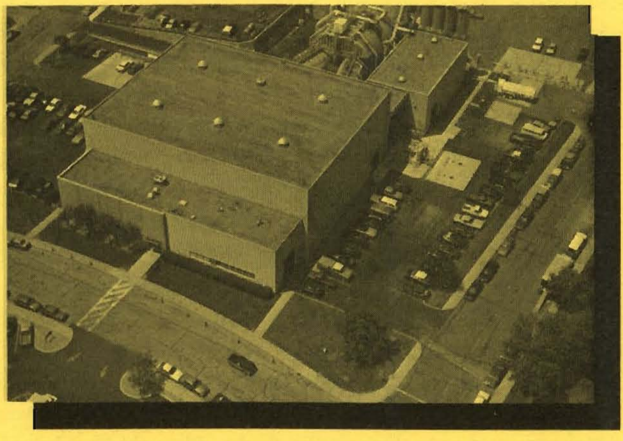
NASA

The Propulsion Systems Laboratory



AFED

AEROPROPULSION FACILITIES & EXPERIMENTS DIVISION

"IDEAS PUT TO TEST"

Lewis Research Center
Cleveland, Ohio

The NASA Lewis Research Center's Propulsion Systems Laboratory (PSL) is the only NASA ground test facility capable of providing true altitude simulation for the testing of full-scale air-breathing gas turbine engines

The PSL

The Lewis Research Center (LeRC) PSL provides world-class test and evaluation capability in support of NASA's Research and Technology (R&T) charter. In addition to R&T studies of engine altitude performance and component evaluation, PSL also supports the Department of Defense and private industry with engine qualification and verification tests.

The PSL complex supports two large engine test cells capable of providing flight simulation to altitudes of 70,000 ft and forward airspeeds to Mach 3.0. Test cells PSL–3 and PSL–4 operate as direct-connect engine test cells, with the LeRC central air supply facility or atmospheric inlet supplying combustion air to the test engines. The LeRC central exhaust supply facility provides the vacuum required to lower test cell pressure.

The test cells simulate aircraft flight by providing test engines with conditioned air matching the temperature and pressure actually seen in flight. Altitude simulation is provided by evacuating the test cells to the proper altitude pressure.

The PSL can test complete engines as well as core engines and components. Component evaluation is performed with a complete engine. This allows evaluation of all component/system interactions. Component evaluations include compressors, combustors, turbines, exhaust systems, and controls. Components are first evaluated individually in other LeRC facilities. Airframe and environmental effects, such as inlet flow distortion and stability, are also studied. The test facility can measure all combinations of forward/deflected/reverse thrust as well as collect engine exhaust gases generated in these conditions.

The PSL Complex

The major components of the PSL test complex are the engine test building, the exhaust cooler, the heater/refrigeration building, the air supply/exhaust plant, and the cooling tower water system.

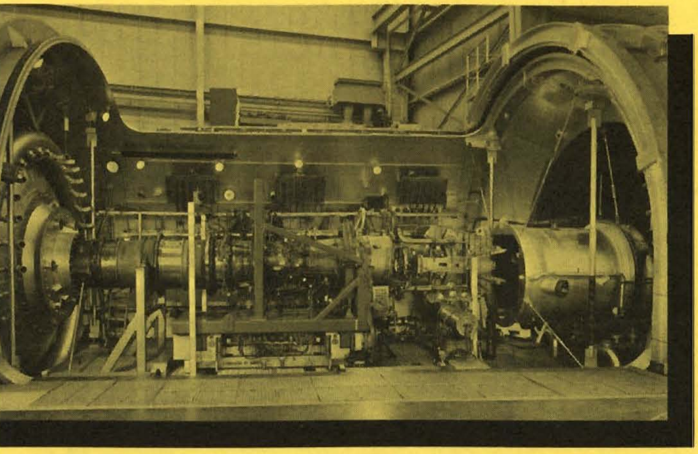
The Test Cells

Test cells PSL–3 and PSL–4 are within the engine test building along with the control valves, the combustion air and bypass valves, the control room, and the data room.

Each test cell is a large pressure vessel, 39 ft long and 24 ft in diameter. The cells isolate the operating engine. Cell access is through large translating hatch covers on each test cell.

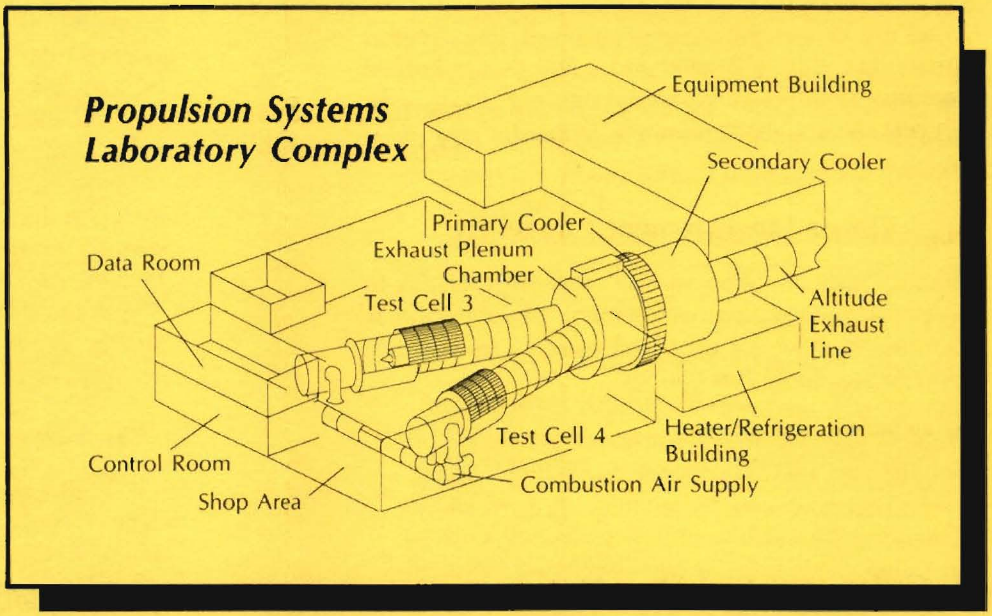
Both cells have a supply plenum on the upstream end, fed from the central air supply facility through the heater/refrigeration building. The engine draws conditioned air from the supply plenum through a pipe directly connected to the engine. An inlet bulkhead isolates the supply plenum from the altitude environment of the test cell.

Engine exhaust is collected in the aft end of the test cell by a specially sized pipe which acts as an ejector/diffuser that minimizes the recirculation of exhaust gases back into the test cell. Thrust measuring systems are built into the engine support beds and are capable of measuring axial, vertical, and lateral forces produced by the propulsion system. Test cell cooling air is introduced by a supply torus at the inlet bulkhead.



open PSL test cell shows an engine and its instrumentation dy for a test run.

Only one test cell may operate at a time since the cells share a common air supply, exhaust supply, and exhaust gas cooling system.



The Control Valves

Three categories of control modes are grouped by function

- In the basic operating mode, inlet control valves admit temperature-conditioned air into the test cell inlet plenum. The valves set and maintain inlet pressure for simulated flight conditions. The valves also adjust in response to test engine airflow demands during engine speed changes. The exhaust control valves set and maintain test tank altitude pressure in response to the engine airflow demands and changes.

- In a more efficient control mode, the test cell bypass loop is used. The loop controls the amount of air bypassed from the inlet plenum, around the test cell and engine, and into the exhaust duct. Since this loop is between the inlet and exhaust control valves, air can be traded between the test engine and the bypass loop during engine speed transients. This is the preferred control mode for engine transient testing since the inlet and exhaust valves may remain nearly fixed.

- In the third control mode, flight transient simulation, all valves may be operated in a preplanned automatic sequence, along with the heater/refrigeration building equipment, to produce varying inlet and exhaust conditions simulating aircraft transient operation.

All valves are controlled by an automated distributed process controller that allows for automatic operation in both steady-state and transient engine and/or aircraft control modes. Manual control is also possible. Isolation valves sequester the cell not in use.

The Exhaust Coolers

Exhaust gases from each cell are channeled to the primary exhaust cooler through water-cooled exhaust ducts since exhaust gas temperature may be as high as 3,000 °F. A 14-ft diameter water-cooled disk at the exhaust cooler acts as a davit valve to isolate the test cell not in use.

The primary cooler is a 50-ft-diameter water-jacketed pressure vessel, containing 2,700 water cooling tubes, designed to reduce incoming exhaust gases from 3,000 to 600 °F. A spray cooler further reduces the temperature of exhaust gases to 150 °F before conducting them to the central exhaust supply plant.

The PSL Control and Data Rooms

All tests are monitored and regulated in the control room. The control room contains the control valve operating station and the test engine control station. The test conductor controls the test from this room. Data acquisition and display functions are controlled from the control room as well. The automated facility control computers are located in an equipment room directly below the control room.

The data room, located above the control room, contains dedicated computerized systems for the acquisition, display, and storage of both steady-state and transient data. Data are automatically transmitted from the test engine to the data room for processing. Planned calculations are preformed on selected data and results are sent to the control room for continuous display and update. This allows test sequence monitoring and modifications to the test to achieve test goals.

The Heater/Refrigeration Building

There are two separate temperature conditioning systems located in the heater/refrigeration building upstream of the test cell inlet control valves: one for heating air and one for cooling air. Heated air is provided by two non-vitiating counter-flow heat exchangers that can operate in parallel and raise test cell inlet temperature to 800 °F. Cool air is provided by three turbo-expanders. This trio of refrigeration turbines operates in parallel and can lower test cell inlet air temperature to −60 °F.

The Air Supply/Exhaust Plant

The air supply/exhaust plant supplies compressed air to the PSL test cells and exhausts gases from the cells. Combustion air is supplied by four sets of 55-psia compressors with supply capability of 500 lb/sec. Two sets of boost compressors may be used to raise air pressure to 165 psia, but reduce supply capability to 400 lb/sec. Exhaust is supplied by four sets of high-flow exhausters matched to the flow capability of the supply compressors.

The plant also has equipment to dry the combustion air to a −60 °F dew point.

The Cooling Tower Water System

Water cooling for the test cell complex, special research needs, the heater/refrigeration building, and the air supply/exhaust plant is provided by the cooling tower water system. The system is comprised of two large cooling towers capable of rejecting in excess of 35 billion btu/hr at a nominal water supply pressure of 45 psig.

Engine Installation

Testing begins with the mounting and instrumenting of the test engine. Since tests are generally one of a kind, each installation is unique. Test-specific hardware such as engine mounting adaptive equipment, inlet ducting, and exhaust collection apparatus requires 9 to 15 months to design and build.

Depending upon the nature of the test, the engine will be mounted either directly on the axial thrust bed or on the multi-axis thrust measurement module.

PSL-3's engine centerline-to-thrust height is 6 ft and PSL-4's is 4 ft. Engine mounting may be on either a cradle below the engine or from a strongback/boathook arrangement above. Actual configuration is determined case by case.

Special LeRC mechanics and technicians do the engine mounting and instrumentation with guidance and assistance from customers.

PSL Test Capability

Specific PSL capability is determined by the capacity of the air supply/exhaust plant and the heater/refrigeration building capabilities. Unlike an aircraft in actual flight, the three simulation parameters of PSL—inlet temperature, inlet pressure, and exhaust pressure—may be varied parametrically.

Special Test Capability

A palletized insert is available for PSL–4, which gives the test cell limited Mach 6.0 direct-connect testing capability. This continuous flow Mach 6.0 capability, coupled with a gaseous hydrogen/gaseous oxygen propellant supply system, provides an industry-unique test capability. The insert is designed to provide 100 lb/sec of air at 125 psia and 3,000 °F to the front of a small hypersonic airbreathing turbine engine. The hardware consists primarily of high-pressure piping and a high-temperature heater. The gaseous hydrogen-fueled vitiating heater raises the inlet air temperature to 3,000 °F. Capability for makeup oxygen exists.

Use of the insert in a free-jet mode is possible and has been demonstrated on various programs.

Fuel Supply System

A high-capacity liquid fuel system supplies both test cells. The stainless steel dual fuel system is capable of flow rates to 200 gal/min and pressures to 65 psia, and a fuel heater is available. The standard fuels are Jet–A and JP–4. Other liquid fuels can be placed in the system. Gaseous hydrogen, gaseous oxygen, and gaseous methane are also available for test engines. Other exotic fuels must be considered on a case-by-case basis due to environmental and central exhaust supply system considerations.

Additional Systems

High-pressure air for research purposes is available at 55 psia, 165 psia, 450 psia, and 2,200 psia at limited flow rates. High-pressure gaseous nitrogen is available. A 3,000 psia red-oil research hydraulic system is available.

Thrust Measurement Capability

Various methods allow engine movement relative to the test cell during thrust measurement. This metric break is located in the inlet duct and usually consists of a labyrinth seal or Teflon O-rings.

Thrust Measurement Capability	
Horizontal (axial) axis	±50,000 lb
Vertical axis	±15,000 lb
Lateral Axis	±15,000 lb

Airflow and Fuel Flow Measurement

Detailed instrumentation in the inlet ducting determines airflow with a high degree of accuracy. A mass flow integration method is employed.

Total engine/afterburner fuel flow is determined by use of calibrated turbine flowmeters.

Steady-State Data Acquisition—Escort D Plus

The Escort D Plus system is capable of acquiring

- 512 electroscan pressures at various ranges
- 480 temperatures from C/A type thermocouples

(photo courtesy of McDonnell Douglas Corp., St. Louis)

The PSL has provided support for a wide range of programs, including work on two-dimensional exhaust nozzles such as those on this experimental F–15.

- 256 voltage measurements such as speed, vibration, and transducers

Limited numbers of special types of thermocouples can be handled.

All steady-state data are acquired and converted to engineering units once per second. During this interval, various calculations are performed and specified parameters are made available for real-time display in the control room. Permanent record data is acquired by freezing single or multiple updates of steady-state data. The data system is entirely self-contained within the facility and is designed to exceed the most stringent security requirements for classified test programs.

Transient Data Acquisition—Masscomp

A high-speed digital data system records transient data. The system consists of 256 input channels, an analog to digital converter with an overall throughput of nearly one million channels/sec, and a high-volume disk recording system.

Other Data and Support Systems

Some of the systems available at the PSL include

- Signal conditioning for vibration, speeds, and flowmeters
- Local FM safety tapes
- Local FM data recorders
- Central analog FM recorder—195 channels
- Analog and digital visicorders
- X/Y plotters
- Graphics systems—both steady-state and transient
- Analog hybrid computer
- Local modicon PLC
- Three infrared imaging systems
- Schlieren system for free-jet recording
- Exhaust system periscopes
- Video monitoring and recording
- Gas sampling

Pretest estimates and post-test data uncertainty analyses may be performed.

Secure Testing

All physical, electronic, and data system security specifications exceed the most stringent classified testing requirements. Secure buildup and storage are available.

Other Considerations

Full-scale engine altitude simulation testing is a highly specialized profession. NASA LeRC employs a number of experts in the field who are ready to assist customers in the design and conduction of experiments. A test typically requires a 2-yr scheduling lead and an 18-mo hardware lead. Test cell occupancy is usually 3–6 months. Potential users should contact the LeRC PSL Facility Manager for further details and information on the cost of testing. Prerequisites for testing include approval by the LeRC Director of Aeronautics and a formal agreement—Space Act or Interagency Agreement.

Other factors potential customers should take into account when determining PSL use are

- Customer space is available at the test complex.
- Arrangements may be made for transmitting data to contractor facilities.
- Full risk-analysis and documentation will be required on all test hardware and instrumentation.
- All tests will be subject to NASA and LeRC safety regulations, area safety reviews, and operational readiness reviews.
- The NASA test conductor is the final authority in the control room during testing.
- Instrumentation services are available at LeRC.
- Fabrication and machine shop services are available.
- A Cardox system provides test cell fire suppression.
- Information on electrical power capabilities, cable lengths, special interfaces, and other test cell details may be obtained from the PSL Facility Manager.

For further information about the use of the PSL and reserving it for testing, contact:

The PSL Facility Manager

NASA Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
216/433–4000

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