 1937, but was unable to get government support for his work until later. And while the Messerschmitt Me 262, Arado Ar 234 and Gloster Meteor saw combat during the war, America's first jet fighter, the Bell XP-59, only flew on October 1, 1942 – and did so only with its imported Whittle engines. It was unfortunately slower than contemporary piston-engined fighters.[30]

The U.S. did not waste any time in catching up, first with developing imported British centrifugal flow engines, but particularly in developing axial-flow jets based on captured German technology from the Junkers 004 and BMW 003 engines. One of the most important of these postwar designs was the Pratt & Whitney JT3 – the civilian version of the military J57 – which powered America's first civil jet airliner, the Boeing 707.[31]

The 707 began life as a company-sponsored project to provide an aerial tanker to support the U.S. Air Force's growing fleet of B-47 and B-52 strategic jet-powered bombers. Immediately after World War II, Boeing was one of many U.S. companies that benefited from the aeronautical research captured from Germany. For Boeing the most important data surrounded the development of the thin, highly-swept 35 degree wing that reduced drag at high subsonic speed. Boeing first incorporated this slender wing on its B-47 Stratojet while concurrently developing distinct engine pods mounted on underwing pylons for greater ease of maintenance and safety while efficiently distributing the weight of the engines and decreasing drag. A similar wing and nacelle arrangement was used on the massive B-52 that continues to serve with distinction today, 62 years after its first flight.[32]

At the time, the only aerial tanker in the fleet was the piston-engined KC-97, which was based on the B-29 airframe. (Incidentally the Boeing 377 Stratocruiser was a direct commercial derivative of the C-97 military transport – its large double-lobed pressurized fuselage proved ideal for carrying passengers and included a spiral staircase of a lounge in the lower level.) Taking a gamble that the Air Force would eventually require a much faster, jet-powered tanker to service its bomber fleet, Boeing spent $16 million and produced the revolutionary 367-80. Using the same “double-bubble” fuselage cross-section as the KC-97, only with its more severe contours smoothed out, the Dash 80 featured a 35 degree swept wing and four JT3 engines each mounted individually in pods under the wings. Unlike the B-52, the Dash 80’s wings were stiffer and mounted low in fuselage and featured pronounced dihedral for stability. Impressed, the U.S. Air Force had Boeing widen the fuselage 12 inches and placed a substantial order in September 1954 for KC-135As.[33]

With their investment secured by this military purchase, Boeing offered the C-135 to the airlines. At that time Pan American Airways was the world’s premier airline having pioneered transoceanic and around-the world air travel with state-of the art aircraft. Desirous of leading the American airline industry into the pure jet age, Juan Trippe took the lead and ordered 20 of the new airliners, now designated the Boeing 707. Boeing had expected Trippe to purchase 40 but their initial unwillingness to widen the fuselage further to accommodate 6-across coach seating forced him to buy 25 of the wider Douglas DC-8 which was still on the drawing board. Boeing got the message and widened the 707 another 4 inches and lengthened it 10 feet as well. Despite the competition from the DC-8, the Boeing 707 brought America into the commercial jet age quickly supplanting the first jet airliner, the British de Havilland D.H. 106 Comet, which had development difficulties, and the Tupolev Tu-104, which had a limited range. With its slender swept wing the 707 was 100 miles per hour faster than its British counterpart. Over 1,000 707s were built and its fuselage remains the narrow-body standard for all of Boeing single-aisle airliners to this day.[34]

As is evident, the U.S. government has played an important role in the development of the first modern airliner, the first pressurized airliner, and America's first jet airliner. Of great significance is the fact that the government, through the Air Force was directly responsible for the creation of the first wide-bodied jet airliner, the Boeing 747 which dramatically increased productivity and transformed the airline industry from a luxury for the rich to a means of indispensable travel for the masses.

In 1963, the U.S. Air Force opened an industry-wide competition for a new military transport of huge proportions to augment is fleet of Lockheed C-141s. The transport had to capable of carrying a maximum payload of 250,000 lb which could include an M-60 tank or other oversized military equipment. Three aircraft manufacturers, Lockheed, Douglas, and Boeing submitted airframe proposals and two engine makers, GE and Pratt & Whitney submitted proposals for the first generation of large thrust high-bypass turbofan engines. The winning contract went to Lockheed for the C-5A and GE for the T39 engine (the military version of what would prove to be the highly successful CF6 turbofan).

Undaunted, Boeing and Pratt & Whitney met commercial success once again with Juan Trippe and Pan American Airways in 1966 when the airline ordered 25 new 747s. Using the research data they had collected for this Air Force proposal, the 747 was inspired by Boeing's losing "C-5A" entry and equipped with Pratt & Whitney's JT9 high bypass turbofan. A close look at the aircraft reveals the connection for the flight deck sits on top of the fuselage to allow clearance for straight-in loading through an upward hinged nose. This would later be incorporated on numerous freighter versions of the 747. Incidentally, the raised cockpit actually improved the 747's aerodynamics by generating area rule and reducing drag (area rule was discovered by NACA engineer Richard Whitcomb in the 1950s - it would not be his only contribution). While the Lockheed C-5A won the battle for the Air Force competition the Boeing 747 won the war as over 1500 747s have been built so far, all because it lost a military contract.[35]

The 747 introduced unheard of efficiencies into the airline industry. It fostered a series a new wide-bodied jet airliners, such as the McDonnell Douglas DC-10, the Lockheed L-1011, and the Airbus A300, all using the high-bypass turbofan engine technology introduced by industry on behalf of the military.

In late 1978, the U.S. Congress abolished the Civil Aeronautics Board which had regulated the airline industry since World War II. In the eyes of leading economists, the regulation was restricting competition and causing high fares. With the nation's air routes now open to all airlines the industry was forced to construct new business models. With the government no longer there to protect their route, pricing, and profits, they were on their own to compete or die. Quickly the hub-and-spoke system was created at numerous centrally located major airports to feed traffic through a central location and better use the airline's equipment. Aircraft utilization rates soared as the airlines quickly learned that the only way an expensive airliner generates revenue is when it flies.[36]

Concurrent with that realization, was the now pressing need to reduce costs. While the airlines confronted the traditionally high cost of labor, they were also forced to look at their equipment. The previous generation of jet aircraft were fast and comfortable, but were inefficient. With this came the realization of the need to acquire a new generation of airliners that were built for efficiency, especially when the difference between profitability and bankruptcy is often only pennies per seat mile.

The first changes came with the introduction of smaller high-bypass turbofan engines particularly from General Electric and its French partner, SNECMA, for smaller, narrow bodied aircraft. The re-engined Boeing 737-300/400/500 became the most successful airliner in history almost overnight as these engines transformed the aircraft from a poor selling machine to the symbol of post deregulation efficiency and success. The 737 after two more generations is still selling extremely well.[37]

The airlines continue to welcome engine improvements but also pushed hard for any new technology that could increase productivity. During this time, the National Aeronautics and Space Administration (NASA) again responded. The successor to the N.A.C.A., NASA is much more than the "Space Agency." Its pioneering research has transformed the airline industry.

During the early 1970s, NASA's Dr. Richard Whitcomb created the highly efficient supercritical wing. This design delayed the formation and reduced the size of the shock wave over the wing just below and above the speed of sound. As most jet airliners fly at these transonic speeds, the large drag reduction produces improved fuel economy and increased range. Supercritical wings are now featured on all new large jet airliners since its introduction in 1972.[38]

From 1969 to 1985, NASA developed the first Digital Fly-By-Wire (DFBW) control systems. Replacing conventional hydraulically-driven cables and pulleys with computer driven flight controls linked only by electrical wires, results in a much lighter, more reliable, and safer control system which increases efficiency. This technology had been developed in part by NASA for the Apollo program to control the spacecraft's maneuvering thrusters. Interestingly, Apollo 11 astronaut and first man to walk on the Moon, Neil Armstrong, was the first to make this connection when he was working in NASA headquarters as Deputy Associate Administrator for Aeronautics and read the proposal from NASA's Dryden Flight Research Center. When told of the problem engineers were having in finding a suitable digital computer for the project, Armstrong reportedly stated, "I just went to the Moon with one." This Apollo hardware and software materially hastened the development of digital fly-by-wire aircraft controls.[39] The Airbus A320 was the first airliner to use digital fly-by-wire controls. FBW is now standard on all new airliner designs the world over.

By placing small vertical fins on wingtips NASA researchers, led by Dr. Richard Whitcomb between 1979 and 1981, were able to reduce the strength of the swirling air flow off the wing, or vortices. These "winglets" create forward thrust in the vortices and reduce the drag of the air flow off the wing. Most airliners are now fitted with some type of winglet which helps reduce drag and lower fuel consumption.[40]

NASA engineers also pioneered the "glass cockpit" with digital electronic displays replacing conventional analog instruments. Introduced in 1982, "glass cockpit" technology provides the flight crew with greatly improved instrumentation and information than possible before.[41] This too has increased the safety and efficiency of flight.

Most recently, Boeing has introduced the 787 widebody airliner. In a revolutionary break with the past, the 787 is built with composite materials rather than the traditional aluminum alloys. The composite technology was pioneered and proven by the military where its lightweight, immense strength, and great resistance to corrosion have made it the new construction material of choice for a new generation of military and now commercial aircraft.

In the nine decades after the beginning of commercial air travel in the United States, the federal government has provided much needed assistance and incentive to the airline industry. It has been and continues to be a fruitful symbiotic relationship and serves the nation and the world.

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