Altitude Wind Tunnel/Space Power Chambers

NOTE: This text-only version of the AWT/SPC website has been created to facilitate printing of the text. The index below links to sections within this document. Please refer to the actual AWT website for more.

Main Page	2
I. Interactive History	3
II. Facility	4
a. Altitude Wind Tunnel	5
1. Tunnel	6
2. Air Flow	8
3. Altitude Simulation	9
4. Test Chamber	11
b. Space Power Chambers	13
1. SPC No. 1	14
2. SPC No. 2	16
3. Control Rooms	18
4. Centaur Test Setup	20
c. Support Buildings	22
1. Shop and Office Building	23
2. Refrigeration buildings	25
3. Exhauster buildings	27
4. Small tunnels	29
III. Research	30
a. Events (1936 – 1957)	31
b. Events (1958 – 2008)	34
c. Tests (1944 – 1975)	38
d. Historical Documents	42
IV. Mitigation	43
a. Community Awareness	44
b. Historical Mitigation	45
c. Demolition	45
V. Students	47
a. History of Wind Tunnels	48
b. How AWT Works	49
c. History of Vacuum Chambers	50
d. How SPC No. 1 Works	52
VI. Gallery	53
VII. External Links	54

MAIN PAGE

Historic Facilities at NASA Glenn

When constructed in the early 1940s, the Altitude Wind Tunnel (AWT) was the nation's only wind tunnel capable of studying full-scale engines under realistic flight conditions. It played a significant role in the development of the first U.S. jet engines as well as technologies such as the afterburner and variable-area nozzle. In the late 1950s, the tunnel's internal components were removed so that hardware for Project Mercury could be tested in altitude conditions. In 1961, a portion of the tunnel was converted into one of the country's first large vacuum tanks and renamed the Space Power Chambers (SPC). SPC was used extensively throughout the 1960s for the Centaur rocket program.

Interactive History

This award-winning multimedia piece allows one to interactively learn about the AWT facility and the research conducted there. The piece contains a chronological history with of the AWT from its construction and testing of early jet engines during World War II, through the space programs of the 1960s, and to its final use as the Microwave Systems Laboratory. In all, there are over 200 photographs and video clips, including a 1961 NASA documentary on the AWT. Also included are layouts with corresponding images of the facility in different configurations. Links to over 70 related reports and publications are provided, as well. **Launch history**

View text-only version

Panoramic Views of the Altitude Wind Tunnel

Click photo areas below to view a Quicktime virtual reality view of that location as it appeared during final photographic surveys of the AWT in 2005 and 2007. The highlighted sections are scheduled for demolition in 2008. **View panoramas**

Displays

AWT Exhibit Display
SPC Exhibit Display
Overview of AWT and SPC Facility

Images: AWT control room, Aerial view of AWT in 2005

I. INTERACTIVE HISTORY

This multimedia piece allows one to interactively learn about the Altitude Wind Tunnel (AWT) facility and the research performed there.

The cd-rom version of the AWT Interactive History was awarded the 2009 John Wesley Powell Award by the Society for History in the Federal Government.

Launch Interactive History
Text only version of Interactive History

The piece contains:

- A chronological history of the AWT from its construction during World War II and the testing of early jet engines, through the Mercury and Centaur programs of the 1960s, and up to the final use of the building for the Microwave Systems Laboratory.
- Photographic surveys of the facility in its wind tunnel, vacuum tank, and final configurations.
- Browsable gallery of over 200 captioned photographs and video clips
- A 9-minute documentary on the AWT produced by NASA in 1961.
- Links to over 70 reports and publications related to AWT research and the history of the NACA and NASA.

Additional Altitude Wind Tunnel Resources

A detailed physical description of the AWT is located in the Facility section of this Web page. Timelines, documents, and a Historical American Building Survey—Historic American Engineering Record (HABS–HAER) report are contained in the Research section. The Mitigation section describes the efforts undertaken to document the AWT before its demolition. The Students area describes the history and operation of both wind tunnels and vacuum chambers.

II. FACILITY

Altitude Wind Tunnel: NACA engineers devised a number of ingenious features for the Altitude Wind Tunnel (AWT) to overcome the difficulties associated with operating engines in simulated altitude conditions. These features included a unique steel shell, an air scoop, a make-up air system, and specially designed banks of cooling coils.

Space Power Chambers: Between 1959 and 1963 the facility was slowly converted from a wind tunnel into two test chambers: one a large area that created altitude conditions similar to those produced during the tunnel years and the other, a smaller chamber, which was significantly modified to create a space environment. The facility was renamed the Space Power Chambers (SPC) in September 1962.

Support Buildings: The AWT complex incorporated several external buildings, which were vital to the operation of the facility. These included the Office and Shop Building, Refrigeration Building, Exhauster Building, and others. The tunnel's cooling system was the largest of its kind in the world and considered one of Willis Carrier's most significant accomplishments.

Overview of AWT and SPC Facility

Images: Diagram of AWT complex, View from top of AWT's western leg
Refrigeration Building and compressors, Interior of SPC No. 1

A. Altitude Wind Tunnel

When it was built in the early 1940s, the Altitude Wind Tunnel (AWT) was among the most complex wind tunnels ever designed. Its large size allowed the testing of full-scale engines instead of trying to replicate engine behavior in small models. It was also the first to create altitude conditions in which to study engine performance under flight conditions. The ability to control altitude conditions while modifying engines was particularly important during the early development of the turbojet. In order to accomplish these tasks, NACA engineers at the Langley and newly completed Ames laboratories developed several components for the AWT that had not been previously used.

Overview of AWT Operation

Tunnel Components

Tunnel Shell: The AWT's shell had to be specially designed to withstand external pressure when the tunnel was evacuated and to endure the low temperatures of the high altitudes without becoming brittle.

Air Flow: The AWT drive fan could produce wind speeds up to 500 mph. Because engines were being run in the tunnel, the airflow had to be constantly purged and replenished with cool, clean air

Altitude Simulation: The most complex aspect of the AWT's operation was the simulation of altitude conditions. A massive exhauster system was built to thin the air and a refrigeration system that was unrivaled in the world was designed to produce the low temperatures.

Test Chamber: The 20-foot diameter test section was one of the largest in the country. It contained an intricate balance chamber to measure the engine's behavior and supply lines to run the engines. The control room used to run the aircraft engines and the tunnel was adjacent to the test section.

Images: Schematic diagram of AWT complex, AWT tunnel

1. Tunnel Shell

The overall shape of the Altitude Wind Tunnel (AWT) was similar to several other contemporary wind tunnels of the National Advisory Committee for Aeronautics, such as the 19-Foot Pressure Tunnel at Langley Memorial Laboratory and the 16-Foot High Speed Wind Tunnel at the Ames Aeronautical Laboratory. The AWT's internal pressure and temperature levels however, required new methods of designing the tunnel's steel shell.

The tunnel itself was a massive rectangular structure, which for years provided one of the highest vantage points on the laboratory. The tunnel was 263 feet long on the north and south legs and 121 feet long on the east and west sides. The larger west end of the tunnel was 51 feet in diameter throughout. The east side of the tunnel was 31 feet in diameter at the southeast corner and 27 feet in diameter at the northeast. The throat section, which connected the northwest corner to the test section in the middle of the long northern leg, narrowed sharply from 51 to 20 feet in diameter.

Image: Aerial of wind tunnel

Foundations: The tunnel was braced by a large elliptical support ring in each corner, the Shop and Office Building's test chamber in the middle, and a series of 120 support rings which lined the tunnel at 6 foot intervals. Eight of these support rings and the four larger corner rings were anchored to concrete and steel piers which elevated the tunnel. Unique steel rollers were used to bear the tunnel shell in a way that allowed the shell to contract and expand during the tunnel's dramatic temperature and pressure fluctuations. One row of five of the 22-inch long and 4-inch diameter rollers was stacked perpendicularly on a second row of five rollers. The rollers were placed between the concrete piers and the support ring buttresses.

Images: AWT foundations , Construction of supports , H-shaped support , Northeast corner of AWT

Shell: A team of engineers at the NACA's new Ames Aeronautical Laboratory were responsible for designing the AWT's distinctive shell in 1941 and 1942. The shell consisted of two steel layers with a blanket of insulation between. The inner steel layer was the primary tunnel structure. Its 1-inch thick steel could withstand external pressure when the tunnel was evacuated to high altitude pressure levels. A T-1 steel alloy with three times the strength of normal carbon steel was used to so that the shell could endure the low temperatures of the high altitudes without becoming brittle.

A 4-inch layer of glass wool was installed with steel mesh over the inner tunnel shell to retain the tunnel's low temperatures. The outer 1/8-inch steel shell was then constructed over this to protect the protection from the environment.

Images: View of inner and outer shells, Exterior in 2005, Wide end of AWT, Fiberglass insulation

Roof: By the mid-1940s, a series of stairs, ladders, and platforms were built on the roof of the tunnel. Access was provided by doorways off the east and west sides of the second floor of the test chamber in the Shop and Office Building. Stairs led to the top of the west end of the tunnel. The walkway, interrupted only by the four corner rings, followed the top of the tunnel until ending at the west side of the test chamber.

Steel grated platforms replaced the original wooden platforms by mid-1945. An elaborate catwalk system would be added to the east end after the Space Power Chamber dome was added in 1963.

Images: AWT roof with walkway, Aerial of office wing, Men on top of tunnel, Aerial of AWT in 1980s

2. Air Flow

The Altitude Wind Tunnel (AWT) could produce wind speeds up to 500 miles per hour through its large 20-foot-diameter test section at the standard operating altitude of 30,000 feet. The average speed at lower altitudes was 345 miles per hour. The airflow was created by a large fan near the southeast corner. Elliptical panels of turning vanes were installed in each corner to guide and even the airstream. The tunnel contracted from a diameter of 51 feet to just 20 feet as it approached the test section. This contraction accelerated the air velocity as it passed the engine studied. Contamination from the engine exhaust had to be removed to maintain the altitude conditions and replenished with clean air while the tunnel was running.

Drive Fan: A 12-bladed 31-foot-diameter spruce wood fan as used to create the airflow. The fan was driven at 410 revolutions per minute by an 18,000-horsepower General Electric induction motor that was located in the rear corner of the Exhauster Building. An extension shaft, sealed in the tunnel's shell with flexible couplings that allowed for the movement of the shell, connected the motor to the fan. A bronze screen secured to the turning vanes protected the fan against damage from failed engine parts sailing through the tunnel. Despite this screen the blades did become worn or cracked over time and had to be replaced. An entire new fan was installed in 1951.

Images: Drive fan, New set of fan blades, Turning vanes, Deterioration of fan blade, Drive system diagram

Air Scoop: A unique air scoop was installed immediately downstream from the test section to collect combustion byproducts as they were exhausted by the engines being tested. This scoop, which resembled an aircraft engine nacelle, was held at the center of the tunnel by a vertical support. Compressors in the nearby Exhauster Building drew the vented air out of the tunnel and discharged it into the atmosphere. It was estimated that this scoop would remove 40 percent of the engine exhaust and that a 6000-pound per minute exchange of air would produce a 95 percent clean airflow. In 1951, a large exhaust-gas cooler was installed underneath this section of the tunnel to improve the system.

Images: Air scoop beyond test section, New compressors, Installation of exhaust gas cooler, J57 engine near air scoop

Make-Up Air: A make-up air system was developed to replenish the air removed by the air scoop. Air from the atmosphere was drawn into a large air dryer located outside the tunnel's southwest corner. The dryer removed condensation from the air to prevent shocks to the tunnel's airflow. After the air was initially cooled in the building's primary coils, its moisture was absorbed by activated alumina beds in the dryer. The air temperature was reduced to the final desired level with a second set of cooling coils. This processed air was introduced into the tunnel through two portals in the western tunnel wall. One of the nozzles extended well into the tunnel and piped the new air directly through the test section. Later this pipe was extended and attached to the engine inlets to increase the tunnel's capacity.

Images: Ramjet with air directed to inlet, Aerial of Dryer, AWT Damper Room, Make-up air line in 2005

3. Altitude Simulation

The two primary aspects of altitude simulation are the reduction of the air pressure and the decrease of temperature. This was accomplished through the Altitude Wind Tunnel's (AWT) large exhauster and refrigeration systems. These were vital components to the AWT's operation and set it apart from other wind tunnels. The tunnel was originally designed for temperature altitude simulation of up to 30,000 feet and pressure altitude simulation of 45,000 feet. This capacity was increased over the years and reached 100,000 feet by the mid-1950s.

Cooling System: NACA engineers were having a difficult time developing a method of cooling the massive airflow in the AWT to levels necessary for the desired altitudes. Pressure was on to complete the tunnel for use during World War II, and Willis Carrier, who's Carrier Corporation had pioneered the refrigeration industry, took on the AWT project. After several months of studies, the Carrier engineers devised a cooling system that was the largest of its kind in the world. Carrier later referred to the AWT as his greatest achievement. The system could lower the tunnel's temperature to –47° F, and it was claimed that if used for other purposes it could generate 10,000 tons of ice per day.

The cooling system was powered by 14 Carrier compressors, which were housed in the Refrigeration Building to the west of the tunnel. The compressors converted the Freon 12 refrigerant into a liquid. The refrigerant was then pumped into the eight identical banks of cooling coils inside the tunnel's return leg. These coils were a collection of 260 copper-plated coils arranged in a zigzag design that covered a 51-foot width of the tunnel. The Freon absorbed heat as the air passed through the coils. The heat was transferred to the cooling water and sent to the cooling tower where it was dissipated into the atmosphere. At its original capacity, 20,000 gallons of cooling water were required for the system every minute.

Images: Control room Cooling coils, Refrigeration equipment, Cooling Tower No. 1, Aerial of refrigeration lines

Exhaust System: In addition to removing contaminated air through the air scoop, the exhaust system was used to reduce the air pressure to create the thin atmosphere found at high altitudes. The Exhauster Building directly to the east of the tunnel housed four 1750-horsepower exhausters. These pumped the air out of the tunnel and expelled it into the atmosphere.

The Exhauster Building pumps could originally only handle two–thirds of the 6000 pounds of air per minute required by the AWT, so the system was complemented by the Roots-Connersville centrifugal compressors in the Engine Research Building's basement. The original configuration could simulate altitudes up to 45,000 feet. Most tests were conducted over a range of altitudes beginning as low as 10,000 feet and increasing incrementally to 35,000 feet.

As part of a larger AWT modernization program in 1951, the exhaust system was overhauled. The Exhauster Building was expanded with more powerful compressors, an exhaust gas cooler installed under the air scoop, and circulating water pump house built. In 1957, the Propulsion System Laboratory's Central Air and Exhauster Building, which began operating in 1952 was linked to the exhaust system AWT and Engine Research Building systems. The result for the AWT was an improvement from 12 to 7 pounds per second at 50,000 feet and 66 to 51 at 28,000 feet.

Images: Worthington exhausters, Exhaust pipe in 2005, Compressor in Exhauster Building annex, Central control room

4. Test Chamber

The size of the Altitude Wind Tunnel (AWT) test section was driven by the desire to test full-scale engines. The 3000-horsepower piston engines, which were larger than those in use in the early-1940s, would require a 20-foot-diameter and 40-foot long test area to operate with all their components. The engine or test article was installed inside the test section on balances beneath the test section and on the wing tip fixtures. Six balances were housed in the sealed chamber and connected to supports from the tunnel floor or at the wing tips on the walls. These control the position of the engine and are used to record data.

Control Room: The soundproof control room was used to operate the tunnel and control the engine being run in the test section. The AWT operators worked with assistants in the Exhauster Building and Refrigeration Building to manage the large systems. Although the configuration of the control panels changed frequently, the principal wall contained the make-up air, drive fan, and engine controls. It also included two sets of pneumatic levers that operated different facets of the engine. The other wall was used to manage the combustion, refrigerated and cooling air, and the exhauster systems.

The control room was modified several times, including a large overhaul in 1951. In the early-1960s, when the facility was converted into two test chambers, the control room was used to operate the large altitude tank known as Space Power Chamber No. 2. The facility was not used during the late-1970s and 1980s. The control room was cannibalized and eventually used as a storage room.

Images: Control panel with instruments blown out, Engine control panel, Tunnel control panel, Control room in 2007

Test Section: At 40 feet in length and 20 feet in diameter, the AWT's test section was one of the largest in the country at the time of its construction. Aircraft engines were prepared in the AWT shop, and then lifted by an overhead crane through the high-bay and the second-story test chamber before being lowered into the test section. Technicians then spent days or weeks hooking up the supply lines and data recording telemetry.

The engines were mounted on wing spans that stretched across the test section. The wing tips attached to the balance frame's trunnions which could adjust the angle of attack. The balance frame included six measurement devices that recorded data and controlled the engine. The measurements were visible in banks of manometer boards next to the control room. Photographs recorded the pressure levels in the manometer tubes and "computers" manually converted the data into useful measurements.

Images: Republic YP-47 in test section, Engine in test section, Manometer boards for small tunnels, Pressure rake over exhaust Engine lowered into test section

Test Chamber: The test section, control room, and balance chamber were located in a three-story test chamber in the rear of the Shop and Office Building. The control room, fan room, and manometer boards were located on the mezzanine level next to the test section. The upper level was a large open space, approximately 50 feet high, with the test section sunken up to its midpoint in the floor. This main level contained a large, open wooden viewing platform with stairs built so that people could get from one side of the test section to the other.

A mechanical pulley system was used to raise and lower the tunnel's large clamshell lid into place. The lid was sealed into place using hand-turned locks accessible from the viewing platform. The lid had viewing windows above and below the test article, which permitted the filming and visual inspection of the tests.

Images: Viewing platform, Allison J71 lifted into high-bay, Tour of AWT test chamber, Test filmed through lid

B. Space Power Chambers

During the rush of the early space era, the Altitude Wind Tunnel (AWT) was used for several rocket engine tests. In 1959 several of the tunnel's internal components were removed from the west end of the tunnel so that a series of Project Mercury tests could be conducted inside that area. The tests were successful, but the removal of two sets of turning vanes, cooling coils, and make-up air valves, ensured the facility would not be used again as a wind tunnel. In 1961, NASA Lewis management decided to convert the facility into two large test chambers and later renamed it the Space Power Chambers (SPC). The conversion, which took over 2 years included removing the tunnel's drive fan, exhaust scoop, and turning vanes from the east end and inserting bulkheads to seal off the new chambers within the tunnel. These chambers were used for a variety of tests on the Centaur second-stage rocket until the early 1970s.

Overview of SPC Environmental Tests

SPC Components

Space Power Chamber No. 1: The eastern section of the tunnel, SPC No. 1, became a vacuum chamber capable of simulating 100 miles altitude. Although other investigations were conducted in the tank, its primary purpose was testing the Centaur rocket's electronics in a space environment.

Centaur Setup: Soon after completing the SPC in 1962, NASA Lewis assumed control of the Centaur Program. The new vacuum chamber would be used to study the Centaur, but it would require an extensive installation of test equipment to create a space environment.

Space Power Chamber No. 2: SPC No. 2 occupied the entire south leg, the west leg, and the throat section of the former tunnel. This large chamber could simulate altitudes of 100,000 feet. It was used for shroud separation and propellant management studies.

Control Rooms: A new control room, which was designed to replicate a launch pad control room, was built underneath the tunnel's test section for SPC No. 1. SPC No. 2 used the former AWT control room to operate its tests.

1. Chamber No. 1

The Space Power Chamber (SPC) No. 1 was among the first wave of large vacuum chambers capable of simulating a space environment. Initial space flights during the late-1950s and early-1960s showed the behavior of engines, flight systems, and hardware was affected by the conditions encountered in space. Although larger chambers would later be constructed, the rapid conversion of the Altitude Wind Tunnel (AWT) into a space tank allowed the SPC to play a vital role in the early years of the space program.

The 100-foot long SPC No. 1 was created in the east leg of the tunnel, which was 31 feet in diameter at one end and 27 feet in diameter at the other. The chamber was used to conduct a series of long-term systems tests on a full-scale Centaur and nose cone separation tests for multiple Surveyor missions. In the 1970s, the new Space Power Facility at Plum Brook Station would supersede the SPC's capabilities.

Image: Isometric drawing of SPC No. 1

Conversion to Test Chambers: The conversion of the AWT into two test chambers was a major undertaking. The actual clearing of the tunnel interior was fairly simple. The turning vanes, cooling coils, and make-up air pipes had been removed in 1959. The drive fan and its assembly, along with the remaining turning vanes, were removed in 1961. After the tunnel was clear, large oval bulkheads were inserted before and after the test section with another near the southeast corner. These effectively created two distinct chambers. Control rooms were installed and a pump house with new vacuum pumps was built underneath the chamber.

Since SPC No. 1 would have to be capable of reaching extremely low pressure levels, the tunnel shell around that area had to be checked for leaks. After the removal of the outer shell and insulation, it was determined that the entire section of the tunnel would have to be rewelded to maintain the required seal. It was felt that the poor work of the original welders was due to the rush to complete the facility during World War II. The necessary repairs were performed for SPC and the shell maintained its seal throughout its tests. The facility was considered ready in September 1962, but the acquisition of the Centaur Program necessitated the addition of a dome and other equipment, which would require another year to complete.

Images: Conversion of AWT to SPC, Insertion of bulkhead, Small bulkhead in SPC, Removal of tunnel's turning vanes

Vacuum Pump House: The vacuum system was the primary element in SPC No. 1's ability to create a space environment. During the conversion of the tunnel to a space tank, the pumping system was replaced by a new oil diffusion-based system, which could create a 10 to the –5 mm of mercury pressure level. Ten diffusion pumps and several roughing pumps were installed in the new Vacuum Pump House building underneath the SPC No. 1. Access ports in the chamber's floor connected directly to the pumps in the building below.

The vacuum was brought down slowly in several phases to prevent excessive airflow over the pumps. The center's central exhauster system could evacuate the SPC to 100,000 feet pressure altitude in about 15 minutes. Then two piston pumps simultaneously removed 12.5 cubic feet of air per second during the roughing stage. A rotary positive displacement pump pulls additional air at 500 cubic feet per second. The final vacuum is pulled down by the ten 32-inch-diameter oil diffusion pumps which could remove 17,650 cubic feet air per second.

Images: Interior of pump house, Construction,
Vacuum portal, Pump house in 2007

Removable Dome: NASA researchers wanted to be able to stand the Centaur rocket up vertically inside SPC No. 1 so it was decided to add an extension to the chamber's roof and cap it with a removable dome. After a year of additional construction, the new dome was completed in September 1963 and became the facility's distinctive feature.

The extension provided a 45-foot vertical area in which to stand the Centaur up. An elevated catwalk was erected around the dome to allow access to the instrumentation portals and cable trays. The 22.5-foot-diameter lid could be removed using a crane so that the Centaur or other test articles could be lowered into the chamber. Smaller items and personnel could enter through a 15-foot-diameter doorway in one of the bulkheads.

Images: Inspection of dome, Exterior in 2005,
Liquid nitrogen separation tank, Interior in 2005

2. Chamber No. 2

Space Power Chamber (SPC) No. 2 was the larger of the two chambers in the former Altitude Wind Tunnel (AWT). It consisted of the entire southern and western legs of the tunnel, as well as the throat section. SPC No. 2 was used for several different Orbiting Astronomical Observatory shroud jettison tests, liquid-hydrogen venting studies, and other investigations.

Unlike the vacuum tank in SPC No. 1, SPC No. 2 did not require a major overhaul to be used as a high-altitude test chamber. In 1959, NASA Lewis management had decided to use this area for several tests for the Project Mercury Program. The existing AWT exhauster and refrigeration systems were powerful enough to achieve the desired altitudes up to 100,000 feet. During the conversion to the SPC, this chamber only required the two bulkheads that sealed it off, some upgraded crane equipment, and a new coat of paint.

Image: Drawing highlighting SPC No. 2 location

Project Mercury Setup: The AWT's turning vanes and make-up air pipes were extricated from the western section of the tunnel creating a large 121-foot long, 51-foot-diameter chamber, which simulated altitudes of the upper atmosphere. An elevated walkway and banks of lights were erected along the western wall. In this chamber, four test setups were erected between September 1959 and March 1960. The first was the Multi-Axis Spin Test Inertial Facility (MASTIF) that included three cages that pivoted, or "gimbaled," on a stand near the tunnel's throat section. A two-level walkway around the rig and a stairway rising into the throat were built so that researchers could operate and observe the rig. The MASTIF was initially used to calibrate the guidance system for Big Joe, the first full-size Mercury capsule launched. It was modified afterwards with the addition of a pilot's chair, control stick, and display panel to train the Mercury 7 astronauts. The astronauts, along with several test pilots, were asked to bring the spinning rig under control.

In another investigation, a mockup capsule was mounted on the floor near the center of the western leg so that its retrorockets could be fired in altitude conditions. Similarly, a rig was set up near the southwest corner that allowed the jettisoning of a capsule from model Atlas and Redstone boosters. The final Mercury tests were of another capsule model outfitted with its escape rocket tower. This was mounted off one of the elevated make-up air portals so the escape rockets could be fired.

Images: Escape rocket test, MASTIF inside AWT, Retrograde thrust stand, Redstone/Mercury capsule separation test

Space Power Chamber No. 2: SPC No. 2 was sealed off from the other chamber by a 31-foot bulkhead near the southeast corner and from the tunnel test section by a 20-foot-diameter bulkhead in throat section, which effectively created a large J-shaped chamber. The long south leg was not utilized as a test area, but the western section and the area just before the throat were used extensively.

The catwalk along the western wall provided access to lighting and cameras used to record the tests. An overhead crane was installed over the chamber to permit the transfer of large test articles. The 51-foot-high chamber allowed the vertical erection of full-scale rocket shrouds so that the jettison systems could be tested at high altitudes. It also was long enough that a mass model Atlas/Centaur rocket could be placed horizontally in the chamber so that its retrorockets could be tested.

Images: OAO-2 shroud test setup, Contraction area in 2007, Atlas/Centaur retrorocket test setup, Interior in 2007

Test Equipment: Like the Project Mercury tests, the studies conducted during the 1960s in SPC No. 2 required the installation of test equipment for varying lengths of time. These would be removed after the tests, but remnants remained permanently mounted inside the chamber. The first involved apparatus for separation tests of an Atlas/Centaur mass model in September 1963. A trolley system that used the overhead crane, landing gear-type wheels, and a large net to catch the jettisoned Atlas was installed.

In order to work on the tall Orbiting Astronomical Observatory shrouds, in 1965 an oval platform elevator was built on two vertical steel girders. The elevator could be raised the entire length of the chamber, and its 11-foot-diameter opening allowed it to be placed around payload shrouds to assist in test preparations. In late-1965 a scale version of the new Zero Gravity Facility was built inside the chamber, so engineers could analyze the performance of several types of deceleration pellets. Items were dropped through a penetration in the chamber roof into a 5-foot-diameter and over 20-foot-tall deceleration stand that was mounted to the chamber floor.

Images: Hydrogen vent rig, Centaur/Surveyor shroud, Platform elevator around OAO-2 setup, Catcher net for OAO-2

3. Control Rooms

The new Space Power Chambers (SPC) facility had separate control rooms for each of its two test chambers. SPC No. 2, which used much of the Altitude Wind Tunnel's (AWT) existing infrastructure, was logically located in the wind tunnel's former control room. The new SPC No. 1 vacuum tank, however, used a new pumping system and possessed additional features. It would be operated from a new control room underneath the former tunnel test section.

During the 1960s the former tunnel test chamber would no longer be needed. It was permanently modified in the early-1960s and used as a workroom and storage area. The facility's shop area continued to be used to prepare test articles for their test runs, but was also used as a setup area for tests in other facilities. Several rooms in the office wing were combined to create larger offices. These were increasingly used by other groups of individuals than just the SPC test engineers.

SPC No. 1 Control Room: A new control room for SPC No. 1 was constructed underneath the former tunnel test section. Efforts were made to make this control room as much like the Centaur launch controls at Cape Canaveral as possible. The eastern wall contained the primary controls including Centaur pressure and tanking controls; hydrogen peroxide, hydraulic, stretch, pneumatic, and canister purge systems; the cold wall and vacuum systems, and solar simulator temperature monitor. The northern section consisted of monitors for temperature, pressure, and the solar simulator. The western wall controlled the guidance system, nose cone, and tank vents. The southern section had data and event recorders, radio frequency and range safety monitors. Racks in the center of the room contained the test conductor and engine controls, ground programmer, a vehicle power monitor, and data recorders.

Images: Data recorders, Construction, Event monitors, Vacuum control panel

SPC No. 2 Control Room: The former AWT control room next to the test section was converted into the control room for the tests in SPC No. 2. This primarily involved rewiring the telemetry and updated the control panels. The floor-mounted pneumatic engine controls were also removed. The original acoustic tiles on the walls and ceiling remained, as did the overhead fluorescent light fixtures.

The eastern panel controlled the exhaust flow from SPC No.2, SPC No. 1, the Propulsion Systems Laboratory, Engine Research Building, and the cooler. These areas were laid out schematically on the panel with toggle switches and indicator lights. The next panel operated the liquid nitrogen system. The panel at the west end contained a large number of controls for cameras inside SPC No. 2.

Images: General Dynamics personnel in control room, SPC No. 2 controls, Control room, Rear view of control panels, Crowded control room, _

Test Chamber: Since the tunnel's test section no longer needed to be enclosed, the large clamshell lid was removed. Flat, steel grating was installed in the bottom of the test section and a pedestrian bridge was built over the 20-foot-wide gap. A new rail crane was installed in the tunnel between the test section and bulkhead so the test articles could be transported into SPC No. 1. The surrounding test chamber room was used as a work area for mechanics in the 1960s and storage area in recent years.

The high-bay was converted into the Microwave Systems Laboratory in the early-1980s to study the large near-field antennas. The high section of the shop area is now being used as an acoustical test bay to test large microwave antennas. 40-foot-tall U-shaped covered with row after row of acoustical foam pyramids were built to absorb any microwave rays that escaped the antenna to provide a more precise test atmosphere. In 1983 the high-bay was sealed off from the rear test section area.

Images: Viewing platform in former AWT, Diagram of vacuum pumps and flooring, Former AWT test section, Inflatable antennae in highbay

4. Centaur Test Setup

With the transfer of the Centaur second-stage rocket program to NASA Lewis Research Center in October 1962, the newly completed Space Power Chambers (SPC) facility had to be modified to accommodate the space vehicle. The chamber was originally designed, but never used, to test satellites, SNAP–8 generators, and smaller space vehicles. The new configuration would take almost a year to complete.

The goal of the test engineers was to subject the Centaur to long durations in conditions that would replicate those encountered during its missions in space. The only elements not replicated were microgravity and meteorites. Other than firing the engines, every aspect of a typical Centaur flight would be performed in SPC No. 1. The most drastic modification was the addition of the dome and detachable lid to the SPC No. 1 chamber, but also included the installation of other elements to simulate the temperatures of space, general setup, work equipment, and infrastructure to power and operate the spacecraft.

Centaur 6A Rocket: A Centaur second-stage rocket was obtained in the late summer of 1963 and flown to NASA Lewis. After several months of studying the rocket in the SPC shop area and installing the Atlas/Centaur-4 electronics packages, the rocket was lowered into SPC No. 1 by crane. Inside the chamber, the delicate Centaur rested on a horizontal stand and was held in place vertically by stretch towers.

Centaur was a unique space vehicle for several reasons, including its ability to restart its engines in space, its use of liquid-hydrogen as a propellant, and its thin inflatable fuel tanks. The 28.5-foot-long and 10-foot-diameter Centaur 6A was powered by two 15,000-pound Pratt & Whitney RL–10 engines, which rotated to steer the rocket when the engine fired. The electronics and control systems were at the forward section of the rocket, while the mechanical and propulsion systems were near the rear.

Images: Isometric drawing of Centaur in SPC ,
Centaur lowered into chamber, Centaur in SPC shop,
Lowering of Centaur stand, Centaur display model

Coldness and Radiation of Space: SPC No. 1 was already capable of creating the vacuum of space, but the test engineers also wanted to simulate the cryogenic temperatures and solar radiation found in space. A large copper cold wall with its interior coated with heat-absorbing black paint was created specifically for these tests and assembled around the Centaur. The 42-foot-high wall had vertical ribs filled with liquid nitrogen which produced the low temperatures. The liquid nitrogen was stored in three 7000 gallon tanks stored outside of the chamber, and its pressurization was managed remotely from the SPC control room.

Six panels of 500-watt tungsten-iodine lamps were arranged around the Centaur to simulate the effect of the Sun's heat on the rocket performance. Four of these arrays were on the upper end of the Centaur, and two were located near the RL–10 engines. Certain lamps could be turned on at different times to recreate the changing areas of the rocket exposed sunlight during a mission.

Images: Top of cold wall, Cold wall in 1985,
Diagram of cold wall, Quartz radiation lamps

Centaur Systems: The actual setup of the Centaur included a pneumatic system to keep the thin fuel tanks pressurized so that they would not collapse, a hydraulic system to rotate or "gimbal" the RL–10 engines as they would be during flight, and a liquid-hydrogen pumping system to fill the propellant tank.

The telemetry for these tests included a high-powered system for powered flight, a lower-power system for coast periods, camera and data transmission systems to view the liquid hydrogen tank, and ground support equipment that controlled and monitored the operation of the Centaur. The instrumentation included 200 transducers, 18 landlines were to record the data in the offsite receiving station, a number of K-logger chart recording systems, and a television camera, which was mounted near the lower section of the Centaur.

Images: Centaur's RL-10 engines, Centaur control panels,
Interior view of dome, Centaur autopilot system

C. Support Buildings

The Altitude Wind Tunnel (AWT) facility comprised a number of components, which allowed the tunnel to study aircraft engines in an altitude environment. Although integrated into the AWT, these components were housed in large out-buildings. The system was so complex that it was claimed that its design required more effort than the Hoover Dam.

The AWT infrastructure was powerful enough to also run several small supersonic wind tunnels, cool the Icing Research Tunnel, and prepare engines for tests in other facilities. The AWT required large amounts of power to run, so it was only operated at night. When it came online in 1944, the press reported that a single run used more electricity than the city of Columbus, Ohio. The AWT's elimination of test flights and the reduction of development time for new engines quickly compensated for this investment.

Shop and Office Building: The Shop and Office Building was the heart of the AWT facility. It contained the test section, control room, and instrumentation, as well as a large shop area, three-story high-bay, and two-floor office wing.

Refrigeration Buildings: The Refrigeration Building housed the Carrier Corporation's large cooling system. It was integrated with Cooling Tower No. 1, which was used to dissipate the heat that the system removed from inside the tunnel, and the Air Dryer Building, which cooled new air before it was added to the AWT's stream.

Exhauster Buildings: The Exhauster Building and its annex contained the compressors, which removed air from inside the AWT to simulate high altitudes. The building also stored the motor that spun the tunnel's drive fan. A water pump house was added in 1951 to improve the system.

Small Wind Tunnels: The AWT's exhauster and make-up air systems were used to created the center's first supersonic wind tunnels. Beginning in 1945, three small supersonic tunnels were built off the AWT's southwest corner and another was created in the AWT's basement.

Images: Drawing of AWT complex, Drawing of high-bay area,
Aerial of cooling lines, Interior of high-bay,
Schlieren shadowgraph from small tunnel

A. Shop and Office Building

The Altitude Wind Tunnel's (AWT) Shop and Office Building was used to perform all the functions related to the facility's studies. The T-shaped building was used to prep the engine or rocket component, to operate both the facility and test article, to record and gather data from the tests, coordinate research projects, and, most importantly, to run the engine in the tunnel's test section. The Shop and Office Building, constructed by the Sam W. Emerson Company in 1942 and 1943, was designed in the same architectural style as the other original buildings at the laboratory. The building is currently named the Microwave Systems Laboratory. The shop and high-bay areas house the lab's Near Field Antenna Facility, and the office wing is used primarily by the Educational Programs Office.

Overview of Shop and Office Building

Image: Shop and Office building as seen at night

Shop Area: The Shop Area is an open two-story room that occupies the entire western wing of the Shop and Office Building and opens up into the high-bay in the center of the building. The shop was used to build and disassemble engines before and after their test runs in the AWT. The engines or other test articles were brought through the truck entrance at the front of the high-bay and set in the shop. Technicians worked with the researchers to install proper instrumentation and ready the engine to be run in the tunnel. This often took weeks to accomplish.

Several tests that did not require the tunnel were conducted in this shop area. These included the Mercury Evaporating Condensing Analysis (MECA), electric motor vehicle studies, and antenna testing. In 1991, the shop and high-bay were expanded for additional antenna testing capabilities.

Images: Fan blades in shop, Staff meets in shop,
Interior of shop area, Electric vehicle study

High-bay: A three-story high-bay area was used to transport test articles between the shop area and the test section on the second floor in the back of the building. When its turn to run in the tunnel came up, the engine was lifted by the overhead crane from the shop to the high-bay. A 10-ton overhead box crane carried it to the test chamber on the second floor in the rear of the building and there it was lowered into the tunnel's test section.

Originally there were no walls between the high-bay and the shop or the upper level of the test chamber. The high-bay was converted into the Microwave Systems Laboratory in the early 1980s, and the bay began being used as acoustical chamber to test large microwave antennas. In 1983, a 36-foot-high U-shaped was built that completely segregated the bay from of the test section area. The facility continues to be used today.

Images: Atlas launcher test setup, Construction, Display panel of AWT wartime tests, Test section in 2007

Office Wing: The eastern wing of the Shop and Office Building consisted of two floors of office space. This area was physically segregated from the rest of the building and similar to other office areas around the laboratory. Originally, the rooms were used by AWT personnel. Members of the educational services staff have used the area since the 1970s.

Several first floor offices were enlarged during the 1960s. In 1973 and 1974 the Office and Shop Building underwent a major rehabilitation. The offices were modernized for the first time since they were built in the 1940s. This wing has not changed much since that project.

Images: Researchers in office, Aerial of office wing, Rear stairwell, Second floor hallway, View of hangar from AWT office

B. AWT Refrigeration

The Refrigeration Building located just to the west of the Altitude Wind tunnel (AWT) contained the primary components of the tunnel's cooling system, which was the largest in the world. The Sam W. Emerson Company built the actual building during 1943, but the unique refrigeration system contained within was developed by the Carrier Corporation.

A cooling tower behind the Refrigeration Building was used to expel heat accumulated in the circulating water. A water pump house was added in 1951 to use refrigerated water to cool the gases exhausted through the air scoop. Both the Refrigeration Building and Cooling Tower No. 1 continue to be used today by the Icing Research Tunnel.

Refrigeration Building: The Refrigeration Building contains 14 Carrier-designed centrifugal compressors and a flash cooler. The interior of the building is largely open, but there is a small control room along the wall. The 1500-horsepower compressors are aligned in pairs with the cylindrical flash cooler running between them.

There are also three 1500-horsepower York compressors that were used to chill the cooling coils in the Air Dryer Building. These compressors supply chill water for office air conditioning. The chill water is distributed by an underground system of pipes to most of the buildings within the central campus at Lewis Field. Approximately 30 different pipes run between the Refrigeration Building and the AWT, which connect the flash cooler to the heat exchangers in the tunnel.

Images: Isometric drawing of Refrigeration Building, Construction, Electrical panels, Carrier compressors, Refrigeration Building in 2005

Cooling Tower No. 1: Cooling Tower No. 1 is a narrow rectangular structure with settling pools off to its side. Cooling Tower No. 1 was originally a wooden structure with eight cells. In 1951, an additional cell was added to each end of the tower. In the mid-1950s it could pump 63,000 gallons per minute. In the mid-1980s, Cooling Tower No.1 was largely rebuilt with all of the cells rehabbed and the wood replaced by composite material. It is still used by the Icing Research Tunnel.

The heat-laden water circulated from the AWT was pumped to the top of the cooling tower. The water was distributed across the cooling tower and sprayed down into the 600,000-gallon basin at the bottom. Sixteen fans in the roof drew air upwards, removing energy from the heat-laden water, and expelling the heat energy to the atmosphere. It then flowed outside into one of the three settling ponds where it cooled further before being recirculated back into the Refrigeration Building.

Images: Settling ponds, Cooling tower in 2005,
Aerial view of tower and Refrigeration Building,
Cooling tower in 1951

Circulating Water Pump House: As part of the 1951 AWT modernization project, a pump house was built underneath the northeast leg of the tunnel. This Circulating Water Pump House drew cooling water to be used by the new exhaust system. The water as circulated through in an exhaust gas cooler tank which was used to reduce the temperature of the air exhausted from inside the tunnel.

The pump house contained four Ingersoll Rand pumps, two 250-horsepower discharge pumps, two 300-horsepower spray pumps, and a 75-horsepower spray pump. These drew water through underground lines from the Cooling Tower. The pumps were removed in the 1960s and the structure has been used as a storage area. It was demolished along with the tunnel in 2008.

Images: Pump House from above, Pump House in 2007,
Sump pumps inside, Pump House in 1960s

C. Exhauster Building

The Exhauster Building was located just to the east of the Altitude Wind Tunnel (AWT). This building served two crucial roles for the wind tunnel—it housed the drive motor that operated the tunnel's fan, and it contained the exhausters and compressors that evacuated the tunnel to simulate the pressures at altitude. It also replaced some of the contamination with fresh air. The building was constructed by the Sam W. Emerson Company in 1943, but experts from the Roots Connersville Company supervised the installation of the exhausters, and General Electric installed the drive motor.

A smaller rectangular addition with new, more powerful exhausters was attached to the northeast corner of the building in 1951. In the 1960s, portions of the original building were used as part of the Solar Power Laboratory. By the mid-1970s the Exhauster Building was converted into a visitors' center. The large exhauster room is now filled with displays and the annex built in 1951 is a 170-seat assembly room with a stage. A lobby area was created at the nexus of the original building and the annex.

Exhausters: The exhaust system was originally powered by four four-cylinder 60-inch-bore and 30-inch-stroke Worthington exhausters. These 1750-horsepower pumps were located in the Exhauster Building's large main floor area. These pumps removed the air from inside the tunnel and expelled it into the atmosphere. Following complaints from local residents during the final days of World War II, mufflers were added to the vent pipes to reduce the low-frequency vibrations which rattled nearby windows.

Three Ingersoll-Rand eight-cylinder reciprocating pumps were installed in a new annex in 1951. The new exhausters significantly increased the system's capacity. In addition, an exhaust gas cooler, pump house, and cooler pit were also installed underneath the tunnel where the exhaust lines exited.

Images: Isometric drawing of Exhauster Building, Delivery of new exhaust gas cooler, Air regulating panel, Former Exhauster Building in 2005

Drive Motor: On the first floor of the Exhauster Building, a 31-foot long, 4200-kilowatt generator was set up in-line with a slightly smaller generator. These generators created the power needed to start up the drive motor used to rotate the large fan inside the AWT. Due to the AWT's massive power loads arrangements had to be made with the local power company before operating the tunnel.

A three-level tower was located in the southwest corner of the building to house the drive system. The lower level contained a small generator, and the upper two levels contained the drive motor. The primary drive motor was an 1800-horsepower, 4000-volt, 2180-amp General Electric induction motor. The drive shaft traveled from the brick tower and into the east wall of the AWT.

Images: Drive motor in 2005, Drive motor face plate, Generators in 2005

Air Dryer Building: The Make-Up Air System was designed to replenish the air in the AWT that was removed by the exhaust scoop. The Air Dryer Building was used to remove condensation from atmospheric air to prevent shocks when introduced to the AWT's airflow. The facility consisted of the air dryer tank and two sets of cooling coils enclosed in a two-story brick building. In 1948 a new air tank was built on top of the existing tank and a new primary coils building built on top of the existing building.

Ambient air entered from the south, then in the primary coils building passed through filters and cooling coils to reduce its temperature to about 40° F. The air enters the 29-foot-diameter dryer tank where beds of activated alumina absorbed moisture to a dew point of -70° F. The air then entered the Secondary Cooling Building north of the dryer, which cooled the air to the desired tunnel temperature. The resulting cool, dry air was pumped to both the AWT and adjacent Small Supersonic Wind Tunnels.

Images: Former make-up air line in 2005, Small supersonic tunnel test section, Aerial view, Exterior of Air Dryer

D. Small Wind Tunnels

The emergence of the turbojet during the final years of World War II transformed aviation virtually overnight. The Altitude Wind Tunnel (AWT), which had been designed for the piston engine, was quickly adapted for the jet engine. The future would be supersonic wind tunnels, though, and during the summer of 1945 the lab's Wind Tunnel Division chief, Abe Silverstein, designed several small wind tunnels that would use the AWT's powerful exhauster system to create supersonic speeds. One building behind the AWT contained three of these tunnels stacked vertically. Another supersonic tunnel was created in the AWT's basement.

Stack Tunnels: Three small supersonic wind tunnels built in 1945, 1949, and 1951 were housed in an L-shaped building directly behind the southwest corner of the AWT. The first tunnel was built in just 90 days. The airflow for the tunnels was supplied by the AWT's make-up air line. After passing through one of the test sections, the exhaust line tied directly into the AWT's south wall.

The control room and manometers were located in the building's basement. Early tests in the first tunnel focused on supersonic diffusers, supersonic ramjets, and supersonic aerodynamics. Tests run in the late 1950s included inlet studies for North American, light gas-injection wing burning, high-altitude rocket ignition for NASA, NASA noise studies, and drogue parachute configurations. The tunnels were deactivated in 1961 as the Center concentrated on space programs. The tunnels were finally demolished in the 1980s.

Images: *Isometric drawing of Small Supersonic Tunnels*, *Ramjet in small tunnel*, *Aerial view of small tunnels*, *Construction*

Duct Lab: In a tunnel between the basements of the AWT's Shop and Office Building and the Engine Research Building, a supersonic wind tunnel with an 8-foot-long, 4-inch-wide, and 10-inch-high test section was built in 1945. Like the Stack Tunnels, the Duct Lab took advantage of the AWT's exhaust system to produce its speeds of Mach 1.6 to 5.0 and temperatures of 400° F. Schlieren and laser anemometry systems are used to obtain flow visualization measurements. Although the AWT has been idle for over 30 years, operation of the Duct Lab continues. In recent years it has been used for development of supersonic injectors, artificial intelligence methods, nonintrusive laser systems, and for flow physics studies and investigations of continuous Mach 1.6 to 5.0 flow physics.

Images: *Removable test section*, *Construction*, *Duct Lab in 1940s*, *Duct Lab today*

III. Historical Research

A great deal of information has been collected regarding the Altitude Wind Tunnel. This includes materials created during the recent documentation of the facility, as well as records, publications, and reports generated during the facility's operating years. In addition, there are many NASA historical publications which are excellent sources of contextual history.

Timelines: These pages include timelines of testing in both the Altitude Wind Tunnel and Space Power Chamber. They also include a general timeline of events that influenced the history of the facility.

Events Timeline (1936 – 1957)
Events Timeline (1958 – 2008)
Tests Timeline (1944 – 1975)

AWT Documents: Here one can find transcriptions and PDFs of original documents, articles, reports, and speeches. These materials span from World War II through Project Mercury and the 1960s space program.

Additional materials describing the Altitude Wind Tunnel and the studies conducted there are available in the Interactive History portion of this website. These include a chronological history of the facility, links to research reports and other AWT-related publications, 9-minute documentary video created by NASA in 1961, and much more.

Image: Original employee, Helen Ford

A. Events (1936 - 1957)

1936

- Fifth Volta conference —"High Velocities in Aviation" attended by NACA
- NACA Committee on Aeronautical Facilities formed
- George Lewis begins visit of Germany aeronautical facilities
- NACA Committee on Relation of NACA to National Defense initiated
- First supersonic wind tunnel built at Peenemunde, Germany

1938

- NACA authorizes study on need for additional research labs
- Wright Brothers Wind Tunnel begins operation at altitudes up to 37,000 feet
- Future Research Facilities Special Committee studies a new NACA lab

1939

- Congress appropriates $10 million for new NACA lab
- British German Heinkel He178 is first jet aircraft successfully flown
- Moffett Field, California, selected as site for new NACA laboratory
- Charles Lindberg recommends NACA build an engine research plant
- NACA approves establishment of an engine research lab
- Forming of Committee on New Engine Research Facilities led by George Mead
- Ames Aeronautical Lab construction begins at Moffett Field

1940

- NACA approves scope and estimates for engine lab
- President Roosevelt calls for 50,000 U.S. aircraft per year
- Congress appropriates $8.4 million for engine research lab
- Italians fly thermal–jet Campini–Caproni CC–2
- Four–man NACA board visits Cleveland to assess the land for new engine lab
- Edward Sharp named Chief of Construction Division at Langley Field
- NACA announces selection of Cleveland, Ohio, for new lab

1941

- Aircraft Engine Research Lab groundbreaking in Cleveland
- NACA Special Committee on Jet Propulsion formed
- First flight of British Gloucester E28/39 with Whittle jet engine
- Edward Sharp arrives to oversee construction of Aircraft Engine Research Lab
- Bell Aircraft given contract to build Whittle engine in United States
- United States enters World War II
- First flight of German Messerschmitt Me262 jet fighter

1942

- Hangar becomes first completed building at AERL
- Carrier Corporation wins contract for AWT refrigeration system
- Formal initiation of research at AERL
- General Hap Arnold requests AERL construction be given Class 1 priority
- Construction of AWT begins
- Messerschmitt ME 262 becomes first operational jet aircraft
- First flight of German V–2 rocket at Peenemunde
- First atomic chain reaction at University of Chicago
- Dr. Sharp appointed AERL manager

1943

- Elliptical corner rings erected for AWT
- Westinghouse 19A is first US designed jet engine
- Installation of AWT drive motor and flash cooler
- GE I–16 turbojet engine secretly tested in Jet Propulsion Static Lab
- Abe Silverstein transfers from Langley to Cleveland

1944

- Altitude Wind Tunnel becomes operational
- AWT tests first jet engine in United States and B–29’s R–3350 engine
- General Henry “Hap” Arnold visits AERL
- Icing Research Tunnel begins operation

1945

- Japan surrenders ending World War II
- Major reorganization of AERL to focus on jet engines
- Modified AWT to muffle low–frequency vibrations
- George Lewis suffers two heart attacks
- Construction on 8–by 6–Foot Supersonic Wind Tunnel begun

1946

- First successful US operation of afterburner in AWT

1947

- AERL renamed Flight Propulsion Research Laboratory
- First supersonic flight by Chuck Yeager in X–1
- AWT Fan and Tunnel Survey
- Lab renamed the Lewis Flight Propulsion Laboratory

1948

- 8–by 6–Foot Supersonic Wind Tunnel begins operation

1949

- Abe Silverstein becomes Director of Research
- Research divisions reorganized for supersonic flight

1951

- AWT undergoes major upgrade and modernization

1952

- Korean War begins
- Propulsion Systems Laboratory begins operation

1953

- AWT reduced hours of operation due to modernization project
- Air Force's Propulsion Wind Tunnel begins operation

1955

- 10–by 10–Foot Supersonic Wind Tunnel completed
- Harold Kaufman conducted tests in AWT for Project Bee
- Walter Olsen issues paper on future rocket propulsion research

1957

- Sputnik I launched
- Rockets discussed at NACA Lewis tri–annual inspection
- B-57 flies using liquid-hydrogen for Project Bee

Images: NACA VIPs in 1939, Aerial View of future AERL site, Edward R. Sharp , Hangar with Construction around, Erection of AWT corner rings , Airacomet in AWT, General Electric TG-190 turbojet, Exhaust gas cooler, Model of 10-By 10-Foot Wind Tunnel

B. Events (1958 – 2008)

1958

- NACA Lewis incorporated into the new NASA space agency
- AWT shut down for tunnel leak test; end of use as a wind tunnel
- George Lewis begins visit of Germany aeronautical facilities
- Big Joe Mercury capsule mock–up tests in AWT
- Big Joe boilerplate capsule launched
- Lewis tasked with five Project Mercury tasks
- Interior of west end of AWT gutted for Mercury tests

1960

- Mercury astronauts train in MASTIF rig in AWT
- Mercury escape tower tests
- Mercury–Redstone 1 launch failure

1961

- Yuri Gagarin becomes first human in space
- Alan Sheppard becomes first American in space
- Abe Silverstein returns to Lewis as Center Director
- Conversion of AWT to the Space Power Chambers (SPC) begins

1962

- First Centaur (F–1) launch fails
- Surveyor program substitutes Centaur for Agena rocket
- AWT renamed the Space Power Chambers
- Centaur Program transferred to NASA Lewis

1963

- Agena Program transferred to NASA Lewis
- Installation of dome on Space Power Chamber No. 1
- Atlas/Centaur separation test rig arrive at NASA Lewis
- Erection of Centaur yoke in SPC
- Atlas/Centaur separation tests are first SPC tests
- Centaur rocket arrives at NASA Lewis
- Atlas/Centaur–2 successfully launched

1964

- Centaur rocket inserted into SPC No. 1
- Cleveland Parade of Progress Exposition features NASA
- Surveyor model launched on Atlas/Centaur–4
- Atlas/Centaur–5 explodes on launch pad

1965 Insert new image here→

- Atlas/Centaur–6 launches successfully
- Atlas/Centaur–8 systems tests in SPC No. 1
- Orbiting Astronomical Observatory–1 satellite launches

1966

- Atlas/Centaur–8 launches
- RL–10 engine program transfers to NASA Lewis

1968

- Centaur, Atlas, and Agena project offices combine as Launch Vehicles Division
- Launch of Orbiting Astronomical Observatory–2 satellite
- 9–by 15–Foot Low–Speed Tunnel added to 8–by 6–Foot Supersonic Wind Tunnel

1970

- Failed Orbiting Astronomical Observatory–B launches

1971

- Shop area used to prep Research Propulsion Module and jet engines
- Study into rehab of AWT for Vertical/Short Takeoff and Landing testing

1972

- Shop area used for electric automobile studies
- Orbiting Astronomical Observatory–C satellite launches

1973

- Shop and Office Building rehabbed
- NASA Lewis closes Plum Brook Station

1975

- Centaur Equipment Module becomes SPC's last test

1976

- Concord flies first flight

1978

- Icing Research Tunnel restored to operational status

1979

- Propulsions Systems Laboratory 1 and 2 closes

1980

- AWT Project Office formed to study tunnel rehab

1982

- Building 7 Shop Area converted into Microwave Systems Lab

1984

- Wind Tunnel Modeling Seminar held at NASA Lewis
- Centaur removed from AWT as part of rehab preparations

1985

- AWT Rehab project cancelled by Congress

1989

- Mercury cleanup project at AWT site

1990

- Shop Area and High Bay area expansion construction begins

1995

- Former control rooms converted into offices

2003

- Crawford Consulting estimated $4 million for repainting

2004

- AWT demolition Requirements Documents released

2005

- Plans for demolition of AWT begins
- AWT historical mitigation work begins

2006

- Community Awareness Meeting held

2007

- Historical documentation of AWT conducted

2008 - 2009

- Demolition of the AWT

Images: New NASA Lewis Research Center sign, Walter Shirra posing by MASTIF, Bulkhead in new SPC, Atlas/Centaur retrorocket test in SPC No. 2 , Centaur rocket in SPC shop, OAO-B failure investigation TF-30 engine in SPC shop, Engineers study AWT model, Researchers in Microwave Lab, Interior of AWT

C. Tests (1944 – 1975)

Altitude Wind Tunnel
1944

- Bell YP–59A Airacomet (J–31/GE I–16)
- Boeing B–29 Superfortress (Wright R–3350)
- Westinghouse 19B and 19XB (J–30)

1945

- Douglas XTB2D–1 Skypirate (Pratt & Whitney 4360)
- General Electric TG–180 (J–35) and afterburner
- Lockheed YP–80A Shooting Star (J–33/GE I–40)
- NACA 20–inch diameter ramjet
- Lockheed TP80S F–80 (J–33/GE I–40)
- Republic YP–47M Thunderbolt propeller tests
- Lockheed XR–60 Constitution (Pratt & Whitney 4360)

1946

- NACA 20–inch diameter ramjet
- General Electric TG–180 (J–35) and afterburner
- General Electric TG–100A turboprop

1947

- Westinghouse X24C–4B (J–34)
- General Electric TG–180 (J–35) and afterburner

1948

- Johns Hopkins 18–inch diameter ramjet
- General Electric TG–180 (J–35) and afterburner
- General Electric TG–190G

1949

- NACA 16–inch ramjet
- General Electric TG–190G (J–47) high altitude starting
- Armstrong–Siddeley Python turboprop

1950

- General Electric TG–19D (J–47) B–7 and RX engines
- Westinghouse 24C–7 and 24C–8 (J–46) afterburner & cooling

1951

- Westinghouse J–40–WE6

1952

- Allison J–71

1953

- Westinghouse XJ34–WE–32 without electronic control

1954

- Pratt & Whitney J–57 and J–57–P–1 air flow

1955

- Wright J–65–B–3 hydrogen transfer test
- Allison J–71

1956

- Rolls–Royce Avon engines (J–54)

1957

- Pratt & Whitney J–57 noise suppression

1958

- Ace piloted ramjet
- NASA solid rocket test
- Atlantic Research's arcite solid rocket test

Project Mercury
1959

- NASA One Axis Table
- NASA Storable propellant
- Big Joe capsule guidance system test
- Hydrogen peroxide test
- Big Joe II capsule guidance system test

1960

- Redstone separation and retrograde rocket tests

Space Power Chambers
1961

- Mercury Evaporating and Condensing Analysis in shop

1962

- S–65 Satellite model (SPC No. 1)

1963

- Atlas/Centaur retrorockets (SPC No. 2)

1964

- Atlas/Centaur–4 Surveyor nose cone (SPC No. 1)

1965

- Centaur environmental tests (SPC No. 1)
- Centaur Insulation Panel test (SPC No. 2)
- Atlas/Centaur–6 Surveyor nose cone (SPC No. 1)
- Centaur Vent Valve Test Rig (SPC No. 2)
- Centaur/Orbiting Astronomical Observatory–1 shroud test (SPC No. 2)

1966

- Hydrogen Vent Test Rig (SPC No. 2)
- Weightless Analysis Sounding Probe (SPC No. 1)

1967

- Atlas launcher shaft (High–bay)
- Surveyor Atlas/Centaur Shroud leak test
- Weightless Analysis Sounding Probe (SPC No. 1)
- Helium Bottle Blowdown Test (SPC No. 2)
- H2O2 Engine Test (SPC No. 2)

1968

- Centaur/Orbiting Astronomical Observatory–2 shroud test (SPC No. 2)

1971

- Centaur/Orbiting Astronomical Observatory–B shroud test (SPC No. 2

1972

- Centaur/Orbiting Astronomical Observatory–C shroud test
- Centaur D–1A shroud test (SPC No. 2)

1975

- Centaur/ High Energy Astrophysical Observatories module test (SPC No. 2)

Images: *B-29 at NACA Cleveland lab*, *Lockheed YP-80*, *GE TG-190 engine*, *Armstrong-Syddeley Python turboprop*, *Pratt & Whitney J57*, *Project Mercury escape rocket test*, *Centaur systems tests*, *Centaur/Surveyor nose cone*, *Centaur/OAO-C shroud test*

D. Historical Documents

Below are digital versions of various historical documents related to the Altitude Wind Tunnel (AWT) or Space Power Chambers (SPC). These include newspaper articles, correspondence, speeches, reports, and other documents.

General

"The History of a Wind Tunnel" film transcript (1961)
"Altitude Wind Tunnel at AERL" by Ernest Whitney (1943)
Wing Tips Newsletter article on AWT (1944)
AWT Facility Specifications (1957)

World War II

William Knudson Letter regarding need for AWT (1941)
NACA Secretary John Victory's Smoker Talk (1944)
General H.H. Arnold Speech to AERL employees (1944)
AERL 1945 Inspection brochure
Schedule of AWT Tests (1944–45)

Turbojets

Authorization for Westinghouse 19B tests (1944)
Authorization for General Electric I-16 tests (1944)
Authorization for General Electric I-40 tests (1944)
"Lab Proves Jet Plane's Promise" article (1945)
Abe Silverstein presentation on AWT Jet Research (1945)
AWT Talks at 1947 Annual Inspection
Excerpts from the NACA's 1946 Annual Report (1947)
Summary of AWT Operations (1944–57)

Project Mercury

Orbit Newsletter Articles on MASTIF (1960)
MASTIF Progress Report (1961)
Application Form for Mercury Astronauts (1958)

Centaur

Silverstein Memo naming the Space Power Chambers (1962)
"AWT Gets New Assignment" Orbit article (1962)
Space Simulation and Full-Scale Testing in a Converted Facility
"Lewis Launch Record Near Perfect" Orbit article (1967)
Centaur Group Achievement Award talks (1966)

IV. Mitigation Project

In 2005 NASA Glenn proposed to remove the entire Altitude Wind Tunnel (AWT) circuit except for the test section. The AWT was unique based on its sheer size alone, but the maintenance costs for the idle facility rivaled that of the center's largest research programs. Although not used since the mid 1970s, this facility has a rich history and played an important role in both NASA and aerospace history. NASA Glenn felt it important to document the facility as thoroughly as possible prior to its destruction.

Public Awareness Meeting: On April 27, 2006, a community awareness meeting was held at NASA Glenn to alert the public of the center's plans to remove the AWT and Propulsion Systems Laboratory 1and 2. Speakers discussed the scope of the demolition, environmental issues, the history of the facilities, and the historical mitigation project.

Description of Mitigation: This website is part of a wider effort to document the history of the AWT. This project was formally begun in May 2005 after the finalization of Statement of Work 6.31 for the NASA Glenn History Office. The project includes the gathering of records, images, films, oral histories, and information on the facility, its tests, and significance. The information is being distributed to the public through a number of methods including a historical publication, documentary video, and this website.

Demolition Process: It was decided in early 2005 to remove the tunnel portion of the AWT from the NASA Glenn campus. Preparation for the demolition work began in early 2008. The demolition itself began in the fall.

Images: Rusting exterior of AWT in 2005, 1944 article on AWT, Inspection of AWT in 2005, Photo documentation of AWT, Announcement flyer for meeting

AWT Ohio Historic Inventory Form

A. Community Awareness Meeting

On April 27, 2006, NASA Glenn Research Center invited the public and NASA employees to a meeting in order to learn more about the NASA's plans to demolish the Altitude Wind Tunnel and the Propulsion Systems Laboratory 1 and 2. The attendees learned details about the proposed demolitions, the history of the facilities, efforts underway to document the facilities, and the results of the environmental impact studies conducted for the projects.

In accordance with the National Preservation Act, the meeting allowed attendees to ask questions and voice any opposition to the projects. The presentations were videotaped, and copies can be obtained by contacting the NASA Glenn History Office at history@grc.nasa.gov. The PowerPoint slides which combine the text of the talks with historic photographs and charts can be viewed below.

Slides from the presentations:
History of the Altitude Wind Tunnel
Demolition Plan and Environmental
Impact Historical Mitigation Project

Documents:
Event Brochure
Site Location Map
Press Release
Announcement

B. Historical Mitigation Effort

Section 106 of the National Historic Preservation Act requires that Federal agencies document their historic facilities before any significant structural changes, demolitions, or relocations. NASA Glenn Research Center has a number of historic facilities, some of which are scheduled to be demolished. The NASA Glenn History Program, Preservation Officer, and facility managers have worked with the Ohio State Historic Preservation Officer to develop strategies, budgets, and work plans to record the history of these facilities.

The result will be a permanent documentary record for the facility, lessons learned insight for internal NASA use, increased public awareness of NASA Glenn contributions to society, educational resources, and a collected body of materials for future researchers. The Altitude Wind Tunnel project consists of two facets—the documentation and preservation of the facility's history and the interpretation and dissemination of that information to the public.

Documentation: The documentation includes the collection of documents from the Glenn Records Management holdings, other NASA centers, retirees, and other sources and the scanning and captioning of over a thousand negatives, digitizing historic films. In addition, a thorough photographic survey, including virtual reality panoramic images, of the facility was performed. A large effort was undertaken to research the history of the facility through these records, existing reports, oral histories, and other sources.

Dissemination: The information that was collected is in the process of being distilled into several different products to be shared with the public and NASA employees. These include this Web site, a book describing the facility's history, a three-part construction document to physically describe the facility, a video documentary, display panels, and an Ohio historical marker

Historic Preservation Documents:
Protection of Historical Properties
Programmatic Agreement Among NASA, NCSHPOs, and ACHP

Images: Glenn Preservation Officer meets Ohio State Preservation Officer, Collage of materials gathered during documentation of AWT, Collage of products created to disseminate information on the AWT, Cover of Ideas Into Hardware book, Plum Brook Reactor retirees, Inspection of Propulsion Systems Lab

AWT Exhibit Display SPC Exhibit Display

C. Demolition of the Altitude Wind Tunnel

In 2003, for the first time in its history, NASA Headquarters allocated funds for the demolition of unused facilities and asked its centers to submit lists for consideration. NASA Glenn proposed the removal of nine buildings, including the Altitude Wind Tunnel (AWT). Minor exterior repairs and repainting of the AWT were estimated in 2004 to be over $4.5 million. NASA Headquarters has concurred with Glenn's decision and advocated the proposed demolition.

NASA Glenn then created a requirements document in September 2004 and a Statement of Work in 2005. The Ohio Historic Preservation Office was notified in May 2004. A Section 106 report was submitted in July 2006 and approved in September 2007. Design services were obtained and demolition plans were created. Bids to perform the work were solicited and the contracted was awarded in 2007.

Demolition Process

The demolition was performed in three phases: utility relocation, lead paint and asbestos remediation, and the actual demolition of the facility. Some of the AWT utilities were rerouted before the demolition so they could be used by other facilities. A pipe bridge was built behind the AWT and along the back wall of the Icing Research Tunnel for this rerouting. The next step was the removal of lead paint from the welds in the tunnel shell where torches would be cutting.

Images: AWT Demolition, Clearing Tunnel, Pipe Bridge, Paint Removal

Workers on lifting platforms cut along the welds to segment the outer shell. As each steel plate was removed, the insulation underneath was also taken away. Next, the segmenting of the thick inner steel shell ensued. Again, workers with torches were hoisted into place to systematically cut away large sections. The work started in the middle of the tunnel and proceeded to the two ends with their larger corner rings. Pieces of the shell were flattened and laid on the muddy ground to support the large cranes.

Images: First Section, Cutting Inner Shell, Flattened Shell

Auxiliary work included the demolition of the Circulating Water Pump House and Vacuum Pump House underneath the AWT. The generators and drive motor were removed from the Visitor Information Center, the former Exhauster Building. A wall was demolished to help extract the generator, and the tower roof was removed so a crane could lift the drive motor out. Once outside on the ground, the large equipment was cut into smaller pieces for transportation. The former Shop and Office Building (now the Microwave Systems Laboratory, Building 7), which previously housed the tunnel's test section, had its asbestos siding removed and replaced. Seals were placed where the former tunnel entered the building. The final step will be soil remediation, regrading, and paving the site of the former wind tunnel.

Images: Pump House, Generator, Drive Motor

View Demolition Slide Show

Demolition Team

The NASA Project Team was lead by **Bryan J. Coates, P.E.** (Project Manager), **Patrick Edmonds** (Quality Assurance Technician), and **Randy Dworznik** (Inspector) from the Facilities Management Branch located in the Facilities Division at the Glenn Research Center.

The NASA Waste Management Team performed critical oversight of the waste streams associated with the demolition, completed weekly inspections of the site, and documented all material leaving the site.

This project was awarded to **Pinnacle Construction** (Prime Contractor). Pinnacle's team consisted of:

Bob Zerbe – Project Manager
Bill Brown – Site Superintendent
Jerry Stevens – Site Superintendent
Lindsey Schweizer – Sky

For a task of this size, a number of subcontractors were used by Pinnacle Construction. The following is a list of project subcontractors:

- Soehlen Piping
- Fowler Electric
- Brandenburg Industrial Service Company
- Norris Brothers Company, Inc.
- Precision Environmental

Soehlen piping performed the utility reroute prior to the start of the tunnel remediation and demolition. Systems involved included 125 psi shop air, steam, steam condensate, and natural gas. Soehlen performed the mechanical isolation and disconnect of these systems.

Fowler Electric performed the electrical isolation and disconnection of all high- and low-voltage electrical equipment associated with the project.

Norris Brothers Company, Inc. removed the large motors and generators from Building 8 and installed the tunnel caps on Building 7.

Brandenburg Industrial Service Company performed the primary task of tunnel remediation and demolition. Mauricio Gonzalez (Foreman) and Rafael Olivencia (Foreman) were responsible for running the demolition crew. Brandenburg augmented their crew with laborers from the **Local 310** (Laborers' International Union of North America) and an operator from **Local 18** (International Union of Operating Engineers).

Images: NASA Project Team, NASA Waste Management Team, Pinnacle Construction, Local 18 Operator, Norris Brothers Crew, Brandenburg Industrial, Local 310 Crew

V. Students

Wind Tunnels: Almost as long as humans have contemplated air travel, they have sought to create flight conditions in a controlled environment to assist the design process. Today, computer- aided design and flight simulators can replicate flight conditions, but traditionally there were two basic methods for simulating flight with model aircraft on the ground—propelling an aircraft through the air or subjecting a stationary aircraft to an airflow. The earliest simulation tools in the mid-18th century used this first method. These "whirling arms" consisted of a pole with a model aircraft held on an extended arm. The arm was then rotated rapidly in circles to simulate actual flight.

The second, and most successful, form of testing was the placement of a stationary model inside a tunnel. Flight was simulated when air was pulled through the tunnel and past the model aircraft. The tunnel method proved to be more practical and efficient than the whirling arms. The tunnel operator can control wind speed and other atmospheric conditions, as well as the aircraft's angle of attack and attitude. Although there are full-scale wind tunnels in existence, most are not large enough to accommodate an actual aircraft. Instead, scaled-down models, which are comparatively inexpensive and easy to modify, are used.

Wind Tunnel History
How the Altitude Wind Tunnel works

Vacuum Chambers: The use of vacuum chambers to simulate high altitudes began during World War I. The air pressure decreases as altitude increases. By reducing the quantity of air in a chamber or tank, one can simulate the air pressures of high altitude. This was done for a variety of aeronautics uses, including studying engine behavior and the effect of altitude on pilots.

Initial space flights during the late 1950s and early 1960s showed the behavior of engines, flight systems, and hardware was affected by the vacuum and cold temperatures found in space. There was a need to test full-size versions of these items in a vacuum chamber before the mission. In the early 1960s there was a wave of large vacuum chambers built for this purpose.

Vacuum Chamber History
How Space Power Chamber No. 1 works

A. History of Wind Tunnels

Wind tunnels have been used for studying the elements of flight since 1871. Initially they were small-scale, open-loop devices such as the Wright Brothers' tunnel with its 16-inch test section. Wind tunnels grew in size and complexity, particularly after the Ludwig Prandtl first closed-loop tunnel in 1909. Tunnels were built in a variety of sizes and shapes with varying speeds depending on the current technology and their intended areas of study. The Altitude Wind Tunnel (AWT) was the first wind tunnel built to study engine performance in altitude conditions. A list of important wind tunnels is below.

Timeline of Wind Tunnel Development

Date	Description	Designer	Location
1871	First wind tunnel	Frank Wenham	Great Britain
1897	Russian tunnel	K. Tsiolkovsky	Russia
1901	16- by 16-inch tunnel	Wright Brothers	Dayton, OH
1901	6- by 6-foot tunnel	Albert Zahm	Catholic University
1904	Russian tunnel	D. Riabouchsinsky	Moscow
1909	First closed-loop tunnel	Ludwig Prandtl	University of Gottingen
1912	Twin tunnels	Gustav Eiffel	Paris, France
1917	First modern tunnel	Ludwig Prandtl	University of Gottingen
1923	Variable Density Tunnel	Max Munk	Langley Field
1927	Propeller Research Tunnel		Langley Field
1931	Full Scale Tunnel	Smith DeFrance	Langley Field
1936	First supersonic tunnel		Peenenemunde
1936	Kirsten Tunnel	William Boeing	Univ. of Washington
1938	Altitude tunnel		Massachusetts Institute of Technology
1939	19-Foot High Speed Tunnel		Langley Field
1942	First U.S. supersonic tunnel		Langley Field
1944	AWT	Young & Monroe	NACA Lewis
1944	40- by 80-Foot Tunnel	Carl Bioletti	NACA Ames
1948	8- by 6-Foot Supersonic Wind Tunnel		NACA Lewis
1955	10- by 10-Foot Supersonic Wind Tunnel		NACA Lewis
1955	Propulsion Wind Tunnel		AEDC

Images: First Langley tunnel, Variable Density Tunnel, Interior of 8-By 6-Foot Supersonic Wind Tunnel, Interior of 10-By 10-Foot Supersonic Wind Tunnel

B. How the Altitude Wind Tunnel Works

The Altitude Wind Tunnel (AWT) at NASA Glenn Research Center was able to test full-scale aircraft engines in airspeed, altitude, and air quality found during flight. Airspeed up to 500 miles per hour was created by a 31-foot-diameter propeller that was spun by a 18,000–horsepower engine in the Exhauster Building. The airflow was straightened by turning vanes located in the tunnel corners. A powerful cooling system in the Refrigeration Building could reduce the tunnel's temperature to –47 °F as the air passed through accordionlike cooling coils in the wide end of the tunnel.

The Exhauster Building contained large compressors, which removed air from inside the tunnel to create the thin atmosphere found at high altitudes. The engine being tested was installed in the 20-foot-diameter test section and operated remotely from the control room. A myriad of instrumentation recorded the tunnel conditions and engine performance during the tests. The engines exhausted contaminants, which were removed from the tunnel through an air scoop located just beyond the test section. Fresh air was introduced into the windstream prior to the test section to make up for the exhausted air.

Launch Tunnel Animation

Glossary

Open-Loop Tunnel: Wind tunnels are generally either open-loop or closed-loop designs. The open-loop type is a simple design that consists of a long open-ended tube. A fan at the far end of the tunnel pulls the air through the tunnel, past the test section, and expels it out the far end of the tunnel. Open-loop tunnels are often inefficient to operate.

Closed-Loop Tunnel: The closed-loop tunnel is usually square shaped. It recycles airflow so is more efficient. The closed-loop tunnel is more expensive to build and requires a larger area. Sets of turning vanes are placed in the corners to guide the airflow through the wind tunnel loop. The AWT was a closed-loop tunnel.

Test Section: Portion of a wind tunnel where the test article and sensors are placed. The AWT had a large 20-foot-diameter test section.

Settling Chamber: Section of a wind tunnel, usually just before the contraction, where the airflow is straightened and turbulence reduced. The AWT had a 51-foot-diameter settling chamber.

Contraction: Section prior to the test section where the tunnel narrows to increase the speed of the airflow through the test section. It is sometimes referred to as the throat section. The AWT contracts from 51 to 20 feet in diameter.

Diffuser: Area past the test section where the tunnel's diameter widens so that the air speed is slowed down.

Drive: The apparatus that forces air through the tunnel. It is usually a large fan that is powered by powerful motor. The AWT had 31-foot-diameter fan spun by an 18,000–horsepower motor.

Pressure Tunnel: Small-scale test articles and the atmospheric airflow resulted in questionable test results due to the Reynolds number. By pressurizing the tunnel to altitudes corresponding to the size of the test article, actual flight conditions are simulated.

Reynolds Number: Early wind tunnel test results were often inaccurate since the air flow around the tunnel model and the actual flight were different. Osborne Reynolds (1842–1912) discovered that flow over a scale model would only be identical to the full-scale object if the Reynolds number was identical. The Reynolds number is a nondimensional factor that indicates the ratio of the momentum to the viscosity in gas or liquid fluid flow. Basically, the Reynolds number expresses the relationship of the fluid density, velocity, the object's size, and the coefficient of viscosity of the fluid relationship.

C. Vacuum Chamber History

The first sustained vacuum was achieved in 1643. The first vacuum pump followed in 1650. As flight began developing in the early 1900s, aeronautical researchers began setting up engines in vacuum test chambers to simulate higher altitudes. As the nation began sending spacecraft into space, the need for test chambers capable of producing a higher level of vacuum was apparent. The Space Power Chamber No. 1 (SPC) was among the first of a wave of large vacuum chambers that emerged in the early 1960s. The Space Power Facility at NASA's Plum Brook Station, which began operation in 1969, is the largest vacuum chamber in the world. A list of vacuum chambers used to simulate altitude is below.

Timeline of Vacuum Chamber Development

Date	Description
1917	First test in altitude chamber at the Bureau of Standards for NACA
	High-altitude test bench at Zeppelin Aircraft Works plant in Friedrichshafen
1918	U.S. School of Aviation Medicine altitude tank
1933	National Bureau of Standards tests appliances in a high-altitude chamber
1938	MIT Wright Brothers Wind Tunnel simulates altitude
1944	AWT begins operation at NACA Lewis
1947	Four Burner altitude test stands built at NACA Lewis
1952	Propulsion Systems Laboratory with two altitude test cells for engines
1959	Interior of AWT gutted to form high-altitude chamber
1960	Space environment chamber build by McDonnell for Mercury capsule
1961	Electric Propulsion Laboratory vacuum tanks built at NASA Lewis
	Republic Aviation Space Simulation Facility
1962	SPC No. 1 vacuum chamber built inside AWT
	Goddard Space Environment Simulator
	Lockheed’s High Vacuum Orbital Simulator
	Bendix Corporation’s Space Simulation Chamber
	General Electric Space Environment Simulator
	25-Foot Space Environment Facility at Jet Propulsion Laboratory
1963	Mark I Aerospace Simulator at Arnold Engine Development Center
1965	Space Environment Simulation Laboratory at Johnson Space Center
1969	Space Propulsion Facility at Plum Brook tests rocket engines in vacuum
	Space Power Facility at Plum Brook is world’s largest vacuum chamber

Images: Four Burner altitude chamber, Electric Propulsion Lab, Neil Armstrong in Space Environment Simulation Lab, Centaur shroud in Space Power Facility

D. How Space Power Chamber No. 1 Works

Space Power Chamber No. 1 (SPC) at NASA Glenn Research Center was able to create conditions found at 100 miles altitude in order to study spacecraft behavior in outer space. The chamber was connected to the center's central air system, which could evacuate the chamber to 100,000-foot pressure altitude. This was followed by two piston pumps that further thinned the air. The final vacuum was brought down by 10 oil diffusion pumps located below the chamber.

A complex setup was installed in the chamber that could 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 spacecraft. Solar radiation was simulated using six banks of quartz lamps. In addition, a hydraulic system rotated the rocket's RL–10 engines as they would during flight. A tanking system used to keep the balloonlike fuel tanks partially filled and a wide array of telemetry was installed. The tests were operated and monitored in a control room that resembled the actual launch pad controls.

Launch Chamber Animation

Glossary

Vacuum: A space entirely devoid of matter, including air. Outer space has a very low-density, which is similar to a vacuum.

Cold Wall: A copper baffle, which has liquid-nitrogen-filled fibs and black interior that produced low temperatures found in outer space. The SPC No. 1 cold wall was 20 feet in diameter and 42 feet high and used a thermal-siphon to draw cryogenic liquid nitrogen into the vertical ribs.
Altitude: Considered the elevation above an acknowledged level. In aerospace situations, this level is usually mean sea level. Height is the elevation above a point on the ground.

Space Tank: A chamber from which air is removed. The resulting vacuum is used to simulate the air pressure levels found in outer space. Space tanks, or vacuum chambers, often include other elements, such as cold walls, to further simulate the space environment.

Atmospheric Pressure: Pressure caused by the weight of the atmosphere. As the altitude increases, the atmospheric pressure decreases. At sea level it has a mean value of one atmosphere.

Vacuum Pump: A pump used to remove air from a space or tank. SPC No. 1 used several types of vacuum pumps. The diffusion pumps, which had no moving parts, directed residual molecules from the chamber using high-speed jets of fluid.

VI. Gallery

The Gallery contains over 1300 photographs related to the Altitude Wind Tunnel and Space Power Chambers facility, tests, events, and staff. Many of these were recently scanned and are available for the first time.

Clicking a thumbnail will launch an Item Detail page that displays the title, filename, date, and, in most cases, a detailed caption, are provided for each image. A high-resolution version of each image is also available from the detail page.

View Gallery page

Displaying records 1 - 16 of 1,345 Page: 1 2 3 4 5 6 7 8 9 | next >

VII. Links to External Resources

NASA History

Glenn History Program
Headquarters History Office
Rocket Engine Test Facility history

NASA Facilities

Glenn Research Facilities
Plum Brook Station Facilities

Historic NASA Glenn Facilities Publications

Science in Flux:
NASA's Nuclear Program at Plum Brook Station (PDF 3.42MB)
NASA's Nuclear Frontier:
The Plum Brook Reactor Facility
Ideas Into Hardware:
A History of the Rocket Engine Test Facility (PDF 2.13MB)
We Freeze to Please:
A History of NASA's Icing Research Tunnel (PDF 3.15MB)
History Series Publications

Additional Research Tools

Glenn ImageNet Online Collection
NASA Technical Report Server
The Wind Tunnel Collection
Satellite Stamps at Colorado State

Historical Preservation

Ohio State Historical Preservation Office
Advisory Council on Historic Preservation
National Park Service Historic Documentation Programs
Society for History in the Federal Government

Contact Information

NASA Glenn History Office
21000 Brookpark Road
Cleveland, OH 44135
Email: history@grc.nasa.gov

NASA Glenn History Officer: Anne K. Power
Archivist: Robert S. Arrighi, Wyle Information Systems

Image: Abe Silverstein with display in AWT high-bay