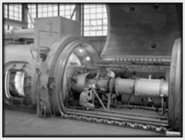
Historic Facilities
Glenn Research Center

Propulsion Systems Laboratory

PSL No. 1 & 2 *1952 - 1979*

- PSL 1 and 2
- Publications
- History
  - Design and Construction
  - Ramjets and Missiles
  - Rocket Engines
  - Return to Turbojets
  - Addition of PSL No. 3 and 4
  - Turbofan Engines
  - Demolition
- Facility
  - Combustion Air Flow
  - Test Equipment
  - Exhaust System
  - Support Buildings
- Research
  - Historical Documents
  - Technical Reports
- Mitigation
  - Community Awareness
  - Historical Mitigation
- Students
  - Events Timeline
  - PSL No. 1 and 2 Testing Timeline
  - PSL No. 3 and 4 Testing Timeline
  - How PSL Worked
- External Links

HISTORIC FACILITIES AT NASA GLENN



PSL Test Chamber

The Propulsion Systems Laboratory (PSL) was the National Advisory Committee for Aeronautics' (NACA) most powerful facility for testing full-scale engines at simulated flight altitudes. The original PSL chambers, referred to as PSL No. 1 and 2, were a technological combination of the old static sea level test stands and the complex Altitude Wind Tunnel, which recreated actual flight conditions on a larger scale. PSL's significance lies in the size and power of the engines it tested. When it became operational in 1952, PSL was the nation's only facility that could run these large full-size engine systems in controlled altitude conditions. The ability to control the test environment was important in the advancement of the ever-increasing and complex turbojet systems.

The two 14-foot-diameter and 24-foot-long chambers were first used to study the increasingly powerful jet engines of the early 1950s and the ramjets for missile programs such as Navaho and Bomarc. With the advent of the space program in the late 1950s, the facility was used to study complex rocket engines, including the seminal Pratt & Whitney RL-10 that was used to power the Centaur rocket and Saturn I upper stages. In the mid-1960s, PSL returned its focus to jet engines, which continued to grow in size and performance. By 1972 two additional, more powerful test chambers were added to PSL to accommodate these new engines. The original chambers continued with jet engine research until being phased out in 1979. PSL No. 3 and 4 still maintains a busy schedule. It is NASA's only facility for testing full-scale engine systems at flight altitudes.

FACILITY LAYOUTS

View the PSL No. 1 and 2 facility as it appeared during construction, when operational, and in a 2008 photographic survey of the facility. Select buttons in the layout to view the images and descriptions. Click this image below to launch.

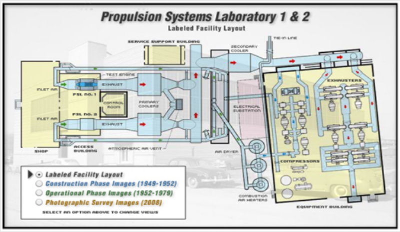
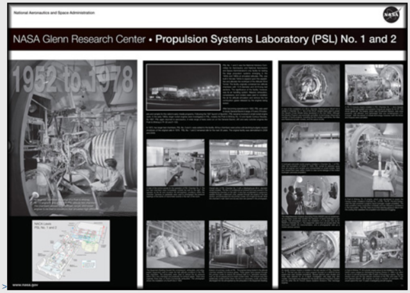


EXHIBIT DISPLAY

An exhibit display was created to highlight PSL No. 1 and 2's physical attributes and important tests. Click the image below for a full-size version of this display panel.



https://pslhistory.grc.nasa.gov/

Propulsion Systems Laboratory

PSL No. 1 & 2 1952 - 1979

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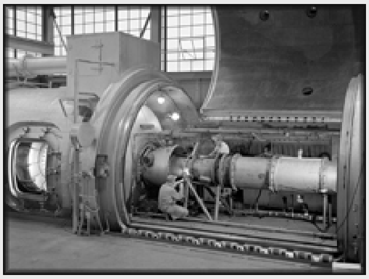

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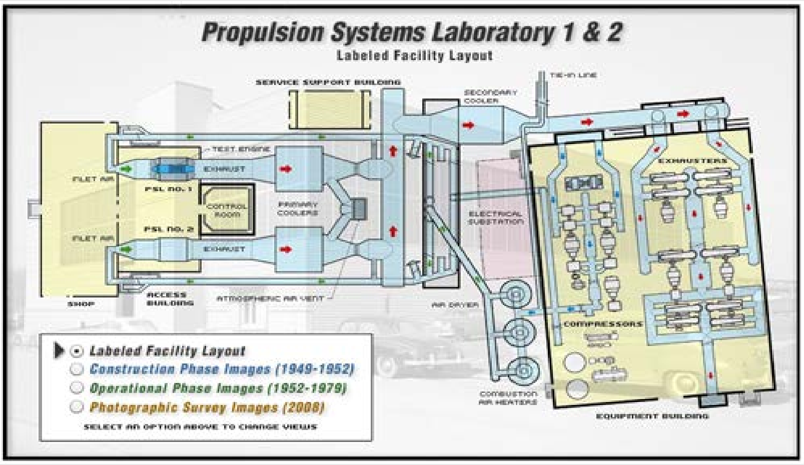

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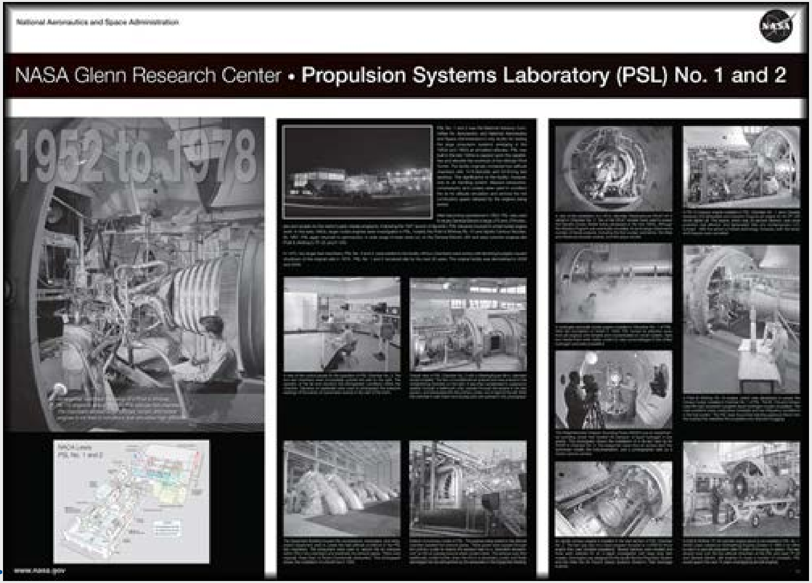
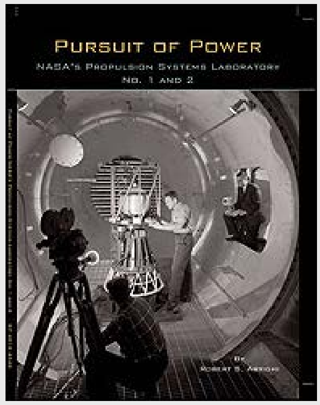

National Aeronautics and Space Administration
NASA Glenn Research Center • Propulsion Systems Laboratory (PSL) No. 1 and 2
1952 to 1978
www.nasa.gov

>

History
Propulsion Systems Laboratory No. 1 & 2

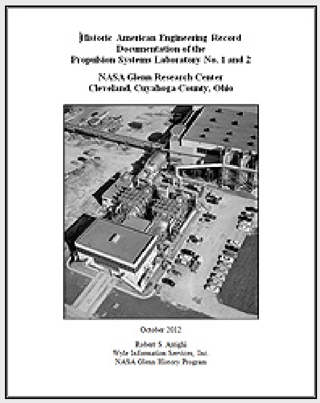
BOOK



Pursuit of Power: NASA's Propulsion Systems Laboratory No. 1 and 2 (NASA SP-2012-4548) describes the research, operations, and people involved with the Propulsion Systems Laboratory (PSL) at the NASA Glenn Research Center. From 1952 until 1972 PSL was the agency's most powerful facility for testing full-scale engines at simulated flight altitudes. The facility's original test chambers, known as PSL No. 1 and 2, were first used to study the increasingly powerful jet engines of the early 1950s and the ramjets for missile programs such as Navaho and Bomarc. With the advent of the space program in the late 1950s, the facility was used to study complex rocket engines, including the Pratt & Whitney RL-10 that was used to power the Centaur rocket and Saturn I upper stages. In the mid-1960s, PSL returned its focus to jet engines, which continued to grow in size and performance. By 1972 two additional, more powerful test chambers were added to PSL to accommodate these new engines. The original chambers continued with jet engine research the chambers were phased out in 1979. This book seeks to restore appreciation of PSL's contributions to complex aerospace programs, demonstrate its importance to the Center's capabilities and 70-year propulsion legacy, and remember some of the facility operators, technicians, and researchers who extracted significant data from the equipment.

The book is available in the following formats:
PDF (PDF, 9.48MB)
eBook
Hard copy - contact the NASA Headquarters History Office at histinfo@hq.nasa.gov or (202) 358-0384

HISTORIC AMERICAN ENGINEERING REPORT


Historic American Engineering Record
Documentation of the
Propulsion Systems Laboratory No. 1 and 2

NASA Glenn Research Center
Cleveland, Cuyahoga County, Ohio

October 2012

Robert S. Arrighi
Wyle Information Services, Inc.
NASA Glenn History Program

American Engineering Report (HAER) documentation of the Propulsion Systems Laboratory No. 1 and 2 to be submitted the Ohio Historic Preservation Office. The report details the physical history of the site, event history of the facility, contemporary facilities, and architectural and operational descriptions of the facilities and their support buildings. Includes numerous photographs, blueprints, and drawings.

PSL HAER Report (PDF, 28.2MB)

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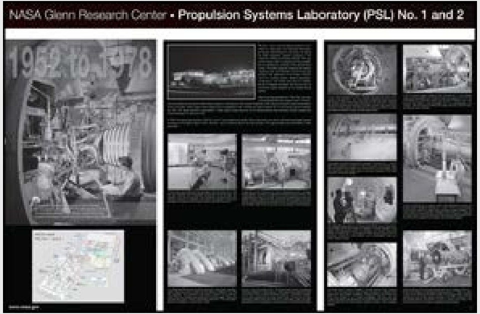
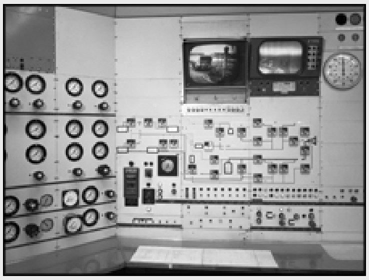

NASA Glenn Research Center • Propulsion Systems Laboratory (PSL) No. 1 and 2
1952 to 1978

History

Propulsion Systems Laboratory No. 1 & 2

HISTORY



PSL Control Room

The Propulsion Systems Laboratory (PSL) No. 1 and 2 was used to test a wide variety of engines during its almost 30 years of operation. NACA's Cleveland lab specialized in aircraft engine research, but its large test facilities were struggling to keep up with the rapid new post-World War II technological advances in propulsion. The addition of the PSL altitude chambers not only permitted the study of new more powerful engines, but also was a key component in the improvement of the overall altitude air system for all of the lab's test facilities.

Read more about the history of PSL No. 1 and 2:

I. Design and Construction (1948 – 1952): The lab had several large engine test facilities. Design work for PSL began in the late 1940s, and after nearly three years of construction, the first test was run in late 1952.

II. Ramjets and Missiles (1952 – 1957): Initially, PSL No. 1 and 2 were used to study ramjets for missiles and large turbojet engines.

III. Rocket Engines (1958 – 1966): After the launch of Sputnik, the facility concentrated on rocket engines. PSL played a significant role in the development of the RL-10 engine, and contributed to the Apollo Contour and 260-inch engines.

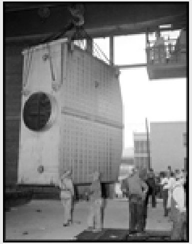
IV. Return to Turbojets (1967 – 1974): As the center returned to aeronautics, PSL was used in conjunction with an F-106 aircraft to calibrate the TF-30 and J85 engines.

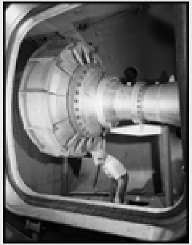
V. PSL No. 3 and 4 (1968 – 1972): Two more powerful test chambers with a slightly different design were added to the facility.

VI. Turbofan Engines (1974 – 1979): After PSL No. 3 and 4 began operating in 1972, use of PSL No. 1 and 2 began to decline. Its last major program was a series of nozzle studies for the F-100 engine.

VII. Demolition (1980 – 2009): PSL No. 1 and 2 was mothballed in late 1979. In 2004 the Center decided to remove the facility. Demolition was performed in 2009.

IMAGES


Construction


Ramjets


Rockets


Turbofans

History
Propulsion Systems Laboratory No. 1 & 2

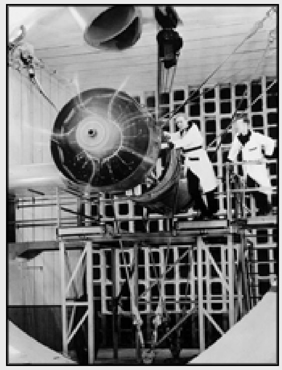
DESIGN AND CONSTRUCTION (1947 – 1952)

The National Advisory Committee for Aeronautics (NACA) was formed in 1915 to coordinate aeronautical research in the United States. Its laboratory in Cleveland, Ohio specialized in aircraft engines and offered many engine test facilities. In the late 1940s the NACA realized it needed yet another, larger facility to test the newest jet engines. Design of the Propulsion Systems Laboratory (PSL) began in 1947, and construction followed in September 1949. The first test was run in October 1952.

Documents:

New Altitude Test Facilities Aid Improvements of Turbojets (PDF, 352KB)
New Lab to Expand Research Articles (PDF, 360KB)

ENGINE TESTING AT THE NACA



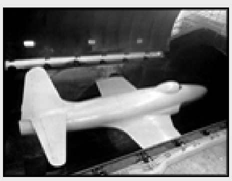
Prop House

Aircraft engines had been largely ignored by the NACA for the first twenty years of its existence. It was the realization of Germany's propulsion advancements in the late 1930s that prodded the NACA to open a new laboratory specifically to study engine systems. This new Aircraft Engine Research Laboratory (AERL) in Cleveland, Ohio became operational in 1942.

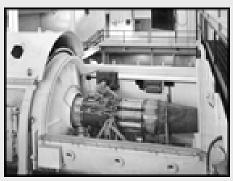
The first major facility to come online was the Engine Propeller Research Building, or Prop House, in May 1942. The Prop House contained four 24-foot-diameter test cells that could run 4000-horsepower piston engines in ambient conditions. The Altitude Wind Tunnel (AWT), which was completed in early 1944, was a much more complex and useful facility. It could run the same size engines in conditions that simulated altitudes up to 50,000 feet and at speeds up to 500 miles per hour. The AWT was so successful that its schedule soon became backed up for months on end. It was decided to quickly build two static engine test stands in the Engine Research Building. This Four Burner Area could also run full-size engines at simulated altitudes up to 50,000 feet. During the late 1940s and early 1950s, the jet engine was rapidly growing in power and size. A more powerful test facility was needed.

Documents:

Altitude Wind Tunnel Website



Altitude Wind Tunnel

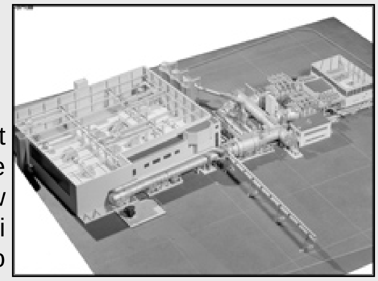


Four Burner Area

Larger Turbojets

DESIGNING THE PSL

Engineers at the lab began planning in 1947 for a new facility that combined the test cell concept of the Four Burner Area with the massive infrastructure of the AWT. It would be part of a comprehensive plan to improve the altitude testing capabilities across the lab by linking the



Building Overview

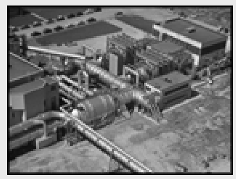
exhaust, refrigeration, and combustion air systems from all the major test facilities. In this way, different facilities could be used to complement the capabilities of one another. Ten million dollars were allocated for the new PSL chambers. Within five months, veteran engineer Eugene Wasielewski converted the recommendations of the lab's Research Facilities Panel into design specifications. The Burns and Roe Company worked closely with the NACA engineers to create the master drawings from these specifications.

The overall concept of PSL was relatively simple, but integrating the massive systems and having them perform at the desired levels was very complicated. The facility consisted of two test chambers, exhaust gas coolers, an equipment building to house the exhausters and compressors, an access building, cooling tower, pump house, and an office building. It also included a compressed air system that supplied combustion air, an altitude exhaust gas system, research equipment installations, a cooling water system, electrical power system, as well as basic utilities, an intercommunication system, control rooms, roads, and a fire protection system.

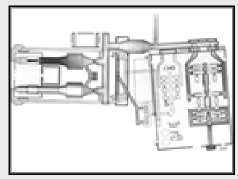
Documents:

- Preliminary Proposal for PSL (1948) (PDF, 4.97MB)
- Wasielewski Retirement Article (1956) (PDF, 320KB)

Wasielewski



Aerial View of PSL



PSL Layout

ORIGINAL CONSTRUCTION

PSL Construction

PSL was projected to cost $11,830,000, which included almost $3 million for the exhaust system. The plan was to build the facility in two phases. The second, more powerful phase would be added shortly after the facility became operational. The Sam W. Emerson Company, which had built many of the lab's buildings in the early 1940s, was selected to perform much of the basic construction work. The Elliott Company and the Ross Heater Company worked on the design of the massive compressors and coolers.

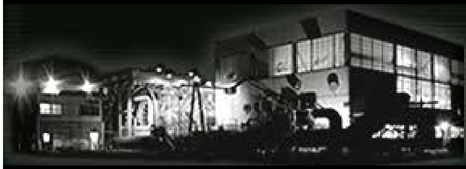
Construction began in late summer 1949 with the installation of an overhead exhaust pipe connecting PSL to the Altitude Wind Tunnel and Engine Research Building. Excavations for PSL began in September. In the spring of 1950, the facility's supports were erected and the two large exhaust gas coolers were installed. Work on the Access Building then began with the large test section pieces arriving in early 1951. Construction of the Equipment Building began in earnest in early 1951. The exhausters and compressors were added in the spring of 1952. The facility was completed in September 1952, three years after construction began.

Construction Footage

PSL Construction

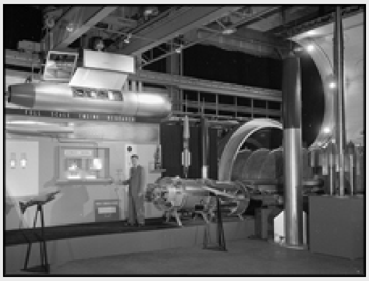
Initial Excavations

Compressors



History
Propulsion Systems Laboratory No. 1 & 2

RAMJETS AND MISSILES (1952 – 1957)



Engineer in front of display in PSL

The Cold War had commenced almost immediately after World War II. The Soviet Union and the United States raced to integrate German technology into their military, particularly the long-range rocket or missile. By the time PSL began operating in 1952, the Korean War was underway, adding an increased urgency to the research. Also, the need continued to test the emerging larger turbojet engines.

Documents:

Engine Research Division Reorganization (1951) (PDF, 1.85MB)
"Jet Engines for War" by Hugh Dryden (1951) (PDF, 1.55MB)
Full Scale Engine Research Inspection Talks (1954) (PDF, 8.23MB)
"Pushing Innovation and Industry Resistance," Chapter 7 of Engines and Innovation
PSL Operations Summary (1953-57) (PDF, 328KB)
Propulsion Research for Hypersonic Flight (1957) (PDF, 7.57MB)

NAVAHO PROGRAM

Installation of 48-inch Ramjet

North American Aviation's Navaho Missile program, started in 1946, was one of the most ambitious attempts to expand upon German rocket technology. The Navaho was a winged missile that was intended to travel up to 3000 miles carrying a nuclear warhead. It was launched using rocket booster engines that were ejected after the missile's ramjet engines were ignited. When it came online in 1952, PSL immediately began studying the Pratt & Whitney XRJ47-W-5 ramjets that were to be used for the Navaho. The 48-inch-diameter engine was again studied in PSL during 1955 and 1956. The engine was run at Mach 2.75 and simulated altitudes between 58,000 and 73,000 feet. Lewis researchers studied engine ignition, the exterior shell of the burner, fuel flow control, different flameholder configurations, and overall engine performance.

While these studies in PSL were occurring, an early turbojet-powered version of the missile was successfully launched numerous times. The second phase of the Navaho Program, which used the ramjets, began launching in late 1956. It took twelve launch attempts get four of the missiles into the air, and those four performed marginally at best. The program was cancelled in July 1957, but its legacy lived on in other programs. Navaho propulsion technology was used on the Redstone, Thor, and Atlas rocket systems, which were used for the Project Mercury launches. Its guidance system would be used on the first nuclear submarine, the Nautilus. The concept of a booster-assisted takeoff for a winged missile came to fruition with the space shuttle.

Documents:

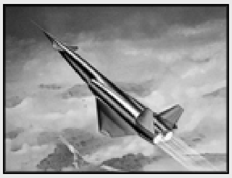
Investigation of Marquardt Shock-Positioning Control Unit (PDF, 1.24MB)
Free-jet Tests of 48-inch Diameter Ramjet with Annular Can-type Flameholder (PDF, 1.63MB)
Investigation of Engine Dynamics and Controls for 48-inch Ramjet (PDF, 13.3MB)
Pentaborane Fuel in a 48-inch Diameter Ramjet Engine (PDF, 1.42MB)
Experimental Investigation of Dynamic Relations in a 48-inch Ram-Jet Engine (PDF, 2.63MB)

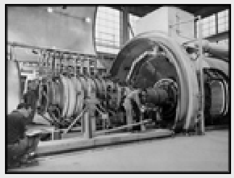
PSL No. 3 and 4 Testing Timeline

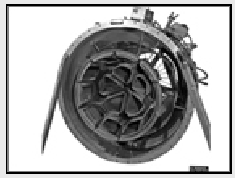
How PSL Worked

External Links


Navaho Footage

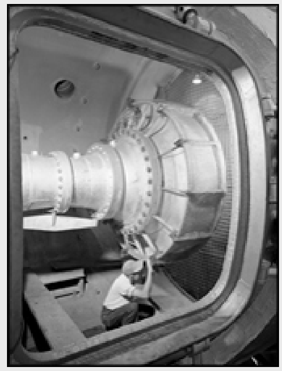

Navaho Missile


PSL 2 with Ramjet


Ramjet Flameholder

BOMARC PROGRAM

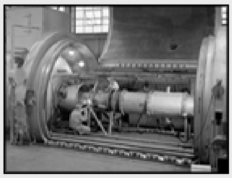
Bomarc was a long-range interceptor missile for the Air Force that underwent a protracted development in the 1950s. The Boeing and University of Michigan-designed missile was launched vertically using a rocket engine, but its flight was powered by two 28-inch-diameter Marquardt ramjets. The ramjets for Bomarc were studied in PSL in 1954 and 1955. The studies covered a variety of performance issues including the systems dynamics response and the pneumatic shock-positioning control unit. The lengthy development was hampered by budget constraints and political in-fighting. In the end, only ten Bomarc sites were established when deployment was finally completed in 1962.

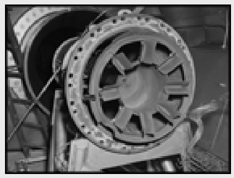

Inlet Section of Chamber

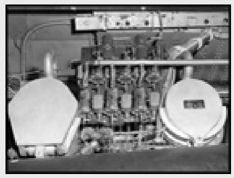
Documents:

- Investigation of Dynamics of a 28-inch Diameter Ramjet (PDF, 1.50MB)
- Investigation of Marquardt Shock-Positioning Control Unit (PDF, 1.24MB)
- Weapons Force Planning: Interceptor Missiles by Richard F. McMullen (PDF, 100KB)


Bomarc Footage


Bomarc Installation


Flameholder


Bomarc Hardware

TURBOJETS


Full-Scale Engines

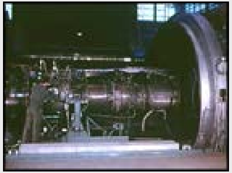
PSL No. 1 was originally used exclusively for turbojets. The first investigation involved a General Electric J73-GE-1A. The 12-stage J73 was a successor to the company's successful J47. The J73s were used primarily on the Air Force's F-86H Sabre jet fighters. During 1952 and 1953, Lewis researchers Carl Campbell, William Conrad, and Adam Sobolewski subjected the J73 to 44 runs in PSL No. 1. They created performance curves showing the optimal range for combustion and compressor efficiency. In September 1954, not long after the PSL tests, the Sabre with its J73 engine set a new world's speed record at the National Aircraft Show in Dayton. The performance of a YJ73-GE-3 version was then studied over almost 200 runs in PSL. Problems with the aircraft design and General Electric's production of the engine resulted in the cancellation of the Sabre program.

General Electric created the Collier Trophy-winning J79 as an advancement of the J73. Its variable stator vanes would permit fighter jets using the engines to reach twice the speed of sound. The Air Force requested that NACA Lewis improve afterburner performance on the engine. Afterburner configurations for the prototype XJ79-GE-1 were tested in PSL during 1957. Basic modifications to the flameholder and fuel system increased the combustion efficiency and reduced the pressure drop. The 17-stage compressor engine was used extensively in the Vietnam War on the F-4 Phantom, F-104 Starfighter, and B-58 Hustler.

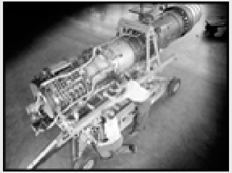
In 1957 PSL also had a chance to test a rare Canadian jet engine, the Iroquois PS.13. The Avro Canada Company began designing its CF-105 Arrow jet fighter in the mid-1950s. Although not originally in the design, the decision was made to use two PS.13 engines developed by another branch of the company. These engines were more powerful than any contemporary U.S. jet engine, lightweight, and fuel efficient. The engines were tested in PSL during the extensive ground testing phase. The Arrow made its flight debut in March 1958, but was cancelled the following year when its perceived mission disappeared.

Documents:

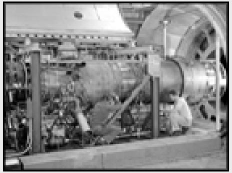
- Altitude Investigation of J73-GE-1A Engine Components (PDF, 6.21MB)
- Performance of YJ73-GE-3 Turbojet Engine in Altitude Test Chamber (PDF, 2.87MB)
- Altitude Performance Characteristics of the J73-GE-1A Turbojet Engine (PDF, 1.22MB)
- Preliminary Performance Data for Variable-Ejector Assembly on XJ79-GE-1 (PDF, 3.99MB)



J73 Footage



GE J79 Turbojet

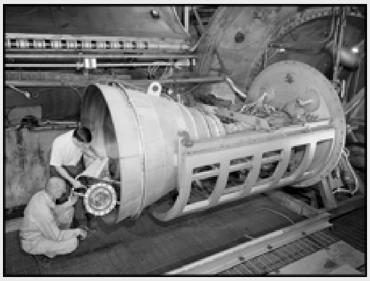


Iroquois Engine

J79 Stator Blades

History
Propulsion Systems Laboratory No. 1 & 2

ROCKET ENGINES (1958 – 1966)



Contour Nozzle

Although NACA Lewis researchers had been working with rocket engines since the mid-1940s, the launch of Sputnik I in October 1957 created a new urgency for rocket research at the laboratory and across the nation. A former employee said that the very night Sputnik began orbiting, PSL ran its final aeronautics test and began switching over to rocket engines. Several small engines were tested during the late 1950s, but major programs such as the Pratt & Whitney RL-10 engine, Contour rocket, and the 260-inch rocket were undertaken at PSL in the mid-1960s.

PRATT & WHITNEY RL-10

Pratt & Whitney developed its 15,000-pound thrust RL-10 engine to power the Centaur second-stage rocket. Centaur would be responsible for sending the Surveyor spacecraft on its mission to land on the Moon and explore the surface in the early stages of the Apollo Program. The RL-10s and Centaur operated on the high-powered cryogenic liquid-hydrogen propellant. This created increased performance but also caused many early technical problems. The Saturn I, a precursor to the Saturn V that was used for Apollo, also used the RL-10s for its upper stages in the early 1960s. Six RL-10s powered the Saturn-IV second stage and two RL-10s powered the Saturn-V third stage.

Centaur Model

PSL was used to throttle and gimbal the engine in simulated altitude conditions. During the tests, the area around PSL was evacuated and the researchers and technicians were locked in the unpressurized control room because of the explosive nature of the liquid-hydrogen. The main problems were combustion instability and low-frequency oscillations in the fuel system. It was found that injecting gaseous helium into the cooling liner stabilized the propellant and reduced chugging. This method reduced the pre-cooling period during a flight and is one of Lewis' most important modifications to Centaur. The Surveyor, launched by Centaur and its RL-10s, made the first soft landing on the Moon on June 2, 1966.

P&W RL-10 Film

RL-10 Firing Footage

Rocket Firing Footage

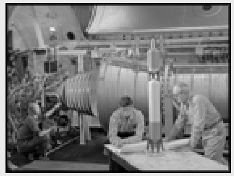
Documents:

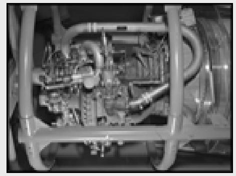
- First Decade of Centaur article (1972) (PDF, 1.33MB)
- "Abe's Baby," Chapter 3 from Taming Liquid Hydrogen (PDF, 2.16MB)
- Design Report for RL-10-A-3-3 (PDF, 3.46MB)
- ASME Report on RL-10 (PDF, 1.81MB)

Reports:

- Characteristics of Centaur Gimbal System Under Thrust Load (PDF, 1.15MB)
- Effect of Several Injector Face Baffle Configurations on Screech (PDF, 5.96MB)
- Effect of Propellant Injection Velocity on Screech (PDF, 1.60MB)


RL-10 in PSL


Researchers in PSL


Instrumentation

APOLLO CONTOUR NOZZLE STUDY

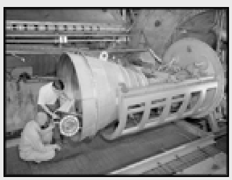

Rocket Engine Nozzles

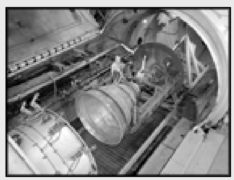
Storable propellants are fuels that can be stored in a tank without any special pressure or temperature control measures. NASA officials intended to use one of these types of propellants, a nitrogen tetroxide and hydrazine blend, for the upper stages of the Saturn V rocket. NASA had been studying the problems of combustion instability and thrust chamber durability for several years, but the important testing of the overall engine and nozzle efficiency remained a problem because of the lack of altitude chambers. NASA Lewis undertook this task in PSL No. 2 in late 1963 and 1964.

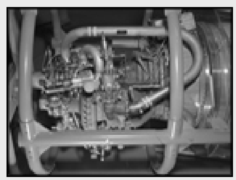
Researchers sought to determine the impulse value of the storable propellant mix, classify the internal engine performance, improve that performance, and compare the results with analytical tools. A special setup was installed in the chamber that included a device to measure the thrust load and a calibration stand. Both cylindrical and conical combustion chambers were examined with the conical large area ratio nozzles. In addition, two contour nozzles were tested, one based on the Apollo Service Propulsion System and the other on the Air Force's Titan transtage engine. Three types of injectors were investigated, including a Lewis-designed model that produced 98 percent efficiency. It was determined that combustion instability did not affect the nozzle performance. Although much valuable information was obtained during the tests, attempts to improve the engine performance were not successful.

Reports:

Experimental Rocket Performance of Apollo Storable Propellants (PDF, 2.39MB)


Apollo SPS Nozzle

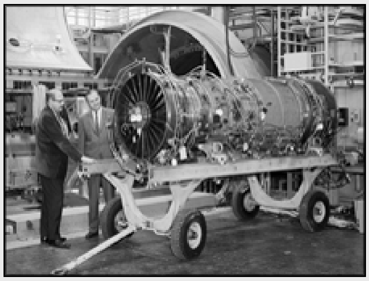

Propellant Test


Control Room

History
Propulsion Systems Laboratory No. 1 & 2

PSL 1 and 2
Publications
History
Design and Construction
Ramjets and Missiles
Rocket Engines
Return to Turbojets
Addition of PSL No. 3 and 4
Turbofan Engines
Demolition
Facility
Combustion Air Flow
Test Equipment
Exhaust System
Support Buildings
Research
Historical Documents
Technical Reports
Mitigation
Community Awareness
Historical Mitigation
Students
Events Timeline
PSL No. 1 and 2 Testing Timeline

RETURN TO TURBOJETS (1967 – 1974)

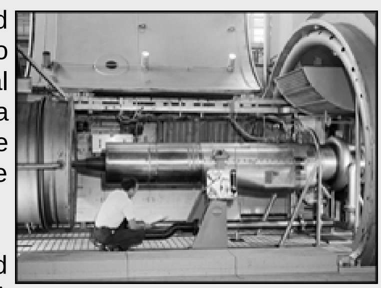


TF-30 Turbofan in PSL

After nearly a decade of concentrating on rockets, NASA Lewis began returning to aircraft propulsion in 1966. The Boeing 707 and Douglas DC-8, powered by Pratt & Whitney J57 and J75 turbojets respectively, were the dominant jet airliners of the late-1950s and 1960s. During the interim, however, the aircraft industry was developing the next generation of the jet engine: the turbofan. These new turbofan engines would need to increase their performance and reduce noise levels before they would be viable. NASA Lewis instituted an Airbreathing Engine Division in 1966 that used the Propulsion Systems Laboratory, the F106 aircraft, a new Quiet Engine Test Stand, and the 10- by 10-Foot Supersonic Wind Tunnel to study the turbofans.

Documents:
Research Division article (1970) (PDF, 452KB)
F14 and F15 Managers Visit (1970) (PDF, 512KB)

ENGINE CALIBRATION STUDY



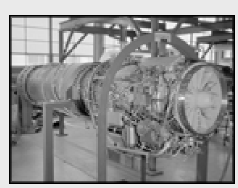
GE J85 in PSL No.2

In order to test different noise reducing components, nozzles, and compressor designs, NASA Lewis engineers first had to be able to determine baseline performance characteristics of an engine. General Electric's J85-13 was selected for this calibration study. The J85 was a relatively slow and lightweight but efficient engine developed in the late 1950s. It was used extensively by the Center's Airbreathing Engine Division in the late 1960s and early 1970s.

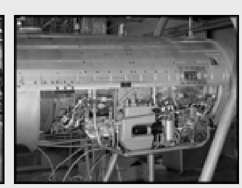
PSL was used to determine the correct nozzle inlet temperature and pressure and gas flow rate at transonic speeds. Using this data, NASA Lewis researchers were able to determine the engine's gross thrust within a 0.06 percent error margin. These measurements could be the basis for future engine and nozzle tests in the PSL, on test aircraft, and in other facilities.

Reports:
Inlet Temperature Distortion on the Stall Limits of J85-GE-13 (PDF, 24.7MB)

J85 on F-106 Aircraft



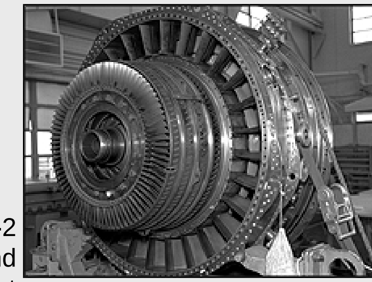
J85 in PSL Shop



Instrumentation

EFFECTS OF AIR FLOW DISTORTIONS AND ALTITUDE

Pratt & Whitney's TF-30 was the first 25,000-pound thrust turbofan. It was developed in the early 1960s for the Navy's F4A Tomcat and the Air Force's F-111. Unlike turbojets, turbofans send much of their intake air around its core. This results in increased thrust and fuel efficiency. It was found that the decreased pressure found at high altitudes and distortions



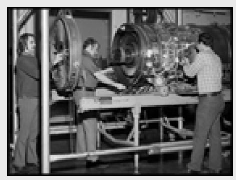
TF-30 readied for test

in the air flow reduce the stability of the engine's compressor.

NASA Lewis conducted a number of tests with TF30-P-1 and TF-30-P-2 engines in PSL No. 1 to examine this phenomenon. Initially screens and other devices were used to create the distortions, but it was found that using nozzles to inject air into the stream was most effective and cost-efficient to simulate the distortions. Using this method, engineers in PSL were able map the engine's likeliness to stall from various pulses or distortions. It was found that the duration of a stall-inducing pulse was the inverse of its amplitude.

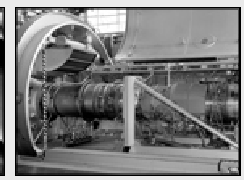
Reports:

Afterburner Equipped Turbofan with and Without Inlet Flow Distortion (PDF, 12.5MB)
Inducing Controlled Steady-state and Dynamic Inlet Pressure Disturbances (PDF, 8.86MB)
Air Jets as a Steady-State Inlet Flow Distortion Device (PDF, 18.9MB)



Engine Assembly

TF-30 Compressor



TF-30 in PSL No. 1

EQUIPMENT BUILDING EXPLOSION

In the early morning hours of April 7, 1971, a massive explosion ripped through the floor of the Equipment Building seriously injuring two employees and causing major damage to the facility. During the confusion of the midnight shift change, a butterfly valve between the exhausters and the exhaust stack was left sealed. Although the crew quickly scrambled to depressurize the system, a 96-inch-diameter head ruptured below the floor. The 6-inch-thick concrete floor, I-beams, windows, and heavy equipment were damaged. A 30-foot-diameter hole was blown in the roof that was 35 feet above the floor. An Accident Review Board found that when the valve was sealed it caused the exhausters to operate like compressors. This action quickly over-pressurized the system. Several check valves were incorporated into the system afterwards and a Recertification Program was established.

Interior Damage

Documents:

Equipment Building Explosion article (1971) (PDF, 512KB)
1971 Bldg 64 Explosion (PDF, 704KB)
Recertification Program article (1987) (PDF, 528KB)

Exterior Damage

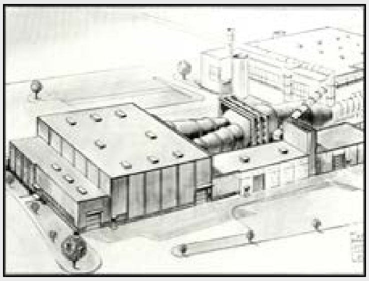
Failed Head

Exterior Damage

History
Propulsion Systems Laboratory No. 1 & 2

PSL 1 and 2
Publications
History
Design and Construction
Ramjets and Missiles
Rocket Engines
Return to Turbojets
Addition of PSL No. 3 and 4
Turbofan Engines
Demolition
Facility
Combustion Air Flow
Test Equipment
Exhaust System
Support Buildings
Research
Historical Documents
Technical Reports
Mitigation
Community Awareness
Historical Mitigation
Students
Events Timeline
PSL No. 1 and 2 Testing Timeline

ADDITION OF PSL NO. 3 AND 4 (1967 – 1972)

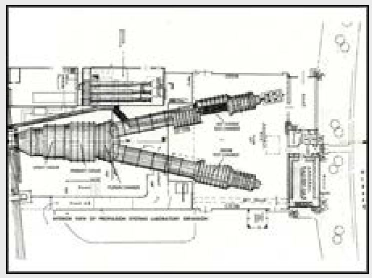


PSL No. 3 and 4

In 1968, twenty years after planning began for the original PSL test chambers, NASA Lewis began preparing to add two additional and more powerful test chambers. The original chambers were an improvement on the Four Burner cells, and the $14 million new PSL No. 3 and 4 chambers would be an improvement on PSL No. 1 and 2. The move coincided with the Center's return to aeronautics. The new chambers were capable of testing engines twice as powerful any then in existence. PSL No. 1 and 2 were to be closed when the new chambers became operational, but the aeronautics program was busy enough that all four chambers remained active for a number of years.

Documents:
PSL No. 3 and 4 Fact Sheet (PDF, 200KB)
PSL No. 3 and 4 Brochure (PDF, 3.13MB)

PSL'S NEW DESIGN

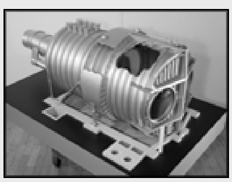


New PSL Design

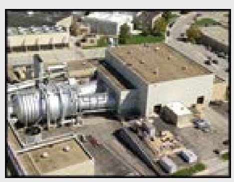
The PSL No. 3 and 4 chambers, 40-feet long and 24 feet in diameter, were substantially larger than PSL No. 1 and 2. Also, unlike PSL No. 1 and 2, the two new chambers shared a common exhaust cooler. This gave the new system a Y-shaped appearance. The exhausters and compressors in the original Equipment Building were expanded for the new chambers. Three Pratt and Whitney J57 jet engines were used to supply hot combustion air to the test chambers. New heater and refrigeration systems were built to properly condition this air flow. The air is direct-connected to the engine in the chamber.

After passing through the engine, the hot exhaust air passed through a 17-foot-diameter water exhaust duct and into the 50-foot-diameter primary cooler. Water flows through 2700 tubes inside the cooler that reduces the temperature of the passing air flow from 3000 to 600 °F. A spray cooler further reduces the temperature of the gases to 150 °F before they are sent to the Central Air Building.

Documents:
Contract Let for PSL Expansion (1968) (PDF, 528KB)



Cooler Model

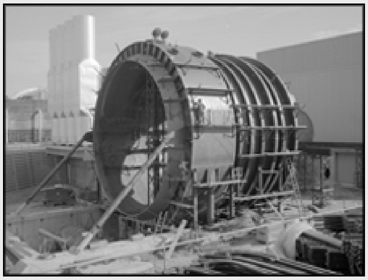


PSL No. 3 and 4

Exterior

CONSTRUCTION OF NO. 3 AND 4

Excavations for the new PSL building were completed by October 1967. The shell of the building was completed a year later. In September 1968, work began on the new test chambers and associated infrastructure. The installation of the combustion air, cooling water, and electrical systems began in September 1970. Nearly 5000 tons of steel were used to build the new facility. Construction was completed in late 1972, and the first test was scheduled for February 1973. The team that included all those responsible for the design, construction, and initial operation of PSL No. 3 and 4 was honored by the Lewis Awareness Program in February 1974.

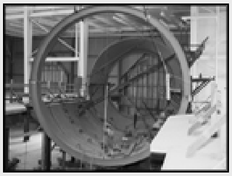


Cooler Installation

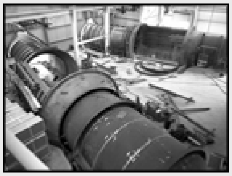
Documents:

PSL 3-4 Construction Articles (1967-70) (PDF, 1.75MB)
PSL No. 3 and 4 Operating article (1972) (PDF, 420KB)

Excavation



Test Chamber



Chambers Assembly

PSL TODAY

Today PSL No. 3 and 4 is NASA's only facility capable of testing full-scale airbreathing engines at simulated altitude conditions. It can simulate altitudes up to 90,000 feet and speeds up to Mach 3 in one cell and Mach 6 in the other. PSL No. 3 and 4 maintains a busy schedule, and the original Equipment Building remains in use. PSL's versatility has allowed it to keep pace with unique test requirements for NASA research programs. The facility has also helped develop advanced altitude testing methods such as multi-axis thrust measurement, vectored and reverse exhaust gas collection, flight transient simulation, and others.

Engine Installation

Documents:

Advances in Engine Test Capabilities at PSL (PDF, 231MB)
Hypersonics Test in PSL article (1998) (PDF, 264KB)

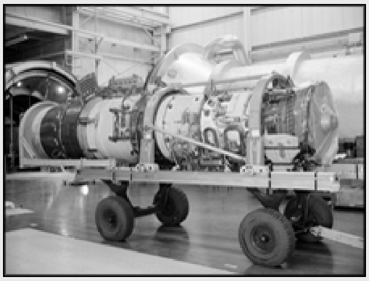
Display in PSL

PSL Test Cell

Control Room

History
Propulsion Systems Laboratory No. 1 & 2

TURBOFAN ENGINES (1974 – 1979)

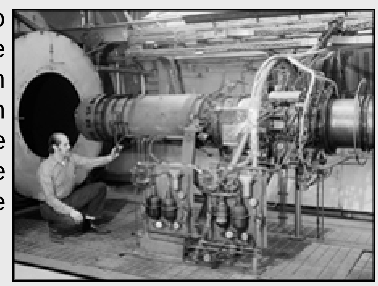


F-100 Turbofan

The NASA Lewis aeronautics program was in full-swing when PSL No. 3 and 4 became operational in 1973. Following the end of the Apollo Program, the Center pushed even further into its aircraft propulsion work. Unlike Lewis' previous research, the majority of the new engine studies would be for civilian aircraft and not the military. Since demand was still high for altitude testing, the Center decided to keep PSL No. 1 and 2 operating for several more years. The jumbo jet generation of airliners was emerging in the early 1970s. The Boeing 747, McDonnell Douglas DC-10, and Lockheed L-1011 were all powered by turbofan engines. During the mid-1970s PSL concentrated on making turbofan engines quieter and more efficient.

Documents:
"Down to Earth Problems," by Virginia Dawson

FULL-SCALE ENGINE RESEARCH

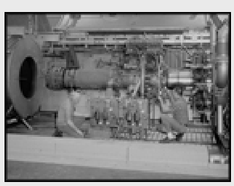


Quiet Engine Test

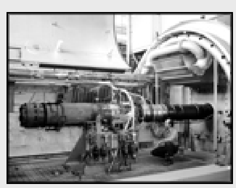
In the mid-1970s, NASA Lewis and the Air Force collaborated on two broad programs that studied a variety of design problems on full-scale engines. The first, the Full-Scale Engine Research (FSER) program utilized surplus Air Force engines as testbeds for a variety of research purposes, including flutter, inlet distortion, and electronic controls. In the late 1970s Engineers from the Airbreathing Engines Division's Engine Research Branch studied two Air Force engines for the FSER in PSL—the Pratt & Whitney F100 and the General Electric J85-21.

A General Electric J85-21 turbojet, a 5000-pound thrust variant of the J85-13, was obtained from the Air Force in early 1975 for the FSER program. The engine was used for two series of investigations—internal compressor aerodynamics and mechanical instability or flutter. The researchers focused on two types of stall flutter, choke flutter, and system-mode instability. The different variations of distortion was unique from the others. The researchers assembled a collection of data from each type of instability.

Documents:
NASA/GE Quiet Engine "A" (PDF, 1.23MB)



J85 in PSL



Test Setup

Distortion Simulator

PRATT & WHITNEY F-100

A full-scale turbofan engine was subjected to long-term study in PSL for the Full-Scale Engine Program. The Pratt & Whitney F-100 turbofan was the first engine analyzed for performance problems. Since the F-100 was similar to the TF30 recently studied in PSL No. 1 much of the test

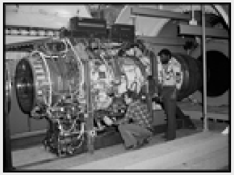
F-100 in PSL No.2

hardware that was purchased for the TF30 tests was adapted and used for the F-100. PSL No.2 had to be renovated to accommodate the large F-100.

The initial turbojet and turbofan engines used fixed-geometry components with fuel flow and nozzle areas as variables. The engines being developed in the 1970s implemented variable shaped compressor and fan blades. These new types of engines required greater control systems that could handle many parameters and additional variables while increasing the accuracy and response of the engine. One tool was the linear quadratic regulator. The Air Force asked NASA Lewis to develop and test the multivariable control system on an F-100 engine. A digital controller was devised and first tested using computer simulation. Afterward the system would be tested on an F-100 in PSL. Pratt & Whitney was asked provide the F-100 and its design information. Systems Control, Inc. developed the computer logic for the system. The project began in 1975 with the hybrid simulation in late 1976. Engine testing in PSL took place in mid-1977.

Documents:

F-100 Full Scale Engine Program article (PDF, 1.78MB)
F-100 Multivariable Control Synthesis Program (PDF, 3.66MB)
Propulsion Controls, 1979 (PDF, 5.94MB)



Wiring of F-100

Digital Controls

F-100 in PSL No.3

History
Propulsion Systems Laboratory No. 1 & 2

PSL 1 and 2
Publications
History
Design and Construction
Ramjets and Missiles
Rocket Engines
Return to Turbojets
Addition of PSL No. 3 and 4
Turbofan Engines
Demolition
Facility
Combustion Air Flow
Test Equipment
Exhaust System
Support Buildings
Research
Historical Documents
Technical Reports
Mitigation
Community Awareness
Historical Mitigation
Students
Events Timeline
PSL No. 1 and 2 Testing Timeline

DEMOLITION OF PSL NO. 1 AND 2 (1980 – 2009)

PSL Demolition

Use of PSL No. 1 and 2 ceased in 1979 after the test of a Pratt & Whitney TF-34 turbofan in Chamber No. 1. PSL No. 1 and 2 had played a key role in the continual development of propulsion systems, but after 27 years of testing the engines had outgrown the facility. While PSL No. 3 and 4 kept a rigorous test schedule, the original chambers sat idle for 25 years. In 2004, NASA Glenn began efforts to remove the structure from its campus. Demolition of the original PSL facility began in late 2008 and was completed in the summer of 2009.

SHUTDOWN AND IDLE YEARS

PSL Exterior in 2008

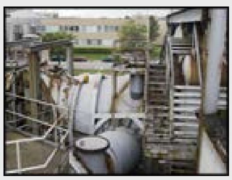
NASA Lewis's budget was drastically cut in the post-Apollo years. After large Reduction In Force actions in 1973 and 1974, the Center's budgets and staffing levels continued to decline throughout the decade. Lewis could not keep all four PSL chambers and all of the other engine test rigs operating. By shutting down PSL No. 1 and 2, twenty technicians would be freed up to help keep the other test rigs operating.

The second floor of the PSL Shop and Access Building soon became an office space for engineering and maintenance staff. Temporary offices were wedged in between and perpendicular to the two altitude chambers. The countless pipes, access platforms, and other equipment on the outside began suffering from lack of maintenance. The Equipment Building and PSL No. 3 and 4 continued to operate and were upgraded over the years.

Documents:

Mothballing of PSL 1-2 (1979) (PDF, 240KB)
Why Phase Out PSL (1978) (PDF, 220KB)

Interior in 2005



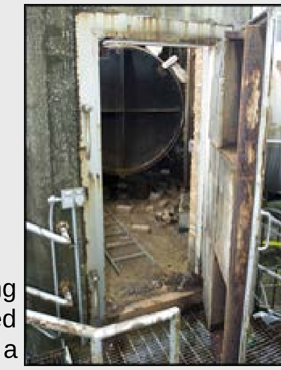
Rusting Exterior

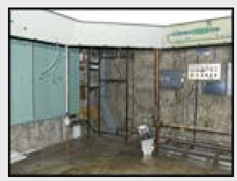
Empty Hallway

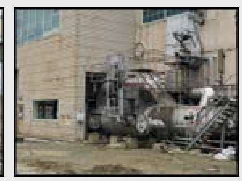
DEMOLITION DECISION

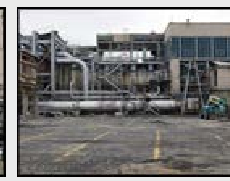
NASA Glenn began reexamining its facilities and infrastructure in 2003. NASA Headquarters had offered funding to the centers to remove its unused facilities. Glenn responded with nine buildings it would like to demolish. Two of these, the Altitude Wind Tunnel and PSL No. 1 and 2, had played significant roles in the advancement of the nation's propulsion technology.

Reactivation of PSL No. 1 and 2 was not an option, even if chamber 3 and 4 were not keeping up with test requests. The piping and air systems would have to be recertified, the control room had been cannibalized, and the mechanical, electrical, and safety equipment were obsolete. The Center was spending $76,000 annually to maintain an under-utilized office space. Headquarters agreed to the $3.17 million proposal and Glenn spent the next two years creating a demolition plan and soliciting bids. Demolition began in the fall of 2008 and was completed in 2009.


Dilapidated Structure


Cannibalization


Marked for Removal


Demolition Begins

DEMOLITION

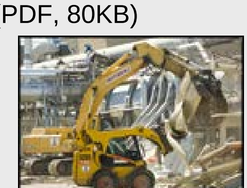
Design services were obtained and demolition plans were created. Bids to perform the work were solicited and the contracted was awarded in 2007. The demolition consisted of three phases: relocation of the utilities, lead paint and asbestos remediation, and the actual demolition of the facility. The first step was the installation of perimeter fencing around the site in the spring of 2008. This was followed by lead paint and asbestos abatement, including the removal of the transite walls around the Access Building and Service Support Building.

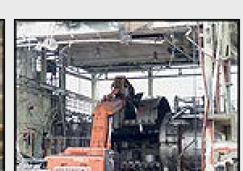

Access Building

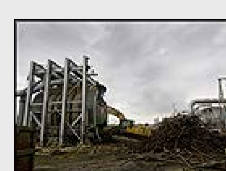
The main demolition began in May 2009 with the removal of the Service Support Building and external pipes. Work ramped up quickly in June. The bulldozers tore into the Shop and Access Building and methodically ripped the two altitude tanks into pieces as the workers hosed down the dust. The interior of the massive primary coolers stood exposed for the first time in 60 years as the rubble piled up around them. The cooling vanes lay in tangled piles like an industrial haystack. By August it was all over. The coolers had been knocked down, and the debris had been loaded into trucks and hauled away. Approximately 1,000 tons of steel had been removed and recycled. Crews had removed the concrete foundations, graded the area, and slowly transformed the site into a parking lot and grassy area.

Documents:

PSL Justification (PDF, 80KB)

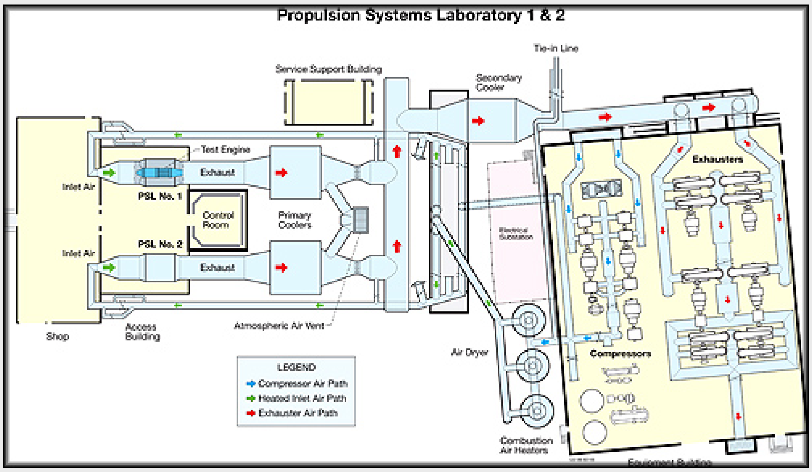

Demolition Begins


Test Chamber Demo


Cooler Demo

FACILITY

NACA engineers built upon their experience with previous, less powerful altitude test facilities to produce the most state-of-the-art facility in the nation for studying full-scale engine systems. The Propulsion Systems Laboratory No. 1 and 2 included two altitude chambers, a modern control room, a combustion air supply system, an exhauster system, and cooling water system. The complex included a number of support buildings, the largest of which was the Equipment Building. In 1972 the two larger test chambers, PSL No. 3 and 4, were added to the complex.



PSL Layout

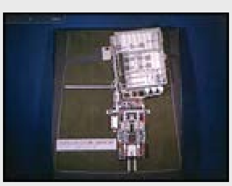
Documents:

PSL Design Specifications (PDF, 4.97MB)

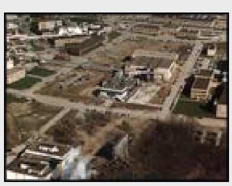
I. Combustion Air System: The combustion air line provided highly pressurized dry conditioned air to the test chambers. The air could be heated or cooled depending on the nature of the test.

II. Test Equipment: The engine being tested was installed in one of the two altitude chambers and operated from the control room. The combustion air flowed through the chambers and engine.

III. Exhaust System: Powerful exhausters reducing the density of the air in the test chambers to simulate the selected altitude for a test. Water-fed coolers were used to reduce the temperature of these exhausted air flows.



Footage of Model



Aerial Footage

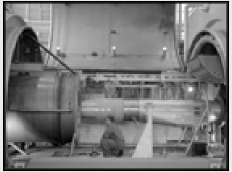
IMAGES

PSL No. 3 and 4 Testing Timeline

How PSL Worked

External Links

Equipment Building

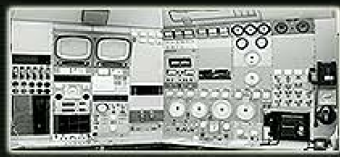


Test Chamber

Support Bldgs.

Facility

Propulsion Systems Laboratory No. 1 & 2



PSL 1 and 2
Publications
History
Design and Construction
Ramjets and Missiles
Rocket Engines
Return to Turbojets
Addition of PSL No. 3 and 4
Turbofan Engines
Demolition
Facility
Combustion Air Flow
Test Equipment
Exhaust System
Support Buildings
Research
Historical Documents
Technical Reports
Mitigation
Community Awareness
Historical Mitigation
Students
Events Timeline
PSL No. 1 and 2 Testing Timeline

COMBUSTION AIR FLOW

Air Flow System

Although not a wind tunnel, PSL could create high-speed airflow through the interior of the engine. Large compressors pushed the air through the system, heating or refrigerating equipment was used to heat or cool the air to the desired temperature, and air dryers were used remove moisture from the air. The system was linked to the lab's central air system, which allowed it to augment the compressors in other test facilities.

COMPRESSED AIR SYSTEM

Air flow was generated by large Elliott Company air compressors in the Equipment Building to simulate the speeds and altitude of flight. The compressors forced the air rapidly through the pipes towards the test section. After passing through temperature adjusting equipment, it was pumped through a pipe to the Shop and Access Building. The pipe split and wrapped around both sides of the building before entering it from the front on the second floor level. The air then entered the north end of one of the two test chambers. It passed through the chamber's air-straightening vanes, then a bellmouth cowl in the bulkhead, and finally through the test section and the engine.

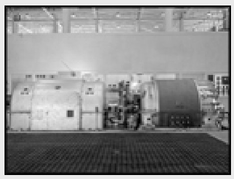
Airflow Inlet Pipes

Over the years the air compression system was continually being upgraded and modified. In 1956 there were three 16,500 horsepower centrifugal compressors capable of delivering 112 pounds of air per second at 45 psig for a total 336 pounds of air. Each of these possessed three wheels in each of their three casings: two casings in the first stage and one in the second stage. A separate booster compressor could provide 183 pounds of air per second at 150 psig. Pressure-regulating valves in the test chambers kept the air supply at the desired range.

Air System Footage

Compressors

Control Room

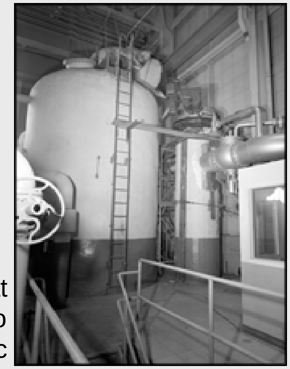


Compressors

AIR TEMPERATURE CONTROL

Depending on the type of test being run, the air flow into the engine would have to be either heated or refrigerated. Ramjets and engines, which would be operated at supersonic speeds, would need to be tested in hot conditions to simulate the heat generated by their velocity. Jet engines traveling at subsonic speeds would need to be tested in cold conditions to simulate the high-altitude air temperature.

The combustion air heaters located on the exterior of the Equipment Building were used to create the high temperatures. Ambient air was taken into the heaters and passed through vertical tubes that had been heated by a natural gas flame.



Air Dryer Tank

PSL No. 1 and 2 contained three gas-powered heaters. Each heater would heat 125 pounds of air per second from 40 °F. Later a pebble bed heater was added to a test chamber to create extremely high temperatures found at hypersonic speeds.

Air Heater

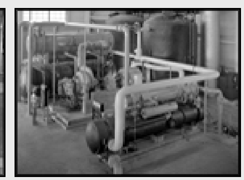
The refrigeration system for the high-altitude testing was not in the original PSL construction, but added soon afterwards. Temperatures found at 50,000 feet at speeds of Mach 0.6 to 1.5 could be recreated without the refrigeration equipment, but slower speeds required colder conditions. The refrigerated air was generated with expansion turbines located in the Equipment Building. Up to 112 pounds of air per second could be cooled by 100 °F as it passed through an expansion turbine.

The air at high altitudes was very dry, so the air flow had to be dehydrated before entering the test section. There were two dehydrator units that could reduce the moisture of 125 pounds of air per second 100,000 cubic feet of air per hour at temperatures between 40 and 600 °F. The air flowed up through a vertical tank and cascade trays with the liquid cooling medium. The air could be dried to 1 grain of moisture per pound as it passed through the dryer. The dryer contained 190,000 pounds of activated alumina.

Heater Footage

Dryer Controls

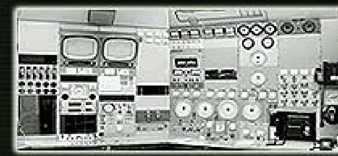
Air Heaters



Refrigeration

Facility

Propulsion Systems Laboratory No. 1 & 2



PSL 1 and 2
Publications
History
- Design and Construction
- Ramjets and Missiles
- Rocket Engines
- Return to Turbojets
- Addition of PSL No. 3 and 4
- Turbofan Engines
- Demolition

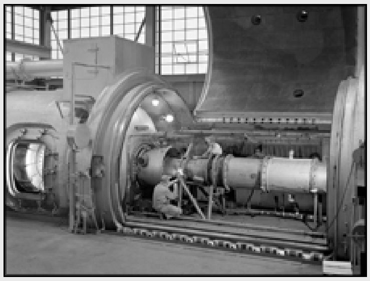
Facility
- Combustion Air Flow
- Test Equipment
- Exhaust System
- Support Buildings

Research
- Historical Documents
- Technical Reports

Mitigation
- Community Awareness
- Historical Mitigation

Students
- Events Timeline
- PSL No. 1 and 2 Testing Timeline

TEST EQUIPMENT



Test Chamber

The PSL No. 1 and 2 Shop and Access Building contained two test chambers, a control room, and balance chamber. The engine being tested was installed inside the test section of one of the chambers. Extensive instrumentation was fitted on the engine prior to the test. Once the chamber was sealed, the altitude conditions were introduced, and the engine was ignited. Operators in the control room could run the engine at the various speeds and adjust the altitude conditions to the desired levels. Obtaining the desired test conditions could be a difficult process; once they were reached the operators would continue running as long as possible.

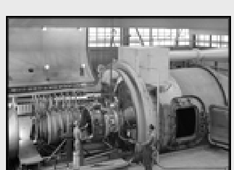
Documents:
Access Building Floor Plans (PDF, 416KB)

ALTITUDE CHAMBERS

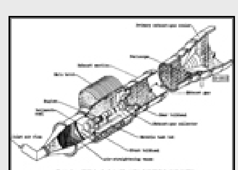
Chamber No. 2

The two 100-foot-long altitude chambers ran parallel to one another inside the Access Building with a control room in between. The chambers were pressurized and water-cooled with a number of access points. Each chamber was comprised of three sections: the test section, inlet section, and exhaust section. The conical inlet section contained a set of vanes that stretched across the chamber to straighten the airflow. The test section was separated from the rest of the chamber by a front and rear bulkhead. An engine platform inside the test section was used to both hold the engine and measure its thrust loads and drag. An overhead crane was used to lower the engine onto the stand. A large clamshell hatch sealed the test section after the engine had been installed. The engine’s exhaust was ejected into exhaust section. This tubular section expanded as it connected to the primary cooler.

PSL could be configured in either a direct-connect or free-jet mode. The direct-connect was the simplest way of studying the internal performance of the engine. The engine was mounted on the thrust stand inside a test chamber with the air flow connected directly to the engine inlet. To test the air inlet system though, a free-jet method was required. A nozzle was used to create a supersonic jet of air that enveloped the engine inlet in supersonic altitude air. The stream was powerful but narrow so it did not permit the study of air flow over the complete engine. The free-jet setup was more beneficial than the direct-connect since the entire engine system, including the inlet duct, could be studied.



Chamber No. 2



Chamber Diagram

Chamber Interior

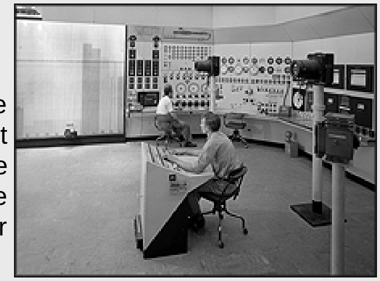
CONTROL ROOM

The control room for PSL No. 1 and 2 was located between the two chambers on the second floor of the Shop and Access Building. The control room had separate stations for each chamber. Inside the control

PSL No. 3 and 4 Testing Timeline

How PSL Worked

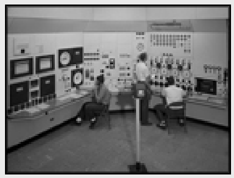
External Links



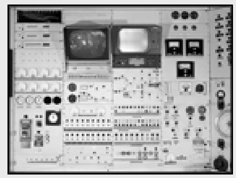
Control Room

room operators ran the engine and worked with other technicians in the Equipment Building to create the proper altitude conditions inside the test chamber. During the 1950s, large manometer boards were set up in the rear of the room. Cameras on fixed stands recorded these pressure measurements. A console was set up in the center of the room to monitor the manometer readings.

The control room was frequently updated and modified. The manometers were replaced with electronic equipment by the early 1960s. A number of television consoles were installed so that the test engineers could view the engine in the chamber during the test. Temporary data recording equipment could be installed for certain tests and later removed, and the control panels were rearranged periodically.



Test Engineers



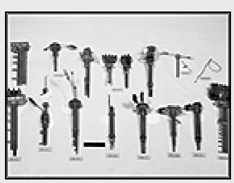
1960s Controls

Updated Control Room

INSTRUMENTATION

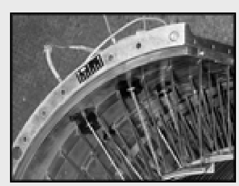
To obtain useful data from the tests, instrumentation had to be installed in both the engine and the test chamber. The setup varied depending on the requirements for the specific test. It could take weeks or even months for technicians and electricians to install the multitude of thermocouples, rakes, and other required instruments. Sometimes each compressor stage had to have its own readings. This could often be begun in the shop area before the engine was installed in the chamber. Once the test article was in the chamber, the staff could access it through the main hatch, which was a large clamshell mechanically operated lid, or a smaller access door in the inlet section. The engine itself was atop a thrust stand that measured the thrust and drag. A periscope camera was set up inside one of the chambers in the 1950s. In the 1960s additional cameras were set up so that researchers could view the tests from the control room.

Technician in PSL



Rakes

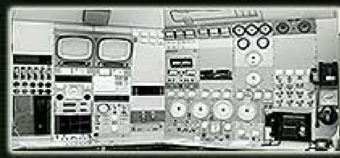
Instrumenting Engine



J71 Compressor

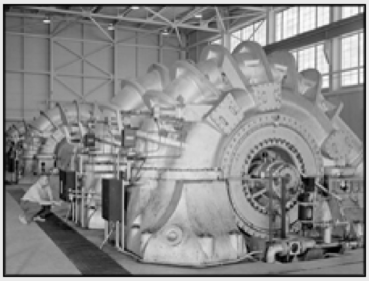
Facility

Propulsion Systems Laboratory No. 1 & 2



PSL 1 and 2
Publications
History
Design and Construction
Ramjets and Missiles
Rocket Engines
Return to Turbojets
Addition of PSL No. 3 and 4
Turbofan Engines
Demolition
Facility
Combustion Air Flow
Test Equipment
Exhaust System
Support Buildings
Research
Historical Documents
Technical Reports
Mitigation
Community Awareness
Historical Mitigation
Students
Events Timeline
PSL No. 1 and 2 Testing Timeline

EXHAUST SYSTEM

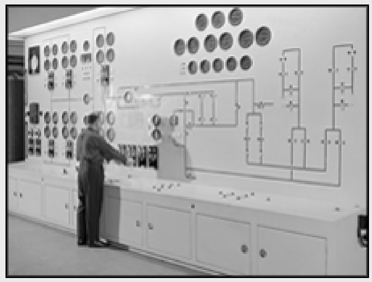


Exhausters

The exhaust system served two roles: reducing the density of the air in the test chambers to simulate high altitudes and removing hot gases exhausted by the engines being tested. This was accomplished by large exhauster equipment in the Equipment Building. When an engine was being tested it expelled extremely hot exhaust gasses. Coolers were used to reduce the temperature of these gases before they reached the exhauster equipment. The coolers required a large quantity of water and a cooling tower.

EXHAUSTERS

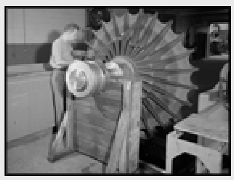
Large Roots-Connersville exhausters in the Equipment Building were used to pump the air and engine exhaust gases out of the PSL system. The original configuration could exhaust the 3500 °F gases at a rate of 100 pounds per second when the simulated altitude was 50,000 feet. Each of the thirteen 5100-horsepower exhauster units contained two J33 compressor wheels that could be adapted to work in tandem to drive and parallel. To control the power load, the number of units used could be varied.



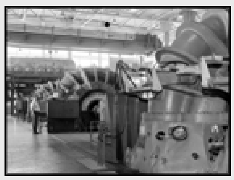
Control Panel

In 1955 a fourth line of exhausters was added. There were three centrifugal exhausters capable of supplying 166 pounds of air per second at the test chamber altitude of 50,000 feet or 384 pounds per second at 32,000 feet. These exhausters had two first stage castings driven by a 10,000-horsepower motor; one second; one third; and one fourth stage casting driven by a 16,500-horsepower motor. The total inlet volume of the exhausters is 1,650,000 cubic feet of gas per minute. The exhausters were continually improved and upgraded over the years.

Equipment Operator



Inspecting Impeller



New Exhausters

COOLERS

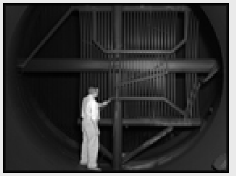
The extremely hot temperature of the engine's exhaust had to be cooled before the air reached the exhauster equipment. As the air flow exited through the 12-foot-diameter and 37-foot-long exhaust section of the test chamber it entered into the giant primary cooler. Narrow fins or vanes inside the cooler were filled with water. As the air flow passed through the vanes, its heat was transferred to the cooling water. The cooling water was cycled out of the system, carrying with it much of the exhaust heat. Each test chamber had its own primary cooler.

Primary cooler

The air flow was then pumped through a secondary cooler that further reduced the temperature. This secondary cooler or spray cooler cooled and scrubbed the exhaust gases to reduce explosion hazards for both test chambers. The air was then pumped through the exhausters in the Equipment Building and expelled out into the atmosphere.


Secondary Cooler


Cooler in 2008


Interior of Cooler

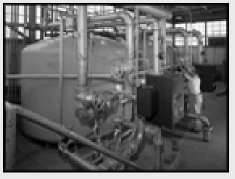
WATER SYSTEM

A water system supplied the primary and secondary coolers and cooled the exhaust ducts and valves from the hot engine exhaust. The water circulated through a closed-loop system with make-up water added.

A cooling tower was used to dissipate the remainder of the heat from the circulating water before recycling it back to the facility. The cooling tower had several large pumps, three water softening units, and a settling basin. The softeners were used to prevent scale and corrosion in the pipes.


De-areators

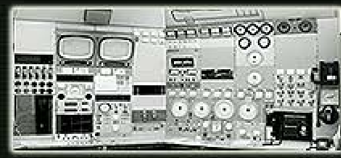

Cooling Tower


Pump House


Aerial View

Facility

Propulsion Systems Laboratory No. 1 & 2



PSL 1 and 2

Publications

History
- Design and Construction
- Ramjets and Missiles
- Rocket Engines
- Return to Turbojets
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- Turbofan Engines
- Demolition

Facility
- Combustion Air Flow
- Test Equipment
- Exhaust System
- Support Buildings

Research
- Historical Documents
- Technical Reports

Mitigation
- Community Awareness
- Historical Mitigation

Students
- Events Timeline
- PSL No. 1 and 2 Testing Timeline

SUPPORT BUILDINGS

PSL Complex

The Propulsion Systems Laboratory (PSL) No. 1 and 2 complex included massive infrastructure, complex systems, and several support buildings that were vital to the operation of the facility. These buildings included the Equipment Building, which contained the powerful exhausters and compressors, the Shop and Access Building with the two test chambers, an office building, and a cooling tower.

EQUIPMENT BUILDING

Equipment Building

The Equipment Building was the heart of PSL. It contained the compressors, exhausters, refrigeration equipment, and other apparatus used to condition the air for the PSL tests. The Equipment Building control room windows were double-paned acoustical-type that were positioned so that all the test equipment could be viewed. In addition, the control panels were arranged so each machine could be seen from its operating panel. The primary equipment was started from the PSL main control room. In emergency situations, however, it could be stopped from the floor of the Equipment Building.

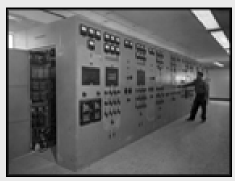
The Equipment Building's foundation, flooring, and footings were reinforced concrete. The main floor was designed to handle a load of 250 pounds per square foot. Areas under the exhausters and where trucks would bring in equipment were designed for higher loads. The placement of the air heaters and transformers were laid out to accommodate oil tanks if the system was ever switched over from electric to gas heaters. The exterior of the building was manganese, spot-face modular-size brick.

Documents:

Exhauster Building Floor Plans (1956-62) (PDF, 752KB)

Equipment Building

Exhausters



Switchgear Panels

SHOP AND ACCESS BUILDING

The Shop and Access Building housed the two altitude chambers, accompanying infrastructure, and control room. The two test chambers were on the second floor. They ran parallel to one another with a shop floor and control room between them. A large overhead rail crane transported engines and equipment into the chambers. In 1956 and 1957 a large extension was added to the front of the building to provide additional space for the shop area. The addition nearly doubled the size of

Shop and Access Building

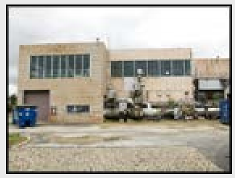
the Access Building.

The control room had two separate work stations, one for each test chamber. From here the operators could control the exhausters and compressors in the Equipment Building and run the engine in the test chamber. Originally there was a set of manometers in the rear of the room. Television monitors were added in the early 1960s to view the tests. After PSL No. 1 and 2 shut down in 1979, temporary offices were built between and around the test chambers on second floor of the Access Building.

Documents:

Access Building Floor Plans 1956-1957 (PDF, 416KB)

Instrument Room



Building Addition

Interior in 2005

PSL OPERATIONS BUILDING (PSLOB)

PSL Office Building

A two-story T-shaped building was built across Walcott Road from PSL to house the researchers who would be using the new facility. It was a standard NACA Lewis office building with similar exterior and windows as the other brick buildings at the lab. It was almost identical in appearance to the Instrument Research Lab built just a few years before in the adjacent lot.

In 1959 the PSLOB residents included the Advanced Propulsion Division, the Facilities Engineering Division, and key members of the Propulsion Systems Division. In the mid-1960s, the lab's library was relocated to the PSLOB. It occupied the rear portion of the building while the remainder of the offices continued to house research and facilities personnel. In 1967 the building had been renamed the Library Services Building and housed most of the Airbreathing Engines Division and the PSL Operations Branch. This arrangement continued until 2008 when the library and aeronautics staffs were relocated so the building could be remodeled.

Documents:

New Building to House Library (1949) (PDF, 448KB)

PSLOB Footage

Construction

Entrance

Researchers

Mitigation

Propulsion Systems Laboratory No. 1 & 2

PSL 1 and 2

Publications

History
- Design and Construction
- Ramjets and Missiles
- Rocket Engines
- Return to Turbojets
- Addition of PSL No. 3 and 4
- Turbofan Engines
- Demolition

Facility
- Combustion Air Flow
- Test Equipment
- Exhaust System
- Support Buildings

Research
- Historical Documents
- Technical Reports

Mitigation
- Community Awareness
- Historical Mitigation

Students
- Events Timeline
- PSL No. 1 and 2 Testing Timeline

MITIGATION PROJECT

Documenting PSL

In 2005 NASA Glenn proposed to remove the original Propulsion Systems Laboratory (PSL) No. 1 and 2. The facility had made contributions to the nation's aeronautics and space programs, but it has not been used as test facility since 1979. Research is now carried out in the newer PSL No. 3 and 4, which will remain in operation. Nonetheless, NASA Glenn felt it important to document the original facility prior to its destruction.

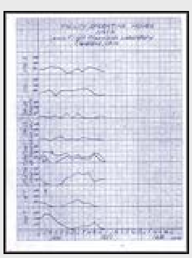
Documents:
PSL Ohio Historic Inventory (1996) (PDF, 2.48MB)

I. 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 PSL No. 1 and 2 and the Altitude Wind Tunnel. Speakers discussed the scope of the demolition, environmental issues, the history of the facilities, and the historical mitigation effort.

II. Description of Mitigation: This Web site is part of a wider effort to document the history of the PSL No. 1 and 2. This project formally began 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 to the nation's aerospace community.

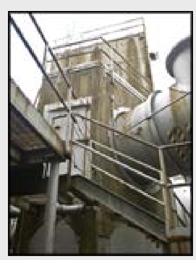
III. Demolition Process: It was decided in early 2005 to remove PSL No. 1 and 2 from the NASA Glenn campus. The demolition project includes the PSL No. 1 and 2 test chambers, the Access Building, primary coolers, Service Support Building, Fuel Storage Building, Oxidant Storage Building, and related piping and infrastructure. Remediation work began in the summer of 2008 and demolition was performed in the summer of 2009.

IMAGES



Research

Inspection



Documentation

Public Meeting

Mitigation

Propulsion Systems Laboratory No. 1 & 2

PSL 1 and 2
Publications
History
Design and Construction
Ramjets and Missiles
Rocket Engines
Return to Turbojets
Addition of PSL No. 3 and 4
Turbofan Engines
Demolition
Facility
Combustion Air Flow
Test Equipment
Exhaust System
Support Buildings
Research
Historical Documents
Technical Reports
Mitigation
Community Awareness
Historical Mitigation
Students
Events Timeline
PSL No. 1 and 2 Testing Timeline

COMMUNITY AWARENESS MEETING

On April 27, 2006, NASA Glenn Research Center invited the public and NASA employees to a meeting at the Center in order to learn more about the NASA's plans to demolish the Propulsion Systems Laboratory No. 1 and 2 and Altitude Wind Tunnel. 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.

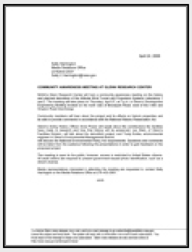
In accordance with the National Preservation Act, the meeting allowed attendees to ask questions and voice any opposition to the projects. The presentations were videotaped, and copies can be obtained by contacting the NASA Glenn History Office at history@grc.nasa.gov. The PowerPoint slides that combine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

Slides from the presentations:

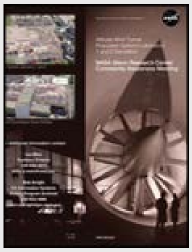
- History of PSL No. 1 and 2 (PPT, 32.9MB)
- Demolition Plan and Environmental (PPT, 1.38MB)
- Impact Historical Mitigation Project (PPT, 2.13MB)

DOCUMENTS

Announcement



Press Release



Brochure

Section 106

Mitigation

Propulsion Systems Laboratory No. 1 & 2

PSL 1 and 2
Publications
History
Design and Construction
Ramjets and Missiles
Rocket Engines
Return to Turbojets
Addition of PSL No. 3 and 4
Turbofan Engines
Demolition
Facility
Combustion Air Flow
Test Equipment
Exhaust System
Support Buildings
Research
Historical Documents
Technical Reports
Mitigation
Community Awareness
Historical Mitigation
Students
Events Timeline
PSL No. 1 and 2 Testing Timeline

HISTORICAL MITIGATION EFFORT

Meeting with Ohio SHPO

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, and some had 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 effort strives to create 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 Propulsion Systems Laboratory No. 1 and 2 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.

Documents:

- PSL Historical Mitigation Agreement (2007) (PDF, 256KB)
- ACHP Section 106 Process for PSL 1 and 2 (PDF, 544KB)
- Programmatic Agreement Among NASA, NCSHPOs, and ACHP (PDF, 180KB)

Documentation: The documentation includes the collection of documents from the Glenn Records Management holdings, the History Office archives, retirees, and other sources. It also includes the scanning and captioning of hundreds of negatives and the digitization of historic films. In addition, a thorough photographic survey and artistic rendering of the facility were 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 collected is being distilled into several different products to be shared with the public and NASA employees. These include this Web site, Pursuit of Power: NASA's Propulsion Systems Laboratory No. 1 and 2 (NASA SP-2012-4548), a Historic American Engineering Report to be filed with the Ohio State Historic Preservation Office, and an exhibit display. See Publications page for additional information.

Documentation

Dissemination

Students

Propulsion Systems Laboratory
No. 1 & 2

PSL 1 and 2

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- Historical Documents
- Technical Reports

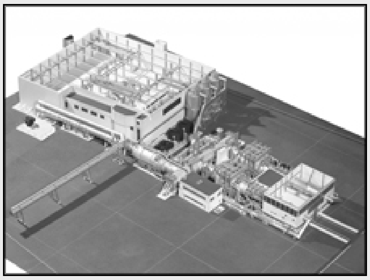
Mitigation

- Community Awareness
- Historical Mitigation

Students

- Events Timeline
- PSL No. 1 and 2 Testing Timeline

STUDENTS



PSL Model

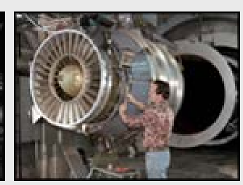
This section provides timelines of Propulsion Systems Laboratory (PSL) events and tests, an animation and film footage demonstrating how the facility works, and a glossary of terms related to PSL.

I. Events Timeline
II. No. 1 and 2 Tests Timeline (1952 to 1979)
III. No. 3 and 4 Tests Timeline (1972 to 1979)
IV. How the Propulsion System Laboratory Worked

IMAGES

PSL Construction

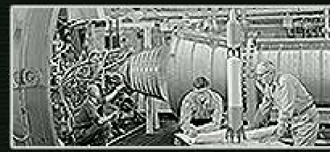
Rocket Nozzle



TF-34 Engine in PSL

Students

Propulsion Systems Laboratory No. 1 & 2



PSL 1 and 2

Publications

History

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- Rocket Engines
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- Turbofan Engines
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- Technical Reports

Mitigation

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- Historical Mitigation

Students

- Events Timeline
- PSL No. 1 and 2 Testing Timeline

EVENTS TIMELINE (1938 – 2009)

This section provides timelines of Propulsion Systems Laboratory (PSL) events and tests, an animation and film footage demonstrating how the facility works, and a glossary of terms related to PSL.

1938
NACA authorizes study on need for additional labs

1939
Congress appropriates $10 million for new NACA lab
British German Heinkel He-178 is first jet aircraft flown
Moffett Field, California, is site for new NACA laboratory
NACA approves establishment of an engine research lab

1944
Altitude Wind Tunnel becomes first propulsion tunnel

1945
Major AERL reorganization to focus on turbojets and high-speed flight
Design of Four Burner Area altitude chambers begins

1946
Air Force approves development surface-to-surface intercontinental missile

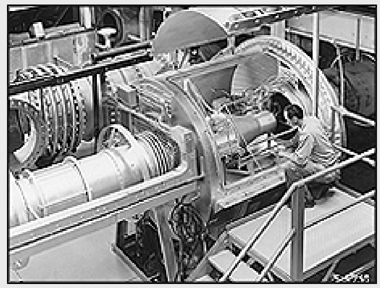
1947
Four Burner Area altitude chambers begin operation
NACA Lewis Research Facilities Panel discuss new altitude facility
AERL renamed Flight Propulsion Research Laboratory
First supersonic flight by Chuck Yeager in X–1
Lab renamed the Lewis Flight Propulsion Laboratory

1948
Congress allocates $10 million for PSL construction
Eugene Wasielewski appointed PSL Project Engineer
8- by 6-Foot Supersonic Wind Tunnel begins operation

1949
Sam Emerson Co. hired to construct Operations Bldg.
Excavation of PSL site and construction of cooling tower begin
Treadwell Construction contracted to build PSL altitude chambers
Abe Silverstein becomes NACA Lewis Director of Research
Research divisions reorganized for supersonic flight

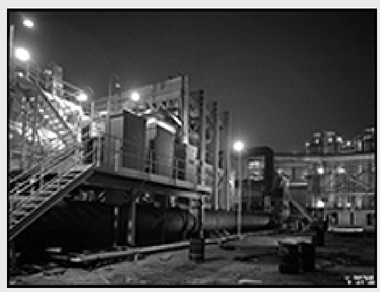
1950
Outbreak of the Korean War
Navaho Missile Program begins
Foundation of Equipment Building complete

AERL Construction



Four Burner Facility

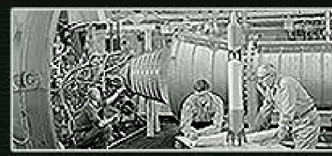
PSL Construction



PSL Begins Operating

Students

Propulsion Systems Laboratory No. 1 & 2



PSL 1 and 2
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History
- Design and Construction
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- Turbofan Engines
- Demolition

Facility
- Combustion Air Flow
- Test Equipment
- Exhaust System
- Support Buildings

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- Technical Reports

Mitigation
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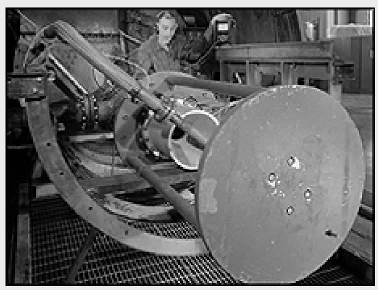
Students
- Events Timeline
- PSL No. 1 and 2 Testing Timeline

TESTS IN PSL 1 AND 2

	PSL No. 1	PSL No. 2
1952	General Electric J73 turbojet	Wright XJ47 for Navaho
1953	General Electric J73 turbojet	Wright XJ47 for Navaho
1954	General Electric J73 turbojet	Wright XJ47 for Navaho
1954	Marquardt RJ43 for Bomarc	Wright XJ47 for Navaho
1955	General Electric J79 turbojet	Wright XJ47 for Navaho
1956	General Electric J70 turbojet	
1957	Orenda PS-13 Iroquois	
1958	NASA 2.5k rocket	NASA isenthropic rocket
1959	NASA regenerative rocket	TRW nozzle project
1960	NASA 20k rocket	Thrust vector rig
1961	Pratt & Whitney RL-10 rocket	NASA fluorine rocket
1962	Pratt & Whitney RL-10 rocket	
1963	Pratt & Whitney RL-10 rocket	RF engine
1964	NASA ablative engine	Contour nozzles
1965	Ablative engine	260-inch Solid Rocket
1966		260-inch Solid Rocket
1967	Pratt & Whitney TF30-P1 distortion	General Electric Lift Cruise Engine
1968	Pratt & Whitney TF30-P1 distortion	General Electric J85-13/Lift Cruise Engine
1969	Pratt & Whitney TF30-P1 distortion	General Electric J85-13/Lift Cruise Engine
1970	Pratt & Whitney TF30-P1 distortion	General Electric J85-13 nozzle
1971	Pratt & Whitney TF30-P1 distortion	
1972	Garrett TFE 731-2 Compass Cope	General Electric J85-13 distortion
1973	Garrett ATF-3 Compass Cope	NASA Low Cost Engine
1973	Pratt & Whitney TF30 P9 controls	
1974	Pratt & Whitney TF30 P1 afterburner	GE J85-13 nozzle, treatment
1975	Pratt & Whitney F-100 FX213 flutter	Pratt & Whitney TF30-P9 controls



1976	Pratt & Whitney F-100 FX213 flutter	GE J85-21 compressor
1977	Pratt & Whitney F-100 XD11 flutter	General Electric J85-21 compressor
1978	Pratt & Whitney F-100 controls	General Electric J85-21 nozzle and flutter
1979	PPPG	Pratt & Whitney F401 controls

PSL No. 3 and 4 Testing Timeline

How PSL Worked

External Links

1951
Burns and Roe completes design work in January
Delivery of altitude chambers to PSL site in January

1952
Compressors and exhausters installed in Equipment Building
PSL No. 1 and 2 completed in September
Westinghouse ramjet is first PSL test in October

1954
1954 Inspection features PSL

1955
New exhauster and compressors installed
Air dryer tank and Reactivation Bldg. constructed

1956
Instrument Room added to Shop and Access Bldg

1956
Desiccant Air Dryer Added

1957
Navaho Missile Program cancelled
Sputnik I launched
Rockets discussed at NACA Lewis tri-annual inspection

1958
Pebble Bed Heater added to PSL in May
NACA Lewis incorporated into the new NASA space agency

1961
Yuri Gagarin becomes first human in space

1962
First Centaur (F–1) launch fails
Centaur Program transferred to NASA Lewis
Bomarc Missiles sites installed

1964
First flight of P&W TF-30 turbofan engine

1966
Creation of Airbreathing Engine Division
Library relocated to PSL Operations Building

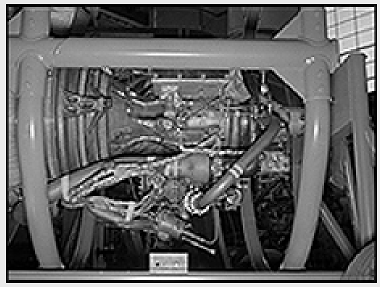
1967
Surveyor spacecraft makes first landing on Moon
PSL switches refocuses on aeronautics research
Design work underway for PSL expansion

1968
Construction underway for PSL No. 3 and 4

1969
Majority of construction on PSL No. 3 and 4 complete
Flamespreader installed on PSL Chamber No.21971

Ramjet test for Navaho Missile

1957 Triennial Inspection



RL-10 Engine for Centaur Rocket

Surveyor Spacecraft on Moon

Pratt & Whitney TF-30 Turbofan

Construction of PSL No. 3 and 4

1971
No testing in PSL-2 during 1971
Explosion in PSL Equipment Building

1972
First test run in PSL No.3 in November

1973
First test run in PSL No.4 in July
Recognition ceremony for PSL No.3 and 4 design and construction
NASA Lewis closes Plum Brook Station

1976
PSL No. 1 closed in September until June 1977 for failure investigation

1979
Final PSL No. 2 test completed in July
Final PSL No.1 test completed in September

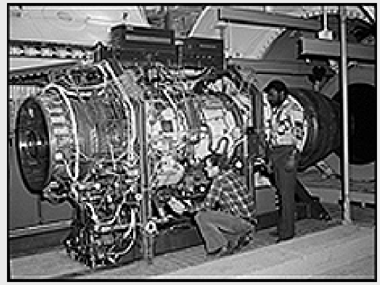
2004
NASA Glenn begins demolition planning

2006
Community Awareness Meeting held April 27

2007
Historical documentation of PSL begins

2008
Demolition of PSL No.1 and 2 begins

2009
Demolition of PSL No. 1 and 2 completed



F-100 Turbofan Testing

PSL Falls into Disrepair

Students

Propulsion Systems Laboratory No. 1 & 2

TESTS IN PSL 3 AND 4

	PSL No. 3	PSL No. 4
1972	Quiet Engine Program	
1973	Quiet Engine Program	Pratt & Whitney J58 emissions
1973	Quiet Engine Program	Pratt & Whitney J58/JT8D Refan
1975	Airflow Airjet Duct Test	Pratt & Whitney TF30 augmentor mixer
1976	Pratt & Whitney TF30 P-3 distortion	Pratt & Whitney F-100 P059 calibration
1977	Pratt & Whitney TF30 P-3 distortion	Pratt & Whitney F-100 P063 afterburner
1978	Pratt & Whitney TF-34 inlet vanes	Pratt & Whitney F-100 P072 afterburner
1979	Pratt & Whitney TF34 inlet vanes	Pratt & Whitney F-100 P072 afterburner

Students

Propulsion Systems Laboratory No. 1 & 2

PSL 1 and 2
Publications
History
Design and Construction
Ramjets and Missiles
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Combustion Air Flow
Test Equipment
Exhaust System
Support Buildings
Research
Historical Documents
Technical Reports
Mitigation
Community Awareness
Historical Mitigation
Students
Events Timeline
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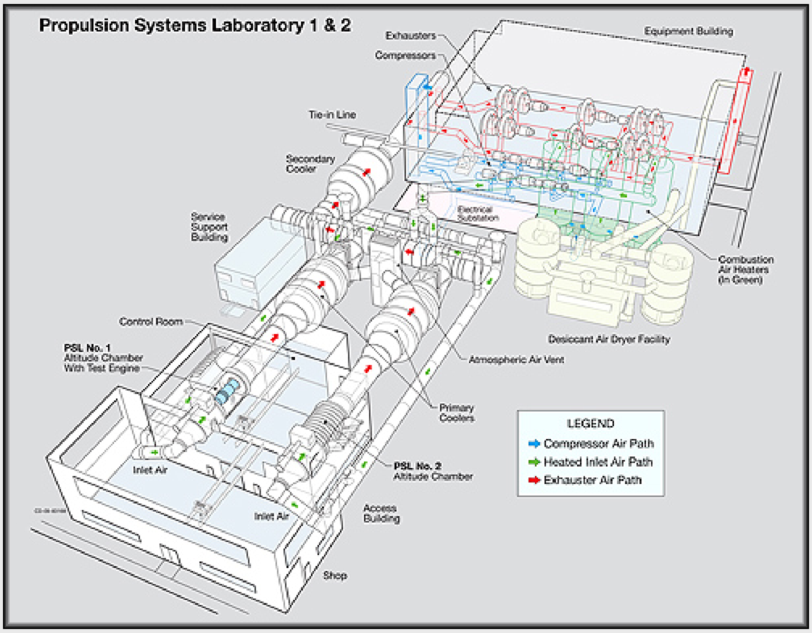
HOW THE PROPULSION SYSTEMS LABORATORY WORKED

The Propulsion Systems Laboratory (PSL) at NASA Glenn Research Center originally contained two altitude chambers for testing full-scale turbojet, ramjet, and rocket engines in conditions that replicated those encountered during flight. A large hatch allowed the installation of the engine on a moveable thrust stand within the test section. Compressors in the Equipment Building pumped air at high speeds towards one of the test chambers. The air was conditioned as it passed through the refrigeration equipment, heaters, and dryer to produce the temperatures found at high altitudes or supersonic speeds. Large exhausters, also located in the Equipment Building, reduced the air pressure within the test chamber to create the thin air of high altitudes.

As the air flow entered the chamber, it passed through straightening vanes and was ducted directly to the engine inlet in the test section. Operators in a control room located between the two chambers ran the tests. Cameras and instrumentation collected data from inside the chamber. After exiting the test section, the engine's hot exhaust gases passed through a primary cooler that reduced the gases' temperature. Some of the remaining heat was dissipated through the atmospheric air vent, and the remainder was cooled as it was drawn through the secondary cooler. The air was then pumped into the Equipment Building and vented into the atmosphere.



Glossary

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.

Propulsion System: The entire system in which an engine operates. This includes inlets, nozzles, fuel supply, and other components besides the engine. Engine components often behave differently when integrated into the entire propulsion system than they do when isolated.

Altitude Simulation: The creation of conditions in a test facility that are similar to those encountered at high altitudes. The temperature, pressure, moisture content, speed, and other factors must be replicated.

Test Section: Portion of a test facility where the engine or test article and sensors are placed. The entire test facility is focused on creating the proper conditions in this test section.

Exhauster: A pump that removes gas or air from one location and expels it in another. By removing air from a test chamber, one can create the low pressures found at higher altitudes.

Compressor: A turbine-powered machine that compresses gas or air. By compressing the air, it is forced from the storage in the compressor through a pipe or line.

Cooler: A device that removes heat from the surrounding air. There are different methods of accomplishing this. One of the most frequently used methods uses tubes filled with water or Freon (DuPont). As the hot air passes around the tubes, the heat is transferred to the water. The water is pumped away and the air temperature is reduced.

LINKS TO EXTERNAL RESOURCES

NASA History
Glenn History Program
Headquarters History Office
Altitude Wind Tunnel history
Rocket Engine Test Facility history
B1 and B3 Test Stands history

NASA Facilities
Glenn Research Facilities
PSL No. 3 and 4 Website

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)
NASA History Series Publications

Additional Research Tools
NASA Technical Report Server

Historical Preservation
National Park Service Historic Documentation Programs
Advisory Council on Historic Preservation

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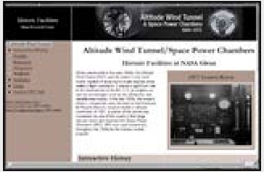
Cleveland, OH 44135
history@grc.nasa.gov

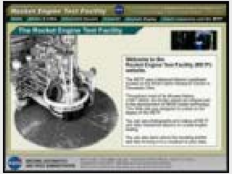
Glenn History Officer: Anne K. Mills
Archivist: Robert S. Arrighi, Alcyon Technical Services

GLENN HISTORY WEBSITES

GRC History



Altitude Wind Tunnel



Rocket Engine Test Facility