Altitude Wind Tunnel – Interactive History

NOTE: This is a text-only version made available for printing purposes. The actual multimedia piece contains many photographs, videos, and other resources not included in this document. They can be viewed here: Launch Interactive History . The main Altitude Wind Tunnel website can be found here: AWT website.

I. Introduction

The Altitude Wind Tunnel (AWT) was capable of operating full-scale aircraft engines in conditions that replicated those actually encountered by aircraft during flight. The AWT was the first wind tunnel in the United States, and possibly the world, with this ability. From 1944 to 1958 it played a significant role in the improvement of turbojet, ramjet, and turboprop engines, and resolved a major engine problem on the B-29 bomber during World War II. The addition of large supersonic wind tunnels for engines and altitude simulating engine test stands between 1948 and 1955, however, reduced the need for the AWT.

This reduction in use coincided with the emerging space program. In 1959 several of the tunnel's internal components were removed so that a series of Project Mercury tests could be conducted inside the actual tunnel. The tests were successful, but the facility would never be used again as a wind tunnel.

In 1961 the facility was converted into two large vacuum chambers and renamed the Space Power Chamber (SPC). The remainder of the tunnel's internal components were removed, and bulkheads were inserted to separate sections of the tunnel. One chamber could create a space environment and was used to qualify systems on a full-size Centaur rocket. Nose cone jettison and propellant management studies were undertaken in the other chamber, which recreated the atmosphere of 100,000 feet.

During its 30 years of operation, the facility continually evolved to meet the nation's ever-changing aeronautics and space needs—from the reciprocating engine to second-stage rockets. This multimedia product seeks to bring the facility's rich history to life through interactive pieces that incorporate a large number of photographs, video clips, documents, and other resources. Although the facility was demolished in 2008 due to lack of mission, high maintenance costs, and environmental concerns, it is hoped that its story and significance will live on through this cd-rom.

II. Chronology

A. Construction

'The difference between freedom and subjugation is the difference between 400 miles per hour and 350 miles per hour; the difference between flying at 30,000 feet and 20,000 feet; the difference between twenty guns and four guns; the difference between a good engine and one that is not good.' Those are the words of Dr. Edward Warner, NACA Chief Physicist, in January 1941, as the war in Europe intensified.

At the time, German aircraft were flying higher and faster than the U.S. fighters. This was primarily due to the lack of attention the US had given to the improvement of aircraft engine technology. The NACA's Aircraft Engine Research Laboratory (AERL) and its Altitude Wind Tunnel (AWT) were created to rectify that situation. The US had never possessed a wind tunnel designed specifically to study the performance of aircraft engines or capable of creating actual flight conditions.

The engineering of this complex facility was said to have required more man-hours than the Hoover Dam. There were three distinct groups of engineers creating blueprints for this new type of wind tunnel—one designing the tunnel structure, one planning the test chamber, control room, fan, and exhaust system, and another creating the world's largest refrigeration system.

Construction for the AWT began in spring of 1942. The nation's involvement in World War II was escalating. This resulted in both an intense need for the new wind tunnel, and a short supply of construction materials. The AWT was completed in January 1944, less than two years after the foundations were sunk.

1. The Need for the AWT

Aided by a strong post-war economy and the immigration of European engineers, the US had a robust aeronautical industry. While the nation invested its energy into producing large quantities of aircraft, the Europeans spent their limited funds on aeronautical and propulsion research. By the late 1930s Europeans were using liquid-cooled engines and were in the process of developing the turbojet. Their aircraft, though fewer in number than the US, could fly higher and faster. The NACA was created in 1915 to coordinate the nation's aeronautical research. In 1920 the NACA created its own research laboratory at Langley Field, Virginia which focused its efforts on aerodynamics and not propulsion. The Propeller Research Tunnel was built by 1927 to study drag caused by engine protuberances and propellers, but not the engine's performance.

The National Bureau of Standards had done some altitude testing of its Liberty engine in 1917, but in general there were no other methods of studying an aircraft engine in flight conditions without the often dangerous test flights. In the mid-1930s the NACA discovered that Germany had an extensive aeronautical research program with an entire laboratory dedicated to engine research. By the end of the decade, Congress approved funding for two new NACA research centers to rectify this disparity. The Ames Aeronautical Laboratory would study high-speed flight and the AERL in Cleveland, Ohio would concentrate on engine and propulsion technology.

The AERL, now the NASA Glenn Research Center, would contain a number of engine test stands, flight research and fuels and lubrications groups, and a massive wind tunnel designed to study full-scale aircraft engines in an altitude environment. The AWT was the most complete facility for testing of full-scale engines prior to production. AERL Executive Engineer, Carlton Kemper, stated that, 'AERL is unique in having the only altitude wind tunnel in the world. We can expect that this one research tool will give answers to the military services that will more than offset the cost of the laboratory.'

2. Design of the AWT

At Langley Raymond Edward Sharp led a group of approximately 30 engineers and draftsmen from the administrative section who created the Cleveland engine lab. Among this assemblage were smaller teams working on specific facilities. One of these led by Al Young and Larry Marcus designed the AWT's fan, exhaust and make-up air systems, as well as the Shop and Office Building and other tunnel support buildings.

The tunnel's shell and test section were designed at Ames by a group led by Carl Bioletti. This group included Walter Vincenti, John Macomber and draftsman Manfred Massa. The AWT's ability to simulate altitude with both pressure and temperatures made the shell's design more difficult than the pressure tunnels at Langley and Ames. Vincenti was unable to calculate that type of thermal stress for the AWT's support rings and shell. Vincenti consulted a former professor of his at Stanford, Stephen Timoshenko. Timoshenko, a leading structural analyst, developed some calculations to measure the stress levels. Vincenti sent the calculations and notes to the Cleveland design team.

Willis Carrier, who was referred to as the Father of Air Conditioning, heard of the NACA's plans for cooling the air inside its new wind tunnel. An effort of this size had never been undertaken before and Carrier felt his company's heat transfer experts, rather than the NACA engineers, should be designing the system. Carrier arranged the tunnel's cooling coils in a zigzag manner to increase the surface area. It was also the first time Freon-12 was used as a refrigerant in a large system, so Carrier modified their compressors accordingly. Carrier referred to the success of the AWT system as one of his most rewarding projects.

3. Construction of the AWT

The United States would enter the war in Europe less than a year after the groundbreaking for the new engine lab, and there was pressure to accelerate the construction schedule. There were still no buildings completed in August 1941 when Ray Sharp arrived from Langley to assume the oversight of the construction. A large contingent of Langley personnel were transferred to Cleveland in December 1941 and were placed under Ernest Whitney and Beverly Gulick. The AWT Project Engineers used Gulick's draftsmen and designers to help design certain aspects of the tunnel.

The AWT foundations were laid in the spring of 1942. Construction of the Shop and Office, Refrigeration, and Exhauster buildings began in September 1942 and was completed the following fall. George Lewis visited the Cleveland lab weekly to keep an eye on its progress. Drastic measures were undertaken to complete the project on schedule. The military pressured Congress and the NACA to expedite the work and a number of measures were taken to that effect. Large portions of the lab were operating in 1943. Assembly of the tunnel and its infrastructure began in late 1942 and was finished in January 1944.

4. Operation of the AWT

The AWT was amongst the most sophisticated test facilities in the country when it came online in 1944. The basic layout of the tunnel shell was similar to other contemporary tunnels, but its altitude simulation and engine firing capabilities required a number of design innovations that made the tunnel unique. These included the powerful refrigeration system, air scoop, make-up air, and unique shell structure.

The airflow was created by a 12-bladed, 31-foot diameter fan that was spun by an 18000-horsepower induction motor. Speeds could reach 500 miles per hour at the pressure altitude on 30,000 feet. Turning vanes in each corner and a long tail fairing on the fan straightened the airflow. Because full-scale engines were operating in the tunnel, special efforts had to be undertaken to remove the engine's combustion products before they contaminated the air stream. A nacelle-like exhaust scoop was located just beyond the test section to ventilate the exhaust out of the tunnel. Two make-up air lines were located upstream of the test section to replenish the stream with cool, dry air. The exhaust pumps, located in the Exhauster Building, also evacuated the tunnel to pressure altitudes up to 50,000 feet.

A massive refrigeration system, powered by 14 Carrier compressors in the Refrigeration Building, could cool the tunnel's interior to -47 degrees Fahrenheit. Freon 12 was liquefied then pumped into 8 identical heat exchangers inside the tunnel. These heat exchangers were a collection of 260 copper-plated coils which stretched across the wide end of the tunnel. As the tunnel air passed through the coils, heat was transferred to the Freon. After being transferred to the Refrigeration Building, the Freon transferred the heat to cooling water which was sent to a nearby cooling tower to be dissipated.

The 20-foot diameter and 40-foot long test section was contained in the test chamber area in the rear section of the Shop and Office Building. The chamber had three floors—a ground level floor, a mezzanine, and an open two-story upper floor. The mezzanine level contained the Control Room and manometers. The upper level was a high-bay area, its floor serving as a viewing platform, was used to load and install test articles in the test section. Engines were incorporated onto aircraft fuselages or sawed-off wing sections. In either case, the wings stretched across the test section to trunnions on the tunnel walls, which were part of the balance frame. The balance frame underneath the test section contained scales which measured thrust, drag, lift, and pitching movements of the test article. Thermocouples and survey rakes installed on the engine measured various pressures.

B. World War II

The Aircraft Engine Research Laboratory (AERL) was created by the NACA specifically to improve military aircraft engines for World War II. This was particularly true for the Altitude Wind Tunnel (AWT), which was the most complete facility for testing of full-scale engines prior to actual production. On December 2, 1941 William Knudson, Director General of the War Department's Production Management Office, wrote the NACA, “The high-altitude wind tunnel is especially needed to solve problems in connection with the cooling and power output of engines in combat planes required to fight at altitudes of 40,000 to 50,000 feet.”

World War II was the first war in which aircraft would play a dominant role. A new, more powerful type of engine, the turbojet, was being developed in Europe, but the U.S. wanted to strengthen their existing reciprocating engines. The AWT was used to improve several of these piston engines. The most important was the Wright R-3350 for the B-29 bomber, but others included a propeller test Republic YP-47, analysis of the Pratt & Whitney R-4360 engine in both the Lockheed's XR-60 Constitution and the Douglas XTBD2 torpedo bomber. Despite the NACA's focus on piston engines, though, the majority of the AWT's investigations concerned the emerging turbojet technology. In fact, its very first test was the Bell YP-59A which was powered by two General Electric I-16 jets.

1. **Bell YP-59A Airacoment**

   British engineer Frank Whittle had developed his version of the jet engine as early as 1930 and operated it by 1934. Head of the US Air Command General Hap Arnold witnessed the first flight of the Whittle engine-powered Gloster E.28/39 on May 15, 1941 and made arrangements to secretly bring the Whittle design back to the States. Using these plans General Electric (GE) quickly created the I-A centrifugal flow engine. In October 1941 Bell Aircraft was given the responsibility to design an aircraft to incorporate the new US jet engine.

   The YP-59 Airacomet aircraft, however, did not perform well with the jet engines. GE updated the engine and renamed it the I-16, which were incorporated into an Airacomet with an elongated fuselage, referred to as the YP-59A. The secret test flights were successful but underwhelming. The AWT would be complete by the end of the year, though. Arrangements were made for the Airacomet to be secretly brought to Cleveland and studied in the new facility.

   The aircraft was tested in its original configuration and afterwards with redesigned boundary layer removal duct, nacelle inlets, and cooling air seals. The modifications allowed better distribution of airflow and reduced drag. Although this improved the aircraft's performance by 25-percent, the Airacomet never did play any significant role during World War II and Bell would be left out of the military's turbojet plans.

2. **B-29 Engine Cooling Studies**

   The military contracted with Boeing to develop a high-altitude daytime bomber that would supersede Boeing's B-19 Flying Fortress. Boeing devised the B-29 Superfortress powered by four Curtiss-Wright R-3350 2200 horsepower gas turbine engines. Although development of the R-3350s began in the mid-1930s the engines continued to be plagued with problems when incorporated into the B-29 design in 1942. Despite this and many other problems with the aircraft itself, the Superfortresses were rushed through production. One of the most serious problems encountered by US airmen was the overheating and burning up of the R-3350s when the B-29 climbed to the high-altitudes at which it was intended to operate.

   The Air Command summoned the new AERL to investigate and solve this problem. Many of the AERL's facilities studied the engines and flight tests were conducted with an actual B-29. In May 1944, a R-3350 was installed in the AWT. Researchers determined the cooling problems stemmed from inconsistent fuel mixtures and poor air flow through the engine. By devising a fuel injection system and redirecting the air flow through the engine's cylinders the AERL researchers were also able to broaden the B-29s flight range and increase its armament capabilities by increasing the fuel efficiency by 18-percent.

3. Wartime Schedule

The pressure on the staff at the AERL to remedy the engine performance problems on military aircraft was tremendous during the final years of the war. Over 92-percent of the AWT and Icing Research Tunnel's tests during the war years were for the Army or Navy. After coming online in February 1944, the AWT crews worked 24 hours a day seven days a week. This strain was exacerbated by a manpower shortage. Although measures were taken to retain NACA employees, a large number were drafted into the Armed Forces. Initially workers were paid overtime for extra hours, but this was rescinded by 1943.

Because of its tremendous power requirements, NACA officials had made a deal with the Cleveland electric company to run the AWT only at night. The first and second shifts general broke down the previous night's setup and prepared for that night's test run. The third shift would come in to run the tunnel and carry out the test. The engineers or researchers often had to work all day then return at night to conduct the tests. Eventually some crew chiefs were trained to run the tunnel. On June 20, 1944 AWT employees were divided into four groups that covered two shifts, 3PM to 1:30AM and 11PM to 7AM.

The operation of the AWT required a large well-coordinated team. The researchers devised the tests and controlled the engine during the test runs. Operational engineers made sure the tunnel was operating properly and coordinated with the electric company and operators in other buildings. Maintenance engineers or mechanics repaired the facility and handled the assembly and disassembly of test articles. Although interrupted by the war, the lab had an apprentice program that for years trained mechanics. At times there was tension between the groups, but during the war years the staff was more like a family.

C. Turbojets

Many in NACA thought the gas turbine engine was not a viable alternative to the well-developed reciprocating engine. It was thought that the weight of the turbine's components would exceed the aircraft's capabilities and require too much fuel. Although, this was initially a realistic assessment, as the turbojet was perfected from the late 1940s and throughout the 1950s, these shortcomings were overcome. The jet engine's speeds, ability to use a wide variety of fuels, the eradication of the propeller, and clearly superior high-speed performance left no doubt of the turbojet's importance to aeronautics.

The first jet engines had centrifugal compressors. General Electric (GE) developed several variations including the I-40 which was used in the nation's first homegrown jet aircraft, the YP-80A Shooting Star. Simultaneously was the development of axial-flow turbojets by the Westinghouse Corporation and GE's Schenectady group. The axial-flow designs would be the basis for the modern jet engine. At the same time, a variation of the gas turbine that included a propeller was being explored. The Altitude Wind Tunnel (AWT) was used to study and improve all three variations of the turbojet in their early stages.

In October 1945, shortly after the end of World War II, the entire laboratory was reorganized to pursue the new realms of high-speed flight and the turbojet. The NACA's engine research lab and its AWT were able to create a succession of advancements on the gas turbine engines that resulted in a tremendous surge in thrust capabilities in the late 1940s and early 1950s. The lab would be renamed to Flight Propulsion Laboratory in 1947 and then renamed the Lewis Flight Propulsion Laboratory the following year.

1. Centrifugal Turbojets

Since the 1920s General Electric had made significant strides developing the gas turbine engine for a variety of uses and had been the prime developer of the turbocharger. For this reason, General Hap Arnold selected GE to build the I-A engine based on Frank Whittle's drawings. The I-A was troubled, but the team at the GE plant in West Lynn, Massachusetts improved the design with the subsequent I-16 engine. Though this eventually resulted in several Airacomet flights, it was not until the engine's next reincarnation as the 4000-pound thrust I-40 that the jet engine's promise was revealed.

After the disappointment of Bell's XP-59A, the Air Force contracted with Lockheed in 1943 to design a new jet fighter. Lockheed's YP-80A Shooting Star was the first complete jet aircraft manufactured in the United States and was the first Air Force aircraft to fly faster than 500 mph. The I-40 underwent its first run in early 1944 and was almost immediately incorporated in the Shooting Star. The aircraft suffered operational problems and crashes during early test flights.

In spring of 1945 Shooting Star with its I-40 was tested in the AWT. These runs were followed up with tests of the I-40 in Lockheed's two-seated version of the Shooting Star, the TP80S. The investigations included both general engine performance at altitudes up to 50,000 feet and specific studies including high-altitude restarting, adjustable tailpipe nozzles, and engine stalls at altitude. The studies resulted in the restarting of the engine above 20,000 feet for the first time. The use of the variable nozzle provided an almost instantaneous 50-percent increase in thrust. The researchers were also able to develop a curve that would allow future I-40 tests to be conducted at sea level and scaled to altitudes. Despite these improvements, the Shooting Star would not be a success until its reincarnation as the F-80 in the Korean War.

2. Axial-Flow Turbojets

The first and only US axial-flow engine to actually be flight tested during the war was the Westinghouse 19A. This axial-flow compressor engine consisted of several identical stages of compressor blades arranged in line. The centrifugal compressor used a single large stage. In 1941 the US Army contracted with Westinghouse and GE's plant in Schenectady, New York to develop axial-flow turbojets. Westinghouse developed the 19A which was improved upon with 19B, 19XB, and various 24C designs. GE's Schenectady group had already been considering using an axial-flow design for a turboprop, but it now also pursued the TG-180 jet engine and its successor, the TG-190. The AWT would be used to investigate all of these axial-flow designs.

The tests in the AWT focused on the operation of the 19B-2 and 19B-8 six-stage prototypes, along with experimental prototypes, the 19XB-1 and 19XB-2, which had ten-stage compressors. The 19B models suffered combustion blowouts and had difficult restarting at altitude, but the new 19XB versions performed well and restarted consistently at altitudes up to 35,000 feet. The 19B would be incorporated into two strange World War II aircraft, the Douglas XB-42A Mixmaster which used both piston and jet engines, and the Northrop XP-70 which was literally a flying wing that was intended to sever the wings of enemy aircraft. Both aircraft flew during 1944, but were still being developed when the war ended.

GE's TG-180 was an 11-stage axial-flow compressor engine whose design began in May 1943. It was studied repeatedly in the AWT throughout the 1940s. The first series of tests in early 1945 focused on increasing the engine’s thrust by using an early version of the afterburner. The researchers experimented with various flame holders and fuel systems to find the optimum configuration. In addition, it was found that when the compressor blades spun due to air flow rather than the turbine, as in the case of an engine stall, a tremendous amount of drag was created. This led to the implementation of retractable nacelle covers.

3. Turboprops

The turboprop engine, which used a jet engine to spin a propeller, was one of the earliest schemes to use the gas turbine for aircraft propulsion. This technology would be successfully resurrected in the mid-1970s for NASA Lewis' Advanced Turboprop Program.

General Electric began development of the first US turboprop in 1941 at the request of the Army, but this TG-100 was not successfully flight tested until December 1945. In late 1946 the TG0-100A was given a thorough analysis in the Altitude Wind Tunnel. Basic engine performance information was gathered and determined over a range of altitudes. Problems with the engine continued, however, and the program was cancelled in 1947 before any being incorporated into any production aircraft.

In 1949, a British Armstrong-Siddeley turboprop was acquired by the NACA specifically for its researchers to study. A frequency-response method was used to predict the dynamic response characteristics at any altitude from the data obtained from any other specific altitude. The dynamic response of the propeller and propeller/engine pairing was obtained during a single test run. The Wyvern torpedo bomber which used the Python had already flown at the time and would be used by the Royal Air Force throughout the 1950s.

D. Second Generation Jets

Although the US aeronautics community lagged behind its European counterparts in the years leading up to World War II, by the late 1940s it had taken the lead. A new generation of larger, more powerful jet engines emerged. The Altitude Wind Tunnel (AWT) was upgraded several times during the 1940s and 1950s to keep up with the ever-growing engines. A massive improvement was undertaken in 1951 that included new exhausters, a new fan, a water pump house, and a tie-in to the Propulsion Systems Laboratory exhausters. Although not originally constructed for the jet engine, the AWT kept up with the changes.

In the 1940s and 1950s the development of ramjets for missile applications was at the forefront of aerospace research. Ramjets are perhaps the simplest type of propulsion system, but their implementation poses many challenges. Beginning as early as May 1945, ramjets were being studied on a regular basis in the AWT. By the late 1950s, several small rocket engines were also being investigated in the facility.

The Westinghouse J34 and J40, Allison's J71, Pratt & Whitney's J57, and the Rolls Royce Avon engines all underwent investigations in the revamped tunnel. Perhaps the most important accomplishment was a test of a liquid-hydrogen tanking system on a Wright J65 engine. The ensuing test flights with this engine would be used to demonstrate that liquid-hydrogen was safe to use in upper-stage rockets.

1. **Pratt & Whitney J57**

   Pratt & Whitney's J57 axial-flow dual compressor engine was probably the most successful of the second wave of jet engines. The J57 powered military aircraft such as the F-100 Super Sabre, B-52 Stratofortress, Lockheed U-2, Boeing C-135, F-102, as well as the Douglas DC-8 and Boeing 707 and 720 civilian jets.

   The 4390-pound engine J57-P-1 had two spools. The inner set had a 7-stage axial-flow compressor and a single-stage turbine. The outer spool had a 9-stage axial-flow compressor and 2-stage shrouded turbine. The engine was studied at altitudes up to 64,000 feet over the winter of 1953 and 1954 in the AWT. They focused their efforts on the engine’s fuel flow and the effect of inlet pressure alteration and altitude. It was determined that the pressure distortions did not alter the engine’s performance.

   Studies were undertaken in an effort to reduce the J57’s noise so that it could be used in civilian airliners. The engine was brought back to the AWT in 1956 for a yearlong noise suppression study. The J57 was run using various nozzle configurations.

2. **Ramjets**

   Like other types of engines, the ramjet is powered by combustion gases which are heated to high temperatures under pressure then exhausted. Unlike other engines, though, the ramjet is an open-ended tube with no moving parts, only a flameholder vane which makes sure the combustion flame is not extinguished. Another difference is that the ramjet runs at constant pressure instead of a constant volume like the piston engine. Combustion gases flow through the ramjet’s nozzle and are accelerated until they are faster than the engine’s intake air thus providing thrust. The ramjet’s power is a measure of this thrust multiplied by the speed during flight.

   The overall performance of a 20-inch diameter NACA-designed ramjet was studied in the AWT during 1945 and 1946. It was mounted on a traditional wingspan with the intake air piped directly to its inlet. This allowed the ram pressure ratio to be comparable to supersonic speeds while running in the subsonic AWT. The tests at altitudes up 47,000 feet found the performance increased by sharply with supersonic speeds but that losses in the supersonic diffuser slowed the rate of increase at higher Mach numbers.

Initially conceived by the Navy in late 1944, the missile known as Project Bumblebee was designed to use ramjet propulsion. The war ended before the missile was completed, but development continued throughout the 1940s at the Johns Hopkins University Applied Physics Laboratory. In 1947 NACA Lewis was asked to study the basic behavior of ramjets for this project. The Lewis program involved a number of flight tests, drops from aircraft, and combustion studies in the AWT. These studies provided optimal performance of an 18-inch diameter version using different types of flameholders. A smaller 16-inch version was also tested in the tunnel with a variety of flameholders during 1949. The Bumblebee tests continued in the 1950s in the 8 by-6-foot and 10 by-10-foot supersonic wind tunnels.

3. Liquid Hydrogen Aircraft

Lewis researchers had been studying high-energy propellants for years. In the mid-1950s interest in liquid hydrogen intensified. The cryogenic propellant was considered dangerous, but its low weight and high-energy were unrivalled. Although it would go on to be a principal component of the space program, Abe Silverstein, Director of Research at the lab, initially conceived of it as propellant for long-range aircraft. One of the early steps was determining if liquid hydrogen could be safely operated in an aircraft fuel system. In 1955 full-system tests of a liquid hydrogen fuel system with the J65-B-3 engine were conducted in the AWT. The system, which was identical to the one intended for use on a B-57 aircraft, was checked using both the jet fuel and hydrogen modes.

A couple of modifications allowed the engine to be tested at higher pressure levels and thus 25 to 30, 000 feet higher altitudes than previous AWT tests. Unlike previous turbojet studies in the AWT, which used external make-up air, this test used tunnel air. This resulted in the exhauster having to only make up for tunnel leakage, rather than leakage plus external air flow. It was found that the jet fuel performance decreased significantly over 60,000 feet, while the hydrogen operated smoothly at at least 80,000 feet, and its blowout altitude exceeded the tunnel’s 85,000-foot capabilities. It was also found that the higher specific heat of hydrogen caused the turbine to produce a greater amount of thrust than obtained from jet fuel.

Although the switch between the jet fuel and hydrogen tanks was tested numerous times in the AWT with satisfactory results, Abe Silverstein secured a contract to work with the Air Force to examine the practicality of a liquid hydrogen aircraft. The endeavor was termed Project Bee. A new B-57B aircraft was obtained by the Air Force especially for this project, and a liquid hydrogen production plant was built in nearby Painesville, Ohio. The aircraft was equipped with 23-foot wing tanks, one of which was modified so that it could be operated using traditional or liquid hydrogen propellants. The other tank would be used to store helium which would be used to pump the hydrogen. After two flights failed to make the switch to liquid-hydrogen, a third attempt in February 1957 was successful. These flights would later be used to help convince NASA leadership that liquid hydrogen was safe to use for the Apollo Program.

E. Project Mercury

New propulsion test facilities were built in the 1950s at NACA Lewis, and by the end of the decade the Altitude Wind Tunnel (AWT) became used less. This coincided with the nation's new fascination with space travel in the wake of Sputnik I. Abe Silverstein was called to Headquarters to help develop a new US space agency. Silverstein and NACA Director Hugh Dryden convinced Congress that the new agency should be based on the NACA. On October 1, 1958 the National Aeronautics and Space Administration was formally founded. Silverstein remained in Washington as part of the Space Task Group (STG) which developed the incipient space program.

Big Joe, a mockup capsule without an escape tower, life support, or several other systems, was to be launched on an Atlas booster from Cape Canaveral. The flight was to simulate the reentry of the capsule without actually placing it in orbit and test the launch and recovery processes. Originally the Space Task Group wanted to qualify the Big Joe capsule's retrorockets, instrumentation, parachute and recovery systems by dropping it from a balloon near the edge of the atmosphere. By May 1959 it was decided to instead qualify Big Joe in the Altitude Wind Tunnel. The tunnel was used to fire the attitude control and retrorockets and expose the capsule to simulated altitudes up to 80,000 for long periods of time. This sped up the pre-flight testing and saved the agency money.

On October 15, 1959 the STG met to allocate test assignments for Project Mercury. The AWT would play an important role in the effort to place an American in orbit. Silverstein was familiar with the facility's capabilities and was able envision use of the tunnel in non-traditional ways. The vast interior of the AWT's western leg would be used to test the Atlas and Redstone rocket separation systems, calibrate retrorockets, and test the capsule’s attitude control system. The AWT was also selected to study the escape tower rocket’s plume and train astronauts how to bring a spinning capsule under control.

1. **Multi Axis Space Test Inertial Facility**

   A gimballing platform had been set up in the AWT to test systems components for the Big Joe capsule. Afterwards it was decided to expand this piece of equipment to include a pilot's chair and nitrogen jet control system. The new Mercury 7 astronauts would practice bringing a tumbling out-of-control spacecraft under control.

   In February and March 1960, the seven Mercury Program astronauts, a female astronaut candidate, and several pilots traveled to Lewis to train on the Multi Axis Space Test Inertial Facility, or MASTIF. An astronaut was secured in a foam couch in the center of the rig. The rig then spun on three axis from two to fifty rotations per minute. The pilots were tested on each of the three axis individually, then all three simultaneously. Small nitrogen gas thrusters were used by the astronauts to bring the MASTIF under control.

   Early tests revealed that astronauts responded well to disorientation on any one axis, but along two or more axis, the pilot's response time was slow. The initial tests spun the pilots at 20rpm and later increased to 50rpm. The MASTIF tests determined that up to 70rpm had no 'measurable influence' on the astronauts' operation of the rig. At that speed, they were also able to perform complex tasks with just a 6.5 to 18-percent error rate while operating the MASTIF at 70rpm. Repetition of these tasks reduced the error rate even further. It was also found that when the astronauts stared at a single point, the effects of nystagmus (rapid, involuntary side-to-side eye movement) were reduced significantly.

2. **Retrorockets**

   The Mercury capsule had six rockets on a “retro-package” affixed to the bottom of the capsule. Three of these were posigrade rockets used to separate the capsule from the booster, and three were retrograde rockets used to slow the capsule for reentry into the earth’s atmosphere. There were several problems while qualifying the posigrade and retrograde rockets, and there was no backup system if the retrograde braking system failed. The STG assigned the Lewis and Ames centers the task of resolving the issue.

   Full-scale separation tests using both Redstone and Atlas boosters were conducted in the AWT at altitudes comparable to the upper atmosphere. The capsule was affixed to the horizontal simulated boosters. The AWT tests in January and February 1960 determined that a gas build-up in the Redstone ballast section actually accelerated the separation process. Mercury Atlas separation tests in mid-April ensured that the firing of the posigrade rockets did not injure any other components and determined the actual boost level of the posigrades.

Three Mercury retrorocket qualifications tests were also begun in April 1960 in the AWT. A retrograde thrust stand was erected in the southwest corner of the tunnel. The studies showed that a previous issue concerning delays igniting the propellant had been resolved. Follow-up test runs verified reliability of the coated igniter's attachment to the propellant grain. In addition, they calibrated the capsule's retrorockets so they would not alter the capsule's position when fired.

3. Escape Rocket Tests

The AWT was also used to determine if the plume from the Mercury capsule escape tower rocket would shroud the spacecraft. The escape tower was a steel rig attached to the nose of the Mercury capsule. The tower had its own propulsion system which could be used to jettison the astronaut to safety in the event of launch vehicle malfunction at any point between prelaunch and the separation. Once the capsule reached its apex of about 2500 feet, the escape tower was jettisoned and the capsule parachuted into the sea.

Qualification tests of the escape tower rocket were conducted in early summer of 1960. The tower and model Mercury capsule were mounted on a make-up air pipe near the southwest corner of the AWT. Three escape-rocket motors were successfully fired at conditions corresponding to approximately 100,000 feet altitude. One motor was tested on a four-component balance system to determine thrust misalignment of the rocket motor. According to test results, the rocket motor appeared to meet operational requirements.

F. Conversion

After the Mercury tests concluded near the end of May 1960, it was decided to construct two test chambers within the Altitude Wind Tunnel (AWT) shell—one capable of simulating the altitudes of outer space, the other of earth's upper atmosphere. At the time there were no large vacuum tanks in the U.S. Initial missions in the late 1950s revealed the behavior of engines, flight systems, and hardware was affected by the conditions encountered in space. The space chamber was originally intended to study a full-scale SNAP-8 nuclear space power conversion system.

Construction began in early summer of 1961 and was completed in a little over a year. Bulkheads were placed within the tunnel to seal off the new chambers, the exterior shell of the east end was rewelded, and a Vacuum Pump House was built underneath the space tank. The facility was officially renamed the Space Power Chambers (SPC) on September 12, 1962. Although larger chambers would later be constructed, the rapid conversion of the AWT allowed the SPC to play an important role in the early years of the space program.

The legacy of the SPC was its contribution to the success of the Centaur rocket. Centaur was, in turn, NASA Lewis' most enduring contribution to the space program. In October 1962, just a month after construction was completed, the troubled Centaur Program was transferred from the Marshall Space Flight Center to Lewis. Centaur was a uniquely designed second-stage rocket that was intended to carry the Surveyor spacecraft on its missions to explore the moon. The SPC would be used throughout the 1960s for a variety of Centaur tests. An elaborate set-up was designed and a removable dome was created in the top of SPC No. 1 to accommodate the Centaur. This process pushed the completion date of the new facility to September 1963.

1. **Construction**

   Construction of the SPC began sometime prior to July 1961 and progressed rapidly. The clamshell lid for the former tunnel test section was removed and a metal bridge and stairway into the tunnel were built at the east end of the test section. Steel grated flooring was installed in the bottom of the test section. A control room for the vacuum chamber, which sought to replicate the launch control room at Cape Canaveral, was created underneath the former tunnel test section. The existing wind tunnel control room was modified to run the tests in the large chamber.

   The tunnel's drive shaft, fan, turning vanes, and exhaust scoop were removed from the east end. Three bulkheads were installed inside the tunnel to create the two chambers. The largest was the 31-foot diameter cap inserted where the drive fan was located. Another seal was created east end of the former test section which completed the sealing off the entire eastern leg of the tunnel, which was referred to as SPC No. 1. Another 20-foot diameter bulkhead was inserted on the western end of the test section before the throat section. This along with the 31-foot seal in the southeast corner created another vacuum test chamber, SPC No. 2 in the remainder of the tunnel.

   A new oil diffusion-based pumping system was installed in the new Vacuum Pump House underneath SPC No. 1. The ten diffusion pumps, connected to the chamber floor from below, worked in conjunction with the Center's exhauster system to create a simulated altitude on 100 miles.

During construction, the outer skin of the tunnel was removed so that the inner shell could be checked for leaks. It was found that the entire SPC No. 1 chamber area had to be rewelded. It was suspected that this was a result of the original hasty war-time construction. The rewelding slowed the conversion progress down and drove up costs. Since the larger SPC No. 2 chamber would be used for upper atmospheric tests it did not have to rewelded and the insulation and outer shell remained in place.

2. Centaur Program

The Centaur rocket was created by General Dynamics for the Department of Defense in 1958. The program was shifted to NASA's Marshall Space Flight Center on November 8, 1959. A Space Task Group committee, chaired by Abe Silverstein, selected a second-stage rocket for the new Atlas booster. Centaur, with its controversial liquid hydrogen propellant and complex design was selected.

The Centaur rocket contained two 15,000-pound thrust engines fueled by the high-energy liquid hydrogen. Unique balloon-like tanks with only a thin boundary separating them were used to store the liquid hydrogen and its liquid oxygen oxidizer. One of the most dynamic aspects of the Centaur was its ability to start and restart its engines in space. This allowed for adjustments of speed and direction. After the final burn, the Centaur separated from the third-stage and fired retro rockets to redirect it back towards earth.

The first Atlas/Centaur launch on May 8, 1962 had a number of defects. It failed shortly after lift-off due to a Centaur malfunction. Marshall had never felt comfortable with Centaur's non-traditional design, and the Centaur Program was on the verge of cancellation. Von Braun felt strongly that liquid oxygen and kerosene should be used for all stages of the Saturn rocket.

Although Lewis had no experience managing a large development program, the center had been performing work with hydrogen and other non-traditional fuels for years, including the use of it in an aircraft. They were confident in its safety and the advantages. In addition, Centaur's RL-10 engines had been undergoing testing in Lewis’ Propulsion Systems Laboratory. In October 1962 Silverstein, by then Director of NASA Lewis, agreed to the transfer of the program to Lewis.

Lewis undertook an extensive effort to test and improve Centaur. Centaur had not only made the Surveyor program a success but would go on to perform over 175 missions with only a handful of failures. These missions m included Pioneer, Viking, the Lunar Orbiter, Orbiting Astronomical Observatories, Cassini, and others.

3. Centaur 6A Test Setup

The intensive testing of the Centaur was divided between the 'E' Stand at Plum Brook Station and the SPC facility. The high-vacuum SPC No. 1 was originally envisioned to test space power devices like the SNAP-8 nuclear generator. With the acquisition of the Centaur Program, however, it was decided to use the tank to study the electronics behavior a full-scale Centaur in a space environment. A number of modifications were made to SPC No. 1 to accommodate Centaur. The most prominent of which was the addition of a 22.5-foot diameter cylindrical extension with a detachable dome near the southeast corner so that the rocket could be stood up vertically.

The rocket used for the tests was a Centaur 6A model originally intended for the follow-up to the Atlas/Centaur-2 flight. A launch pad rehab delayed the launch, and the Centaur was instead removed and transported to Cleveland. The 28.5-foot long and 10-foot diameter Centaur 6A had two Pratt & Whitney RL-10 engines. The electronics and control systems were at the forward section of the rocket so access ports were created in the dome. The Centaur rested in an approximately 9-foot tall triangular stand that sat on the chamber floor below the dome.

Besides creating a vacuum equal to 100 miles altitude, a complex set-up was installed in SPC No. 1 to replicate all aspects of outer space except microgravity and meteors. The cryogenic temperatures of space were supplied by a nitrogen-filled cold wall which enveloped the Centaur. Solar radiation was replicated using 6 banks of quartz lamps. In addition a hydraulic system rotated the rocket’s RL-10 engines as they would be during flight, a tanking system used to keep the balloon-like fuel tanks partially filled, and wide array of telemetry was installed.

G. Centaur

When the Centaur Program was brought to Cleveland in October 1962 the rocket was in poor shape. Its novel design was troublesome, and its only launch attempt ended in a fiery explosion. Abe Silverstein had been Lewis Center Director for almost a year, and had already begun implementing a broad space program in Cleveland. Silverstein felt strongly that anything flown in space should be tested thoroughly first on the ground in the conditions and configuration of the mission.

Although several Lewis facilities participated on smaller components of the program, the primary Centaur testing was divided between the dynamic and vibration studies of the Atlas/Centaur in the E Stand at Plum Brook Station and environmental and shroud jettison tests in the new Space Power Chambers (SPC) facility created in the former Altitude Wind Tunnel (AWT).

The facility's vacuum tank, SPC No. 1, was used to soak a full-size Centaur in a space environment for extended periods of time to verify the performance of its electronics systems. A series of shroud jettison tests were also conducted in SPC No. 1 for two of the Surveyor developmental launches in 1964 and 1965. The facility's first investigations, however, were a series of Atlas/Centaur separation tests during the fall of 1963 in the larger SPC No. 2. SPC No. 2 was also used to qualify shroud separation systems for three different Orbiting Astronomical Observatory missions. New systems for controlling the motion of liquid hydrogen inside the Centaur's fuel tanks were also tested inside SPC No. 2.

1. Centaur System Tests

It had already been determined that space flight systems and hardware behaved differently in space than in an earth environment. It was decided to study the behavior of electronics systems on a full-scale Centaur in the simulated space atmosphere of the SPC No. 1. In October 1963 a Centaur 6A rocket was flown to Cleveland on a C-130 aircraft. For several months General Dynamics personnel worked with NASA Lewis researchers as they studied and began reassembling the rocket in shop area. On March 19, 1964 a 100-foot crane was used to lift the Centaur through the opened dome and into SPC No. 1.

SPC No. 1 possessed a cryogenic cold wall and quartz lamps to replicate both the coldness and solar radiation of space, and the vacuum system created an altitude of 100 miles. The Centaur vehicle utilized a number of systems including autopilot, guidance, main propulsion, hydraulic, hydrogen peroxide supply, boost-pump attitude control, telemetry, tracking, range safety, and pneumatic systems. These were tested in SPC No. 1 under flight conditions except the firing of the rockets. The initial three minute Atlas booster phase was followed by activation of the Centaur systems for separation, including the engine ignition systems. The simulated firing was followed by a 25-minute coast phase. A second engine activation was followed by simulated payload separation, course reversal, and systems final shutdown.

After a series of tests involving the Atlas/Centaur-4 configuration, the rocket was reharnessed again to match the Atlas/Centaur-8 design. Over the span of several years, the 20 to 30 simulated missions verified Centaur's basic reliability after long durations in space. The tests revealed that the pressurization of canisters that housed the electronics caused problems and that minimizing the necessary power level reduces overheating. After a shaky start, the intricate Centaur rocket went on to be one of the nation’s most dependable spacecraft.

2. Atlas-Centaur Retrorockets

The SPC's first studies analyzed the Atlas/Centaur jettison system. It was found that the retrorockets which separated the Centaur from the Atlas booster behaved inconsistently. A version of the Atlas/Centaur vehicle was hung horizontally on a trolley system inside SPC No. 2. The model was constructed in a whale-bone configuration which simulated the mass properties of a full-size Atlas/Centaur without using actual rockets.

The first set of tests in the fall of 1963 verified the poor performance of the Rocket Power, Inc. retrorockets. Lighters manufactured by Thiokol, Librascope, and Ordnance Associates were tested in the retrorockets at 98,000 feet altitude. Foam panels were also placed behind the retrorockets to record their flame disbursement. It was determined that the original lighters were often manufactured out of spec resulting in the unpredictable firing with the propellant grain sometimes not even igniting.

Rocket Power, Inc. took the results and created their own lighter which included a longer flame with which to light the propellant grain. The Atlas/Centaur configuration with the new lighters was tested again in spring of 1964 in SPC No. 2. It was determined that the retrorockets with several variations behaved well at 100,000 feet. The researchers were also able to configure the retrorockets in such a way that failure of one would not upset the mission. These changes fundamentally altered the separation system.

3. Surveyor Nose Cones

After a year of modifications and testing at Lewis, the Centaur's second launch from Cape Canaveral was successful. The third launch almost failed, though, due to a brief disruption of the guidance system during the jettisoning of the nose cone. The Centaur's nose cone had been tested repeatedly prior to the mission in ambient conditions by the manufacturer, but it was becoming apparent that space flight hardware behaved differently in a space environment. The fourth, Atlas/Centaur-4, was intended to insert a mockup Surveyor spacecraft in orbit, and there was tremendous pressure to keep the program on schedule.

It was decided to verify that the separation system worked by testing it repeatedly in Space Power Chamber No. 1's 100 mile altitude space tank. The shroud was mounted on a platform with hinges at the lower end to keep the split halves fixed to the platform. Catcher pads were installed to grab the tops of the jettisoned fairing. During the first test at

70,000 feet altitude, however, the tips of both halves of the faring were broken off. The team regrouped and obtained a new shroud, and redesigned the bulkhead using aluminum channels and a new attachment fixture. One of the catchers was replaced by a net, and the setup was moved away from the Centaur rocket setup for the systems testing. The nose cone tests continued through the fall of 1964 with improved results. Lewis researchers determined that internal jet expansion separation devices could successfully jettison the fairing without damaging the payload. It was also determined that these separation tests must be conducted in a vacuum environment. All modifications implemented between the third and fourth Centaur missions were verified in the SPC. Atlas/Centaur-4 was the first Centaur mission to have an error-free shroud jettison.

After the spectacular launch pad explosion of the Atlas/Centaur-5, the Centaur was slightly modified. The changes required a requalification of its nose cone in SPC No. 1. These early summer 1965 studies tested the nose cone design, determined the impact on the payload envelope, and studied the shroud’s effect on the new, thinner Centaur fuel tanks. NASA Lewis researchers approved the entire nose fairing design and load limits for flight. The envelope between the thermal bulkhead struts and the Surveyor had to be altered, though, because of interference with a thermal bulkhead strut. Atlas/Centaur-6, launched from Cape Canaveral on August 11, 1965, successfully placed the Surveyor into an elliptical earth orbit. The success restored NASA’s confidence in the Centaur’s capabilities.

4. Orbiting Astronomical Observatory Shrouds

The Orbiting Astronomical Observatory (OAO) satellites were designed by Goddard Space Flight Center to study and retrieve ultraviolet data on stars and galaxies which earthbound and atmospheric telescopes could not view due to ozone absorption. It was hoped that this ultraviolet radiation would help researchers date stars. Due to the atmosphere's filtering, this not possible from earth. The telescopes required a large stable platform so that the telescope could focus for long periods of time on dim objects. Their shrouds were much larger than the Surveyor nose cones. SPC No. 2was used to test the shroud separation system for several OAO missions.

OAO-1 was the heaviest payload to date carried by the Atlas/Agena-D launch vehicle. The vehicle's shroud was successfully qualified in SPC No. 2 at altitudes of 20 miles during the summer of 1965. The shroud was set up on a mockup Agena adaptor. A large nylon net was stretched horizontally 11 feet above the chamber floor to catch the one half of the fairing that was ejected during the tests. Although the shroud performed well during the April 9, 1966 launch, the satellite failed early in the mission.

The payload for OAO-2 was redistributed due to problems encountered during the OAO-1 launch. OAO-2 would be launched on an Atlas/Centaur with a modified Agena shroud. The elongated shroud was 18 feet longer than the Surveyor shrouds. This new piece of hardware had to be qualified in SPC No. 2. Three SPC tests at 90,000 feet altitude during April 1968 were successful. For the first time, x-rays were used to verify the payload clearance once the shroud was sealed. OAO-2 was launched on December 7, 1968 and was an extremely successful mission.

The next OAO mission, OAO-B, failed on November 30, 1970 when one of 16 bolts securing the shroud did not release. Not long afterwards NASA Lewis began using SPC No. 2 to conduct the failure investigation. Although a single cause of the failure was not pinpointed, the studies led to a redesign of the shroud so that the two-step jettison process would be condensed to a single motion. This new shroud was qualified in SPC No. 2 in the spring of 1972 for the final and most successful OAO mission, OAO-C or Copernicus. Following its August 21, 1972 launch the satellite’s telescopes remained active for 8 years.

5. Hydrogen Venting Tests

The liquid-hydrogen propellant used by Centaur provided a very high thrust/weight ratio, but it also posed a number of technical difficulties. The tanks required vents because the cryogenic liquid-hydrogen vaporized at an extremely low temperature. The second burn of the Centaur's engines also required that the remainder of the propellant be stabilized inside the tank so that it did not slosh when the first burn was completed. In addition, solar radiation caused the liquid-hydrogen to boil off in a gas form. These gases had to be vented from the tank. The Atlas/Centaur-4 and Atlas/Centaur-8 missions were designed to study the propellant's behavior.

When the first engine burn ended on Atlas/Centaur-4, the liquid-hydrogen sloshed forward resulting in the venting of some of the hydrogen in liquid form rather than gas. The propellant's motion and resulting inability to maintain the vehicle's balance during venting skewed the Centaur's trajectory causing additional spillage of the liquid propellant and tumbling. Approximately 90-percent of the liquid-hydrogen was lost. The engines could not be restarted for the second burn and the mission ended.

A new balanced venting system was developed for the Atlas/Centaur-8 mission that expelled off-gasses in an even and non-propulsive manner. The system also included a baffle to prevent sloshing inside the tank. Between 1964 and 1966 the new even distribution system underwent extensive testing and qualification runs in SPC No. 2. The vent system was installed on a rig which allowed the gaseous pressure to be pumped in and vented in a high-altitude environment. The May 30, 1966 Atlas/Centaur-8 mission was the first time the Centaur was able to successfully restart its engines in space.

H. Proposed Rehabilitation

The Centaur Program had survived the agency cutbacks that battered NASA Lewis in the 1970s, but use of the Space Power Chambers (SPC) diminished. The Space Power Facility (SPF) at Plum Brook Station, which began operating in 1970, was the largest vacuum tank in the world. Structural tests in spring 1975 of the Centaur equipment module for a series of OEAH missions were the last runs in SPC No. 2. SPC No. 1 had not been used in years by that point.

In 1976, Center Director Bruce Lundin requested a study restoring the facility as a wind tunnel for VSTOL studies. The $39 million proposal was not acted upon. By the early 1980s, NASA Lewis seemed to have weathered the budgetary storm. In the early 1980s a number of large facilities that were mothballed in the 1970s were being restored. These included SPF, the Electrical Propulsion Lab, the 10 by-10-Foot Supersonic Wind Tunnel, and the Icing Research Tunnel. There was renewed interest in restoring the Altitude Wind Tunnel (AWT) for icing and VSTOL studies. In the summer of 1980 an AWT Project Office was formed and an extensive feasibility study was undertaken. Although there was a strong case made by the Project Office, the proposed restoration of the tunnel was cancelled by Congress in 1985.

1. The Proposal

In 1981 Sverdrup Corporation was hired to conduct an extensive Preliminary Engineering Report to explore the costs and options for remodeling the SPC for use once again as a wind tunnel. Sverdrup delivered cost estimates and a feasibility study for future use of existing AWT structures. It was determined that the existing infrastructure was robust enough for the new upgraded tunnel. An AWT Project Office was established to oversee the proposed tunnel rehabilitation. Since the tunnel’s internal elements had been removed during the creation of the SPC, a new test section, heat exchanger, two-stage fan system, exhaust scoop, and set of turning vanes would have to be installed.

A Congressional Advisory Committee on Aeronautics Assessment cancelled the rehabilitation in March 1985. The AWT Project had consumed a substantial amount of personnel and financial resources, and it appeared that the actual rehabilitation of the tunnel would exceed the $160 million already proposed. The committee also questioned the AWT's predicted capabilities and suggested that the research needs could be met by existing wind tunnels.

2. Microwave Systems Laboratory

In 1982 various areas in the Altitude Wind Tunnel's (AWT) Shop and Office Building were converted into a facility to test large antennas for the Applied Radio Frequency Branch of the Communications Division. Eventually this new Microwave Systems Laboratory would incorporate four antenna ranges.

The largest range, the Planar Near-Field facility was created in the high-bay. The bay was narrow, but its 40-foot high walls were a perfect location to study these large antennas. The walls were covered with row after row of anechoic foam pyramids that absorbed any microwave rays that escaped the antenna. In this setting, researchers could scan a 22 by-22-foot area from just a few thousandths of an inch away. This facility was used to test new sophisticated higher frequency space communications antennas and antennas for the Advanced Communications Technology Satellite. The ability to study these large antennas at such a close distance allowed the researchers to extrapolate the data of the antenna beam's behavior when connecting to orbiting communications satellites. The only other alternative for this testing would require miles of distance between the antenna and probe.

A smaller Far-Field facility was created in the former SPC control room underneath the tunnel's test section. This range is used to study small prototype antennas such as phased arrays. In early 1991, the building's high-bay area was expanded by 2400 square feet to accommodate two new ranges. The Compact Range Facility was built to conduct antenna and scattering measurements. The fourth range, the Cylindrical Near-Field Facility, was created inside the Planar Near Field control room to research small prototype antennas.

I. Demolition of the Tunnel

The Glenn Research Center decided to demolish the bulk of the Altitude Wind Tunnel (AWT) circuit and adjacent AWT facilities and utilities related to part of the Building No. 7 and No. 8 complex. Although the AWT was unique based on its sheer size alone, the maintenance costs for the facility were so high as to be justified only by the largest of research programs. A cost estimate provided in 2004 to do minor exterior repairs and repaint the tunnel circuit and utilities was in excess of $4 million.

In 2004 NASA Headquarters concurred with and advocated the NASA Glenn's proposal to demolish the tunnel. The facility had been out of service for more than 30 years. No significant research work had been done in the tunnel circuit since the early 1970s. Demolition work began in early 2008.

The National Historic Preservation Act mandates that for all demolitions of historical structures at NASA centers or any other federal agency formal notification of the State Historic Preservation Office (SHPO) is required before the start of the project. The agency and the SHPO must reach an agreement on an appropriate level of documentation of the facility prior to any work being performed.

NASA Glenn has undertaken an extensive effort to both physically document the AWT and compile the history of its creation, research, and role within the nation’s aerospace community. Documents, photographs, films, and oral histories have been gathered. The facility has been extensively photographed and filmed prior to its removal. A great deal of research has been performed, as well, resulting in detailed reports and publications describing the tunnel and its history.

II. Facility Layouts

A. Altitude Wind Tunnel images
B. Space Power Chambers images
C. Test and Setup Location images
D. 2005–07 Photographic Survey images

III. Documentary

"History of a Wind Tunnel" documentary
NASA Glenn Research Center film No. C-210
9 minutes, 40 seconds, Black & White

This film describes the NASA Lewis Research Center's Altitude Wind Tunnel (AWT). It provides background information on the center's past twenty years of research on reciprocating engines, turbojets, and alternative propulsion. Drawings are used to explain how the tunnel was able to simulate altitude conditions. The AWT research on the B-29's Wright R-3350 engines, the Airacomet and Shooting Star early turbojets, jet engine flameouts, and the reduction of the tunnel test section to increase speeds are explained. The film also describes the founding of NASA in 1958 and the ensuing focus on space research. This included the use of the AWT for astronaut MASTIF training and Mercury capsule separation tests. The film includes footage of many of the tests, aerial views of the lab and the AWT, and construction of the tunnel. "History of a Wind Tunnel" was created just prior to the conversion of the facility into the Space Power Chambers in 1962.

IV. Gallery

This section includes 110 images with captions and 34 videos. These can be browsed by project, year, or media type.

V. Resources

This section contains 70 technical reports and histories. One must be connected to the Web in order to view these files.