8-25-2017

Designing Simplicity to Achieve Technological Improvement: The General Electric J79 Turbojet Engine; Innovations, Achievements and Effects

Matt C. Brimer
mcb47a@mail.umsl.edu

Designing Simplicity to Achieve Technological Improvement: The General Electric J79 Turbojet Engine; Innovations, Achievements and Effects

By

Matt Brimer

A Thesis for a Master of Arts in History

Submitted to The Graduate School of the

University of Missouri-St. Louis
in partial fulfillment of the requirements for the degree
Master of Arts

In

History

December 2017

<u>Advisory Committee</u>

Peter Acsay, Ph.D.
Chair of Committee

Daniel Rust, Ph.D.

Carlos Schwantes, Ph.D.

Abstract

With the beginning of powered, manned flight, the piston engine drove a propeller or multiple propellers to provide the thrust for lift required to overcome the forces of drag and gravity for flight. As aircraft speeds gradually increased over time, the power needed to overcome the aerodynamic inefficiencies of the propeller to greater speeds and altitudes were quickly realized as a hindrance to the potential of aircraft. With the turbojet engine, this new mechanism and subsequent aerodynamic changes revolutionized aircraft to increased speeds and altitude never before achievable with a piston engine. The United States, after acquiring further and more extensive turbojet engine knowledge from the British during World War II, steadily developed the technology. In a relatively brief amount of time, the turbojet was able to power aircraft reliably beyond the speed of sound.

The General Electric axial flow J79 turbojet engine generated a lasting technological innovation with the first use of production ready variable incidence stator vanes that allowed jet engines to begin to overcome compressor stall. Compressor stall can occur as air flows through the jet engines various air compressing guide and stator vanes with low air pressure building just behind a given blade. The low pressure air cell can cause damaged vanes; build to the point of causing a rotational stall which critically impedes the rotation of the engine, can migrate to the combustion chamber starving the fuel of oxygen needed for ignition, or cause the complete reversal of air flow within the engine. These events can cause minor to catastrophic engine damage or even complete engine failure. Variable incidence stator vanes were no longer static but were adjustable to allow the optimum angle of airflow around the various vanes and thus controlled the compressibility of the airflow through the engine reducing the likelihood of stalls. The use

of the this variable stator design within the J79 turbojet allowed the engine to be smaller in diameter, removed complexity, and weighed considerably less than other competing turbojet engines of the time, laying the groundwork for a production run of over thirty years and speeds exceeding Mach 2, or twice the speed of sound.

The purpose of this study is to analyze the General Electric J79 Turbojet engine as it relates to its contemporary turbojet engines, the aircraft it powered, and the effects for General Electric and the military powerplant industry. Additionally, the purpose of this study is to illustrate how the engine helped assist aircraft designers and their companies to satisfy Armed Forces proposals for increased speeds, payloads, systems and the missions to meet a national philosophy of deterrence of a newly perceived threat during the Cold War with the Soviet Union and her Warsaw Bloc allies.

Acknowledgements

First, I wish to thank Dr. Acsay, Dr. Rust, and Dr. Schwantes for their guidance and consideration. They have all been gracious with their time, answered numerous questions, and assisted throughout this endeavor.

I wish to thank the staff at the Thomas Jefferson Library and especially Mary Zettowich for assistance in obtaining various books and journals. They made this thesis possible.

I wish to thank Bill Knowles for providing answers to questions concerning aircraft platforms whose knowledge of aviation is only paralleled by his love of the McDonnell Douglas F-15 Eagle. His information of any item related to aircraft was an invaluable resource.

I also wish to thank Richard Gaines for assisting in translation of articles and editorial suggestions. He provided an honest and thorough assessment of the text.

Finally, I wish to thank my family: my wife Janelle, and my daughters Madeline & Riley. Their continued support and understanding for the hours I spent reading and behind the computer made this process possible.

Table of Contents

List of Pictures

List of Tables

List of Graphs

1.0 History of the Jet Engine: The Ideas Germinate

During the early months of the Korean War, propeller driven Boeing B-29 Superfortresses roamed the skies during daylight bombing raids over Korea virtually unopposed.[1] Exceeding even the Manhattan Project that produced the atomic bomb, the B-29 was the most expensive weapons program of World War II, and one of the most advanced bombers of the time with a pressurized personnel compartment and remote control gun turrets to protect the aircraft.[2] With the advent of the Soviet Union into the conflict, and supplying the jet powered Mikoyen-Gurevich MiG-15 (North Atlantic Treaty Organization [N.A.T.O.] code named Fagot) to the communist North Korea, the fortunes of the B-29 Superfortress quickly changed. The jet powered MiG-15's had the speed and power to easily climb from below or swoop in from behind before the tail gunner could react or shoot the MiG down.[3] With staggering losses to the expensive B-29 aircraft mounting and straight-winged Lockheed F-80 Shooting Stars incapable of being fighter escorts, United States Air Force (U.S.A.F.) commanders quickly changed tactics to night

[1] Robert Frank Futrell, *Ideas, Concepts, Doctrine: Basic Thinking in the United States Air*
[2] Phillips Payson O'Brien, *How the War Was Won* (Cambridge, United Kingdom: Cambridge University Press, 2015), 48-49.
[3] Lou Fulgaro, *Giants Over Korea: A Sky too Far* (Bloomington, Indiana: Stars and Stripes Publishing, 2003), 87-88.
Soviet pilots had trained against Tu-4's, which was a copy of the B-29 acquired during WWII. They learned the gunner could not see an aircraft climbing from below which was not an issue during WWII since most propeller aircraft did not possess the power or speed to vertically climb to attack the B-29's.

attacks in an attempt to decrease losses.[4] The United States Armed Forces commanders learned a lesson: speed, altitude and power equaled air superiority.

During and after the Korean War, the U.S. Armed Forces would seek to resolve their perceived problems of lack of speed and power during the jet age. The capabilities of the MiG-15 exposed and endangered the United States Air Force Strategic Air Command's (S.A.C.) approach to bombarding its Cold War enemy, the Soviet Union, over its homeland with conventional or nuclear armament. The future of the United States as a leader of Western countries, and as the perceived, legitimate adversary could be openly questioned if the deficiency was not corrected. The fortune of S.A.C.'s very mission and viability depended on its ability to deliver a bomber or interceptor carrying a nuclear deterrent that could fly higher and faster than the Soviet Union's defenses was necessitated. From both the aircraft and jet engine manufacturers, the boundaries of technology were pushed in order to meet the challenging requests, to stay as a supplier to an emerging military customer, and to maintain the U.S.'s newly found status as a superpower. The companies that stayed in business as a supplier to the U.S. Armed Forces would gamble with technological innovations to achieve pioneering results.

Companies that competed for aircraft and powerplant contracts needed to overcome daunting technological issues as desired speeds went into unchartered regions. Both the companies and the military financed explorations into the unknown to attempt to accomplish goals of greater speeds and higher thrust. In the quest for higher speeds, one of the issues encountered was compressor stall. There are several types of compressor stall that occur when the aircraft is at certain speeds or angles as the jet engine ingests

[4] Igor Seidov, *Red Devils Over the Yalu: A Chronicle of Soviet Aerial Operations in the Korean War 1950-1953*, trans. Stuart Britton (West Midlands, United Kingdom: Helion & Company Limited, 2014), 234.

more air than it can consume causing a disruption of service anywhere from shut down, internal damage of components, to complete engine loss. Besides operations outside of an aircraft or engine's operating parameters, or ingestion of foreign objects, compressor stall can occur as compressed air flows through the guide and stator vane stages with low air pressure building just behind a given blade. The low pressure air cell can cause damaged vanes, build to the point of causing a rotational stall critically impeding the rotation of the engine, and/or migrate to the combustion chamber starving the fuel of oxygen needed for ignition. A compressor stall can become a compressor surge, which occurs when a complete reversal or interruption of airflow within the engine causes loss of compression. Engine manufacturers looked for ways to resolve the issues by devising creative methods or equipment to the early jet engines. One innovative attempt to resolve the issue of compressor stall was the General Electric J79 turbojet engine.

The G.E. J79 was not the first jet engine to attempt to address the issue of compressor stall, but it combined relatively low weight, size, and fuel consumption, while still producing high thrust for supersonic speeds beyond Mach 2 by introducing or advancing a number of new technologies including variable stators, which reduced the probability of compressor stall. The variable stator system in the J79 controlled the first six rows of guide vanes that automatically adjusted to regulate the amount of air into the engine, and forced them at the proper angle to increase air pressure for combustion. The J79 turbojet variable stator technology would be utilized on multiple subsequent jet engines not just within G.E., and powered multiple military aircraft to supersonic speeds. The development of the J79 turbojet engine advanced the technology surrounding jet engines, confirmed General Electric's position as a leader in jet engines, and was a major contributing factor that provided the means to progress military aircraft, giving S.A.C the potential ability to achieve its strategic bombing objective.

G.E. did not invent the jet engine, and it did not produce the first jet engine concept in the United States, but it did produce a licensed copy of a British jet engine that powered the United States first jet propelled aircraft, the Bell XP-59A Airacomet.[5] G.E. was an early leader in steam engines, and turbo-superchargers used to compress air for piston engines in aircraft at higher altitudes, but had not developed a jet engine prior to the licensed W.1X centrifugal turbojet designed by Frank Whittle for the XP-59A.[6] The first actual jet engine concept was patented by Maxime Guillaume in 1921, but was never produced.[7] Other engineers such as Alan Arnold Griffith, Hans Holzwarth, and G.E.'s Stanford Moss skirted with the idea, but German Hans Joachim Pabst von Ohain and British Frank Whittle developed working turbojet engines in parallel to each other in the 1930's.

In the 1920's and 1930's engineers began to realize aircraft would soon reach the zenith of their capability with a piston driven propeller. Studies showed as a propeller neared or reached supersonic speeds it would encounter compressibility issues, or it was moving too fast to grab the air and became ineffective.[8] Volatile and potentially damaging shock waves could form around propellers or other surfaces as speeds increased to near

[5] Steve Pace, *X-Fighters: USAF Experimental and Prototype Fighters, XP-59 to YF-23* (Osceola, Wisconsin: Motorbooks International Publishers, 1991), 8.
[6] Ed. Roger D. Launius, *Innovation and the Development of Flight* (College Station, Texas: Texas A&M University Press, 1999), 280.
[7] Maxime Guillaume, "Propulseur par réaction sur l'air," French patent no. 534,801 (filed: 3 May 1921; issued: 13 January 1922).
Vaclav Smil, *Two Prime Movers of Globalization: The History and Impact of Diesel Engines and Gas Turbines* (Cambridge, Massachusetts: Massachusetts Institute of Technology Press, 2010), 86-87.
[8] John David Anderson, *A History of Aerodynamics and Its Impact on Flying Machines* (New York, New York: Cambridge University Press, 1997), 319, 396.

supersonic speeds. In 1926, a study by B.M. Jones illustrated how aircraft of the time wasted two-thirds of their power overcoming preventable aerodynamic drag, which was supported by Theodore von Kármán's own wake drag theory that allowed for the calculation of turbulent air induced by airfoils.[9] Additionally that year A.A. Griffith composed "An Aerodynamic Theory of Turbine Design" in which he believed an axial flow turbine could efficiently drive a propeller, and showed the development of a multi-stage axial turbine and its benefits.[10] In 1929, G.E.'s own Glenn B. Warren suggested the propulsion of gas from a jet engine could propel an aircraft to greater speeds than achievable at the time, but aerodynamic concerns would need to be resolved.[11] Metallurgical concerns needed to be addressed with proper formulations to solve the intense temperatures materials were subjected to within jet engines, but ideas were being devised and then refined. When combined with improved aerodynamics and a radically different powerplant from the current piston powered propeller, the aircraft could exceed speeds far greater than imagined possible.

Several individuals developed or attempted their own turbojet engine nearly simultaneously, but the originators of the engine were Frank Whittle and Hans von Ohain. Frank Whittle first submitted a patent for a turbojet engine in 1930, but with only limited

---

[9] Edward W. Constant II, "A Model for Technological Change Applied to the Turbojet Revolution," *Technology and Culture*, Volume 24, Number 4 (October, 1973), 560. Theodore von Kármán, *Aerodynamics* (Ithaca, New York: Cornell University Press, 1954), 61-102.

[10] Ian Philpott, *The Royal Air Force – Volume 2: An Encyclopedia of the Inter-War Years: Volume II: Re-Armament, 1930-1939* (South Yorkshire, Great Britain: Pen & Sword Books Ltd., 2008), 197.
Later tests showed Griffith's idea did produce a working turbojet engine, but did not achieve the efficiency due to compressor blade design.

[11] Glenn B. Warren, "Jet-Propelled Airplanes," *General Electric Review*, Volume 55, 1952, 34-36.

support from just his private business Power Jets Limited, he was not able to operate a functional engine until 1937.[12] The British government supported the advancement of the turbojet in 1939, but not until near necessity due to both an impending war, and the progress of Whittle and his team developing the jet engine.[13] The Power Jets W.1 turbojet powered the Gloster E.28/39 on its first flight in May of 1941.

Whereas Whittle struggled for support during his development of the jet engine, Hans von Ohain was able to gain assistance for his endeavors. Von Ohain had patented his turbojet design in 1935 without knowledge of Whittle's patent.[14] Von Ohain designed a centrifugal turbojet, in which air was compressed through a central impeller before combustion, and gained support of his project by Ernst Heinkel, the aircraft builder. This partnership garnered the first jet aircraft, the Heinkel He 178 that first flew in August 1939, and the first production jet fighter, the Heinkel He 280. The He 280 was supplanted in a competition for a German jet powered fighter aircraft by the more capable Messerschmitt Me 262 that terrorized Allied bombers with a speed greater than anything the Allies flew against it during WWII.[15] With its slightly swept back wings for center of gravity concerns, the Me 262 first showed that overwhelming speed could influence or even decide the outcome of an air battle.

---

[12] Frank Whittle, "Improvements relating to the propulsion of aircraft and other vehicles," British patent no. 347,206 (filed: January 16, 1930, Issued: April 16, 1931). http://v3.espacenet.com/origdoc?DB=EPODOC&IDX=GB347206&F=0&QPN=GB347206 Edward W. Constant II, "A Model for Technological Change Applied to the Turbojet Revolution," *Technology and Culture*, Volume 24, Number 4 (October, 1973), 560.
[13] Daniel Ford, "Gentlemen I Give You the Whittle Engine," *Air & Space*, October/November, 1992, 90-91.
[14] Margaret Conner, *Hans von Ohain: Elegance in Flight* (Reston, Virginia: American Institute of Aeronautics and Astronautics, 2001), 34.
[15] Walter J. Boyne, *Roaring Thunder: A Novel of the Jet Age* (New York, New York: Tom Doherty Associates, LLC., 2006), 89.

As jet powered aircraft were about to fly, in the United States other individuals started contemplating the need for alternate powerplants to push aircraft to greater speeds and started the process of building a jet engine. On the basis of its prior experience with the Navy, Westinghouse received a contract on December 8, 1941, the day after the Japanese attacked Pearl Harbor, for a booster turbojet to assist Navy aircraft in taking off from aircraft carriers.[16] The engine would not operate until the beginning of 1945, but would eventually be modified for the Navy's first jet powered aircraft, the McDonnell Aircraft XFD-1 Phantom, later designated the FH-1. Lockheed Aircraft Company's Nathan Price designed an axial turbojet, in which airfoils rotate around a central datum with compressed air flowing parallel to the axis of rotation, designated the L-1000. Price, who began work on the engine in 1938, anticipated 5,100 pounds of thrust and a fuel economy comparable to contemporary piston engines of similar size. The United States Army Air Corps (U.S.A.A.C.) deemed the overall proposal too potentially problematic due to the engine's complexity, size and mass, along with the intended L-133 aircraft, whose revolutionary design proposed forward canards, nose inlet and aft wings. Lockheed was awarded a contract to develop the engine despite trepidations from the military about aircraft manufacturers producing engines, and the diversion of funds away from piston engines needed for the war effort.[17] Lockheed was never able to manufacture the engine during the war, and efforts to develop the engine were given to Menasco Manufacturing

---

[16] Anthony Kay, *Turbojet: History and Development 1930-1960. Volume 1: Great Britain and Germany* (Ramsbury, United Kingdom: Crowood Press, 2007), 105-106.
[17] Dennis R. Jenkins & Tony R. Landis, *Experimental and Prototype U.S. Air Force Jet Fighters* (Hinekley, United Kingdom: Midland Publishing, 2008), XI.
Sterling Michael Pavelec, *The Jet Race and the Second World War* (Westport, Connecticut: Greenwood Publishing, 2007), 138.

Company, which would eventually turn over its work to the Wright Aeronautical division of the Curtis-Wright Corporation. The engine was never realized for aircraft usage.

2.0 The Turbojet Lands in the United States

In February of 1941, U.S. intelligence reports of German and British jet development led to the formation of the Durand Committee, whose purpose was to coordinate American jet research and development. The chairman of the National Advisory Committee for Aeronautics (N.A.C.A.) Vannevar Bush asked William Durand, who helped found the N.A.C.A. and provided innovative research into aerodynamics and propellers, to head the committee, which included representatives from the Massachusetts Institute of Technology, Johns Hopkins University, National Bureau of Standards, Navy Bureau of Aeronautics and the Army Air Force, whose representative was General Henry “Hap” Arnold. Arnold arranged for an initial briefing with British officials that included D. Roy Shoults, a G.E. turbosupercharger specialist on loan to the United States Army Air Force (U.S.A.A.F.) Technical Staff in London. By October 1941, G.E. received a set of W.2B centrifugal turbojet drawings, an improved version of the Power Jets W.1, and a W.1X engine. The Americanized engine was designated the I-A, and G.E. assembled a team of engineers from their turbosupercharger division led by Donald F. “Truly” Warner to improve its performance wherever possible. By March 1942, initial tests of the new engine were performed that indicated it had compressor stall problems before full speed operation. One month later after modifications to the guide vanes, compressors and compressor casing, the engine ran up to full speed for 1300 pounds of thrust. Two I-A engines were fitted into the Bell XP-59A Airacomet, and test pilot Bob Stanley flew a couple of short initial flights from Muroc Army Airfield on October 1, 1942.[18] Subsequent improvements to the turbojet engine and comparisons to the British W.2/500 turbojet resulted in a final total of 1650 lbs. of thrust and the designation J31 engine, but performance drawbacks to the overall aircraft meant it never saw combat and was eventually phased out of inventory by 1949.[19]

General Electric continued to assist in the maturation of the turbojet in the United States with the next pursuit/fighter aircraft for the U.S.A.A.F. After failing to build the L-133 aircraft with the L-1000 jet engine, Clarence “Kelly” Johnson, Lockheed’s chief design engineer, was given an opportunity to build the XP-80, a straight winged aircraft around the British de Havilland H.1 Goblin Turbojet engine. The engine was to be license built by Allis-Chalmers as the J36, but due to production setbacks the aircraft was redesigned around the G.E. J33, which was larger, but produced more thrust than the H.1 Goblin. Development began in 1943, but no aircraft saw combat during WWII as only two aircraft were sent to the European theater for training purposes.[20] Due to the end of WWII, production of the P-80 ended with 917 aircraft built in September 1945, with Allison having won manufacturing rights for the J33 in multiple configurations from G.E.[21] The P-80, whose military designation was changed to the F-80 Shooting Star in 1947,[22] flew in the

---

[18] Muroc Army Airfield would eventually change its name to Edwards Air Force Base after test pilot Glen Edwards who was killed along with five other crewmen flying the experimental Northrup YB-49 in 1949.
[19] Steve Pace, 17-18.
[20] Don Berliner, *Surviving Fighter Aircraft of World War Two: A Global Gide to Location and Types* (South Yorkshire, Great Britain: Pen & Sword Books, Ltd., 2011), 35.
[21] Marcell Size Knaack, *Post-World War II Fighters; 1945-1973* (Dallas, Texas: Government Printing Office for the Office of Air Force History, 1986), 4-8.
[22] Department of Defense, DoD 4120-L: Model Designation of Military Aerospace Vehicles, Office of the Under Secretary of Defense, May, 2004).

Korean War, but was outclassed by the faster, more powerful and more maneuverable swept wing MiG-15.

Even with the end of WWII, and the curtailing of most aircraft production, concerns over American aircraft capabilities, advanced research and fears of long range attacks began to spur ideological changes within the United States Armed Forces. President Franklin D. Roosevelt's call for 50,000 aircraft at the beginning of the U.S. entering the war compelled both the aircraft industry and the Armed Forces to focus on quantity of parts versus advanced research.[23] When the war ended and the German research into jet engines, rockets, and aerodynamics was revealed, Allied combatants quickly gathered up as much intelligence and personnel as possible to assist in their research.[24] Armed Forces personnel realized they were behind in technology, facilities, and their aircraft lacked the aerodynamic efficiency of German jets.[25] A change was needed to compete with the Soviet Union, a new adversary that emerged after the war, as further research was needed in jet technology and aerodynamics out of fear of a possible bomber attack over the North Pole and to bomb the Soviet Union. The need to focus on quantity of production was moving towards advanced products that pushed the technological envelope, and yielded greater results.

"Aircraft of Interim Air Force," *Flying Magazine*, Volume 43, Number 2 (August, 1948), 37, 56.
Walter J. Boyne, *Beyond the Wild Blue: A History of the United States Air Force; 1947-1997* (New York, New York: St. Martin's Press, 1997), 40.
The U.S. Air Force created its own system of aircraft designations in 1947, which amongst many changes, dropped the Pursuit (P) designation in favor of Fighter (F). A joint system for all services was adopted in 1962, which removed the services unique designation nomenclature.
[23] David Kaiser, *No End Save Victory: How FDR Led the Nation into War* (New York, New York: Basic Books, 2014), 101, 149-150.
[24] Neil Sheehan, *A Fiery Peace in a Cold War: Bernard Schriever and the Ultimate Weapon* (New York, New York: Random House Publishing, 2009), 321-331.
[25] Kay, 95.

The pursuit of increased aircraft speeds required a concentrated effort by many disciplines and organizations into the research of aerodynamics and thermodynamics, and the power demands required. Immediately after the end of WWII, the United States lacked the wind tunnel facilities to provide data for testing at high speeds approaching or exceeding the speed of sound.[26] Collaborating on the research and expenditures, the N.A.C.A., Air Force, and Navy prepared in March 1944, a comprehensive research plan for fully instrumented piloted aircraft to exceed the speed of sound.[27] This association broke through a perceived impenetrable barrier with the first airplane to exceed the speed of sound on October 14, 1947, when Chuck Yeager piloted the rocket powered Bell XS-1 (later just the X-1) to 662 miles per hour at 35,000 feet.[28] The partnership continued to develop experimental aircraft to record flight data, and six years after exceeding Mach 1, another rocket-propelled aircraft exceeded Mach 2. The Douglas D-558-II Skyrocket piloted by Scott Crossfield reached Mach 2.01 on November 20, 1953, but only for a few seconds in a shallow dive with ideal weather conditions, and with strict obedience to a previously calculated flight plan.[29] Flying and powering an aircraft to Mach 2 demanded perfect conditions to be achieved, yet a turbojet engine was already being developed at the time of Crossfield's flight that would make achieving the speed nearly routine.

---

[26] Richard P. Hallion, "Supersonic Revolution," *Aviation History* (May, 2011). http://www.historynet.com/supersonic-revolution.htm
Ed. Roger D. Launius, 287-288.

[27] Robert McLarren, "XS-1: Design and Development," *Aviation Week*, July 26, 1948, 22-23.

[28] Robert McLarren, "Bell XS-1 makes Supersonic Flight," *Aviation Week*, December 22, 1947, 9-10.

[29] Robert B. Hotz, " Douglas Skyrocket Reaches Mach 2.01," *Aviation Week*, November 30, 1953, 13.

3.0 The General Electric J79 Turbojet Engine

In early 1952, General Electric's Aircraft Gas Turbine Division (G.E.A.G.T.D.) laid out the generic design parameters for a turbojet engine needed to meet future design requirements for high levels of supersonic flight. C.W. 'Jim' LaPierre who lead the division demanded a revolutionary advance in their next major turbojet that would obtain good fuel economy at Mach 0.9 with a light weight design, yet had the flexibility, strength, and thrust to achieve Mach 2.0 before an aircraft had even achieved the speed[30]. Two design groups were given the opportunity to study the design requirements with additional considerations of cost to manufacture, maintenance, and overall performance. One group utilized a twin spool or rotor design that was being used successfully by Pratt & Whitney (P&W) to nearly control the turbojet market at the time, and the other group was utilizing a variable stator approach.[31] Each design offered advantages and disadvantages with little data within G.E. for guidance. Dr. Chapman Walker headed the twin rotor team for G.E.'s internal turbojet engine competition. A twin rotor or dual spool turbojet employed two central shafts operating independently of each other at high and low pressures which provided relatively high thrust and low fuel consumption with reduced stall characteristics, but was larger in diameter, comparably heavier, and complicated in that the dual spools needed a complex set of bearings to operate, and could still require inefficient bleed valves to help control

---

[30] Bill Gunston, *World Encyclopedia of Aero Engines: From the Pioneer to the Present Day* (Gloucestershire, United Kingdom: Sutton Publishing, 2006), 86.
[31] J.S. Butz, Jr., "Low Lead Time, Lightness Mark J79," *Aviation Week & Space Technology*, May 27, 1957, 29-30.
Robert V. Garvin, *Starting Something Big: The Commercial Emergence of GE Aircraft Engines* (Reston, Virginia: American Institute of Aeronautics and Astronautics, Inc., 1998), 12-14.

stall issues.[32] Gerhard Neumann led the variable stator turbojet team. The variable stator was first tested by Roll-Royce in 1949 for the Avon turbojet concept, but variable inlet guide vanes and bleed valves were employed instead due to issues in making the variable stators work properly.[33] The variable stator turbojet could be lighter and smaller in diameter due to utilizing a single shaft, fewer bearings and seals, but suffered from leakage of high-pressure air around the base of the adjustable stators.[34] After a comparison of data from the two teams, the variable stator concept engine was chosen.

The variable stator turbojet engine concept had offered the best opportunity to achieve the earlier design requirements and meet the performance specifications. G.E. had been drawn to the possibility of variable stators being developed for jet engines to obtain higher flight speeds as early as 1951.[35] Gerhard Neumann, with assistance from a dozen other engineers at building 29G of the G.E.'s Lynn, Massachusetts facility, designed and built a prototype compressor to demonstrate the feasibility of the technology. The tests showed a successful operation, and a patent was eventually filed for variable stators in Neumann's name.[36] The engine was a fixed fourteen-stage turbojet converted for variable action within the first five stages of the stators and the inlet guide vanes (I.G.V.). Typical jet engines flowed well within their design region, but at off design points or as low air speeds

---

[32] Jack Conner, *The Engines of Pratt & Whitney: A Technical History as Told by the Engineers Who Made the History* (Reston, Virginia: American Institute of Aeronautics and Astronautics, 2010), 225.
The advantages and disadvantages of the twin spool turbojet are taken from the contemporary Pratt & Whitney J57 (JT3A) engine since the G.E. twin spool engine never progressed beyond the concept phase.

[33] Bill Gunston, *Rolls-Royce Aero Engines* (Somerset, United Kingdom: Patrick Stephens Limited, 1989), 133-134.

[34] Garvin, 13.

[35] F.L. Smith and Neil Burgess, "Design and Development History of the J79 Engine," *Society of Automotive Engineers*, October, 1960, 2.

[36] Gerhard Neumann, "Variable Stator Compressor," United States Patent 2933235 (Filed January 11, 1955, Issued: April 19, 1960).

flowed into the engine, airflow angles and volume misalign with the resultant compressors. The vector and quantity of air hitting the compressors could form a low-pressure zone. The variable stator system worked to match the pressure and air speed differential directing the air to the correct angle of attack for the subsequent compressor stage. The stators could pivot and thus vary the air's trajectory and volume to ensure the air affected the compressor vanes at the intended point for maximum air compression and an alleviation of stall characteristics. By May 1952, the variable stator experimental engine, code named VSXE with the layout drawing nomenclature of X24A within G.E., had concluded testing and proven the potential of the technology.[37]

Gerhard "Herman the German" Neumann led the team developing the VSXE demonstrator turbojet engine. Neumann was born November 8, 1917, in Germany to a non-practicing Jewish family, and attended the technical school Ingenieurschule Mittweida where he gained experience as an engine mechanic and engineer. In 1938, as the prospect of war seemed increasingly likely and with persecution of Jews increasing within Germany, Neumann saw an announcement on the school bulletin boards of a German Army deferment to assist the Chinese Nationalist government. The Chinese government needed German mechanical engineers, and Neumann accepted a possible position with only vague references to a possible location of employment within the interior of China.[38] He would eventually arrive in Hong Kong in June 1939, but did not immediately depart for the interior of China due to employment issues. When WWII began in September 1939,

[37] Bill Gunston, *World Encyclopedia of Aero Engines: From the Pioneer to the Present Day* (Gloucestershire, United Kingdom: Sutton Publishing, 2006), 86.
[38] Gerhard Neumann, *Herman the German: The Former Enemy Alien and Air Corps G.I. Whose Inventive Skills and Maverick Management Techniques Made Jet Engine History* (New York, New York: William Morrow and Company, Inc., 1984), 35-36.

the British gathered all German nationals at the La Salle College in Kowloon. The British confiscated Neumann's passport, and just a day before being removed from British controlled Hong Kong he meet W. Langhorne Bond of the China National Aviation Corporation in an elevator where Neumann explained his plight.[39] Bond immediately arranged for Neumann to leave Hong Kong without a passport, and before working briefly in a Chinese civilian aircraft company, Neumann eventually accepted a position within China as a mechanic with the American Volunteer Group, or Flying Tigers. In 1942, he was sworn into the U.S.A.A.A.F. and would subsequently twice reconstruct, initially and then again due to a landing accident, a captured Mitsubishi A6M Zero, Japan's dominant all-purpose fighter during WWII.[40] With the assistance of General Bill Donovan, Neumann was granted United States citizenship by an act of Congress in May 1945.[41] After the war in 1948, Neumann, his wife Clarice, whom he had met on a visit to Washington, D.C., and their dog trekked across Asia by Jeep to Israel to travel to the United States where he eventually settled in Lynn, Massachusetts, working for G.E. as a test engineer.

Neumann and G.E. worked to provide a family of three different turbojets utilizing variable stators to present to the U.S. Air Force (U.S.A.F.) for future applications. The U.S.A.F. chose the X-24A on December 3, 1952, to have a basic thrust rating of nearly 14,000 pounds of force; it was given the designation of J79 by the U.S.A.F., and the overall project was designated MX2118. The other two engines presented, an advanced J73 and engine designation J77, were terminated from further development.[42] An additional engine, the GOL-1590, was authorized as an engineering demonstrator for

---

[39] Ibid, 57.
[40] Ibid, 98-107.
[41] Ibid, 135.
[42] Bill Gunston, *World Encyclopedia of Aero Engines: From the Pioneer to the Present Day* (Gloucestershire, United Kingdom: Sutton Publishing, 2006), 86.

design and test data and was known within G.E. as the D-1. Prior to the U.S.A.F. decision for the J79, the U.S.A.A.C. had realized by October 1946, it needed to develop a future large supersonic aircraft capable of delivering an atomic bomb called Generalized Bomber Study (G.E.B.O.). By 1949, the original G.E.B.O. study was concluded and revised for a medium bomber. Convair and Boeing emerged as early contenders, and in 1951, the companies were given contracts for aerodynamic and conceptual design studies. After several revisions to the design concepts and bomber configurations, Convair was chosen to develop the first supersonic bomber, and the U.S.A.F. had the impetus for a supersonic jet engine capable of powering the bomber to Mach 2. They turned to G.E. and its new turbojet with variable stators to power the aircraft.

G. E. was now responsible to develop the engine as quickly as possible to power future fighter and bomber aircraft within their design phase to secure strategic advantage over the Soviet Union. General Donald Putt, commander of Air Research and Development, indicated to G.E. that the J79 greatly influenced “to a very major degree, this country’s ability to defend itself during the 1958-1965 period” and “this responsibility should not be treated lightly.”[43] G.E. responded with a management of the program that consisted of a team of handpicked engineers, draftsmen, metallurgists, managers, and secretaries, and they toiled within a common area to achieve the necessary engineering drawings and data for the 12,000 parts that comprised an engine.[44] The GOL-1590 engine ran for the first time on December 16, 1953, with its inlet painted in the same shark mouth motif as on

---

[43] Marcelle Size Knaack, *Encyclopedia of U.S. Air Force Aircraft and Missile Systems: Post-World War II Bombers, 1945-1973; Volume II* (Washington, D.C.: Office of Air Force History, 1988), 367.
[44] Neumann, 214.

the Curtis P-40 Warhawks of the Flying Tigers in honor of Gerhard Neumann.[45] The engine immediately started, increased its speed so quickly within its starting cycle, and accelerated so suddenly the test crew lost control of the test engine's manual variable stator controls. The engine vibrated intensely causing a break in the 'dog-bone' bracket holding the suspended engine, which dropped the front of the engine, and it hit off of the test frame. The test engine was damaged, but it had shown promise with its brief but astonishing performance.

The GOL-1590 engine was repaired three weeks later, and tests resumed with test personnel and engineers better prepared for the instantaneous starting cycle and rapid acceleration characteristics of the engine. The newly built test chamber at the 29G facility, which could simulate altitudes from sea level to 60,000 feet, expedited testing of the engine and reduced costs.[46] The engine exceeded full power within the first eight hours of testing, and its overall impressive performance results caused the engineers to doubt and double check the instrumentation.[47] The first prototype XJ-79 was tested on June 8, 1954, achieving its fundamental goals of exceptional supersonic and subsonic performance all within a lightweight design. The development milestones of the revolutionary J79 turbojet with its use of unproven variable stator technology proceeded at a nearly identical rate as another G.E. internally developed engine, the J47-D17, which was an evolution of an already existing model requiring only the addition of an afterburner. An afterburner on turbojet engines injects fuel to burn aft of the turbine into the exhaust gases to provide additional thrust during operational needs such as takeoffs, but at the expense of

---

[45] Ibid, 215.
[46] Kay, 140.
[47] Bill Gunston, *World Encyclopedia of Aero Engines: From the Pioneer to the Present Day* (Gloucestershire, United Kingdom: Sutton Publishing, 2006), 86.

increased fuel consumption. The original configuration model, the J79-3A, possessed a diameter of 38.0 inches, an inlet diameter of 32.0 inches, a length of 204.0 inches, a weight class of 3200 pounds, and ingested 162 pounds of air a second through its inlet at static sea level conditions.[48] By comparison, the J47-D17 had a 1.0 inch larger diameter, a 2.0 inch larger inlet diameter, was 22.5 inches longer, produced half the thrust at 7500 pounds of thrust, was capable of half the overall speed class at Mach 1.0, and ingested 61 fewer pounds of air a second at static sea level.[49] G.E. had planned, tested and achieved a turbojet engine capable of sustained Mach 2 or greater flight less than a month after Scott Crossfield in a Douglas D-558-II Skyrocket powered by a rocket had momentarily achieved it under the most ideal situation.

The autonomous mechanisms controlling the variable stator system supported operational performance of the engine over a varying range of conditions without the need for pilot control. The simplicity of the concept belied the complexity of the synchronization of the various electro-mechanical mechanisms to achieve the result. A few years earlier Rolls Royce had avoided variable stators and concluded other options were easier due to the complexity for its Avon turbojet.[50] The variable stator system was an organization of parts that required harmonious control of their functions to achieve the desired results. A predetermined program with input from different sensors measuring engine speed and temperature determined the position of the stator. The main fuel control mechanism received high-pressure fuel, and housed a variable vane cam that was positioned by the inlet temperature and engine speed. This in turn provided a signal to the variable vane

---

48 F.L. Smith and Neil Burgess, Figure 5.
49 F.L. Smith and Neil Burgess, "Design and Development History of the J79 Engine," *Society of Automotive Engineers*, October 1960, 4-7 and Figure 5.
50 Bill Gunston, *Rolls-Royce Aero Engines* (Somerset, United Kingdom: Patrick Stephens Limited, 1989),133.

scheduling valve, then signaled an actuator to move a set of bellcranks attached to an actuating ring and master-rod that moved the bellcranks, and in turn the stators [reference Picture 1.0A: General Electric J79-17 Turbojet, Picture 1.0B: Variable Stator Outer Control Mechanism (Close-Up), and Picture 1.0C: Variable Stators (View Looking Out). The variable stators along the first six stages of the engine controlled the flow of air through the engine between approximately 63% and 95% of engine operating speeds within the predetermined schedule.[51] G.E. had succeeded in facilitating the various mechanisms into a harmonious control of the variable stators to achieve the desired results.

While the variable stators were the key technological advancement of the engine, there were also several other key features that succeeded in creating the first Mach 2 turbojet engine. Due to the requirement of the engine to operate efficiently within sub and supersonic speeds, a convergent – divergent ejector type nozzle was chosen to control the exhaust. With a convergent – divergent exhaust in the J79, an adjustable mechanical linkage could reduce the upstream exhaust as necessary before the divergent section could allow the exhaust to expand with secondary air used to apply pressure against the mechanisms. This feature helped to speed up the outgoing exhaust to supersonic speeds. Conical construction was used when possible in areas such as the main engine frames and several different supports. Conical supports provided the required strength and support without having to resort to heavier stiffeners or gussets.[52] Additionally a conical turbine shaft was also employed for the main turbine shaft, which reduced the wall thickness and weight, and aided in the swift acceleration characteristics of the aircraft the

[51] *J79-8A & 8B Turbojet Engine: Operation and Service Manual* (Cincinnati, Ohio: General Electric Product Support Publications, Flight Propulsion Division, September 1965), 6-1.
[52] F.L. Smith and Neil Burgess, 11.

J79 was installed within. The overall diameter and volume was kept to a minimum with the majority of controls and accessories integrated within the forward section of the powerplant, which allowed more efficient possible aerodynamics, operation and maintenance for its intended application in military aircraft, but would prove a detriment when the engine was later converted for commercial usage and a fan was applied to increase the fuel economy of the engine.

The design and manufacture of the J79 utilized a number of different materials due to production requirements, cost, and attributes. The single shaft of the J79 only required three sets of bearings in the forward, compressor, and turbine frames. The compressor blades and stator vanes were manufactured from 403 stainless steel because they offered a higher level of corrosion resistance, and a high temperature operating range of up to 1,300° Fahrenheit.[53] Titanium, which would have offered less weight, better fatigue resistance, and similar corrosion and temperature operating range, was not used within any stage of the blades or stators within the initial J79's due to G.E.'s previous negative experience and cost associated with the material at the time.[54] Although discovered in the 1700's and used sparingly since then, titanium had only first been used in major airframe components within an aircraft in the experimental Douglas X-3 Stiletto that first flew in October 1952.[55] The engine mounting attach points employed uni-ball and thrust pin construction, formed within the frame along the forward section of the engine. They were

[53] Ed. John W.R. Taylor., *Jane's All the World's Aircraft; 1973-1974* (New York, New York: Haymarket Publishing Group, 1974), 720.
The J79-3B & -7A models utilized A286 stainless steel for the Lockheed F-104 Starfighter.
[54] "Aero Engines 1957," *Flight*, July 26, 1957, 133.
J.S. Butz, Jr., "J79 Uses Built-Up Parts to Save Weight," *Aviation Week & Space Technology*, August 11, 1958, 71.
[55] James R. Hansen, *The Bird is on the Wing: Aerodynamics and the Progress of the American Airplane (College Station*, Texas: University of Texas A&M Press, 2004), 119-120.

all made of high strength chromolloy steel, along with various other engine components, due to it being stronger than standard steel to control thrust loads, with pads to control vibrations, and strut links to control aft side loads. Mounting point usage was controlled by the requirements of the particular aircraft.

Engineering considerations were also given to design simplicity to achieve fewer maintenance hours needed to overhaul or repair the engine in service. Straightforward designs offered more reliability and ease of operation in service. The turbine casings were divided parallel with the turbine datum to aid inspection of the interior of the turbine.[56] The design of the compressor section of the engine was devised so the balance of the engine could be removed or retained for maintenance, or just the complete removal of the compressor from the rest of the engine.[57] The single shaft of the J79 with only three bearings enabled fewer moving parts, less wear, and greater overall reliability than most of its turbojet engine competition.[58] Maintainers of the engine could use these features to aid in their inspections or repairs as required. The plumbing for engine airflow extraction was internalized to reduce external piping problems of pressurization loss common in the era, and provided a more streamlined engine. Engine air flow was extracted for accessory power, cooling, cabin pressurization and systems such as boundary layer control, which blew air along the surface of wing flight controls to provide extra lift and allowed for reduced air speeds during landings, reducing airframe stress as seen in the Lockheed F-

---

[56] J.S. Butz, Jr., “J79 Uses Built-Up Parts to Save Weight,” *Aviation Week & Space Technology*, August 11, 1958, 73.
[57] F.L. Smith and Neil Burgess, 8.
[58] J.R. Nelson, *R-2103-AF: Life-Cycle Analysis of Aircraft Turbine Engines* (Santa Monica, California: Rand Corporation, 1977), 45.
Reliability is based off Air Force base maintenance costs per engine flying hours. The J79-GE-15 & -17 had less cost per flying hour than the P&W J57 & & J75 turbojet engines, except the J57-P-43 installed in the B-52.

104 Starfighter.[59] These innovations exemplified the forethought of G.E. engineers to understand that an uncomplicated design resulted in a more reliable engine, and would prove to be advantageous with other aspects for its customers.

Fewer hours maintaining the engine equaled lower costs to its customers, and the aircraft itself was more operationally ready for its sorties due to less down time being maintained. Several components were designed for easier maintenance or designed to last for prolonged service. Compressor casings were split horizontally upper and lower, forward and aft, and designed so that the entire upper or lower section could be removed or just one section at any time. Honeycomb seals were employed along the turbine tip shrouds, which provided better sealing and metal wear of the shroud seal thus providing longer life. Initial maintenance of 2,400 man-hours were undesirable due to inexperienced maintenance of the engine as it operated within the first few years of service, and preliminary problems found in most innovative technological devices during the first few years of usage and development.[60] Eventually G.E. resolved the problems, improved processes and techniques, and the engine maturity brought the maintenance time between overhauls (M.T.B.O) down to a level commensurate or greater than rival American turbojet engines. A 1977 Air Force study by the Rand Corporation of the total life cycle costs associated with six different turbojet and two turbofan engines showed the J79 M.T.B.O was better than all but the J57-P-43, labor rates were the lowest, and while aircraft dependent, base maintenance costs per engine flight hour (B.M.C./E.F.H.C.), average time to overhaul and depot costs per flying hour were comparable or less than other turbojet or

[59] Ed. Robin Higham, *Flying American Combat Aircraft: The Cold War* (Mechanicsburg, Pennsylvania: Stackpole Books and Sunflower University Press, 2005), 115.
Peter Davies, *F-104 Starfighter Units in Comba*t (Oxford, United Kingdom: Osprey Publishing, 2014), 11.
[60] "Aero Engines 1957," *Flight*, July 26, 1957, 133.

turbofan engines.[61] A turbofan is different from a turbojet engine in that a turbofan is more contemporary technology and employs a ducted fan to bypass a portion of the air from the combustion process through the engine core with both heated and bypass air providing thrust. The amount of air bypassing the engine core is referred to as the bypass ratio. Typical military fighters employ a low bypass ratio turbofan, while most military transport and commercial passenger aircraft use high bypass turbofan engines. The J79 turbojet required an inspection at 600 flight hours, and at 1,200 hours required a depot level overhaul, or a specialized inspection and repair at a dedicated facility, which was comparable to the other Mach 2 capable turbojet, the P&W J75, and beat early turbofans. The ease of maintenance permitted a more efficient operation of the aircraft on the ground and in the air.

The overall size of the J79 aided in its efficient operation within aircraft and allowed for improved performance. Compared to its main competition of the time, the P&W J57 and later the J75, it weighed well over one thousand pounds less than both models, was shorter, smaller in diameter, and easily provided more thrust to weight than either model, but a negative feature of the J79 was that it burned slightly more fuel that the two P&W engines which would have damaging repercussions when the J79 was converted for commercial use. For the design engineer of an aircraft, weight reduction was a key design characteristic to achieve the increasing performance requirements of the United States Armed Forces. Unnecessary increased weight meant potentially lost performance for the aircraft. Kendall Perkins, Vice-President of Engineering at McDonnell Aircraft Corporation, in 1954 for an internal engineering design manual, wrote “Whenever an extra pound is added, performance is lost which can never be fully regained,” and “…when we add weight

[61] J.R. Nelson, 29-45.

we can't change the airplane size and power but must accept instead the loss in performance which is, almost by definition, equally objectionable."[62] The size of the engine also meant that considerations had to be made for other components or items being constrained within the airframe. Greater size and weight of the engine meant stronger and thicker structures to carry the weight, and the increased size of the engine and structures resulted in less room for other items such as fuel tanks within the airframe. A smaller diameter engine required less area within the airframe or a more compact nacelle when the engine is hung outside of the main airframe, and thus reduced the amount of drag the airplane was subjected to within flight.[63] All of these features endowed the J79 with the necessary characteristics to better its engine competition of the time, and provide military aircraft the thrust to potentially exceed Mach 2, continuing the perceived requirement of speed to intercept potential threats, or air interdiction quickly into enemy territory to bomb targets.

The J79 engine was in many ways an engineering marvel with all of its characteristics and a solid design. In less than ten years after WWII, the fastest piston engine aircraft of the war was potentially capable of only around a quarter of the speed of the soon to be released aircraft powered by the J79. It attained many of the quality design characteristics such as meeting the requirements of the customer, size and efficiency, simplicity, reliability, cost and maintainability that G.E. aspired to achieve in its original turbojet proposal. G.E. needed to prove these characteristics and qualify the engine for aircraft usage.

---

[62] Kendall Perkins, *How to Design Good Aircraft* (St. Louis, Missouri: McDonnell Aircraft Corporation Service Engineering, 1954), 2-3.
[63] Jack D. Mattingly, William H. Heiser and David T. Pratt, *Aircraft Engine Design* (Reston, Virginia: American Institute of Aeronautics and Astronautics, Inc., 2002), 427.

Before the engine could be released for full rate production of the engine, flight-testing beyond a wind tunnel was required all while management within G.E. was changing. A specially designed North American B-45 Tornado was fitted with the J79 into its bomb bay, and on May 20, 1955, from the Schenectady, New York facility, the four J47 engines on the B-45 were shut down and the single J79 was lowered from the bomb bay and powered the aircraft. The engine was subjected to a fifty-hour qualification testing over the next few months. Later in December of the same year, Roy Pryor piloted a Douglas XF4D Skyray from Edwards Air Force Base (A.F.B.) with its Westinghouse J40 replaced by a J79 for flight-testing.[64] During this time, the former project manager of the J47 turbojet who had co-developed an anti-icing system for jet engines, Neil Burgess, replaced the original project manager, Perry Egbert, due to health reasons.[65] Burgess and Bernhard Neumann were the two individuals within G.E. most closely associated with the development and success of the J79 over its production life.[66] Back in January 1953, just after the J79 project was officially established, J79 project leaders including Neumann met with officials at Convair in Fort Worth, Texas, to discuss application of the J79 in Convair's proposal for the Air Force MX-1964 bomber project.[67] The proposal would eventually become the Convair B-58 Hustler, but it would not be the first application of the J79 into a military aircraft.

---

[64] Bill Gunston, *World Encyclopedia of Aero Engines: From the Pioneer to the Present Day* (Gloucestershire, United Kingdom: Sutton Publishing, 2006), 86.
[65] General Electric Company, *Seven Decades of Progress: A Heritage of Aircraft Turbine Technology* (Fallbrook, California: Aero Publishers, Inc., 1979), 75.
Neumann, 216.
[66] Guy Norris, "Power Points: Milestone Developments Mark Propulsion's Remarkable Progress," *Aviation Week & Space Technology*, December 7-20, 2015, 55-56.
Promotional pictures publicized Burgess and Neumann in front of a J79.
[67] F.L. Smith and Neil Burgess, 3.

3.1 The Lockheed F-104 Starfighter

The J79 turbojet was first fitted into the Lockheed F-104 Starfighter for the U.S.A.F., but the aircraft was not what the U.S.A.F. requested or envisioned. Kelly Johnson had interviewed pilots to understand what attributes they needed in aircraft to combat their Cold War adversaries on an exploratory visit to see how Lockheed aircraft were performing during the Korean War.[68] All pilots agreed they needed greater speed and altitude to defeat their opponents. Korean War era U.S.A.F. pilots flew out-matched F-80 Shooting Stars until the introduction of the North American F-86 Sabre, which only proved an equal to the MiG-15.[69]

Hal Hibbard and Kelly Johnson went back to their Advanced Development Projections Section of Lockheed or "Skunk Works" group and designed an uncomplicated, lightweight interceptor aircraft, even though there was no U.S.A.F. contractual requirement for an aircraft of this type at the time.[70] Relying heavily on N.A.C.A. data from the Douglas X-3 Stiletto, Hibbard and Johnson designed the smallest, most aerodynamically efficient airframe of the time around a single engine with relatively straight, razor thin wings to reduce drag, and a high "T-Tail." The trapezoidal shaped wings measured just 7.5 feet long and only 4.2 inches thick at the inboard most section mating to the fuselage, tapering to less than 2.0 inches at the outboard tips, and were a departure from the prevailing swept back wing philosophy of the time to obtain supersonic speeds. The fuel, landing

---

[68] Clarence L. Johnson, *Kelly: More Than My Share of It All* (Washington, D.C.: Smithsonian Books, 1985), 107.
[69] Kenneth P. Werrell, *Sabres Over MiG Alley: The F-86 and the Battle for Air Superiority in Korea* (Annapolis, Maryland: Naval Institute Press, 2005), 78-79.
[70] Dave Windle and Martin W. Bowman, *Lockheed F-104 Starfighter: Interceptor, Strike, Reconnaissance Fighter* (South Yorkshire, United Kingdom: Pen & Sword Aviation, 2011), 7.

gears, and most controls had to be installed in the fuselage with only one-inch thick hydraulic cylinders to actuate the control surfaces within the thin wings. Testing to evaluate possible outboard wing tip designs was performed using scaled models launched by rockets to verify if the wing structure could withstand various configurations. The results and conclusions from the testing developed into a controversial proposal and subsequent aircraft over its entire service life.

The proposal brought to the U.S.A.F. was well received by the service, and forced an open competition amongst several of the leading aircraft companies. General Donald Putt, head of the U.S.A.F. Systems Command, issued Weapons System General Operational Requirement 303A for an air superiority day fighter that needed a high climb rate, speed, and altitude to supplement and eventually replace the North American F-100 Super Sabre.[71] Republic, Northrop, and North American also offered submittals for the requirement. Lockheed's proposal, Model 83, was smaller, with a potential for a high thrust-to-weight ratio for advantageous speed and climb rates, and possessed about half the weight of the other proposals.[72] In January 1953, Lockheed's submittal was the winner of the competition, and by March the U.S.A.F. issued a contract for two prototypes to be flown the following year, but there was still a major decision to be made concerning which engine would power the aircraft.

Several engine manufacturers had engines available or were in the process of being readied that promised high thrust and the potential for a speed exceeding Mach 1.

---

[71] Dave Windle and Martin W. Bowman, 9.
[72] Ibid, 9-10.

P&W promised the yet to be available large and powerful J75; Allison offered the older J71; and G.E. offered the J79, but it was not thought to be available until 1956.[73] Consequently, the F-104 Starfighter was originally designed to be tested with the license built Wright Aeronautical J65-W-6, non-afterburning, and J65-W-7, with afterburner, which were built from British Armstrong-Siddeley Sapphire axial-flow turbojets, but the J79 was chosen to power the production aircraft. Lockheed had to design two different aircraft at certain sections due to the two engines different sizes, weight distribution, and their air inlets and exhaust outlets differing needs. By January 1954, two XF-104's were flown to Edwards A.F.B., aircraft 53-7786 for aerodynamic evaluation and 53-7787 for armament tests. Aircraft 786 revealed landing gear issues which required a redesign before returning to flight tests, and aircraft 53-7787 flew to the highest speed achieved with a J65 powered XF-104 when Lockheed test pilot Ray Goudey flew the aircraft to Mach 1.79 on March 25, 1955, before its eventual loss in April of 1955 when a bullet casing ejected from the G.E. M61 30mm Vulcan gun caused explosive decompression.[74] Despite efforts to achieve a higher speed in the 250 hours of flight testing performed with the J65 powered XF-104, it had yet to achieve the intended maximum speed of the aircraft.[75] Flight-testing would continue with the envisioned engine and greater speed would be achieved.

The U.S.A.F. issued a new contract in March 1955 for seventeen YF-104 Starfighters equipped with early configurations of the G.E. J79 for further testing. Lockheed had promised Mach 2 performance from its aircraft and they hoped to achieve the goal as

---

[73] Martin W. Bowman, *Lockheed F-104 Starfighter* (Marlborough, United Kingdom: The Crowood Press, 2001), 29-31.
[74] Jim Upton, *Lockheed F-104 Starfighter – Warbird Tech Volume 38* (North Branch, Minnesota: Specialty Press Publishers, 2003), 37-38.
[75] Upton, 38.
Dave Windle and Martin W. Bowman, 12.

they tested J79-GE-3, -3A and -3B versions of the engine. The YF-104's were also redesigned with additional fuel cells, a revised horizontal flight surface on the vertical tail, and a revised nose, besides the changes needed for the basic geometry of the J79.[76] G.E. delivered its first engine to Lockheed at the end of December 1955, and it flew over a month later in February 1956 ahead of the USAF contract. Just over two months later on April 27, 1956, the F-104 flew to Mach 2.13 at a level altitude making it the U.S.A.F.'s first aircraft to achieve the feat.[77] The U.S.A.F. placed an additional order of 722 F-104's, but eventually acquired only 294 of the aircraft, which were sent to different commands with the first being sent to the 83rd Fighter/Interceptor Wing based at Hamilton A.F.B. in California.[78] The F-104 Starfighter's high speed and rate of climb at that location potentially allowed it to intercept the perceived threat of bombers approaching the West Coast from Soviet bases along its eastern border. The Soviet Union had developed long range Tupolev Tu-95 Bear and Myasishchev M-04 Bison capable of carrying long-range intercontinental ballistic missiles by this time, and the F-104 could provide a deterrence to quickly intercept the bombers at elevated altitudes.[79] Based on the success of the aircraft and its astonishing achievements, the U.S.A.F. and the industry team of Lockheed with Kelly Johnson, and G.E. with Neil Burgess and Gerhard Neumann, won the 1958 Collier Trophy, awarded annually to the individual or group accomplishing the greatest

---

[76] Irving Stone, "USAF F-104 Completes Test Program, Enters Squadron Use," *Aviation Week*, February 10, 1958, 66-67.
Pace, 131.
[77] Dave Windle and Martin W. Bowman, 13.
[78] "F-104: Holder of the Absolute Records for Speed and Altitude," *Flight International*, May 30, 1958, 743.
[79] Ed. Barry Leonard, History of Strategic Air and Ballistic Missile Defense: Volume 1: 1945-1955 (Washington, D.C.: United States Army Center of Military History, 1975), 128-129.
http://www.history.army.mil/html/books/bmd/BMDV1.pdf

achievement in aerospace. Lockheed had achieved its original goal of a lightweight fighter for the U.S.A.F., but concerns over the overall performance of the aircraft remained.

Due in part to its design for overall speed, the F-104 Starfighter was limited in its operational capabilities compared to its contemporaries. Its short and slender wings limited its ability to carry ordinance or fuel, which proved highly disadvantageous to strategic planners within the U.S.A.F. When it used just its internal fuel load, the F-104's had limited range for its intended intercept role, which meant if a F-104 was to reach a bomber target at an altitude of 45,000 feet, it would practically have to do so over its base.[80] The original requirement of being a day fighter proved to be detrimental when more adaptable all-weather aircraft were in service. Its slender nose allowed installation of only a small radar with a very limited radar range of ten miles in clear conditions.[81] In order for it to be more capable and carry nuclear ordinance, the F-104 had to employ a trapeze type mechanism exposed to the airstream along the fuselage centerline.[82] The problems with the F-104 were due to its raison d'être: it was lightweight with thin, small wings built for speed and to reach extreme altitudes as quickly as possible. It was also not very maneuverable, as its thin and small flight controls did not allow the aircraft an acceptable turn rate. Test pilot Milton O. Thompson concluded the F-104 "was designed only to get to high altitude fast and pass by the enemy at high enough speed to avoid a dogfight and a retaliatory missile. It was never intended to be a dogfighter; instead, it was a greyhound."[83] Just like a greyhound, it was built for ultimate speed as the J79 propelled the F-104 to speed and altitude records, and was the first aircraft to hold both records.

[80] Dave Windle and Martin W. Bowman, 18.
[81] Ibid, 22.
[82] Bowman, 60, 79.
[83] Dave Windle and Martin W. Bowman, 10.

The thrust of the J79 and its nearly singular purpose design propelled the F-104 Starfighter to its records, and as a result gave it some of its nicknames and reputation. On May 7, 1958, a YF-104 piloted by U.S.A.F. Major Howard C. Johnson surpassed the world altitude record with a record of 91,243 feet, and less than two weeks later Captain Walter W. Irwin achieved a speed record of 1404.09 mph becoming the first aircraft to hold both altitude and speed records.[84] On December 14, 1959, a F-104C model flown by U.S.A.F Captain Joe Jordan, in an inter-service rivalry, flew to 103,389 feet, and captured the altitude record from a Navy prototype YF4H-1 powered by a J79 set a week earlier.[85] After having already beaten multiple speed to altitude records, it established the speed to altitude record for 100,000 feet with a time of five minutes and 4.92 seconds on the same flight by Jordan.[86] It was built for speed and it looked the part. It was sleek and futuristic compared to propeller planes of less than a decade before and signified the jet age of the 1950's. It also earned an array of nicknames. The positive nicknames focused around it speed such as "zipper," "Zip-4," or "missile with a man in it," but it also earned less than flattering monikers due to it high accident rates such as "widow-maker", "ground nail", or "flying coffin."[87] Unfortunately for Lockheed, most of the derogatory nicknames originated from N.A.T.O. countries that acquired the F-104 Starfighter.

---

[84] "Altitude Record Fall," *Aviation Week*, May 12, 1958, 27.
Walter J. Boyne, *Beyond the Wild Blue: A History of the United States Air Force; 1947-199*7 (New York, New York: St. Martin's Press, 1997), 474.
[85] Peter Davies, *F-104 Starfighter Units in Comba*t, 36.
[86] Dave Windle and Martin W. Bowman, 26.
[87] Ed. Robin Higham, 113.
Colin D. Heaton and Anne-Marie Lewis, *The German Aces Speak II: WWII Through the Eyes of Four More of the Luftwaffe's Most Important Commanders* (Minneapolis, Minnesota: Zenith Press, 2014), 274.
There are two notions for the origin of the "zipper" nickname. The first has the F-104 alphanumeric nomenclature being continually shortened from "0-4" to "Zip-4" which finally

The F-104 Starfighter was sold to other countries with varying consequences for Lockheed and G.E. Both companies embraced offset or coproduction work packages in which a portion of the manufacturing was performed in the country buying the aircraft or engine, which enticed companies to buy the products. After West Germany was permitted to join N.A.T.O. in 1956, it was also allowed to rebuild its air force, the Bundesluftwaffe, after it had been terminated following the end of WWII. While some German industries had recovered since the end of WWII, the aircraft industry had not due to strict postwar controls so that by the mid-1950's it lacked the expertise to design and build a suitable competitive aircraft. The West German government looked to procure a foreign aircraft, and the purchase would be its first postwar acquisition of aircraft. The entirely new force needed to assist in the defense of Western Europe, so the potentially lucrative deal meant multiple aircraft entries into the competition.

Being the "frontline" of N.A.T.O. against Warsaw Pact countries meant West Germany required an aircraft that could reach the necessary altitude quickly to intercept potential adversaries, but it did not require the range or payload to reach deep into the Soviet Union which would potentially incite and cause political provocation.[88] The West Germans considered the French Dassault Mirage III, the British English Electric Lightning, and the United States Grumman F11F-1F powered by a J79, but the Lockheed F-104 won the competition. Other countries within N.A.T.O. such as Belgium, Canada, the Netherlands, Italy, and Japan acquired and license built the F-104, with all but the Netherlands doing the same with the J79. These N.A.T.O. countries understood the advantages of standardization both militarily and financially, and the intellectual, political,

evolved into "zipper." The other belief claims the "zipper" nickname originated due to the F-104 being faster than a pilot could zip up his pants.

[88] Robert V. Garvin, 80-81.

and economic benefits of gaining even limited production rights to the aircrafts and engines. G.E. supported the manufacture of the J79 in these N.A.T.O. countries with engineering assistance and utilizing the existing supply base. Denmark, Greece, Jordan, Norway, Pakistan, and Turkey also acquired the F-104 either through direct purchase or else they were given former U.S.A.F. F-104's.

While the F-104 Starfighter had a long production life and was sold to many countries, it was a controversial aircraft for Lockheed. The nicknames "Flying Coffin" or "Widow-Maker" were due to its high accident rate, especially in West Germany where government and military officials openly questioned the decision to procure the airplane. West German Lt. General Werner Panitzki, claimed the decision to buy the F-104 was based on political motives, and the issues surrounding the F-104 were due to multiple factors including insufficient pilot training and flight experience.[89] Lockheed faced criticism over the sales of the F-104 in the 1970's when it was revealed Lockheed employees had paid key government officials in West Germany, Japan, and the Netherlands to select the F-104 over its competition.[90] G.E. was never implicated in the bribery scandal, but it did benefit in the increased sales of the F-104 and the resultant J79 sales.

---

[89] Warren C. Wetmore, "F-104G Dispute Spurs Crisis in Germany," *Aviation Week & Space Technology*, August 29, 1966, 23.
[90] "Justice Department Asked to Scrutinize Alleged Lockheed USAF Bribes," *Aviation Week & Space Technology*, May 6, 1976, 20.
"Lockheed Ripples Spread," *Flight International*, March 13, 1976, 624.
"US Pay-Off Repercussions," *Flight International*, February 28, 1976, 451.

3.2 The Convair B-58 Hustler

The F-104 Starfighter was the first aircraft to be propelled by the J79 in flight as it beat another U.S.A.F. Mach 2 aircraft powered by the J79 into the air by less than a year. The Convair B-58 Hustler was the U.S.A.F.'s first bomber capable of speeds in excess of Mach 2, and it first flew in November 1956. The U.S.A.F. originally conceived of a medium-sized bomber to replace the Boeing B-47 Stratojet in 1949, and later refined the requirements for high altitude flight at Mach 2 to fly faster than air defenses could intercept the conceptual aircraft for its MX-1626 program.[91] The announcement of the program and its high priority were made just weeks after the Soviet Union had shown its own swept wing bomber powered by four turbojets with potential long range capability at its May Day display in Moscow in 1954, and the U.S.A.F. hoped to counter the perceived threat.[92] With inflight refueling, the bomber was expected to penetrate enemy air defenses at supersonic speeds, drop its nuclear payload, and return.

Convair was awarded the contract over entries by Boeing and Douglas to design and provide total program management of the bomber. Convair engineers had developed the concept of the delta wing for supersonic aircraft with the assistance of German engineer Alexander Lippisch, who had developed tailless aircraft for Germany during WWII.[93] Convair also learned from the aerodynamic issues of their F-102 Delta Dagger, whose original design had initially failed to reach its designed altitude, and was incapable

[91] Bill Holder, *Convair B-58 Hustler* (Atglen, Pennsylvania: Schiffer Publishing Ltd., 2001), 7-10.
[92] Robert Hotz, "AF Speeds B-58 Development Program," *Aviation Week*, May 24, 1954, 13.
[93] Alexander Lippisch, *The Delta Wing History and Development*, trans. Gertrude L. Lippisch (Ames, Iowa: Iowa State University Press, 1981), 45-55.

of reaching Mach 1. Convair designed a full delta winged medium sized bomber with four J79 engines hung from separate pylons under the wing, a central pylon under the fuselage to house fuel and nuclear weapons, and a Whitcomb area ruled fuselage.[94] Named after Richard Whitcomb of N.A.S.A., the fuselage is pinched perpendicular to the surface of the wings to reduce buffeting and drag during high-speed flights. Convair studied multiple placements of the engine and designs before they settled on a production version that entered service in November 1959.

The design of the B-58 Hustler featured a number of advanced features, and these characteristics and the attributes of the J79 assisted in its revolutionary capabilities. Due to the high-speed capability of the B-58, the aircraft was one of the first to employ aluminum and stainless steel honeycomb core bonding which helped to dissipate heat, reduced weight and smoothed the outer surface contour due to the resultant reduction of fasteners needed. Even with the honeycomb panels, the skin temperature limited the top speed as heat built up due to the friction of the air, but ample thrust remained to propel the bomber to greater speeds.[95] An ejection pod was developed in case the aircrew were forced to eject at supersonic speeds at extremely low altitude due to an accident during mission evaluation testing.[96] Variable conical inlets forward of the J79's were employed to ensure the transonic air shockwaves above Mach 1.5 still provided the optimum air flow into the engine, and they helped decrease the radar signature of the B-58 to reduce detection by

---

[94] David A. Anderton, "B-58 Hustler Packs a Big Punch in a Small Frame," *Aviation Week*, December, 17, 1956, 28.
"Convair's F-102A's Supersonic Shape," *Aviation Week*, April 25, 1955, 14.
[95] Craig Lewis, "Irvine Details B-58 Design Advances," *Aviation Week*, July 15, 1957, 29.
[96] Douglas H. Robinson, *The B-58 Hustler* (New York, New York: Arco Publishing Company, Inc., 1967), 41-42.

enemy radar.[97] Due to the conical inlet and the overall shape of the B-58 with its smooth outer contours, Nike anti-aircraft missile site radar operators routinely had to request B-58 pilots to "show themselves" by climbing to a higher altitude where lower altitude clutter and the reduced radar signature of the B-58 obscured it being located.[98] The streamlined outer mold line and the thrust of the J79's enabled a top speed exceeding Mach 2, and an excellent rate of climb even when carrying a bombing load. The J79's in the B-58 were capable of providing up to 107% thrust for five seconds or 104% for slightly longer intervals if operational conditions were warranted.[99] Faster than a .45 caliber bullet, which was astonishing for a bomber, the B-58 powered by J79's set multiple speed records and acquired several awards. It set fourteen world speed records; won the Bleriot Trophy for being the first aircraft to average over 1,242.74 mph for at least thirty minutes, the Mackay Trophy awarded by the U.S.A.F. Chief of Staff for a B-58 flying from Carson A.F.B. to Paris in five hours and fifty-five minutes, the Thompson Trophy for averaging 1,284.73 mph in a twenty-nine minute flight between Washington, D.C. and Chicago while carrying a payload; the 1962 Bendix Trophy for flying from Los Angeles to New York at 1,214.65 mph in two hours and fifteen minutes; and the 1961 Harmon Trophy to William R. Payne piloting a B-58 for "outstanding and extraordinary feats of individual piloting skill." [100] While speed records and awards garnered pride, swagger and publicity for G.E., Convair, and the U.S.A.F., it did not secure the B-58 an extended service life.

---

[97] Robert H. Cushman, "Principles of B-58 Inlet Control Systems Revealed," *Aviation Week*, January 14, 1957, 50-51.
[98] Colonel George Holt, Jr., *The B-58 Blunder: How the U.S. Abandoned its Best Strategic Bomber* (June 26, 2015), 25.
[99] Bill Holder, 11.
[100] Robinson, 46-50.
Wesley S. Griswold, "World's Fastest Bomber," *Popular Science*, August 1961, 182.

Despite its prodigious speed capability over the U.S.A.F.'s other bombers within service during the 1960's (reference Graph 3.2A: U.S. Bomber Maximum Speed Capability Historical Perspective), the B-58 was retired due to issues with the aircraft itself and with changing Armed Forces strategies. Even though global reach meant global power and speed meant survivability, one of the most negative factors surrounding the weapon system was the B-58's were expensive. Before the bomber even reached operational status, President Eisenhower in 1959, had declared the B-58 cost more than its weight in gold.[101] Only 116 aircraft were ever manufactured for a program that cost over three billion dollars. It was also expensive to maintain. The AN/ASQ-42 navigation/bombing system possessed a complicated wiring schematic to connect sensor and radar subsystems throughout the aircraft, which made it difficult to repair, and general maintenance could require the entire airplane be placed in a tooling jig to prevent aircraft distortion.[102] Convair, aware of its high per unit cost, made a number of proposals: B-58B and B-58C variants, a "Kingfish" edition in a design competition with the Lockheed A-12, a B-58 that potentially could exceed 90,000 feet with a parasite aircraft attached to extend its range, and a commercial version in hopes of maintaining production and amortizing costs.[103] B-58's also suffered from a high attrition rate due to landing gear issues, hard landings, and general loss of control due to the flight characteristics associated with the delta wing configuration, which required higher take-off and landing speeds.[104]

Costs and capabilities aside, the B-58 was under development when the Soviet Union launched Sputnik into orbit, and it came into service at the same time a Soviet Union

---

[101] "Text of President Eisenhower's Message to Congress on the State of the Union," *New York Times*, January 10, 1959, p. 6.
[102] Holder, 48-49.
[103] Ibid, 34-37
[104] Ibid, 49.

surface-to-air missile (S.A.M.) had just downed the high altitude Lockheed U-2 spy aircraft. Rockets with a nuclear warhead seemed destined to be the cheaper and less risky alternative to the manned bomber. S.A.M. site radars easily recognized high altitude flights and missiles could intercept the bombers, which limited the missions for the B-58. While the B-58 could potentially operate at lower altitudes to evade radar, it had not truly been designed for multiple mission, sustained low-level interdiction, and its speed and range were reduced while fuel consumption increased due to higher aerodynamic drag at low altitudes.[105] The wings were never designed for these missions and would have required higher costs to maintain.[106] The B-58 was never popular with U.S.A.F. General and Chief of Staff, Curtis Lemay, for its size and range, and with the advent of intercontinental ballistic missiles, the overall cost and risk of manned bombers appeared to make them obsolete.[107] Secretary of Defense Robert McNamara, who never believed in the importance of the bomber either, announced in December 1965, the B-58 would be phased out by 1970.[108] The U.S.A.F. did not give up on the high altitude, Mach 2 plus bomber concept, and proposed another high altitude Mach 2 bomber again in the 1970's in the Rockwell B-1 Lancer before it too was cancelled, and redesigned as a low level penetration bomber that could withstand the increased aerodynamic loads of low altitude flights by just flying over the speed of sound. While the U.S.A.F. was finished with high altitude, Mach 2 plus bombers, it was not finished with aircraft powered by the J79 as the

[105] R. Cargill Hall, "To Acquire Strategic Bombers: The Case of the B-58 Hustler," *Air University Review*, September-October 1980, 18.
[106] John T. Bohn, *Development of Strategic Air Command: 1946-1976* (U.S. Department of the Air Force: Strategic Air Command, 1976), 101, 122.
[107] Norman Polmar and Robert Stan Norris, *The U.S. Nuclear Arsenal: A History of Weapons and Delivery Systems Since 1945* (Annapolis, Maryland: Naval Institute Press, 2009), 102.
[108] Holt, Jr., 77.

powerplant had proved its ability to reliably power aircraft faster and higher than seen before.

3.3 The Grumman F11F-1F Super Tiger

The U.S.A.F. would accept and fly a United States Navy (U.S.N.) aircraft powered by the J79 in the McDonnell F-4 Phantom II, but first the U.S.N. would test the engine on another aircraft.[109] The Grumman F11F-1 Tiger, later designated the F-11, was a U.S.N. single seat jet fighter developed in the early 1950's and was capable of just over the speed of sound powered by a license built Curtiss-Wright J65 turbojet. The F11F employed left and right engine air inlets parallel to the single pilot, mid-mounted swept wings with full length leading edges, trailing edge flaps and swept horizontal stabilizers for additional control to land on carriers. The U.S.N. acrobatic demonstrator flight squadron, the Blue Angels, used it from 1957 until 1969. Already having issues with the performance and engine availability of the Wright J65, the U.S.N. accepted Grumman's proposal to adopt the J79 into the last two production Tigers for flight tests with the new designation of F11F-1F Super Tiger. The U.S.N. believed it would gain experience with the new engine, and Grumman hoped to parlay the Super Tiger into further sales.[110] The installation of the J79 required modifications to the aircraft structure surrounding the engine, larger engine inlet

[109] The F-4 Phantom II was originally developed under McDonnell Aircraft Company, but the majority of its production and service life has been under the McDonnell Douglas Company.
[110] Tommy H. Thomason, *U.S. Naval Air Superiority: Development of Shipborne Jet Fighters; 1943-1962* (North Branch, Minnesota: Specialty Press, 2007), 247.

ducts, and wing leading edge extensions.[111] After initial test flights, the J79 powered F11F-1F Super Tiger became the first U.S.N. aircraft to exceed Mach 2, which far exceeded Grumman test engineering expectations, and on April 16, 1958, it temporarily set the altitude record of 76,928 feet.[112] The speed and altitude of the J79 powered Super Tiger far exceeded the regular J65 powered Tigers with only minor modifications to the platform. The U.S.N. did not order additional Super Tigers, and even though it appeared to be the favorite for several countries within aircraft competitions, it was ultimately never chosen, and only the two were ever produced. The F11F-1F Super Tiger was capable of Mach 2 performance, but it lacked the capability to carry heavy armament, and especially nuclear weapons, so it never saw service beyond a demonstrator.

3.4 The McDonnell Douglas F-4 Phantom II

The next U.S.N. aircraft to be powered by the J79 was one of the most versatile aircraft produced, was also flown by the U.S.A.F., the United States Marine Corps (U.S.M.C.), and multiple nations, but it had an inauspicious inception. In 1953, McDonnell Aircraft Corporation (M.A.C.) lost the U.S.N. fighter competition to the Chance-Vought F8U Crusader, and the future of the company appeared grim.[113] M.A.C. began as an aircraft parts supplier in 1939, and by 1945 it had developed the U.S.N.'s first jet powered carrier

---

[111] "J79 Demands Larger Fuselage for F11F," *Aviation Week*, October 29, 1956, 28-29.
[112] Tony Buttler, *American Secret Projects: Fighters and Interceptors; 1945-1978* (North Branch, Minnesota: Specialty Press, 2007), 114-115.
"Altitude Records Fall," *Aviation Week*, May 12, 1958, 27.
[113] Glenn E. Bugos, "Testing the F-4 Phantom II: Engineering Practice in the Development of American Military Aircraft, 1954-1969," *Business and Economic History*, Volume 18 (1989), 13.

based aircraft in the FH-1 Phantom. It had built over a thousand various U.S.N. aircraft, but lacked a future naval production contract so it was seeking to extend the manufacturing life of its F3H-H Demon. From its advanced design cage, an office cubicle surrounded by chicken wire, a group of six engineers created multiple designs that were designated Model 98A through Model 98D. The respective projects were to be powered by two Wright J65's or J67's capable of Mach 1.52 to Mach 1.69, or J79's capable of Mach 1.97.

M.A.C. sought input from various naval operating commands for ideas of requirements for the next carrier based aircraft, built a mock-up aircraft based off of the Model 98B, and requested an assessment of it by naval commanders.[114] Without a firm proposal, but encouraged by the Bureau of Aeronautics (BuAer), James S. McDonnell, the company founder, submitted a proposal for a twin engine, single seat, all-weather attack aircraft in 1954. Designated the AH-1, it lacked a mission, and thus a viable reason for further development despite an order for two prototypes. Meeting in St. Louis in April 1955, within two hours two Chief of Naval Operations officers (C.N.O.) and two BuAer officers created a mission for a new aircraft: an aircraft for the carrier fleet defense, that would utilize air-to-air missiles without guns to strike potential Soviet Union fighters or bombers before they could bomb the carrier and associated task group, cruise and loiter at a two hundred fifty mile radius from the carrier fleet, and be capable of returning to flight within three hours of landing.[115] The requirements had almost been set, but M.A.C. was still not assured of building the aircraft.

---

[114] René J. Francillon, *McDonnell Douglas Aircraft since 1920: Volume 2* (Annapolis, Maryland: Naval Institute Press, 1988), 175-176.
[115] H.D. Barkey, "Evolution of the F-4 Phantom" (paper presented at the Technical Program Management Seminar of the American Institute of Industrial Engineers, Washington, D.C., April 19-21, 1971), 1-2.

With the continued assistance from the BuAer and C.N.O., the design was remade for two crewmen, the front position for the pilot and the rear for the radar intercept officer (R.I.O.), and in 1955, a fly-off competition was set. Chance-Vought was invited to submit an aircraft meeting the same requirements, and submitted the F8U-3 Crusader III, an evolution of the original F8U Crusader. Utilizing a single P&W J75 engine and flown by a single pilot without a R.I.O., the F8U-3 was a fast and maneuverable fighter, but it lost to the now F4H-1 due to the latter's larger payload, the R.I.O. who could handle radar and missile firings, the dual engines, and its ability to perform multiple missions.[116] Even if unintentional, a singular purpose aircraft had lost to the multipurpose capabilities of an aircraft adept at defense of the fleet, air-to-air and air to ground attacks, and extending the bombing range of the fleet. The U.S.N. also had it first Mach 2 aircraft, and had accomplished it by achieving over 75% of its contract requirements (reference Table 3.4A: F-4A Phantom II Requirements).[117] Following M.A.C.'s previous supernatural derived designations, the F4H-1 was given the official name of Phantom II on July 3, 1959, the 20th anniversary of the founding of the company. It would not be the last nickname of the aircraft, and the F4H-1 was re-classified as the F-4 when the Armed Forces restructured their naming convention.[118]

The F-4 Phantom II was not considered aesthetically pleasing, but it was still a very proficient, record breaking aircraft while still being able to perform multiple missions for numerous armed forces. The F-4 was a relatively large, twin engine, tandem seat

---

[116] Erik Simonsen, *A Complete History of U.S. Combat Aircraft Fly-Off Competitions: Winners, Losers, and What Might Have Been* (Forest Lake, Minnesota: Specialty Press, 2016), 113-114.
[117] Peter Davies, *USN McDonnell Douglas F-4 Phantom II* (New York, New York: Osprey Publishing, 2016), 9.
[118] Reference footnote #22.

aircraft with large, rectangular variable intakes, area ruled fuselage, swept wings with sawtooth leading edges and positive dihedral outboard folding wings, negative dihedral horizontal tailplane aft of the engine exhaust that terminate near the water-line of the wing, and a single, short vertical to fit within carriers. It employed boundary layer control for the leading edges and trailing edge flaps to improve low air speed flight characteristics and improve stall speeds with air bleed from the seventeenth stage of the J79, and nine hard points for armament or fuel, including semi-submerged points along the bottom of the fuselage for the air-to-air, semi-active guided Sparrow missiles being developed at the time. Due to its stature and physique, the F-4 was considered a “heavy slugger” that gained multiple nicknames, some of which were less than appealing, besides its official designation of Phantom II.[119] The F-4 earned monikers such as the Rhino, Flying Anvil, Double Ugly, Big Ugly, Flying Footlocker, Lead Sled, St. Louis Slugger, and the Spook, which was the wide-brimmed-hat wearing, faceless, caped unofficial mascot of the Phantom II that adorned everything from squadron patches to promotional or inspirational posters within the M.A.C. factory buildings.[120]

Despite its looks and questionable aerodynamic qualities, the U.S.N. decided to demonstrate the performance of its new aircraft by using it to break flight records. The F-4 to set or surpassed fifteen records from 1959 through 1962 (reference Table 3.4B: F-4 World and Class Records Set), including a record speed run of Mach 2.5 by Lieutenant

---

[119] Edward H. Kolcum, “Israel Pushes Design of Strike Fighter,” *Aviation Week & Space Technology*, August 16, 1976, 18.
[120] Michael Green, *Combat Aircraft of the United States Air Force: Rare Photographs from Wartime Archives* (South Yorkshire, United Kingdom: Pen & Sword Books, Ltd., 2016), 162.
Lee R. DeHaven, “Phifty Years of Phantom II Phighters,” *American Aviation Historical Society,* Summer 2008, 83.
“Origins of the Spook,” *American Aviation Historical Society,* Summer 2008, 104-105.

Colonel Robert B. Robinson on November 22, 1961, in a modified, but still capable of greater speed, F-4.[121] It also won the 1961 Bendix Trophy when Lieutenant Richard Gordon flew across the continental U.S. by flying from Ontario, California, to New York City in two hours forty-seven minutes averaging 869.7 mph.[122] The exploits of the F-4 drew the attention of other U.S. services and other nations to the potential of the aircraft.

As the Phantom started to break records, the Department of Defense took notice of the potential of the aircraft for other services. The U.S.A.F. conducted Operation Highspeed as a tactical fighter evaluation between the Convair F-106 Delta Dart and the F-4 to replace its fleet of F-100 Super Sabres, F-101 Voodoos, F-102 Delta Daggers, and F-104 Starfighters. Even though the F-4 was developed as fleet interceptor, it[123] bettered the F-106 in multiple parameters including high and low altitude top speed, climb rate, and it could carry up to twenty-two 500 pound bombs to the Delta Dart's zero.[124] While neither aircraft was a true tactical fighter, the F-4's strongest asset lay in its versatility and with the engines in that it possessed "more raw power than any previous fighter could muster. With more than seven times the thrust of the F-86A, the F4H-1 could take full advantage of its load-carrying performance and turn its apparent disadvantages into war-winning fighter-bomber qualities."[125] The U.S.A.F. Phantom was initially assigned the alphanumeric designation of F-4C because it received a number of modifications including a change to

---

[121] Thomason, 253-257.
F-4 "Phantom" Aircraft and Ogden Air Logistics Center: Thirty Years of Pride and Progress (Hill Air Force Base: Ogden Air Logistics Center, 1988).
[122] Thomason, 254.
[123] The two evaluation aircraft were delivered as F-110 Spectres to the U.S.A.F. in January 1962, but with the naming convention change later in 1962, all Phantom II's became F-4's.
[124] Pace, 169-170.
[125] Peter Davies, *USAF McDonnell Douglas F-4 Phantom* II (Oxford, United Kingdom: Osprey Publishing, 2013), 4.

the refueling system from the U.S.N.'s hose and drogue to the flying boom system, flight controls for the Weapons System Operator (W.S.O.) in the rear seat, a cartridge starter for the J79's, and larger tires that necessitated a redesign to the wheel wells which caused protruding contours near the upper wing roots. The U.S.A.F. would acquire the greatest quantity of F-4's and utilize the Phantoms as tactical fighter-bombers in the 1960's as an ideological shift occurred from the need for a high altitude bomber-interceptor to close air support and dogfighter against MiG-17 Frescoes, MiG-19 Farmers, and MiG-21 Fishbeds during the Vietnam War.

The final U.S. Armed Service to acquire the F-4 was the U.S.M.C., and as a branch of the U.S.N., it had been closely involved with the development of the F-4 from the beginning. The U.S.N. along with the U.S.M.C. received the first twenty-four production F-4's and shared initial transition training and evaluation. While the U.S.M.C. had traditionally received older or unacceptable U.S.N. aircraft for carrier operations, such as the Vought F4U Corsair and the Grumman F7F Tigercat, the Marines received their own production F-4B's for operations beginning in August 1962.[126] The Marines finally had an aircraft envisioned for carrier operations capable of exceeding Mach 2, and carrying over 22,000 pounds of ordinance. The U.S.M.C.'s primary focus for aircraft was providing support for its land forces including all-weather, close air support, attack of targets, reconnaissance, yet still able to defend itself and defeat enemy aircraft. The U.S.M.C. also adapted a U.S.A.F. RF-4C Phantom II that was an all-weather tactical reconnaissance aircraft with specialized cameras and side-looking airborne radars (S.L.A.R.) as the RF-4B for use in a similar

---

[126] Peter Davies, *US Marine Corps F-4 Phantom II Units of the Vietnam War* (Oxford, United Kingdom, Osprey Publishing, 2012), 6-10.

role.[127] These various models of the F-4 would serve with the U.S.M.C. and its reserve units for nearly thirty years.

The F-4 Phantom was also sold to multiple countries in numerous different configurations, and the first country to acquire the F-4 was the United Kingdom (U.K.). The British acquired their own version of the Phantom II for the Royal Navy, the F-4K (British internal designation Phantom FG.1), and the Royal Air Force, the F-4M (British internal designation Phantom FGR.2), but the U.K. mandated the replacement of J79's with the larger and recently developed Rolls-Royce Spey turbofan engines to aid its own jet engine industry. Due to the larger size of the Spey engines, the aft section of the fuselage was redesigned along with the air intakes for British Phantom II's, and due to the needed redesign of parts and smaller production run, the British Phantoms cost twice as much as a comparable U.S.N./U.S.M.C. F-4J.[128] Despite the Spey's increased thrust of 20,515 pounds in afterburner, the J79 equipped F-4's had a higher operational altitude, larger combat radius, and higher maximum speed.[129] After the Falkland War, in which Argentina and the U.K. fought over the Falkland, South Georgia, and South Sandwich Islands in the South Atlantic in 1982, the British acquired surplus U.S.N. F-4J's to be stationed at the Falkland Islands. Those Phantom II's retained their J79's, which were deemed to have a more immediate response to pilot inputs for speed than the F-4's with Spey engines.[130] The British Phantoms stationed in the Falklands were just a deterrent and never saw combat, but other Phantoms outside the U.S. were operated in combat.

---

[127] DeHaven, 84, 92-93.
[128] David Hobbs, *The British Carrier Strike Fleet: After 1945* (Annapolis, Maryland: Naval Institute Press, 2015), 329-330.
[129] Mike Hirst, "Five Thousand Phantoms," *Flight International,* May 27, 1978, 1622.
[130] Peter Davies, *USN McDonnell Douglas F-4 Phantom II* (New York, New York: Osprey Publishing, 2016), 30.

The Israeli Defense Force Air Force (I.D.F./A.F.) acquired the most F-4 Phantom II's outside of the U.S. and saw numerous combat engagements. The I.D.F/A.F. acquired F-4E's, which had been redesigned to finally resolve a tactical inadequacy by adding an internal M61 Vulcan cannon for dogfights. Nicknamed the Kurnass or Sledgehammer, Israel acquired F-4's through the "Peace Echo" program and its multiple subsequent variant programs. The I.D.F./A.F. employed the F-4 in multiple conflicts until 2004, being utilized foremost as ground attack, but it still ranked second to the Dassault Mirage III in kills.[131] The I.D.F./A.F. also acquired RF-4E reconnaissance Phantom II's, but due to the introduction of the MiG-25 Foxbat and its Mach 2.5 plus capabilities, it desired a faster reconnaissance/interceptor. The I.D.F./A.F. initiated the F-4X program in the mid 1970's, in which a modified F-4 with larger air inlets, modified flight controls, and pre-compressor cooling using water injection for the J79's, could increase thrust enough to propel the "Sledgehammer" to Mach 3.2.[132] The program was never completed due to technical issues and concerns that a F-4 could achieve speeds exceeding Mach 3 may reduce or cut funding of the U.S.A.F.'s new air superiority fighter, the McDonnell Douglas F-15 Eagle.[133] Even though more modern turbofan engines had been introduced and were utilized in multiple aircraft platforms at the time, the J79 was still seen as being capable of achieving the desired speed of the F-4X program. Israel was not the only country to attempt to upgrade or maintain its fleet of F-4 for years as other countries realized the F-4

---

[131] Shlomo Aloni, *Israeli F-4 Phantom II Aces* (Oxford, United Kingdom: Osprey Publishing, 2004), 7.
[132] Peter Davies, *USAF McDonnell Douglas F-4 Phantom* II (Oxford, United Kingdom: Osprey Publishing, 2013), 36.
[133] Emil Petrinic, "The Fastest Phantom: A Joint American-Israeli Program Sought to Modify the F-4 for Mach 3 Reconnaissance Missions," *Aviation History*, March 2015, 14-15.

with modernization packages could remain a successful aircraft even fifty years after its introduction.

The F-4 Phantom II was sold to eleven different countries outside the U.S. and over five thousand were manufactured. This was all the more remarkable given that the aircraft was originally designed for carrier usage, so components were more robust due to being designed for the increased strain of carrier landings and thus heavier than a traditional aircraft. Besides the versatility and load carrying capabilities of the Phantom II, its greatest strength laid in the J79 engines. The F-4 had not been designed for dogfights, and it lacked the maneuverability to turn in the horizontal plane with the various MiG's during the Vietnam War. Its size, weight, and possible mission to carry bombing loads further exacerbated its dogfighting deficiencies. The F-4's advantage was found in the thrust the J79 provided where its propulsion and speed gave it superiority in the vertical plane. Ultimate top speed was not always needed in a dogfight, but the versatility of the J79 to provide instant acceleration and the force to propel Phantom II's to acquire the energy needed for rolling vertical movements was an effective technique against the MiG's greater turning ability.[134] U.S.N. pilot Guy Freeborn noted the J79's in the Phantom II were its "biggest asset, particularly in situations where the aircraft's handling characteristics were pushed to its limits."[135] The F-4's tactical flexibility was a change to its original fleet interceptor mission of obtaining high altitude quickly in order to fire a missile at an incoming bomber, and the J79 showed it was adaptable to the requirements of the F-4's other missions of both overall top speed and instant thrust throughout multiple flight envelopes and missions without stalling.

[134] Boyne, 164-165.
[135] Peter Davies, *USN McDonnell Douglas F-4 Phantom II* (New York, New York: Osprey Publishing, 2016), 21.

The most visible drawback for the F-4 that brought unwanted attention to itself at the most inopportune time originated from the J79. Like most U.S. turbojets, aircraft employing the J79 were exposed by over a twenty mile long smoke trail that could reveal the aircraft's position to its adversaries.[136] The largest quantity of smoke usually occurred during military power cruise settings, but was diminished with use of the afterburner. The smoke trail became such a well-known situation for F-4 Phantoms, that the journal for the F-4 Phantom II Society is titled *Smoke Trails* after the condition. G.E., the U.S.N., and the U.S.A.F. invested in studies to alleviate or eliminate the smoke trails emitted from the engine. A Smoke Abatement system that injected an additive into the combustion chamber was added to some F-4's over Vietnam, but this was not very practical due to its required manual operation and the associated loss of engine efficiency. An improved solution was finally obtained with a later J79 engine configuration, but most pilots who flew the F-4 had to accept and deal with the exposing smoke trail. The smoke trail may have disclosed the position of the F-4, but the J79 provided the power to perform a variety of missions, armament loads, and the power to be a capable dogfighter.

---

[136] Brad Elward and Peter Davies, *US navy F-4 Phantom II MiG Killers: 1965-70* (Oxford, United Kingdom: Osprey Publishing, 2001), 15-16.

3.5 The North American A-5 and RA-5C Vigilante

Another U.S.N. aircraft that employed the J79 and was forced to revise its original mission, but in this instance from a fleet nuclear strike bomber to a reconnaissance aircraft was the North American A3J Vigilante, later designated the A-5 and RA-5C.[137] It was originally conceived under an internal North American study under Frank G. Compton to study low-level aircraft bombing in 1953. The U.S.N. hoped to retain a portion of the nuclear strike role, even though the size of nuclear weapons and the limited size of aircraft suitable for carrier launching and landing had limited their abilities. Early U.S.N. aircraft capable of carrying and delivering a nuclear bomb had been subsonic aircraft such as the Douglas A3D Skywarrior or North American AJ Savage. A concern with these aircraft was they lacked the speed to achieve enough safe distance from the shockwaves of increasingly stronger nuclear weapons. Compton's study had concluded future aircraft would need to be supersonic in order to escape the resultant shockwaves from the nuclear blast, and they required more precise delivery.[138] In 1955, the U.S.N. accepted North American's proposal, North American General Purpose Attack Weapon (N.A.G.P.A.W.), and a contract was awarded a year later for a Mach 2, high altitude penetration aircraft capable of carrying nuclear ordinance, with a secondary mission of low level penetration and bombing.

The North American proposal resulted in the A-5 Vigilante, and it was one of the largest aircraft to ever operate on a carrier with high, swept wings that utilized boundary

---

[137] Reference footnote #22. The North American Vigilante will be referred to as the A-5 within this paper.
[138] Michael Grove and Jay Miller, *North American Rockwell A3J/A-5 Vigilante* (Osceola, Wisconsin: Motorbooks International Publications, 1989), 2.

layer air, tandem seats, a tall, single vertical, and two variable intakes commencing under the forward edge of the wing root. The Vigilante exhibited a number of new technological attributes including single piece wing skins milled from aluminum-lithium, single piece acrylic canopy windscreens, and gold plated components within the engine bay to reduce engine heat.[139] Its unique feature was the internal, cylindrical, linear bomb bay between the two engines, which was capable of storing a nuclear weapon, and two disposable fuel tanks that were all jettisoned aft of the aircraft when the bomb was released. Despite its large size, the Vigilante was still able to break a record when an A-5 flew to 91,451 feet carrying a load of 2400 pounds on December 13, 1960.[140] But like the B-58, the A-5 was confronted with a number of issues over its original operational objective.

First and foremost, its mission evaporated while it was still in initial production. In 1963, and known of the certainty of the policy as early as 1961, the U.S.N. relinquished its tenuous assertion of carrier aircraft delivering nuclear weapons, yielding to the U.S.A.F. the mission of conventional aircraft carrying nuclear weapons.[141] The size and speed of the Vigilante, then redesigned to A-5B and already in production, became an asset as production Vigilantes were converted to reconnaissance versions, or RA-5C's. The reconnaissance versions were capable of carrying an array of different equipment including frame and panoramic film, S.L.A.R., and electronic countermeasures to improve survivability from S.A.M. attacks.[142] This allowed further production of the Vigilante, but reconnaissance missions within Vietnam were extremely perilous due to flying along a

---

[139] Robert R. Powell, *RA-5C Vigilante Units in Combat* (Oxford, United Kingdom: Osprey Publishing Limited, 2004), 8.
[140] Powell, 9.
[141] Michael Grove and Jay Miller, 8
[142] C.M. Plattner, "The War in Vietnam: Combat Dictates Shift in Navy Air Tactics," *Aviation Week & Space Technology*, February 7, 1966, 70.

fixed line at medium level over the previously bombed sites. RA-5C aircrew also faced other issues when attempting to take off or land. The linear bomb bay was converted for additional fuel tanks, and these were prone to accidental ejection during launches resulting in carrier deck fires.[143] In spite of the boundary layer control, which was just over the trailing edge flaps, the Vigilante demanded a high approach speed for landing on the limited deck of carriers. The high approach speeds could cause landing gear or tire failure upon landing.[144] Additionally, the Vigilante was expensive to procure. Due to the limited production run, and even with the additional purchase of thirty-six Vigilantes in 1968 due to lost aircraft, development costs were amortized over just one hundred fifty-six aircraft. Due to the size, technology, and overall cost per unit, naval commanders were at first reluctant to use the Vigilante over hostile terrain over fear of losing one.[145] This reluctance was overcome and the Vigilante was launched as a reconnaissance platform as naval commanders would use the arsenal of aircraft they had available.

The Vigilante was once conceived as a vehicle that would fly from carrier decks to strike deep into Soviet Union territory with nuclear armament as a projection of U.S. and U.S.N. dynamic strength, and as an attempt to maintain the established mission of aircraft delivery of nuclear bombs to resist the increasing challenge of missiles delivering nuclear ordinance. When the mission vanished, it was converted to a reconnaissance aircraft and its secondary mission capability of low level penetration and the thrust of the J79's became an asset. This allowed it a longer service life than its U.S.A.F. cousin, the B-58, with the RA-5C Vigilante lasting until it was retired in 1979.

---

[143] Powell, 47.
[144] Ibid, 37.
[145] Ibid, 17.

3.6 The Israel Aircraft Industries Kfir Lion Cub

Over twenty years after its introduction and even though more modern jet engines were being manufactured and were in service, another aircraft would employ the J79 in the 1970's. The Israel Aircraft Industries (I.A.I) adapted the J79 for use in its internal Kfir Lion Cub all-weather, delta winged, Mach 2 plus aircraft. In the mid-1960's, Israel requested from French manufacturer Dassault Aviation an attack version of its Mirage IIICJ's, which were to be designated the Mirage V. As the decade progressed the relationship between France and Israel was strained due to Israel's wars with its Arab neighbors and France's engagements and courting of Arab countries surrounding Israel.[146] In 1968, France imposed an arms embargo on Israel that ended the agreement for the new Mirages, but Israel was determined to acquire the aircraft anyway. Israel decided to build a semi-indigenous aircraft based off drawings and documents acquired through espionage of the Mirage V, but redesigned components to fit Israeli hardware, improved the flight dynamics and installed the J79 engine.[147]

Israel discarded the Mirage's Snecma Atar 9C engine in favor of a J79-17 due foremost to the arms embargo, but also because the J79 could be license built in Israel, the recently acquired F-4 Phantoms used the same engine, and it provided higher thrust with better fuel consumption including an appreciably greater compression ratio than the Atar 9C.[148] Due to the J79's higher operating temperatures, increased air consumption,

---

[146] Sylvia K. Crosbie, *A Tacit Alliance: France and Israel from Suez to the Six Day War* (Princeton, New Jersey: Princeton University Press, 1974), 190-199.
[147] Patrick Pesnot, *Great Spies of the 20th Century* (South Yorkshire, United Kingdom: Pen & Sword Books, Ltd., 2016), 103-109.
[148] Yehuda Borovik, "IAI Kfir — Mirage Successor," *Flight International*, July 17, 1975, 80-82.

and shorter but slightly wider geometry, the airframe was reconfigured with larger air inlets, the fuselage with shorted and widened along the aft section, and an air inlet was added at the base of the vertical tail for the afterburning section of the single J79.[149] The Kfir entered operational status in 1975, and became a multi-mission aircraft capable of the fighter/bomber role.[150] With the Kfir, Israel had built its own ground attack fighter aircraft capable of Mach 2 performance carrying a larger payload further and faster, and it assisted in the cultivation of the Israeli aerospace industry.

The I.A.I. was able to export the aircraft with some success, including leasing Kfir's to the U.S.N. and U.S.M.C. Due to the installation of the J79 and its potentially sensitive technology, sale of the Kfir required U.S. State Department approval for all exports outside of Israel.[151] Even with this restriction, the Columbian Air Force, the Ecuadorian Air Force, and the Sri Lanka Air Force purchased the Kfir. With various hardware and aerodynamic upgrades, and despite newer engine technology and proposals for replacements, the Kfir powered by the J79 remains in service in these countries at the time of this paper. The U.S.N. and U.S.M.C. leased twenty-five Kfirs in 1985, and modified them for further maneuverability for training purposes. Designated as the F-21A, the Kfirs were to be mock adversaries in the supersonic aggressor role for fighter training in dissimilar air combat training (D.A.C.T.).[152] The single engine Kfir was utilized in the role because it could represent the characteristics of the quick Soviet Union MiG's, and it was capable of accelerating faster than the already strong performance of the U.S.N.'s dual turbofan

---

[149] Herbert J. Coleman, "Israel Melds Many Technologies in Kfir," *Aviation Week & Space Technology*, April 21, 1975, 17.
[150] "Two-Seat Kfir Now Flying," *Flight International*, March 28, 1981, 904.
[151] "Israel Studies 'Lion' Strike Fighter," *Aviation Week & Space Technology*, March 13, 1978, 208.
[152] Michael A. Dornheim, "Navy's Strike Combat Center Intensifies Air-to-Ground Training," *Aviation Week & Space Technology*, November 11, 1985, 188-191.

engine Grumman F-14 Tomcat.[153] With its proven reliability, and low maintenance costs, rebuilt Kfir's have been upgraded with modern avionics and radars as part of a Block 60 program improvement for sales as a potentially cheaper alternative to other competitor's similar aircraft, with the J79 turbojet remaining as the engine to power the aircraft.[154] The venerable J79 turbojet remained a relevant performance option to power the aircraft despite is juxtaposition against modern hardware nearly sixty years after its introduction.

3.7 The General Dynamics F-16/79 Fighting Falcon

Finally in 1980, the J79 was installed in the General Dynamics F-16 to meet then president Jimmy Carter's Presidential Directive 13, and to be part of the Fighter for Export (F.X.) program. Designated the F-16/79, the aircraft met the mandates of arms controls to limit the transferal of advanced technology to foreign countries within the directive and subsequent F.X. program. With downgraded avionics and the installation of the J79 turbojet over the P&W F100 turbofan, the F-16/79 was marketed as an inexpensive and reliable alternative more appropriate to the requirements of non-N.A.T.O. countries unable to afford the expense of the full-fledged model.[155]

---

[153] John W. Golan, *Lavi: The United States, Israel, and a Controversial Fighter Jet* (Lincoln, Nebraska: University of Nebraska Press, 2016), 8.
"Navy Sets F-14 Reengining Schedule," *Aviation Week & Space Technology*, September 21, 1981, 96.
[154] David Eshel, "Aged but Upgraded: IAI Pitches Kfir as Fourth-Generation Fighter at One-Third of the Price," *Aviation Week & Space Technolog*y, October 14/21, 2013, 43.
[155] Alexi J. Cowett, "The F-20: The Ultimate Flying Machine? *Harvard International Review*, Volume 8, Number 5 (April, 1986), 35.

The modifications to incorporate the configuration changes and flight-testing of the F-16/79 were funded by General Dynamics and General Electric.[156] A F-16B model had to be adapted with a revised air inlet using a fixed compression ramp due to the lower airflow requirements, a longer fuselage to accommodate the J79, over 2,000 lbs of insulation shielding due to the higher operating temperatures of the J79, and a secondary air inlet by-pass system for cooling and airflow management. Flight testing showed the F-16/79 was still capable of nine times the gravitational force (9 g's) turning capability, but due to the lower thrust and heavy insulation shielding, its climb performance, fuel consumption, range, and sustained turn suffered.[157] Hampered by a heavier aircraft and marginally less thrust than the newer turbofan, the more reliable J79 were modified to J79-GE-17X prototypes, with the final designated of J79-GE-119, and were still capable of accelerating the aircraft to Mach 2.

The ultimate speed of the aircraft would not be enough to garner export sales as politics and circumstances ensured the F-16/79's demise. Although the F.X. program was allowed to continue in case a country could not manage the more sophisticated models, the basic F-16A/B was also offered for export sales when President Ronald Reagan revised the arms sales policy. The potential military and political influence, and the economic gains if aircraft sales were lost to other countries' topline aircrafts ensured the basic configuration F-16 was offered for export sales.[158] Sales of the F-16 models increased due to a perception the F-16/79 was an inferior product with its lesser radar and

---

[156] K.G. Timpson, "AIAA-81-2414 The F-16/79 Test Program" (paper presented at the AIAA/SETP/SFTE/SAE/ITEA/IEE 1st Flight Testing Conference, Las Vegas, Nevada, November 11-13, 1981).
[157] Robert R. Ropelewski, "F16/79 Offers Export Market New Capability," *Aviation Week & Space Technology*, November 23, 1981, 38-47.
[158] Jo Husbands, "Reagan's Arms Sales Programs," *Arms Control Today*, Volume 12, Number 8 (September, 1982), 4-5.

older turbojet engine, even though the J79 possessed a higher reliability level and thus a potentially higher sortie rate.[159] No F-16/79 was ever sold for export, or the Northrup F-20 Tigershark, the other aircraft within the F.X. program. Foreign customers and its military had the perception it was acquiring previous generation technology when newer was available doomed the program. The F-16/79 was the last new application of the J79 into a military aircraft four decades after its introduction as more efficient and powerful low by-pass turbofans were installed in military fighters, but the J79 would continue to power aircraft for decades to come even if it had become mature versus the ever evolving technical sophistication of jet engines.

3.8 The Chance Vought SSM-N-9 Regulus II

The military attempted to use turbojets to power supersonic guided missiles carrying nuclear weapons to be launched from U.S.N. specially manufactured submarines or surface cruisers. The first such missile, the Regulus I, had employed an Allison J33 to power it to subsonic speeds, and the initial Regulus II's had Wright J65's capable of achieving Mach 1.8.[160] When the J79 was installed, the speed increased to over Mach 2. The missile had been designed to carry nuclear ordinance, and had a conventional aircraft type framing architecture with landing for a possible return, but required uniquely designed submarines to surface in order to launch the missile. The considerable size of the missiles

[159] Mike Gaines, "Fighter Marketplace," *Flight International*, September 3, 1988, 113. See also J.R. Nelson, *R-2103-AF: Life-Cycle Analysis of Aircraft Turbine Engines* (Santa Monica, California: Rand Corporation, 1977).
[160] Pace, 76.

also limited the number of weapons the ships could carry on a deployment. Additionally, the considerable cost of the missiles of over one million dollars, their vulnerability to defensive weapons, and the introduction of the solid fuel Polaris Submarine Launched Ballistic Missile with its greater accuracy, spelled the end of the Regulus missiles.[161] The Regulus missile system was meant to be an interim deterrent system using known hardware to power a missile quickly and reliably to a target, and the J79 once again had shown it was capable.

3.9 Convair 880 and 990

For G.E., even with a few minor issues, the J79 turbojet had been a huge success for military applications, but its commercial use of it presented both advantages and disadvantages some of which were out of the control of the company. G.E. had not previously been a supplier of commercial engines, not even jet engines prior to the J79. Curtiss-Wright and P&W had dominated piston engines within the U.S. market, and P&W nearly monopolized the commercial jet engine market with its civilian version of the J57 turbojet, the JT3, powering the Boeing 707 and the Douglas DC-8.[162] G.E. sent executives and Neil Burgess to the major airlines within the U.S. and Europe to gage their reaction to a G.E. turbojet powered aircraft. Convair, who had experience with the J79 in the B-58,

[161] David K. Stumpf, *Regulus: America's First Nuclear Submarine Missile* (Paducah, Kentucky: Turner Publishing Company, 1996), 75.
[162] Jack Conner, *The Engines of Pratt & Whitney: A Technical History as Told by the Engineers Who Made the History* (Reston, Virginia: American Institute of Aeronautics and Astronautics, 2010), 254-255.

expressed interest and requested a proposal for a J79 to power the 880, its new competitor to the 707 & DC-8. The J79 was modified for civilian use by adding a thrust reverser, a sound suppressor, and the deletion of the afterburner, and was designated the CJ805. The 880 was designed to be a narrow body medium sized jet for medium range with configurations capable of carrying ninety-two to one hundred thirty-nine passengers, and faster than the 707 or DC-8.[163] While the 880 was the fastest commercial aircraft at the time powered by the CJ805, it posed problems for both companies.

For Convair, having the fastest commercial aircraft did not translate into sales of the aircraft. Their original customer, Trans World Airlines owned by the mercurial Howard Hughes, demanded exclusive operating service for the first year of operations, and only paid a relatively small deposit on the first thirty aircraft ordered. This exclusive right, the overall size of the aircraft when airlines needed additional seats, production delays, and its late arrival into the market dominated by Boeing and Douglas, hampered sales.[164] Additionally, to directly compete with the 880, Boeing released the 707-020, which was renamed the 720.[165] Convair had anticipated a large order from United Air Lines (U.A.L.) for the 880 to bolster its production run, but U.A.L. instead purchased the Boeing 720.

Desperate for orders, Convair designed a larger and longer-range aircraft for American Airlines, designated the 990. The 990 was originally contracted to fly from coast to coast as the fastest aircraft, but lacked the range to fulfill the obligation. The design of the aircraft was modified, but it was still incapable of its contractual obligation. American

---

[163] "Convair 880," *Flight International*, July 25, 1958, 138.
[164] Donald M. Pattillo, *Pushing the Envelope: The American Aircraft Industry* (Ann Arbor, Michigan: The University of Michigan Press, 1998), 218-219.
[165] Jon Proctor, Mike Machat, and Craig Kodera, *From Props to Jets: Commercial Aviation's Transition to the Jet Age: 1952-1962* (North Branch, Minnesota: Specialty Press, 2010), 119-120.

threatened termination of the contract, but Convair renegotiated for fewer deliveries and thus a financial loss on each aircraft delivered. With few prospects for additional sales, Convair was forced to eventually write-off its commercial venture having manufactured just 114 aircraft between the 880 and 990.[166] Convair effectively abandoned the commercial jetliner market after the failure, and would not design its own aircraft for a major airliner again.

For G.E. the 880 and 990 were seen as both an achievement and a disappointment for the commercial version of the J79 and the company. G.E. could boast it powered the fastest commercial airliner in the 880, but it failed to realize the range or fuel economy based on the passenger capacity to be a successful commercial aircraft for the airlines. Due to the increased size of the 990, airline restrictions for greater passenger seats, and its quest to maintain the title of fastest airliner within Convair, the aircraft demanded an increase in thrust and fuel economy with a further noise reduction, so a fan was added to the engine. G.E. had experimented with placing a fan at the forward section of the engine, but when it was coupled to the available single shaft operating the compressor, the engine was difficult to start and run.[167] Instead the fan was attached to the rear section of the engine. The aft turbofan, designation CJ805-23B, offered the benefit of less air pressure against the core of the engine, increased thrust up to 16,000 lbs, and increased fuel economy versus regular turbojets, but the aft fan was difficult to install on aircraft and required a bulge in the contour of the nacelles covering the rear of the engine.

---

166 Hartman L. Butler, Jr., George J. Podrasky and J. Devon Allen, “The Aerospace Industry Re-Revisited: Commercial Aircraft,” *Financial Analysts Journal*, Volume 33, Number 5 (September – October, 1977), 55.
167 Robert V. Garvin, 16.

The development of the engines had been costly but it also provided the initial foundation for building relationships within the commercial industry. The price of the CV805 had cost G.E. eighty million dollars before taxes, but over time spare parts and support had reduced the loss.[168] When the CV805's were developed for commercial use, G.E. was known as a supplier of jet engines for the military only.[169] G.E. did not have established relationships with the airlines and was not considered a competitor to the established leader of jet engines to the airlines, P&W, as evidenced when Northwest Airlines chief executive Don Nyrop commented with contempt during a G.E. engine sales proposal that "Whenever I want a light bulb, I pick G.E."[170] G.E. assisted the airlines maintenance and support, and continued the development of the engine. The CV805 program allowed G.E. to establish separate support organizations to handle commercial product support and spare parts sales to acquire and grow airline confidence in their products. G.E. continued to provide resources to increase the durability of the engine despite the associated short term costs. Aerospatiale, the French aerospace company, convinced G.E. to purchase a Caravelle and install a pair of CV805-23 turbofan version as a demonstrator aircraft for possible sales within Europe. While no customers were attracted by the venture, it did establish a relationship between G.E. and the French aerospace industry that cultivated in a joint venture with French engine manufacturer, Société nationale d'études et de construction de moteurs d'aviation (SNECMA), and the CFM56 high by-pass turbofan engine. The Convair 880 and 990 sold in relatively low numbers, had cost both companies monetarily, and the CV805 had never achieved the fuel economy necessary to surpass its competition, but G.E. was able to parlay it the

[168] Ibid, 19.
[169] Hartman L. Butler, Jr., George J. Podrasky and J. Devon Allen, 58-59.
[170] Neumann, 233.

commercial version of the J79 into a harbinger for future commercial relations and had established an organization within G.E. devoted to building that portion of the business. The J79 core had been an instrumental base for G.E. to build a reputation and rapport with commercial customers despite its origins as a military powerplant.

3.10 Development Beyond the J79

For G.E. the success of its military jet engines and its limited, yet foundational commercial venture allowed it to foster and expand into related businesses. In 1961, based on the strength and success of the J79 and its prior jet engines, Gerhard Neumann took over control of G.E.'s aircraft engine division and continued to develop the business by employing an economy of scale to reduce costs. Utilizing another military engine for civilian usage, G.E. employed a civilian version of its J85 without an afterburner, the CJ610, a small and lightweight turbojet, to gain market share within the business jet sector. The CJ610 powered civilian business jets such as the I.A.I. Westwind and the Learjet 23. The practice of employing a military jet engine for civilian use reduced the cost per unit. This practice continued when G.E. employed its TF34 in the military Lockheed S-3 Viking and Fairchild Republic A-10 Thunderbolt II, and applied the engine in the civilian Canadair CL601 Challenger.

G.E. manufactured a series of military engines that were also operated by commercial operators, which also incorporated new design features as well as heritage technology. The successor to the J79 came in the YJ93 turbojet with six engines that powered the XB-70 Valkyrie, S.A.C.'s prototype large bomber designed in the late 1950's, and first flown in the early 1960's to fly at 70,000 feet at Mach 3 to avoid potential interceptors. Much like the B-58, the XB-70 was a design that lacked a mission as flying high and fast was being replaced by low altitude runs where the XB-70 was only slightly faster than an existing B-52.[171] The YJ93 was a larger, wider, and heavier engine than the J79, produced nearly 30,000 lbs of thrust, and also employed variable stators around a single shaft.[172] The same engine was to be employed on the U.S. Supersonic Transport (S.S.T.) program, which was the U.S. government funded plan to finance a commercial supersonic aircraft. Over the objections of maintaining the U.S.'s technical leadership, the program was cancelled in 1971 due to cost, sonic booms over populated areas, repeated design changes, environmental impact, and economic viability.[173] While the YJ93 had not been produced in large quantities, it had illustrated the technology of G.E.'s turbojet design was capable of the continual development of greater speeds even if ultimate velocity was no longer a necessity.

G.E. continued the process of utilizing a military powerplant to power commercial aircraft with the technology originally developed on the J79. After earlier studies for a heavy transport to replace existing large transports, a request for proposals for the Cargo/Transport Experimental - Heavy Logistics System (CX-HLS) program was sent out to the major aircraft contractors and the engine manufacturers. Curtiss-Wright's submittal was eliminated from the initial competition, and after the down-selection G.E.'s engine

---

[171] L.J. Taube, Study Manager, "SD 72-SH-0003: B-70 Aircraft Study Final Report: Volume II," North American Rockwell Space Division, April, 1972, II-2.
Meg Greene, *The B-52 Stratofortress* (New York, New York: Rosen Publishing Group, 2003), 17.
[172] "Mach 3 Engine: General Electric Unveil the YJ93," *Flight International*, September 26, 1963, 543-544.
[173] Joshua Rosenbloom, "The Politics of the American SST Programme: Origin, Opposition and Termination," *Social Studies of Science*, Volume 11, Number 4 (November, 1981), 407-412.

proposal beat P&W for a large turbofan capable of powering the aircraft plus 100,000 pounds of payload.[174] The turbofan was designated the TF39 for military application, and was capable of 41,000 lbs of thrust, an eight to one air bypass ratio of air entering the engine core, with a seven stage variable stator system over the sixteen stage compressor. G.E. had always hoped to adopt the engine in commercial applications, and the TF39 became the CF6 with even higher thrust depending on the engine model. Introduced when fuel prices were rising, the CF6 offered vastly better fuel consumption than its competitors, and despite initial fan assembly failure issues due to foreign object ingestion and G.E.'s limited commercial market experience, the engine was employed on multiple twin, three, and four engine wide body aircraft for multiple customers.[175] The engine was part of the leap in flight performance as great as those seen when the early turbojets were introduced into commercial use. The CF6 was another successful engine for G.E., with production orders continuing into the 2020's, over 50 years after its initial service introduction.[176] After an initial slow start entering the civilian market, G.E. had effectively established itself in the commercial engine market and continues to be one of the major companies within it.

---

[174] "CX-HLS Requirements," *Aviation Week & Space Technology*, March 23, 1964, 20.
[175] Peter Middleton, "CF6-Powered 747," *Flight International*, August 9, 1973, 244-252. "G.E. Readies CF6 Engine Fix," *Aviation Week & Space Technology*, February 2, 1976, 30.
[176] "Production Line Continues beyond 2024 for CF6 Engine," GE Aviation Press Release, July 9, 2012, https://www.geaviation.com/press-release/cf6-engine-family/production-line-continues-beyond-2024-cf6-engine.

4.0 The Impact of the J79

The ongoing success of G.E. jet engines for both commercial and military applications would not have been possible without G.E. taking a risk on an innovative, yet untried technology and successfully achieving a desirable turbojet engine capable of Mach 2 plus speeds in the J79 turbojet. G.E. had originally hoped the J79 would lead into powering bombers, transports, and commercial aircraft besides just fighter/interceptors, much like P&W had been able to accomplish with the J57 in the few years prior and within the introduction of the J79. The J57 had been utilized in aircraft such as the Martin B-57 Canberra, the F-100 Super Sabre, the Boeing B-52 Stratofortress, the F-102 Delta Dagger, the Douglas A-3 Skywarrior, the F4D Skyray, the F8U Crusader, the Boeing KC-135 Stratotanker, and the Boeing 707 near the service introduction of the J79 into aircraft. P&W was nearly monopolizing both the military and commercial jet engine markets to near 70% of all military jet engine contracts and all of the commercial contracts by 1958.[177]

G.E. had produced several capable jet engines such as the J33 and J47, but it still needed a winning engine design or it faced possible elimination from the market. The jet engine market for military use within the U.S. in the early 1950's had started with Allison, Continental, Fairchild, G.E., Lycoming, P&W, and Westinghouse. Before the end of the decade, Fairchild and Westinghouse left the business and Curtiss-Wright entered the arena. Most of the companies had only built license built turbojets or had modified an existing engine, and had yet to develop and manufacture their own in-house designed engine. G.E. needed to show it could continue to design and build an engine from a "clean

[177] Louis R. Eltscher and Edward M. Young, *Curtiss-Wright: Greatness and Decline* (New York, New York: Twayne Publishers, 1998), 150.

sheet" while significantly improving performance. Companies that had yet to show they could design and build their own turbojet engine capable of supersonic speeds were increasingly denied requests for proposals of new jet engines for aircraft programs, denied research and development funding for competitions, and were finally eliminated from the business. By the 1970's, only Allison, G.E. and P&W remained as manufacturers of larger jet engines for the military.

The technology surrounding the turbojet required a major commitment and investment into the infrastructure, processes, and research in order to succeed within this transformative time. The technological demands of supersonic flight contributed to changes in materials, manufacturing processes, and test facilities in order to meet the challenges to power ever complex systems and heavier airframes. Competition had spurred risk and innovation, but it also needed a monetary investment and a willingness to change. When visiting the U.S., Frank Whittle saw G.E. was investing twelve times as much as Power Jets was in a plant to test compressors and turbines, and in order to meet turbojet engine demand, G.E. purchased the old Curtiss-Wright Plant at Evendale near Cincinnati, Ohio, which at the time was the second largest manufacturing site in the U.S.[178] Curtiss-Wright, who was the largest producer of reciprocating engines for WWII and into the Korean War, was finally out as a major manufacturer of jet engines, because it failed to maintain its engineering talent, focused its existing resources on propeller driven engines, neglected to invest in research and technology in the face of the changing technology of jet engines by producing or redesigning license built jet engines, and rebuffed both

[178] Edward W. Constant II, *The Origins of the Turbojet Revolution* (Baltimore, Maryland: The Johns Hopkins University Press, 1980), 229.
Neumann, 211.

commercial and military customers,.[179] Further and continual investment by G.E. in the Evendale Plant allowed G.E. engineers to perform over 90% of testing at the facility for the J79, which in turn reduced the development time significantly.[180] G.E. properly capitalized on its opportunity within the aircraft engine industry upheaval, yet it did not did not rest on its achievement as it continued to resolve issues associated with the J79.

While the J79 and the technology associated with it was a gateway for G.E. to further build upon within the market, there were obstacles requiring resolution throughout its lifecycle. Early in testing of the F-104 Starfighter, the engine experienced uncharacteristic flameouts, stalling and high fuel consumption. G.E. installed a dual ignition to resolve the flameouts and stalling, and a model configuration change to the J79-GE-7 alleviated some of the high fuel burn for the F-104.[181] The J79 continued to be plagued by high fuel consumption, especially when pilots employed the afterburner. While it was most associated with the F-4 Phantom and like most U.S. turbojets, aircraft employing the J79 displayed a smoke trail that revealed it altitude and trajectory to its foes. A Smoke Abatement system was tried in F-4's over Vietnam, but an improved solution was finally obtained in the J79-GE-17C model when the combustor was redesigned to be shorter with a cooling manifold and inner liner, and the intake air was swirled with cross ignition tubes along the forward section connecting combustors. Fuel nozzles were also modified for fuel atomization to improve the fuel and air mixture, and subsequent ignition.[182] Unfortunately,

---

179 Louis R. Eltscher and Edward M. Young, 134, 147-150, 159-160.
180 J.S. Butz, Jr., "Low Lead Time, Lightness Mark J79," *Aviation Week & Space Technology*, May 27, 1957, 29.
181 "New Dual Ignition Installed in J79's," *Aviation Week*, April 15, 1957, 32.
"Industry Observer" *Aviation Week*, January 27, 1958, 23.
182 General Electric Company Aircraft Engine Group, "Evaluation of Fuel Character Effects on J79 Combustor," *Technical Report AFWAL-TR-80-2092*, November 1980, 7-13.

the alleviation of the smoke came late in the service life of the J79, and most pilots were forced to contend with the aircraft exposing deficiency before the improvement was incorporated, if at all, into the existing platforms.

With these and other ongoing enhancements to the engine, it was still considered a viable option for fleet modernization programs even decades after the engine was first manufactured and newer low by-pass turbofans were potentially available. The I.A.I. still utilizes the J79 in its Kfir Block 60 modernization program and considered the J79 capable of powering its F-4 to Mach 3 for reconnaissance. In the mid 1980's, nearly thirty years after the J79 introduction, McDonnell Douglas with the help of the G.E. Component Improvement Program offered an improved J79 over a turbofan engine in a proposal to upgrade the overall performance of F-4's for use into the 21st century.[183] Weighing the cost of possibly reconfiguring engine attach points within the aircraft to obtain a potentially minor improvement of mission capability with a newer turbofan engine, an existing or upgraded J79's performance proved to be a cost effective alternative.

For G.E., even with continual configurations and upgrades over its lifetime, the J79 was a success economically, and its technological innovation was incorporated into subsequent jet engine designs both internally and externally. G.E. has sold over 17,000 variations of license or internally manufactured J79 engines to cement its position within the industry. Even though turbojets were superseded by turbofans, various components from the turbojets were added to turbofans. Amongst several different companies, G.E.'s

---

[183] D.H. Freeburg, *F-4 Modernization Program: Phantom 2 Plus for the Twenty-First Century: Volume 1, Technical Proposal*, McDonnell Douglas Corporation, January 4, 1985, 1-1 - 1-9.
Rudolf G. Penner, *Tactical Combat Forces of the United States Air Force: Issues and Alternatives*, The Congress of the Unites States Congressional Budget Office, April, 1985, 41-45.

main American engine rival P&W used the variable stator technology, and G.E. eventually used P&W's twin spool technology also. P&W had first used the twin spool technology for its J57, and had been successful when it integrated a fan along the forward section of the turbojet for a low by-pass turbofan in the JT3D. The twin spool design made it easier to combine a forward fan on the engine by coupling the fan to one of the shafts independent of the spool for the engine core. For both companies to be successful on successive turbofan jet engines, technologies had to be merged in order to achieve the desired thrust and fuel consumption. The variable stators allowed more precise control of inlet air onto compressor vanes and increased the engine efficiency as the pressure continued to rise in engines. The J79 revolutionized the use of variable stators with the technology being used on engines by other companies; yet it was a major mechanism in an innovative time for jet engines.

The J79 was another progressive step in the ongoing jet engine revolution. The jet engine had only been introduced into the U.S. within the previous decade of the J79's first flight. The J79's conception and successive introduction was the first to normalize the propulsion of various aircraft to speeds of Mach 2, which was just barely obtainable under the most optimum of conditions a few years earlier. The thrust of the J79 allowed it to push aircraft to higher speeds both for military and commercial applications, yet it required other interrelated innovations in order to achieve these results.

Advancements in aerodynamics and materials were required as the heat generated by the air passing over aircraft flight controls at increased speeds demanded new design considerations. New facilities, engineering practices, and even how the aircraft programs were managed were adopted to cope with the ever-increasing complexity of integrating the various systems into a functional aircraft with the Armed Forces pushing the responsibility of a holistic acquisition to the manufacturers themselves.[184] The turbojet needed a harmonious union with a proper aerodynamic platform in order to achieve the desired results for most aircraft, the F-4 being the exception. With the additional thrust of turbojet engines such as the J79, designers could install improved avionics, new defensive countermeasures, and build heavier airframes capable of carrying more fuel and armament faster and farther. Aircraft without enough thrust had been an issue in aircraft such as the McDonnell F3H Demon, but the J79 was part of a new group of turbojets with the capability to provide enough thrust to allow manufacturers to realize the requirements military planners desired.[185] The J79 turbojet gave pilots increased throttle response and was known to spool up quickly for its immediate throttle responses.[186] For pilots and their aircraft, "speed is life" and the J79 provided it with greater thrust and fewer stall characteristics than previous jet engines.

For the J79 and other turbojets of the time, the military aided in the development of the turbojets by providing complete or supplemental funding for the costly research and development efforts and expenses. Without this funding and the impetus for increased performance, the majority of the aircraft industry prior to and during W.W. II had not shown it was committed to the expenditures necessary for innovative results, preferring quantity over quality.[187] A cooperative partnership developed between the aircraft industry and the

[184] Glenn E. Bugos, "Manufacturing Certainty: Testing and Program Management for the F-4 Phantom II," *Social Studies of Science*, Volume 23, Number 2 (May, 1993), 266, 281-296.
[185] Peter Davies, *USAF McDonnell Douglas F-4 Phantom* II (Oxford, United Kingdom: Osprey Publishing, 2013), 5-6.
[186] Kevin R. Walsh, *Summary of the Effects of Engine Throttle Response on Airplane Formation-Flying Qualities: NASA Technical Memorandum 4465*, Dryden Flight Research Facility, Edwards, California, 1993, 1.
[187] William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000* (Chicago, Illinois: University of Chicago Press, 1982), 358.

U.S. Armed Forces, which helped foster the new developments and commercial uses of the turbojet; a collateral effect that aided everyone. The U.S.A.F. had helped invest in the research surrounding the J79 due in part to the outbreak of the Korean War, but also due to the perceived threat of nuclear war.

The U.S. military and politicians wanted a potential deterrent to the perceived nuclear threat and manpower advantage of the Union of Soviet Socialist Republics (U.S.S.R.), so it needed a vehicle or vehicles with a delivery system for nuclear weapons, intercept potential Soviet Union bombers, and with the power and speed to defeat the threat of MiG's. Speed and altitude capability of aircraft was thought to enable a missile to reach its target faster, more reliably, and with the benefit that if desired it could still be called back when necessary. Critics of intercontinental nuclear missiles pointed out that once the missile was launched, there was no ability to recall it if the situation that first caused the launch had been dramatically altered after the fact.[188] Mechanical malfunctions, human mistakes, or communication errors could cause a missile to be launched, but with a manned bomber there was still time for contemplation and recall. In this respect, the J79 was just a component in a nuclear delivery and defensive weapon system for S.A.C. and the U.S. government diplomacy efforts against the U.S.S.R. The U.S. wanted a jet engine with the strength and flexibility to deliver a nuclear vehicle high and fast, and still be able to power a fighter to intercept an incoming threat.

For the Armed Forces and the engine industry, setting new records were not only for inter-service bragging, but also as propaganda of their potential abilities. Speed and altitude records gave a glimpse into the overall capabilities of an aircraft, and the J79 was the first to power a production aircraft past Mach 2. While records were quantifiable, they

[188] Joseph A. Angelo, Jr., *Rockets* (New York, New York: Infobase Publishing, 2006), 70.

were still only subjective proof of an ability to get missiles delivered or intercepted. The achievements did not quantify the quality of the aircraft. The Century Series aircraft, the nickname given for the series of fighter produced in the 1950's and early 1960's with the designation in the 100's such as the F-101 Voodoo, were all designed to carry a nuclear weapon. Most of the Century Series aircraft were progressively able to fly higher and faster, had a wider combat radius, and could carry considerable bombing loads, but about half of them were unable to turn well and lacked maneuverability, making them poor fighters for air-to-air combat. Most were just interceptors and small penetration bombers.[189] These aircraft and the engines necessary to power them were a reaction to the previous conflicts and fulfilled a perceived need to deliver weapons ranging up to a nuclear bomb.

An actual bomber capable of delivering a nuclear bomb as a quick first strike or even a second strike option flying high and fast to the target, while being able to avoid enemy interceptors, was thought to be achieved in the B-58. The B-58 and fighters of the time were part of ever increasing nuclear delivery system that were both functional for the military and posturing for politicians to ensure both the capability to deliver a nuclear bomb and to ensure one did not get dropped. Being able to project strength or the perception of power could also ensure nuclear weapons were not used. John Lewis Gaddis noted, "The problem now was not so much how to defeat an adversary as how to convince him not to go to war in the first place."[190] The J79 and other jet engines of the time aided in this type of strategy in that they were a mechanism in the strategy of S.A.C. and politicians to put bombs on targets as quickly as possible to ensure a possible war was as terrible as

[189] Colonel Edward V. Coggins Jr., *Wings that Stay on: The Role of the Fighter Aircraft in War* (Paducah, Kentucky: Turner Publishing Company, 2000), 111-113.
[190] John Lewis Gaddis, *The Cold War: A New History* (New York, New York: Penguin Books, Ltd., 2005), 62.

possible so an adversary did not consider the option.

The J79 was not just merely a portion of a strategy, but was also a piece in an overall technology race between Cold War adversaries after WWII that started with the atomic bomb. Aircraft speed and altitude capability was increasing, and the U.S. strategy was to show its technological might with these achievements. The J79 was the first jet engine to propel an aircraft past Mach 2. Speed was thought to be a valuable resource to deliver a weapon or to intercept incoming fighters or bombers due to range and time to reach the threat needed to protect assets. Mach-2-plus speed gave military planners the capability for interceptors to reach threats within dogfight range before a bomber could reach its intended target and the bomber had the speed to reach its target before it was intercepted. The Soviet Union met this advance with its own Mach 2 interceptor in the MiG-25 Foxbat, and countered with more maneuverable fighters, and increased range from S.A.M.'s, which made flying at high altitudes obsolete.

Some individuals within the U.S. viewed Soviet air power between WWII and the Korean War with contempt and derision. After WWII, both the U.S. and Soviet forces had obtained German aeronautical and rocket scientists and their data, which became a catalyst for the aerospace industries in both countries. Still experiencing technical difficulties with jet engines, and with their latest MiG aircraft design slowed by the need for a suitable engine, the Soviet government requested from the British government Rolls Royce centrifugal Nenes and Derwent turbojets in 1946. Even though Stalin wondered with bewilderment "What fool will sell us their secret?" they were still able to acquire twenty-five Nenes and thirty Derwents which were promptly reverse-engineered and enhanced as VK-

1 engines installed in MiG-15's.[191] These events, the revelation of a series of espionage cases such as Klaus Fuchs who revealed atomic secrets to Soviet agents, and general propaganda gave rise to the belief that Soviet technology was simple and inferior, was not inventive, and their abilities laid "in their own plodding way systematic research with endurance and singleness of purpose, to devise solutions of expediency, and to design matériel which is well adapted to the general backwardness of the country."[192]

The MiG-15 was a shock to this belief as it outclassed P-80 and B-29's, and was a formidable opponent to the F-86 in Korea. U.S. Air Force Chief of Staff and General Hoyt S. Vandenberg helped solidify the mystique of the MiG-15 when he testified before the Senate Armed Services and Foreign Relations Committee that "they [the Soviet Union] have a jet engine in the MiG-15 that is superior to any jet engine that we have today…They have the advantage of speed and climb and operations at altitude."[193] The U.S. military was able to analyze the true abilities of the MiG-15 when North Korean pilot Ro Kum Suk landed a MiG-15 in Kimpo Air Base, South Korea, on September 21, 1953.[194] After analysis and test flights by pilots, including Chuck Yeager, it was concluded the aircraft had advantages and disadvantages, and the engine was improved over the original Rolls Royce Nene.

Soviet engineers continued the development of jet engines by producing their own jet engines. Much like their engineering counterparts in other countries, centrifugal jet

---

[191] Stanley Sandler, *The Korean War: No Victors, No Vanquished* (London, United Kingdom: University College London, 1999), 175.
[192] Ramsay D. Potts, Jr., "The Foundations of Soviet Air Power: A Historical and Managerial Interpretation," *The Annals of the American Academy of Political and Social Science*, Volume 299 (May, 1955), 39-44.
[193] "What Vandenberg Told Senators," *Aviation Week*, June 11, 1951, 17.
[194] David A. Anderton, "Red MiG-15: AF Test Pilots Analyze Captive Fighter," *Aviation Week*, November 30, 1953, 16-17.

engines gave way to more efficient and powerful axial flow engines. Soviet engineers faced similar issues of controlling power and stall, and also turned to both the twin spool and variable stator technology. The dual spool for Soviet engines was first developed in 1956, and utilized in engines such as the Tumansky R-11 for use in the MiG-21 and then the Sukhoi Su-15 Flagon interceptor. In the early 1960's, in one of the last turbojets designed by any Soviet manufacturer, variable stators were employed on the Lyulka AL-21 jet engine, which was installed in Su-17 Fitters and Su-24 Fencers. Although produced years after the J79, the AL-21 represents the Soviet turbojet that is most similar to the J79, and like the J79, the AL-21 remains in operation at this time with the Su-24.

The combination of speed and maneuverability of MiG-15s in the Korean War had diminished U.S. military strategy and bombers, and it happened again when agile MiG's in Vietnam revealed the limitations of purpose built interceptors that lacked the agility to compete. Aircraft such as the Republic F-105 Thunderchief suffered high losses during bombing runs early in the war over Vietnam, and was eventually removed from the theater due to these failures.[195] The versatility of the J79 powered F-4 Phantom II showed an aircraft could operate successfully within multiple missions from attack runs to reconnaissance, and with the appropriate tactics it was able to dogfight even if was not maneuverable enough to compete in all aspects of a flight envelope. Even with this adaptability, the F-4 could not operate within different roles on the same mission revealing its limitations.

The subsequent generation of fighters such as the U.S.N. Grumman F-14 Tomcat

[195] *Intelligence Memorandum: US and South Vietnamese Air Losses in Southeast Asia*, Directorate of Intelligence, Office of Current Intelligence, March 1, 1966, 1, Annex 1 & 3. Peter E. Davies, *F-105 Thunderchief Units of the Vietnam War* (Oxford, United Kingdom: Osprey Publishing, 2010), 6.

and the U.S.A.F. McDonnell Douglas F-15 Eagle were designed to be fighters, and some were designed to operate dual roles within the same mission such as the McDonnell Douglas/Northrup F/A-18 Hornet. These aircraft did not have significant increases in ultimate speed, if any at all, as the military found it was unnecessary for missions (reference Graph 4.0A: U.S. Fighters Top Achievable Speed). Bombers followed the trend as succeeding aircraft from the B-58 such as the Rockwell B-1B Lancer and B-2 Spirit would not fly anywhere close to Mach 2 (reference Graph 3.2A: U.S. Bomber Maximum Speed Capability Historical Perspective). More sophisticated avionics and accompanying missiles gave aircraft the ability to detect an enemy aircraft beyond visual and fire upon them, further reducing the necessity for an ultimate speed aircraft. Land-based, solid-fueled, intercontinental ballistic missiles further reduced the critical need for high speed within U.S. fighters, as bombers were no longer seen as the only first strike option so interceptors were no longer a necessity. The generation of fighters built for maneuverability was eventually complimented with aircraft designed for stealth or low observable features to elude or reduce radar signature.

The design and mission profile of aircraft were revised through subsequent generations, and the J79 and its innovations were seen in engines for these aircraft. The performance of the J79 was persuasive enough to be considered for use in aircraft from different generations.[196]The J79 was at the end of the evolutionary refinement of the

---

[196] Mark Lorell, *The U.S. Combat Aircraft Industry, 1909-2000: Structure, Competition, Innovation* (Arlington, Virginia: Rand Corporation, 2003), 5-6.
Bill Sweetman, “Generation Next,” *Aviation Week & Space Technology*, February 29-March 13, 2016, 20.
There are multiple interpretations of how to qualify aircraft generations even within the jet age. Lorell gives his interpretation of five distinct aircraft generations starting with biplanes and ending with stealth technology. It also gives a footnote to six generations of aircraft commencing at the jet age. Another categorization has the five generations within the jet

turbojet and the beginning of the turbofan era. Turbojets were transcended by more efficient turbofans, and G.E. attempted to make the J79 more fuel-efficient by adding a fan along the aft section of the engine for commercial applications, but the industry chose forward fans. The technology feature that enabled the J79 to be a single spool turbojet with stall free characteristics in the variable stators was utilized in turbofans for both commercial and military applications. As an example, the G.E. F404 low by-pass turbofan applied variable stators to its powerplant for both subsonic and supersonic aircraft in the subsonic Lockheed F-117 Nighthawk stealth fighter and the supersonic F/A-18 Hornet. The F404 was designed to build upon the stall free operation of the J79 while still being able to cope with the varying throttle inputs of pilots and high angle of attack capability of the newer generation of fighters such as the F/A-18. Even as aircraft increased their flight envelope with ever increasing maneuverability, the J79 and its technological achievements were still relevant for aircraft across multiple generations.

The significance of the technology and thrust provided by the J79 was not lost on another industry seeking to establish straight-line records of speed never seen before on land. In the 1960's, racers looked to set a land speed record employing surplus military jet engines. This was not a new phenomenon as some vehicles in the 1920's were purposely built to break existing speed records.[197] In the 1930's, British racers Malcolm Campbell, John Cobb, and George E.T. Eyston traded the land speed record back and forth until, after a hiatus for WWII, Cobb reached 394 m.p.h. in 1947. After WWII, the popularity of quarter-mile races between competing automobiles grew in popularity in the U.S. Art

---

age based on the technological capabilities of the aircraft. In any classification, the J79 was utilized in aircraft in at least two generations.

[197] Martin Hogue, "A Site Constructed: The Bonneville Salt Flats and the Land Speed Record, 1935-1970," *Landscape Journal*, Volume 24, Number 1 (2005), 32.

Arfons, a navy diesel mechanic during WWII, and his half-brother Walt Arfons obtained a war surplus U.S.A.A.C. Allison V-12 for a Lockheed P-38 Lightning, and stuffed it into a dragster nicknamed the "Green Monster." The dragster reached over 300 m.p.h. at the Bonneville Salt Flats, and was sold because newer turbojets engines were becoming available.

After a dispute arose, a rivalry developed between the Arfons brothers and Craig Breedlove to establish the record. Art Arfons acquired and rebuilt a damaged J79 without a repair manual from a F-104, and Craig Breedlove first used a J47 turbojet before switching to a J79 from a F-4 for their respective racers. In 1963, Breedlove claimed the speed record of 407 m.p.h. using the J47 in his Spirit of America vehicle over two other racers; Nathan Ostich, and Glenn Leasher who crashed and was killed making his attempt at the record. Walt Arfons' car, the Wingfoot Express, powered by a J46 briefly set the record at 413 m.ph. Then over the next three years Art Arfons and Craig Breedlove raised the land speed record eight times before Breedlove finally capped it at just over 600 m.p.h. in a nearly back and forth battle for supremacy in the their J79 powered racers. Art attempted to take the record again, but crashed at just over 600 m.p.h. suffering only minor injuries in what would have been a record run.[198] After the crash, no other attempt was made by the pair as interest in establishing the record diminished until it was subsequently broken by a rocket powered racer almost four years later. British racer Richard Noble broke the record again in 1983, and eventually he cracked the sound barrier in 1997. While the record was a remarkable technological achievement, the excitement of racers in the 1960's utilizing J79's and other turbojets was never duplicated. In the 2000's, a joint Canadian and

[198] Robert C. Post, "The Land Speed Record and the Last Green Monster," *Technology and Culture*, Volume 50, Number 3 (July, 2009), 590-591.

American group led by Ed Shadle and Keith Zanghi used the fuselage of a F-104 and a rebuilt J79 out of a F-4 from Davis-Monthan in Arizona for their North American Eagle Project.[199] As of this writing, testing is still being performed with speed exceeding 400 mph verified.[200] Much like Curtiss JN-4 "Jenny's" after World War I that were used by barnstormers, North American P-51 Mustangs used by racers in the Bendix Trophy transcontinental air race after WWII, military hardware had found its way into civilian hands for exhibition and racing. The most technologically sophisticated jet engine of the 1950's used to power aircraft to speeds exceeding Mach 2 for military defense and to power the fastest commercial aircraft was used to power vehicles on land to over 600 mph by civilians just over ten years later.

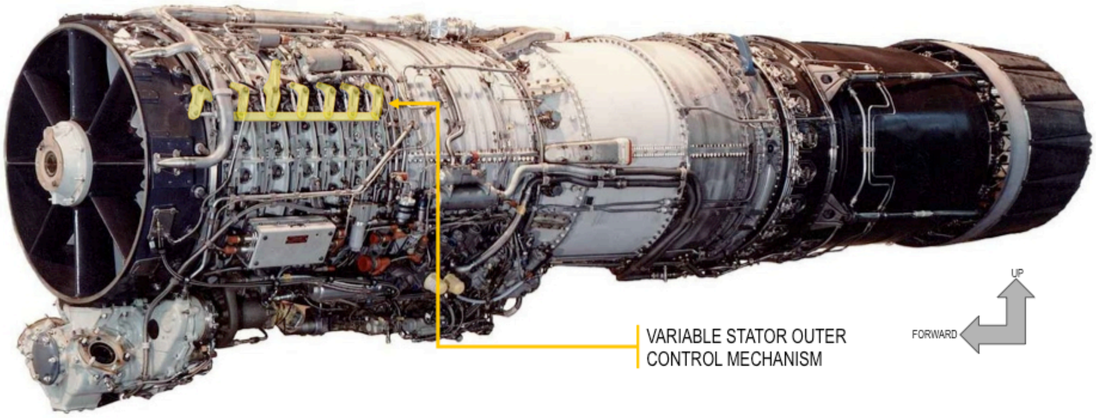
The J79 had found its way into a multitude of different applications ranging from the 1960's movement of racers seeking to break land speed records to military and commercial aircraft seeking to be the fastest in their given industry. As of this writing, the J79 has seen seven different decades and will be around at least into the eighth, which is a remarkable achievement given it was a just an element of the technology refinement at the end of the turbojet era before more efficient turbofans supplanted them as the powerplant of choice for both commercial and military aircraft. At the time the J79 was conceived, it was believed the dual shaft turbojet was the logical choice because it was already producible, and a single shaft turbojet was thought to be highly inefficient due to all of the components spinning about a single axis.[201] G.E. was given the contract to bring

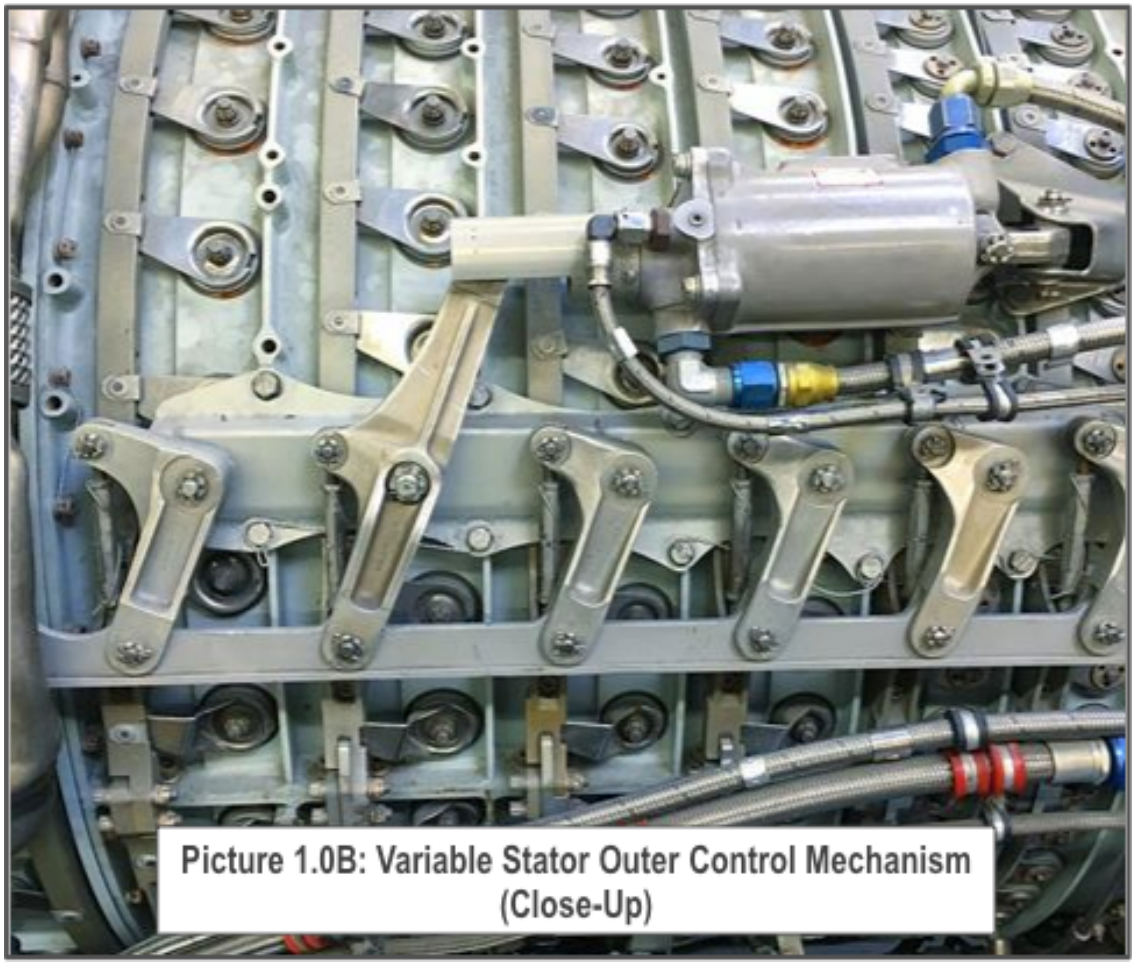
[199] "A Jet Without Wings," *American Society for Engineering Education Prism*, Volume 13, Number 5 (January, 2004), 15.
[200] Jonathon M. Gitlin, "A Missile with Wheels on it – The Pride of a Nation: The North American Eagle Land Speed Record Project." https://arstechnica.com/cars/2016/10/the-pride-of-a-nation-the-north-american-eagle-land-speed-record-project/.
[201] "Military Engines," *Flight International*, January 17, 1981, 153-154.

functionality to the technology because the U.S. Armed Forces needed an engine capable of powering bombers and interceptors to speeds exceeding Mach 2. Using technology that another company had abandoned because it was thought to be unfeasible, G.E. produced a relatively inexpensive engine that produced a high amount of thrust with quick response from throttle inputs, and alleviated most of the stall conditions plaguing previous turbojet engines. The engine proved G.E. was capable of resolving technological problems and incorporating new technology into the refinement of the turbojet engine allowing G.E. to be viewed as a major manufacturer for the military, and it gave them access to commercial aviation industry. The J79's variable stators automatically adjusted, which was a further step in allowing pilots to focus on flying their aircraft and the mission instead of worrying about the throttle position at a specific flight envelope possibly inducing a stall.

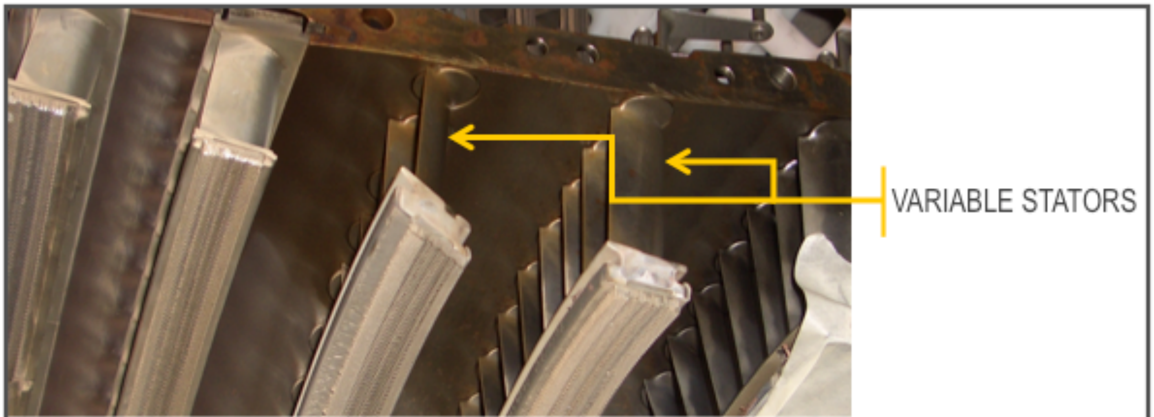
Ultimately, the J79 was a piece in the overall Cold War military strategy and the further refinement in a technology revolution. The speed and altitude abilities of the MiG-15's in the Korean War had shown U.S. Armed Forces strategists that slow flying bombers and pursuit aircraft could not compete, and new engines and aircraft were needed to combat the threat. MiG-15's were more advanced technologically than comparable U.S. aircraft and thus the delivery system of bombers for atomic weapons were no longer capable of performing the mission. The Korean War revealed that a limited war where the threat of atomic bombing could keep adversaries from openly fighting each other without resorting to the use of atomic weapons. A limited war without nuclear weapons is only achievable if the adversary believes its enemy is still capable of delivering these weapons. The U.S. military needed a leap in speed and altitude capability so they helped sponsor firms such as G.E. to provide the powerplants to fulfill their goals. G.E. delivered with the J79, and at least for a time gave S.A.C. a bomber capable of high altitudes and Mach 2 performance to potentially deliver nuclear weapons in the B-58 and to potentially intercept Soviet bombers with Mach 2 interceptors in the F-104 and F-4. The J79 was the leap forward in speed capability of over Mach 2 at level flight and higher altitude abilities S.A.C. demanded all while producing a technological achievement in variable stators, which helped to reduce stall characteristics that only a few years before the J79's introduction had been accomplished only under the most ideal circumstances with experimental aircraft.

Picture 1.0A: General Electric J79-17 Turbojet





Picture 1.0B: Variable Stator Outer Control Mechanism
(Close-Up)



Picture 1.0C: Variable Stators (View Looking Out)

Graph 3.2A: U.S. Bomber Maximum Speed Capability Historical Perspective

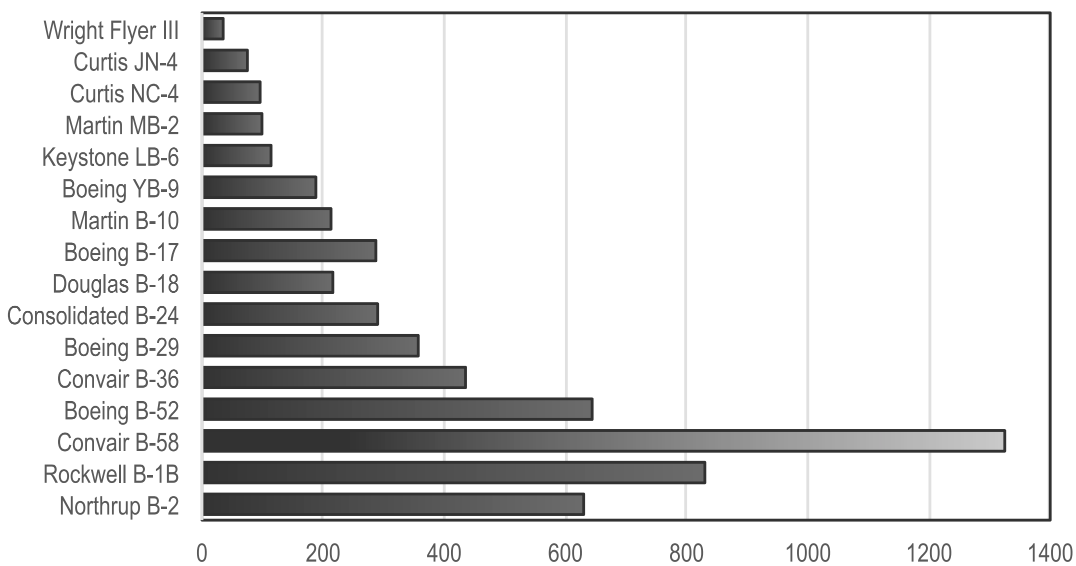
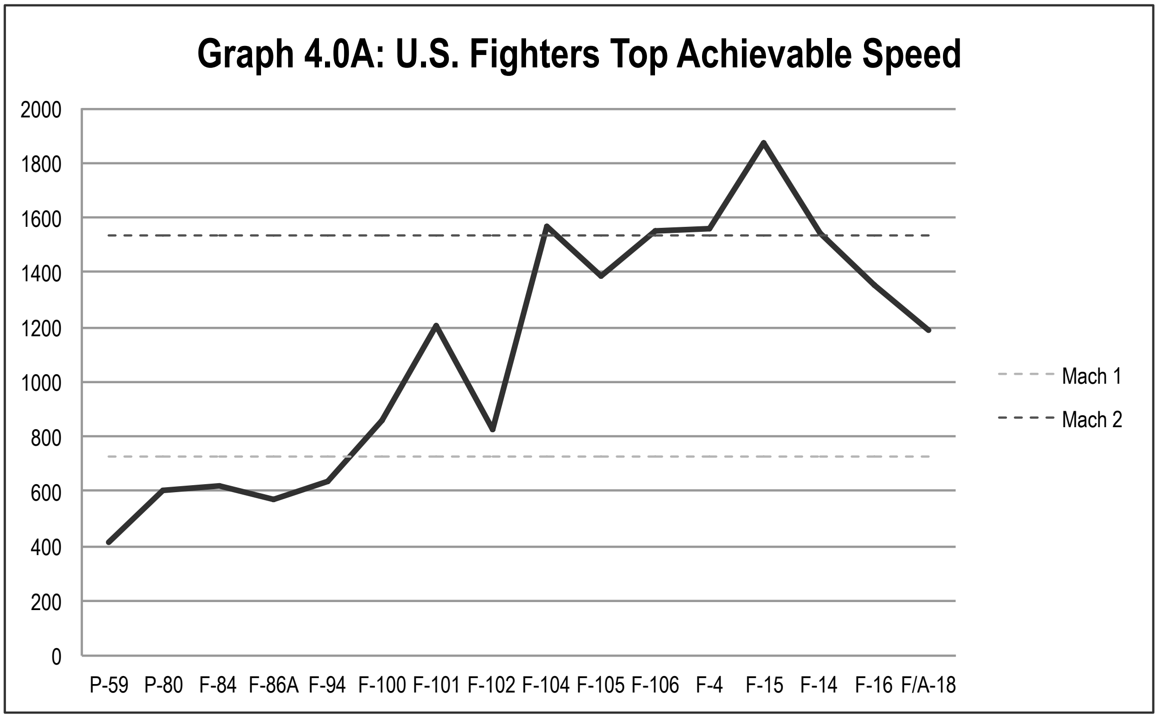


Table 3.4A: F-4A Phantom II Requirements			
System Parameters	Units	F-4A	
		Required	Demonstrated Capability
Mmax - Maxiumum Power	Mach	2.04	2.03
Mmax - Military Power	Mach	0.99	1.01
Rate of Climb at 35000 ft Maximum Power	Feet/Minute	12.258	17.500
Time of Climb from Sea Level to 35000 ft Maximum Power	Minute	1.30	1.13
Time to Accelerate from Military Rated Thust Vmax to Mmax at 35000	Minute	0.81	0.59
Supersonic Combat Ceiling with Maximum Power	Feet	55430	56900
Maximum Specific Range	Nautical Mile/Pound Fuel	0.1107	0.1173
Combat Gross Weight	Pounds	36817	36817

Table 3.4B: F-4 World and Class Records Set		
Date	Parameters	Record
06 DEC 1959	Altitude	98,557 ft
05 SEP 1960	500 km Closed Course	1216.76 mph
25 SEP 1960	100 km Closed Course	1390.24 mph
24 MAY 1961	Los Angeles to New York	2 hr 49 min 9.9 sec
28 AUG 1961	3 km	902.769 mph
22 NOV 1961	15/25 km	1606.342 mph
05 DEC 1961	Sustained Altitude	66,443.8 ft
21 FEB 1962	Time to Climb: 3,000 m	34.52 sec
21 FEB 1962	Time to Climb: 6,000 m	48.78 sec
01 MAR 1962	Time to Climb: 9,000 m	61.62 sec
01 MAR 1962	Time to Climb: 12,000 m	77.15 sec
01 MAR 1962	Time to Climb: 15,000 m	114.54 sec
31 MAR 1962	Time to Climb: 20,000 m	178.50 sec
03 APR 1962	Time to Climb: 25,000 m	230.44 sec
04 APR 1962	Time to Climb: 30,000 m	371.43 sec



Graph 4.0A: U.S. Fighters Top Achievable Speed
2000
1800
1600
1400
1200
1000
800
600
400
200
0
P-59
P-80
F-84
F-86A
F-94
F-100
F-101
F-102
F-104
F-105
F-106
F-4
F-15
F-14
F-16
F/A-18
Mach 1
Mach 2

Bibliography

Articles

"Aero Engines 1957," *Flight*, July 26, 1957, 133.

"Aircraft of Interim Air Force," Flying Magazine, Volume 43, Number 2 (August, 1948), 37, 56.

"Altitude Records Fall," *Aviation Week*, May 12, 1958.

Anderton, David A., "B-58 Hustler Packs a Big Punch in a Small Frame," *Aviation Week*, December, 17, 1956, 26-29.

Anderton, David A., "Red MiG-15: AF Test Pilots Analyze Captive Fighter," *Aviation Week*, November 30, 1953, 16-17.

Borovik, Yehuda, "IAI Kfir — Mirage Successor," *Flight International*, July 17, 1975, 80-82.

Butz, Jr., J.S., "J79 Uses Built-Up Parts to Save Weight," *Aviation Week & Space Technology*, August 11, 1958, 69-75.

Butz, Jr., J.S., "Low Lead Time, Lightness Mark J79," *Aviation Week & Space Technology*, May 27, 1957, 29-30.

Coleman, Herbert J., "Israel Melds Many Technologies in Kfir," *Aviation Week & Space Technology*, April 21, 1975, 16-17.

"Convair's F-102A's Supersonic Shape," *Aviation Week*, April 25, 1955.

"Convair 880," *Flight International*, July 25, 1958, 138-140.

"CX-HLS Requirements," *Aviation Week & Space Technology*, March 23, 1964, 20.

Cushman, Robert H., "Principles of B-58 Inlet Control Systems Revealed," *Aviation Week*, January 14, 1957, 50-59.

Dornheim, Michael A., "Navy's Strike Combat Center Intensifies Air-to-Ground Training," *Aviation Week & Space Technology*, November 11, 1985, 188-191.

Eshel, David, "Aged but Upgraded: IAI Pitches Kfir as Fourth-Generation Fighter at One-Third of the Price," *Aviation Week & Space Technolog*y, October 14/21, 2013, 43.

"F-104: Holder of the Absolute Records for Speed and Altitude," *Flight International*, May 30, 1958, 739-743.

Ford, Daniel, "Gentlemen I Give You the Whittle Engine," *Air & Space*, October/November, 1992, 88-98.

Gaines, Mike, "Fighter Marketplace," *Flight International*, September 3, 1988, 111-113.

"G.E. Readies CF6 Engine Fix," *Aviation Week & Space Technology*, February 2, 1976, 30.

Griswold, Wesley S., "World's Fastest Bomber," *Popular Science*, August 1961, 71-74,182.

Hallion, Richard P., "Supersonic Revolution," *Aviation History* (May, 2011): http://www.historynet.com/supersonic-revolution.htm

Hirst, Mike, "Five Thousand Phantoms," *Flight International,* May 27, 1978, 1621– 1633.

Hotz, Robert, "AF Speeds B-58 Development Program," *Aviation Week*, May 24, 1954, 13.

Hotz, Robert B., "Douglas Skyrocket Reaches Mach 2.01," *Aviation Week*, November 30, 1953, 13-14.

"Israel Studies 'Lion' Strike Fighter," *Aviation Week & Space Technology*, March 13, 1978, 208.

"J79 Demands Larger Fuselage for F11F," *Aviation Week*, October 29, 1956, 28-29.

"Justice Department Asked to Scrutinize Alleged Lockheed USAF Bribes," *Aviation Week & Space Technology*, May 6, 1976, 20.

Kolcum, Edward H., "Israel Pushes Design of Strike Fighter," *Aviation Week & Space Technology*, August 16, 1976, 18-19.

Lewis, Craig, "Irvine Details B-58 Design Advances," *Aviation Week*, July 15, 1957, 28-29.

"Lockheed Ripples Spread," *Flight International*, March 13, 1976, 624.

"Mach 3 Engine: General Electric Unveil the YJ93," *Flight International*, September 26, 1963, 543-544.

McLarren, Robert, "Bell XS-1 makes Supersonic Flight," *Aviation Week*, December 22, 1947, 9-10.

McLarren, Robert, "XS-1: Design and Development," *Aviation Week*, July 26, 1948, 22-27.

Middleton, Peter, "CF6-Powered 747," *Flight International*, August 9, 1973, 244-252.

"Military Engines," *Flight International*, January 17, 1981, 152-161.

"Navy Sets F-14 Reengeering Schedule," *Aviation Week & Space Technology*, September 21, 1981, 96.

"New Dual Ignition Installed in J79's," *Aviation Week*, April 15, 1957, 32.

Norris, Guy, "Power Points: Milestone Developments Mark Propulsion's Remarkable Progress," *Aviation Week & Space Technology*, December 7-20, 2015, 54-56.

Plattner, C.M., "The War in Vietnam: Combat Dictates Shift in Navy Air Tactics," *Aviation Week & Space Technology*, February 7, 1966, 64-72.

Ropelewski, Robert R., "F16/79 Offers Export Market New Capability," *Aviation Week & Space Technology*, November 23, 1981, 38-47.

Stone, Irving, "USAF F-104 Completes Test Program, Enters Squadron Use," *Aviation Week*, February 10, 1958, 66-84.

Sweetman, Bill, "Generation Next," *Aviation Week & Space Technology*, February 29-March 13, 2016, 20.

"Two-Seat Kfir Now Flying," *Flight International*, March 28, 1981, 904.

Wetmore, Warren C., "F-104G Dispute Spurs Crisis in Germany," *Aviation Week & Space Technology*, August 29, 1966, 23.

"What Vandenberg Told Senators," *Aviation Week*, June 11, 1951, 17-18, 67-70.

Books

Aloni, Shlomo, *Israeli F-4 Phantom II Aces* (Oxford, United Kingdom: Osprey Publishing, 2004).

Anderson, John David, *A History of Aerodynamics and Its Impact on Flying Machines* (New York, New York: Cambridge University Press, 1997).

Angelo, Jr., Joseph A., *Rockets* (New York, New York: Infobase Publishing, 2006).

Berliner, Don, *Surviving Fighter Aircraft of World War Two: A Global Gide to Location and Types* (South Yorkshire, Great Britain: Pen & Sword Books, Ltd., 2011).

Bowman, Martin W., *Lockheed F-104 Starfighter* (Marlborough, United Kingdom: The Crowood Press, 2001).

Boyne, Walter J., *Roaring Thunder: A Novel of the Jet Age* (New York, New York: Tom Doherty Associates, LLC., 2006), 89.

Boyne, Walter J., *Beyond the Wild Blue: A History of the United States Air Force; 1947-199*7 (New York, New York: St. Martin's Press, 1997).

Buttler, Tony, *American Secret Projects: Fighters and Interceptors; 1945-1978* (North Branch, Minnesota: Specialty Press, 2007).

Coggins Jr., Colonel Edward V., *Wings that Stay on: The Role of the Fighter Aircraft in War* (Paducah, Kentucky: Turner Publishing Company, 2000).

Conner, Jack, *The Engines of Pratt & Whitney: A Technical History as Told by the Engineers Who Made the History* (Reston, Virginia: American Institute of Aeronautics and Astronautics, 2010).

Conner*,* Margaret, *Hans von Ohain: Elegance in Flight* (Reston, Virginia: American Institute of Aeronautics and Astronautics, 2001).

Constant II, Edward W., *The Origins of the Turbojet Revolution* (Baltimore, Maryland: The Johns Hopkins University Press, 1980).

Crosbie, Sylvia K., *A Tacit Alliance: France and Israel from Suez to the Six Day War* (Princeton, New Jersey: Princeton University Press, 1974).

Davies, Peter, *F-104 Starfighter Units in Comba*t (Oxford, United Kingdom: Osprey Publishing, 2014).

Davies, Peter, *F-105 Thunderchief Units of the Vietnam War* (Oxford, United Kingdom: Osprey Publishing, 2010).

Davies, Peter, *US Marine Corps F-4 Phantom II Units of the Vietnam War* (Oxford, United Kingdom, Osprey Publishing, 2012).

Davies, Peter, *USN McDonnell Douglas F-4 Phantom II* (New York, New York: Osprey Publishing, 2016).

Davies, Peter, *USAF McDonnell Douglas F-4 Phantom II* (Oxford, United Kingdom: Osprey Publishing, 2013).

Eltscher, Louis R., and Edward M. Young, *Curtiss-Wright: Greatness and Decline* (New York, New York: Twayne Publishers, 1998).

Elward, Brad, and Peter Davies, *US navy F-4 Phantom II MiG Killers: 1965-70* (Oxford, United Kingdom: Osprey Publishing, 2001).

Francillon, René J., *McDonnell Douglas Aircraft since 1920: Volume 2* (Annapolis, Maryland: Naval Institute Press, 1988).

Fulgaro, Lou, *Giants Over Korea: A Sky too Far* (Bloomington, Indiana: Stars and Stripes Publishing, 2003).

Gaddis, John Lewis, *The Cold War: A New History* (New York, New York: Penguin Books, Ltd., 2005).

Garvin, Robert V., *Starting Something Big: The Commercial Emergence of GE Aircraft Engines* (Reston, Virginia: American Institute of Aeronautics and Astronautics, Inc., 1998).

General Electric Company, *Seven Decades of Progress: A Heritage of Aircraft Turbine Technology* (Fallbrook, California: Aero Publishers, Inc., 1979).

Golan, John W., *Lavi: The United States, Israel, and a Controversial Fighter Jet* (Lincoln, Nebraska: University of Nebraska Press, 2016), 8.

Green, Michael, *Combat Aircraft of the United States Air Force: Rare Photographs from Wartime Archives* (South Yorkshire, United Kingdom: Pen & Sword Books, Ltd., 2016).

Greene, Meg, *The B-52 Stratofortress* (New York, New York: Rosen Publishing Group, 2003), 17.

Grove, Michael, and Jay Miller, *North American Rockwell A3J/A-5 Vigilante* (Osceola, Wisconsin: Motorbooks International Publications, 1989).

Gunston, Bill, and Mike Spick, *Modern Air Combat: The Aircraft, Tactics and Weapons Employed in Aerial Warfare Today* (New York, New York: Crescent Books, 1983).

Gunston, Bill, *Rolls-Royce Aero Engines* (Somerset, United Kingdom: Patrick Stephens Limited, 1989).

Gunston, Bill, *World Encyclopedia of Aero Engines: From the Pioneer to the Present Day* (Gloucestershire, United Kingdom: Sutton Publishing, 2006).

Hansen, James R., *The Bird is on the Wing: Aerodynamics and the Progress of the American Airplane* (College Station, Texas: University of Texas A&M Press, 2004).

Heaton, Colin D. and Anne-Marie Lewis, *The German Aces Speak II: WWII Through the Eyes of Four More of the Luftwaffe's Most Important Commanders* (Minneapolis, Minnesota: Zenith Press, 2014).

Ed. Higham, Robin, *Flying American Combat Aircraft: The Cold War* (Mechanicsburg, Pennsylvania: Stackpole Books and Sunflower University Press, 2005).

Hobbs, David, *The British Carrier Strike Fleet: After 1945* (Annapolis, Maryland: Naval Institute Press, 2015).

Holder, Bill, *Convair B-58 Hustler* (Atglen, Pennsylvania: Schiffer Publishing, Ltd., 2001).

Holt, Jr., Colonel George, *The B-58 Blunder: How the U.S. Abandoned its Best Strategic Bomber* (June 26, 2015).

Dennis R. Jenkins & Tony R. Landis, *Experimental and Prototype U.S. Air Force Jet Fighters* (Hinekley, United Kingdom: Midland Publishing, 2008).

Kaiser, David, *No End Save Victory: How FDR Led the Nation into War* (New York, New York: Basic Books, 2014).

Kármán, Theodore von, *Aerodynamics* (Ithaca, New York: Cornell University Press, 1954).

Kay, Anthony, *Turbojet: History and Development 1930-1960. Volume 1: Great Britain and Germany* (Ramsbury, United Kingdom: Crowood Press, 2007).

Knaack, Marcell Size, *Post-World War II Fighters, 1945-1973* (Dallas, Texas: Government Printing Office for the Office of Air Force History, 1986).

Ed. Launius, Roger D., Innovation and the Development of Flight (College Station, Texas: Texas A&M University Press,1999).

Lippisch, Alexander, *The Delta Wing History and Development*, trans. Gertrude L. Lippisch (Ames, Iowa: Iowa State University Press, 1981).

McNeill, William H., *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000* (Chicago, Illinois: University of Chicago Press, 1982).

O'Brien, Phillips Payson, *How the War Was Won* (Cambridge, United Kingdom: Cambridge University Press, 2015).

Pace, Steve, *X-Fighters: USAF Experimental and Prototype Fighters, XP-59 to YF-23* (Osceola, Wisconsin: Motorbooks International Publishers, 1991).

Pattillo, Donald M., *Pushing the Envelope: The American Aircraft Industry* (Ann Arbor, Michigan: The University of Michigan Press, 1998).

Pesnot, Patrick, *Great Spies of the 20th Century* (South Yorkshire, United Kingdom: Pen & Sword Books, Ltd., 2016).

Philpott, Ian, *The Royal Air Force – Volume 2: An Encyclopedia of the Inter-War Years: Volume II: Re-Armament, 1930-1939* (South Yorkshire, Great Britain: Pen & Sword Books, Ltd., 2008).

Polmar, Norman and Robert Stan Norris, *The U.S. Nuclear Arsenal: A History of Weapons and Delivery Systems Since 1945* (Annapolis, Maryland: Naval Institute Press, 2009).

Powell, Robert R., *RA-5C Vigilante Units in Combat* (Oxford, United Kingdom: Osprey Publishing Ltd., 2004).

Powell, Robert R., *RA-5C Vigilante Units in Combat* (Oxford, United Kingdom: Osprey Publishing Ltd., 2004).

Proctor, Jon, Mike Machat, and Craig Kodera, *From Props to Jets: Commercial Aviation's Transition to the Jet Age: 1952-1962* (North Branch, Minnesota: Specialty Press, 2010).

Robinson, Douglas H., *The B-58 Hustler* (New York, New York: Arco Publishing Company, Inc., 1967).

Sandler, Stanley, *The Korean War: No Victors, No Vanquished* (London, United Kingdom: University College London, 1999).

Seidov, Igor, *Red Devils Over the Yalu: A Chronicle of Soviet Aerial Operations in the Korean War 1950-1953*, trans. Stuart Britton (West Midlands, United Kingdom: Helion & Company Limited, 2014).

Sheehan, Neil, *A Fiery Peace in a Cold War: Bernard Schriever and the Ultimate Weapon* (New York, New York: Random House Publishing, 2009).

Simonsen, Erik, *A Complete History of U.S. Combat Aircraft Fly-Off Competitions: Winners, Losers, and What Might Have Been* (Forest Lake, Minnesota: Specialty Press, 2016).

Smil, Vaclav, *Two Prime Movers of Globalization: The History and Impact of Diesel Engines and Gas Turbines* (Cambridge, Massachusetts: Massachusetts Institute of Technology Press, 2010).

Stumpf, David K., *Regulus: America's First Nuclear Submarine Missile* (Paducah, Kentucky: Turner Publishing Company, 1996).

Ed. Taylor, John W.R., *Jane's All the World's Aircraft; 1973-1974* (New York, New York: Haymarket Publishing Group, 1974).

Thomason, Tommy H., *U.S. Naval Air Superiority: Development of Shipborne Jet Fighters; 1943-1962* (North Branch, Minnesota: Specialty Press, 2007).

Upton, Jim, *Lockheed F-104 Starfighter – Warbird Tech Volume 38* (North Branch, Minnesota: Specialty Press Publishers, 2003).

Werrell, Kenneth P., *Sabres Over MiG Alley: The F-86 and the Battle for Air Superiority in Korea* (Annapolis, Maryland: Naval Institute Press, 2005).

Windle, Dave, and Martin W. Bowman, *Lockheed F-104 Starfighter: Interceptor, Strike, Reconnaissance Fighter* (South Yorkshire, United Kingdom: Pen & Sword Aviation, 2011).

Government Documents, Publications, and Papers

Barkey, H.D., “Evolution of the F-4 Phantom” (paper presented at the Technical Program Management Seminar of the American Institute of Industrial Engineers, Washington, D.C., April 19-21, 1971).

Bohn, John T., *Development of Strategic Air Command: 1946-1976* (U.S. Department of the Air Force: Strategic Air Command, 1976).

Department of Defense, DoD 4120-L: Model Designation of Military Aerospace Vehicles, Office of the Under Secretary of Defense, May, 2004).

F-4 “Phantom” Aircraft and Ogden Air Logistics Center: Thirty Years of Pride and Progress (Hill Air Force Base: Ogden Air Logistics Center, 1988).

Freeburg, D.H., *F-4 Modernization Program: Phantom 2 Plus for the Twenty-First Century: Volume 1, Technical Proposal*, McDonnell Douglas Corporation, January 4, 1985.

Futrell, Robert Frank, *Ideas, Concepts, Doctrine: Basic Thinking in the United States Air Force, 1907-1960* (Maxwell Airforce Base, Alabama: Air University Press, 1971).

General Electric Company Aircraft Engine Group, “Evaluation of Fuel Character Effects on J79 Combustor,” *Technical Report AFWAL-TR-80-2092*, November 1980.

Guillaume, Maxime, "Propulseur par réaction sur l'air," French patent no. 534,801 (filed: May 3, 1921; issued: January 13, 1922).
http://worldwide.espacenet.com/publicationDetails/originalDocument?CC=FR&NR=534801&KC=&FT=E

Hall, R. Cargill, “To Acquire Strategic Bombers: The Case of the B-58 Hustler,” *Air University Review*, September-October 1980, 2-19.

Intelligence Memorandum: US and South Vietnamese Air Losses in Southeast Asia, Directorate of Intelligence, Office of Current Intelligence, March 1, 1966, 1, Annex 1 & 3.

J79-8A & 8B Turbojet Engine: Operation and Service Manual (Cincinnati, Ohio: General Electric Product Support Publications, Flight Propulsion Division, September 1965).

Knaack, Marcelle Size, *Encyclopedia of U.S. Air Force Aircraft and Missile Systems: Post-World War II Bombers, 1945-1973; Volume II* (Washington, D.C.: Office of Air Force History, 1988).

Ed. Leonard, Barry, *History of Strategic Air and Ballistic Missile Defense: Volume 1: 1945-1955* (Washington, D.C.: United States Army Center of Military History, 1975). http://www.history.army.mil/html/books/bmd/BMDV1.pdf

Lorell, Mark, *The U.S. Combat Aircraft Industry, 1909-2000: Structure, Competition, Innovation* (Arlington, Virginia: Rand Corporation, 2003).

Mattingly, Jack D., William H. Heiser and David T. Pratt, *Aircraft Engine Design* (Reston, Virginia: American Institute of Aeronautics and Astronautics, Inc., 2002).

Nelson, J.R., *R-2103-AF: Life-Cycle Analysis of Aircraft Turbine Engines* (Santa Monica, California: Rand Corporation, 1977).

Neumann, Gerhard, "Variable Stator Compressor," United States Patent 2933235 (Filed January 11, 1955, Issued: April 19, 1960).

Penner, Rudolf G., *Tactical Combat Forces of the United States Air Force: Issues and Alternatives*, The Congress of the Unites States Congressional Budget Office, April, 1985.

Perkins, Kendall, *How to Design Good Aircraft* (St. Louis, Missouri: McDonnell Aircraft Corporation Service Engineering, 1954).

Smith, F.L., and Neil Burgess, "Design and Development History of the J79 Engine," *Society of Automotive Engineers*, October, 1960.

Taube, L.J., Study Manager, "SD 72-SH-0003: B-70 Aircraft Study Final Report: Volume II," North American Rockwell Space Division, April, 1972.

Timpson, K.G., "AIAA-81-2414 The F-16/79 Test Program" (paper presented at the AIAA/SETP/SFTE/SAE/ITEA/IEE 1st Flight Testing Conference, Las Vegas, Nevada, November 11-13, 1981).

Walsh, Kevin R., *Summary of the Effects of Engine Throttle Response on Airplane Formation-Flying Qualities: NASA Technical Memorandum 4465*, Dryden Flight Research Facility, Edwards, California, 1993.

Whittle, Frank, "Improvements relating to the propulsion of aircraft and other vehicles," British patent no. 347,206 (filed: January 16, 1930, Issued: April 16, 1931). http://v3.espacenet.com/origdoc?DB=EPODOC&IDX=GB347206&F=0&QPN=GB347206

Memoirs and Autobiographies

Johnson, Clarence L., *Kelly: More Than My Share of It All* (Washington, D.C.: Smithsonian Books, 1985).

Neumann, Gerhard, *Herman the German: The Former Enemy Alien and Air Corps G.I. Whose Inventive Skills and Maverick Management Techniques Made Jet Engine History* (New York, New York: William Morrow and Company, Inc., 1984).

Periodicals, Journals and Annuals

Bugos, Glenn E., “Manufacturing Certainty: Testing and Program Management for the F-4 Phantom II,” *Social Studies of Science*, Volume 23, Number 2 (May, 1993), 265-300.

Bugos, Glenn E., “Testing the F-4 Phantom II: Engineering Practice in the Development of American Military Aircraft, 1954-1969,” *Business and Economic History*, Volume 18 (1989), 13-18.

Butler, Jr., Hartman L., George J. Podrasky and J. Devon Allen, “The Aerospace Industry Re-Revisited: Commercial Aircraft,” *Financial Analysts Journal*, Volume 33, Number 5 (September – October, 1977), 53-66.

Constant II, Edward W., “A Model for Technological Change Applied to the Turbojet Revolution,” *Technology and Culture*, Volume 24, Number 4 (October, 1973), 553-572.

Cowett, Alexi J., “The Ultimate Flying Machine? *Harvard International Review*, Volume 8, Number 5 (April, 1986), 35-37.

DeHaven, Lee R., “Phifty Years of Phantom II Phighters,” *American Aviation Historical Society,* (Summer, 2008), 82-103.

Hogue, Martin, “A Site Constructed: The Bonneville Salt Flats and the Land Speed Record, 1935-1970,” *Landscape Journal*, Volume 24, Number 1 (2005), 32-49.

Husbands, Jo, “Reagan’s Arms Sales Programs,” *Arms Control Today*, Volume 12, Number 8 (September, 1982), 4-6.

“A Jet Without Wings,” *American Society for Engineering Education Prism*, Volume 13, Number 5 (January, 2004), 15.

“Origins of the Spook,” *American Aviation Historical Society,* (Summer, 2008), 104-105.

Petrinic, Emil, “The Fastest Phantom: A Joint American-Israeli Program Sought to Modify the F-4 for Mach 3 Reconnaissance Missions,” *Aviation History*, March 2015, 14-15.

Post, Robert C., “The Land Speed Record and the Last Green Monster,” *Technology and Culture*, Volume 50, Number 3 (July, 2009) 586-593.

Potts, Jr., Ramsay D., “The Foundations of Soviet Air Power: A Historical and Managerial Interpretation,” *The Annals of the American Academy of Political and Social Science*, Volume 299 (May, 1955), 38-48.

Rosenbloom, Joshua, “The Politics of the American SST Programme: Origin, Opposition and Termination,” *Social Studies of Science*, Volume 11, Number 4 (November, 1981), 403-423.

"Text of President Eisenhower's Message to Congress on the State of the Union," *New York Times*, January 10, 1959, 6.

Warren, Glenn B., “Jet-Propelled Airplanes,” *General Electric Review*, Volume 55, 1952, 34-36.

Miscellaneous

Gitlin, Jonathon M. “A Missile with Wheels on it – The Pride of a Nation: The North American Eagle Land Speed Record Project.” https://arstechnica.com/cars/2016/10/the-pride-of-a-nation-the-north-american-eagle-land-speed-record-project/.

“Production Line Continues beyond 2024 for CF6 Engine,” GE Aviation Press Release, July 9, 2012, https://www.geaviation.com/press-release/cf6-engine-family/production-line-continues-beyond-2024-cf6-engine.

Acronyms

A.F.B.	Air Force Base
B.M.C./E.F.H.C.	Base Maintenance Costs per Engine Flight Hour Cost
BuAer	Bureau of Aeronautics
C.N.O.	Chief of Naval Operations
D.A.C.T.	Dissimilar Air Combat Training
F.X.	Fighter for Export
G.E.	General Electric
I.A.I.	Israeli Aircraft Industries
I.D.F./A.F.	Israeli Defense Force Air Force
I.G.V.	Inlet Guide Vanes
G.E.A.G.T.D.	General Electric Aircraft Gas Turbine Division
G.E.B.O. I	Generalized Bomber Study I
M.A.C.	McDonnell Aircraft Corporation
mph	miles per hour
M.T.B.O.	Maintenance Time Between Overhauls
N.A.C.A.	National Advisory Committee for Aeronautics
N.A.G.P.A.W.	North American General Purpose Attack Weapon
N.A.T.O.	North Atlantic Treaty Organization
P&W	Pratt & Whitney
R.I.O.	Radar Intercept Officer
S.A.C.	Strategic Air Command

S.A.M.	Surface to Air Missile
S.L.A.R.	Side Looking Airborne Radar
T.A.C.	Tactical Air Command
U.A.L.	United Air Lines
U.K.	United Kingdom
U.S.	United States
U.S.A.F.	United States Air Force
U.S.M.C.	United States Marine Corps
U.S.N.	United States Navy
U.S.S.R.	Union of Soviet Socialist Republics
W.S.O.	Weapons System Operator
WWII	World War II