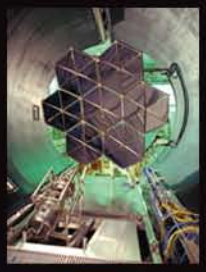
National Aeronautics and Space Administration

Glenn Research Center Test Facilities



Message from the Director, Facilities, Test and Manufacturing

The vision of the National Aeronautics and Space Administration (NASA) is to reach new heights, and reveal the unknown so that what we do and learn will benefit all humankind. Here at the NASA John H. Glenn Research Center (GRC), we have a long history of discovery in the areas of aeronautics and space exploration. Through our partnerships with government, industry, and academia, our highly-qualified, diverse team undertake cutting-edge testing and technology development to advance the aeronautics and space state-of-the-art.

Our facilities are uniquely positioned to meet the technological needs of NASA and its partners, now and into the future. Our sites at Lewis Field in Cleveland, Ohio and Plum Brook Station in Sandusky, Ohio, are home to 25 major test facilities, 4 different highly-capable research aircraft and over 100 research/engineering laboratories. We have a wide range of capabilities from the world's largest vacuum facility, to large aeropropulsion wind tunnels, microgravity research facilities and in-space propulsion test stands.

We continue to make investments in our facilities to ensure that they remain world class. We have increased their technical capability and improved data acquisition, while at the same time making them more cost-effective and efficient.

Our highly-skilled engineers and technicians work closely with our customers to ensure that unique test article, instrumentation and test environment requirements can be met. Our commitment to quality test operations is demonstrated with our ISO 9001 and AS9100 certifications.

I hope that you find this information about our GRC test facilities useful and it gives you a better understanding of our ground and flight capabilities. If you would like more information on any of our test facilities, please contact any of our facility managers listed in the back of this booklet. We look forward to showing you how we can meet your research and testing needs.

Sincerely,

Thomas W. Hartline
Director, Facilities, Test and Manufacturing

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NASA Glenn's Premier Research Test Facilities

Engine Components

NASA Glenn Research Center (GRC) offers a large variety of engine component facilities supporting turbine engine research and development. These facilities are essential to support NASA, industry, and academia in advancing future development of aerospace engine technologies. Supporting NASA's efforts for quieter and more fuel-efficient turbine engine technology development, as well as research for access to space propulsion systems, are just some of the varied test capabilities supported at these facilities. Detailed facility test capabilities information is available on page 39.

The Aero-Acoustic Propulsion Laboratory (AAPL) provides unique nozzle and fan test rigs to evaluate engine noise-reduction concepts.

The Engine Research Building (ERB) is the largest and most adaptable test facility complex at GRC, housing more than 60 test rigs. Most aspects of engine development can be studied here with numerous facilities specializing in turbomachinery, tribology, flow physics, combustion, aerochemistry, mechanical components, and heat transfer.

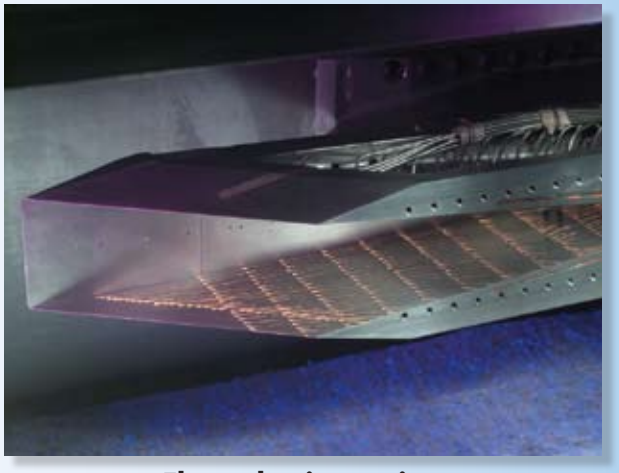
The Engine Components Research Laboratory (ECRL) Cell 1B is a unique combustor facility able to evaluate augmentor and afterburner concepts. ECRL can support a variety of test configurations and in recent years has evaluated hybrid propulsion systems for aerospace applications.

The Advanced Subsonic Combustor Rig (ASCR) is NASA GRC's unique high-pressure combustor facility, able to simulate combustor inlet conditions up to 900 psig.

Turbomachinery testing

Combustor testing

Nozzle and fan acoustics testing



Flow physics testing

Aero-Acoustic Propulsion Laboratory (AAPL)

The AAPL is essential in supporting NASA's engine noise-reduction research for nozzle and fan components.

The AAPL is an acoustically treated geodesic dome that houses three acoustic tests rigs supporting engine noise-reduction research at GRC. AAPL's two nozzle rigs and one fan rig have been actively used to support these research efforts.

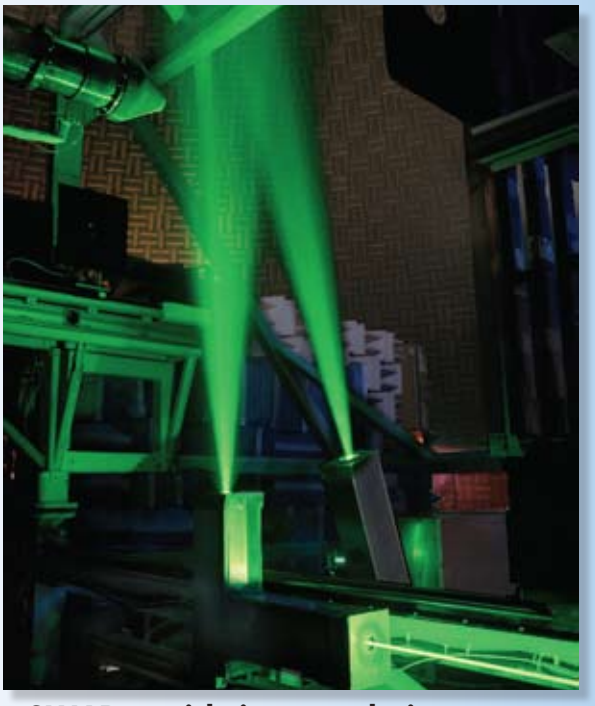
The Nozzle Acoustic Test Rig (NATR) is a free-jet acoustic tunnel used to evaluate acoustic performance of nozzle concepts at simulated flight conditions up to Mach 0.35. Two microphone arrays are used to acquire sideline and flyby acoustic data. These microphone arrays are located about a 50 ft radius from the nozzle exhaust, providing a unique far-field acoustic environment to evaluate nozzle concepts. A High Flow Jet Exit Rig (HFJER) is used to mount nozzle concepts in the NATR and can simulate engine cycle conditions in single- or dual-flow nozzle configurations. The NATR has contributed significantly to research in chevron nozzle development, which has demonstrated substantial noise reduction with no impact on thrust performance.

The Small Hot Jet Acoustic Rig (SHJAR) is a small nozzle acoustic test rig for fundamental nozzle acoustic research that allows researchers to evaluate potential noise-reduction nozzle concepts very economically. The SHJAR is tested in a single-flow configuration with no tunnel flight simulation. Promising nozzle concepts can be scaled up and acoustically evaluated using the NATR.

The NATR and SHJAR can support several advanced diagnostic testing capabilities to provide researchers a means of better understanding nozzle exhaust conditions. Measurements of pressures and temperatures can be acquired using a traversing plume survey system. Particle Image Velocimetry (PIV), phased-array acoustic source identification, and Schlieren and shadowgraphy help researchers gain invaluable insight into the physics of jet noise generation and methods for its reduction.

The Advanced Noise Control Fan (ANCF) rig is used to support fundamental noise-reduction research on fan components and allows researchers the flexibility to evaluate a variety of rotor and stator configurations. It was developed to test noise-reduction and noise measurement concepts, and provide a flexible and realistic aeroacoustic source for computational aeroacoustic (CAA) code verification. The unique rotating rake measurement system can obtain both radial- and circumferential-mode measurement for the inlet and exhaust ducts. ANCF uses a 4-ft-diameter fan and can support testing up to 2,600 rpm. A compact farfield acoustic array is used to obtain inlet and exhaust acoustic measurements.

NATR nozzle acoustic test



SHJAR particle image velocimetry test

ANCF acoustic test

Engine Research Building (ERB)

The ERB supports research on all aspects of engine development, providing superior testing of turbomachinery, aerodynamics, flow physics, aeropropulsion heat transfer, mechanical components, and combustor facilities.

Combustor Facilities

GRC provides modern combustor facilities supporting low-emission combustor research and development testing in partnership with industry. Fundamental and applied research is aimed at advancing the technology of the combustion processes of aeronautical gas turbine engines and advanced space transportation concepts. Research is focused on providing improved understanding of chemical kinetics of reacting flows, heat transfer phenomena, advanced high-temperature materials, alternate fuels, low nitrogen oxide (NOx) combustion, and code development and validation.

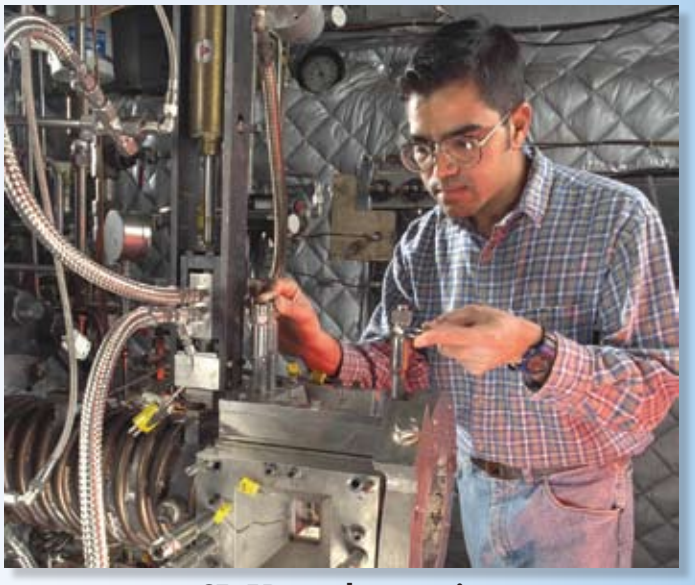
GRC's ERB complex offers a wide variety of combustor facilities and currently has 15 facilities supporting these research efforts. ERB combustor facilities vary in capabilities simulating pressures up to 450 psig, flow rates up to 30 lbm/sec, and inlet combustor temperatures up to 1,350 °F.

Heat Transfer Facilities

Testing capability for experiments to advance fundamental understanding of the heat transfer process and to contribute to the predictive capability for heat transfer in aeronautical and space propulsion systems is provided in the heat transfer facilities. Research in these facilities centers on gas-turbine-related heat transfer with special emphasis placed on gas path aero and heat transfer. Six aeropropulsion heat transfer technology facilities are located in the ERB.

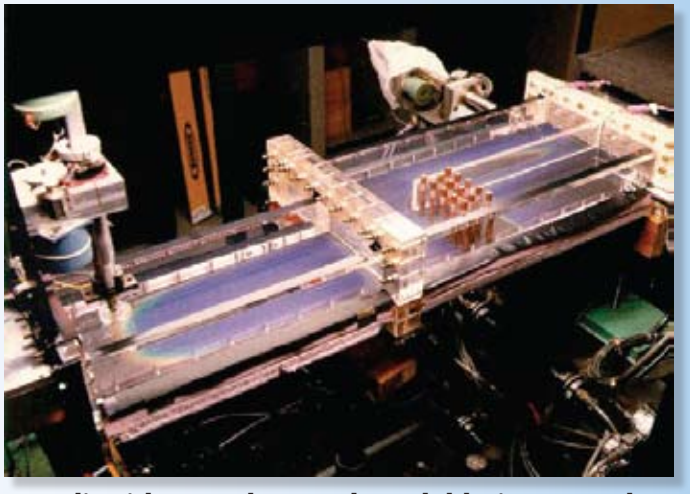
Mechanical Components Facilities

Research and development in mechanical components and systems technologies to improve the performance, reliability, and integrity of aerospace drive systems, high-temperature seals, and space mechanisms is performed in the facilities. Several gear, bearing, and transmission facilities are located in ERB to support research on fatigue life testing, lubrication, materials, noise, vibration, and thermal effects on these components.



CE–5B combustor rig

CE–9B–B high-temperature flametube injector test stand



A liquid-crystal-coated model being tested in SW–6

Engine Research Building

Turbomachinery Facilities

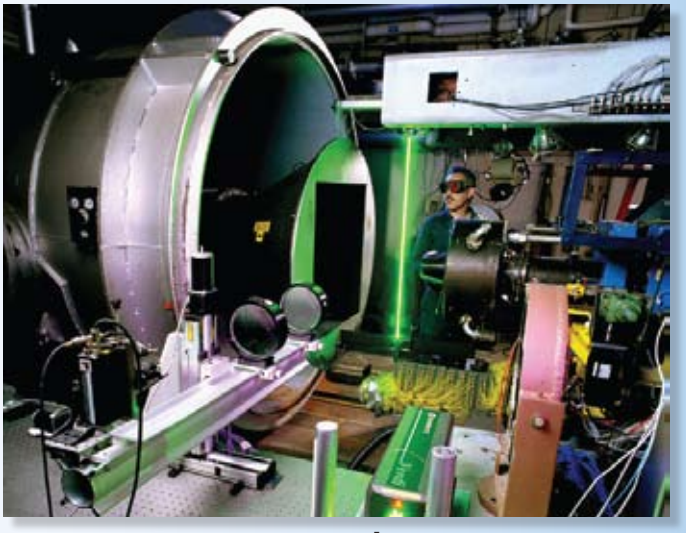
Fundamental and applied research to advance compressor and turbine component technology for aeronautical gas turbine engines is conducted in the facilities. Both axial- and radial-type machinery are studied. Research is focused on improved understanding of steady and unsteady aerodynamics, flow physics, and modeling and advanced numerical flow code development and validation. Research experiments utilize advanced instrumentation systems such as hot-wire anemometry and laser diagnostics where detailed flow data is obtained on a nonintrusive basis. GRC currently has 11 facilities supporting this research effort.

GRC's ERB complex offers a wide variety of turbomachinery facilities and currently has eight facilities supporting these research efforts. ERB turbomachinery facilities can support axial compressor and fan component testing ranging in sizes up to 22 in. in diameter. A maximum of 15,000 hp at rotational speeds up to 21,000 rpm can be supported. Also, a centrifugal compressor facility can support testing up to 60,000 rpm for compressor ranging from 8 to 20 in. Supply airflow and exhaust conditions can be varied at each facility depending on the test requirements.

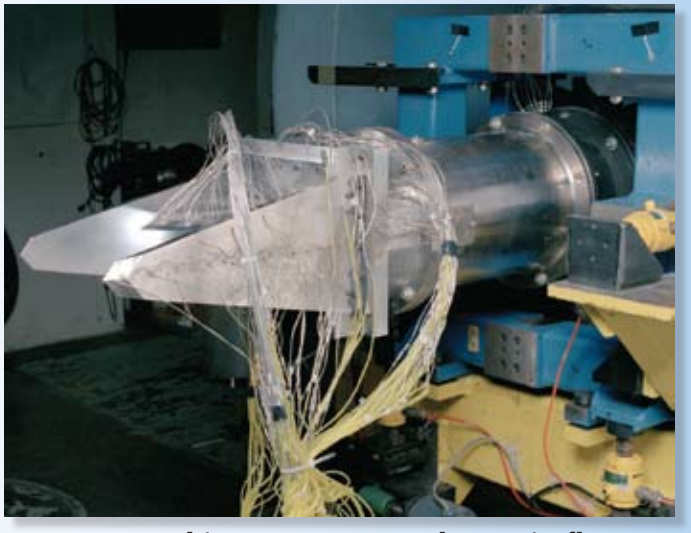
Flow Physics Facilities

Research advancing the understanding of subsonic-to-supersonic flow physics phenomena fundamental to ducted wall-bound flows is conducted in the flow physics facilities. Research involves the development, assessment, and application of computational fluid dynamics tools for ducted flows and for the acquisition and analysis of experimental measurements of flows in inlets, ducts, and nozzles. Typically, testing is performed to define basic flow properties, to predict and validate component performance, and to investigate specific phenomena including shock systems, boundary layers, bleeds, diffusion, separated flows, heat transfer, cooling, spillage, acoustics, and stability. GRC currently has eight facilities supporting this research effort.

Compressor test in W–7



CE–22 nozzle test



Pratt & Whitney F–119 nozzle test in flow physics facility

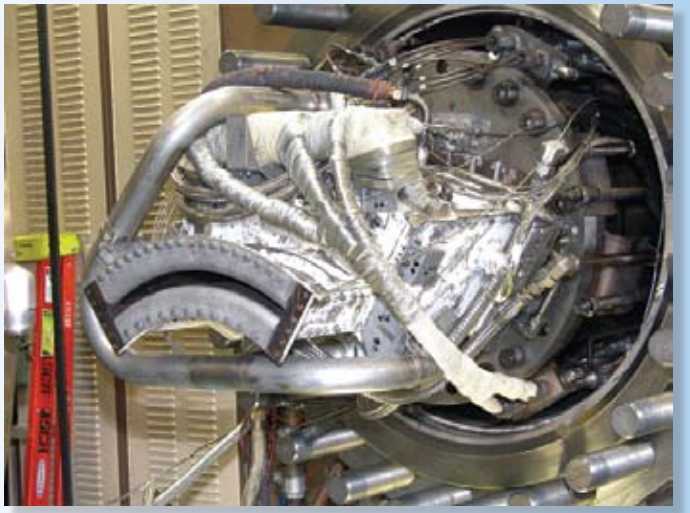
Advanced Subsonic Combustion Rig (ASCR)

The ASCR is the highest pressure combustor facility in the United States, able to simulate combustor test conditions up to 900 psig.

The ASCR is NASA GRC's unique high-pressure and high-temperature combustor facility supporting the emissions reduction projects. The facility has the capability of simulating combustor inlet test conditions up to a pressure of 900 psig and temperature of 1,200 °F (nonvitiated). To accomplish the higher pressure test capability, ASCR has a dedicated high-pressure compressor, which pressurizes the GRC centrally supplied 450 psig combustion air to 900 psig. The maximum facility airflow is 50 lb/sec and maximum combustor exhaust gas temperature is 3,400 °F.

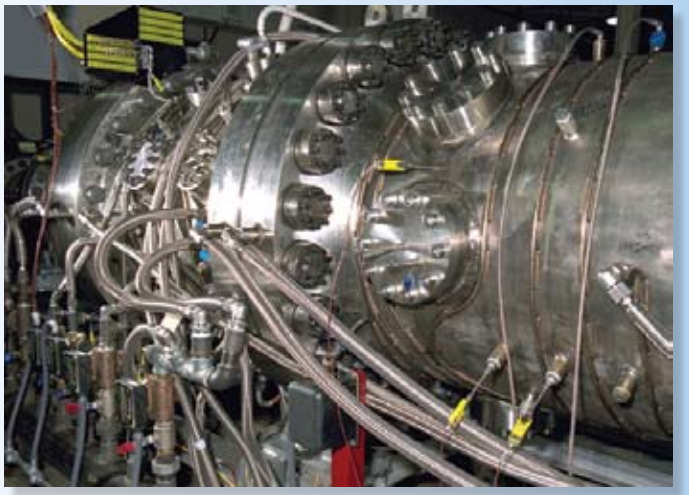
NASA and its industry partners are working to develop low NOx combustors, which will operate at pressure ratios up to 55:1 as part of turbine engine technology development programs. A facility like ASCR is essential to support combustor development at these high pressures and provides NASA and U.S. engine manufacturers with the ability to quantify the effects of higher pressure on combustor emissions, durability, and operability.

The first-ever laser diagnostics measurements in a practical gas turbine combustor at high pressures was conducted in the ASCR. Nonintrusive laser-based diagnostic measurements are performed in windowed test sections. ASCR acquired two-dimensional fluorescence measurements within a gas turbine combustor sector at 42 atmospheres and one-dimensional Raman scattering measurements within a gas turbine combustor sector at 48 atmospheres. These measurements can be used to visualize the fuel injection, fuel-air mixing, and combustion processes within high-temperature, high-pressure gas turbine combustor sectors and simulators.



General Electric combustor test

ASCR sector



ASCR sector stand

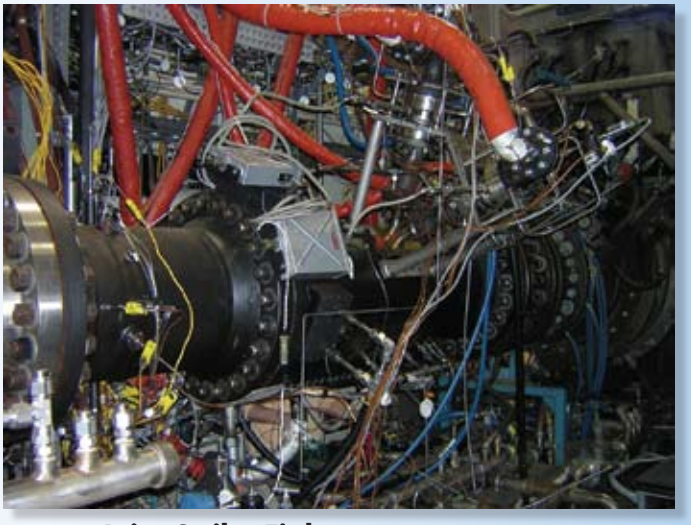
Engine Components Research Laboratory (ECRL) Cell 1B

The ECRL Cell 1B is a versatile combustor facility supporting development for a wide range of engine propulsion concepts.

ECRL Cell 1B is a full-scale combustor rig used to test and evaluate advanced engine combustor and afterburner concepts in a realistic engine environment. Inlet air pressure can be supplied at 40, 125, or 150 psig with flow rates up to 100 lbm/sec. The air can be heated to 625 °F via a nonvitiating preheater. Aviation fuels used in ECRL Cell 1B are typically JP–4, JP–5, or Jet-A; though specialized fuel can be utilized.

The test section is typically 4 to 5 feet long, and the flow can be split into a core and fan stream. The ratio of core airflow is usually 1.2, but can be varied by changing the orifice plates. Core air can further be heated by a J–58 combustor; the maximum J–58 outlet temperature is 2,000 °F. Additional fuel can be added in the test section area, thereby increasing the exit temperature beyond 2,000 °F. ECRL Cell 1B can use its own atmospheric exhaust, or it can use the GRC altitude exhaust, which has a maximum exhaust vacuum of 2 psia (50,000 ft altitude).

This cell has supported testing for pulse detonation engines and Rocket-Based Combined Cycle (RBCC) combustor instability and materials durability research. Gaseous hydrogen (1,500 psig at 1.0 lb/sec) and oxygen (1,500 psig at 4.0 lb/sec) testing capability were added to support RBCC aerospace propulsion research. Gas analysis, facility controls, and data system enhancements have been incorporated for versatile support of varied test requirements. The cell is very useful to the research community providing the flexibility to test a wide variety of hardware configurations.



Joint Strike Fighter augmentor test

Control room

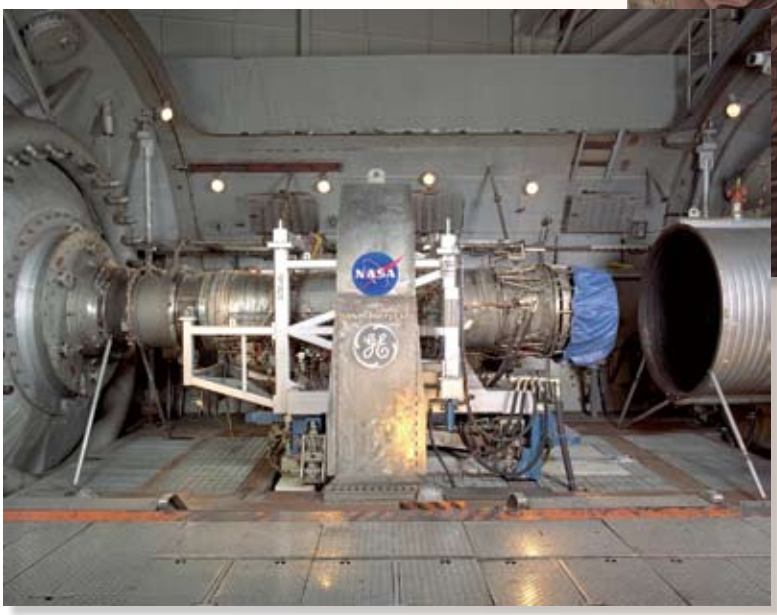
Rocket-Based Combined-Cycle test

Engine

GRC has the unique ability to conduct a full spectrum of jet engine testing including product development, component testing, and full-scale testing. The Propulsion Systems Laboratory (PSL) is NASA's only ground-based test facility that provides true flight simulation for experimental research on air-breathing propulsion systems. This continuous flow altitude simulation facility is equipped to conduct full-scale and component testing for base research, advanced aircraft, space transportation, general aviation propulsion, and hypersonic propulsion. The Engine Component Research Laboratory (ECRL) Cell 2B supports small turbine engine research. Detailed facility test capabilities information is available on page 40.

Williams International FJX engine test in PSL

T–700 active stall control engine demonstration test in ECRL



General Electric (GE) F–110 engine test in PSL

Engine Components Research Laboratory (ECRL) Cell 2B

The ECRL Cell 2B is NASA's small turbine engine test facility conducting research in partnership with the Army Research Laboratories.

The ECRL Cell 2B has been in use since 1979 to conduct turbine engine research on T–700, T–800, and T–55 engines of mutual interest to the U.S. Army and NASA GRC. Past test programs have investigated ceramic and brush seal technology, hydrogen burner thermal inlet distortions, active vibration control of high-speed shafting, alternate fuels, compressor stall and active stall control, and digital fuel control technology.

The test cell can be operated as a ground-level turboshaft facility or as an altitude facility for core engine tests. As a ground-level test facility, the cell can operate turboshaft engines up to 2,500 shp. The cell is equipped with a water brake system. Engine inlet air is supplied from the test cell through an inlet flow measurement venturi and a 78-in.-diameter plenum. The facility has an engine inlet particle separator (IPS) scavenge and measurement system, which utilizes a blower and control valves for setting IPS back pressure conditions. Engine exhaust is scavenged by a 48,000 scfm blower or through the GRC centralized altitude exhaust system.

The facility also has the capability of testing turbofan or turbojet engines under simulated altitude conditions in a 6-ft-long by 6-ft-wide by 7-ft-high chamber. This chamber is connected to the GRC altitude exhaust system and can achieve pressures down to 2.0 psia simulating altitudes of 46,000 ft.

The facility can accurately measure and record approximately 600 channels of instrumentation including pressures, vibrations, temperatures, and flow rates. These can then be analyzed in our data system to determine engine performance and operability.

T–700 engine test

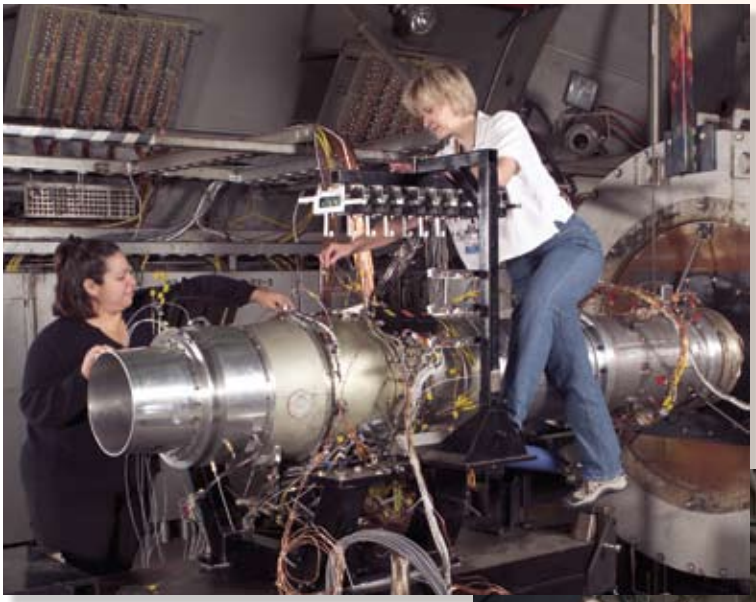
T–55 engine test

Propulsion Systems Laboratory (PSL)

The PSL is NASA's only ground-based test facility that provides true flight simulation for experimental research on air-breathing propulsion systems.

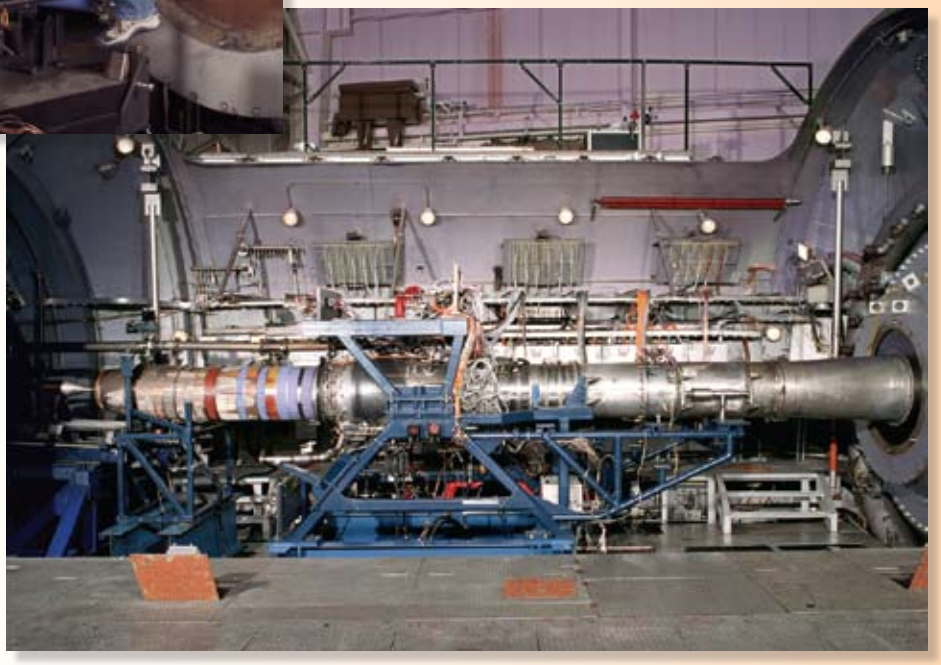
The PSL is a national resource to ensure the technical leadership and economic strength of the U.S. industry, which designs, develops, and manufactures jet engines and propulsion systems for aeronautical and space applications. PSL supports the development of new technology critical to our national defense and security. The research performed provides detailed information on the performance and operability of jet engines and propulsion systems at extreme conditions over the entire flight envelope, which can only be obtained through altitude-simulated, ground-based testing. This facility is significant because it is NASA's only ground-based, full-scale engine test facility that can provide true flight simulation. There are two large engine test chambers for conducting experimental research on air-breathing propulsion systems.

Using onsite compressors, exhausters, and heating and cooling systems, PSL can accurately create temperature and pressure inlet conditions that propulsion systems experience in high-speed, high-altitude flight. Of the two test chambers, PSL–3 is used primarily for military class turbine engines and explores all facets of advanced aircraft research. PSL–4 incorporates a high temperature and pressure inlet plenum and can meet the needs of high speed and altitude propulsion system research for both aviation and access to space applications.



Williams International F–J33 turbofan engine test

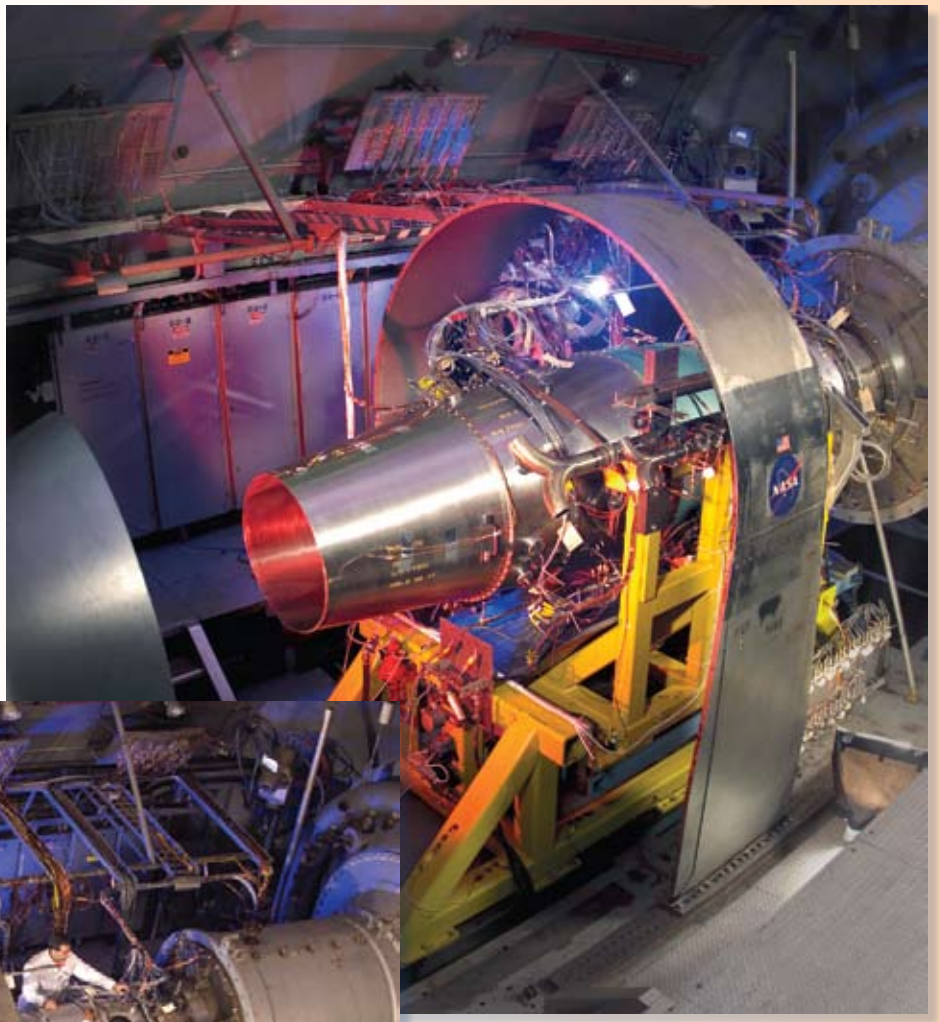
F–405 engine test



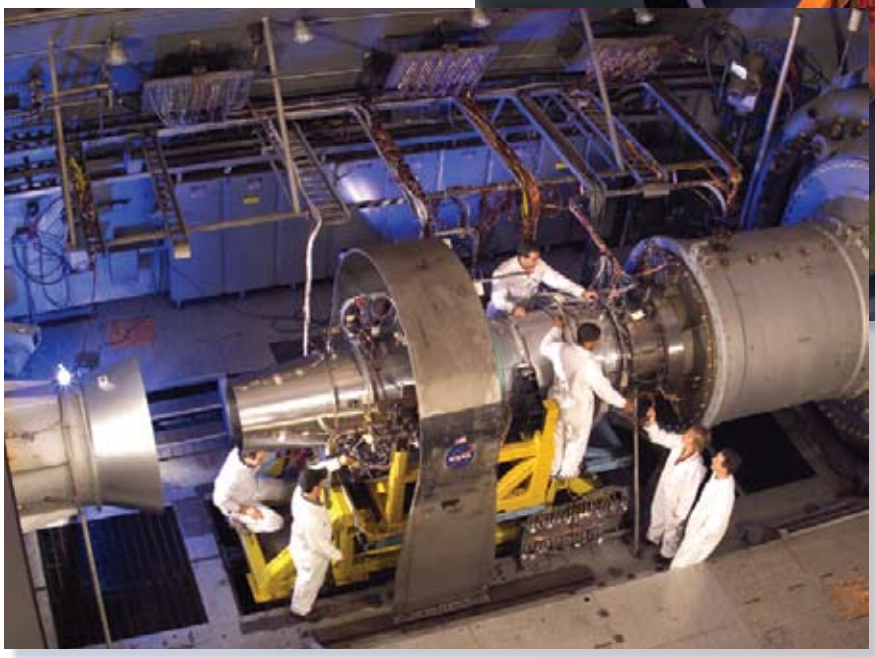
Propulsion Systems Laboratory

PSL uses a variety of additional specialized systems to investigate these future propulsion systems including liquid and gaseous fuels, multi-axis thrust measurements, and exhaust vectoring and collection. A user friendly, configurable data acquisition system is capable of displaying and recording over 1,000 static measurement channels, and an additional 126 channels with sampling rates from 1,000 to 200,000 samples per second per channel for time-varying measurements. NASA has highly experienced, versatile personnel with the ability to react to new program goals and changes that arise unexpectedly from ongoing experimental research. The scientists and engineers that employ the capabilities at PSL are experts in engine performance, maintenance, and operations, aeroelastic measurements, flight transient operations, and transient temperature and pressure distortion simulations.

PSL has supported such aircraft programs as the SR–71, F–16, F–15 STOL, and the B52 and has conducted basic research on advanced aircraft, space transportation, general aviation propulsion, and hypersonic propulsion.



Pratt & Whitney engine test

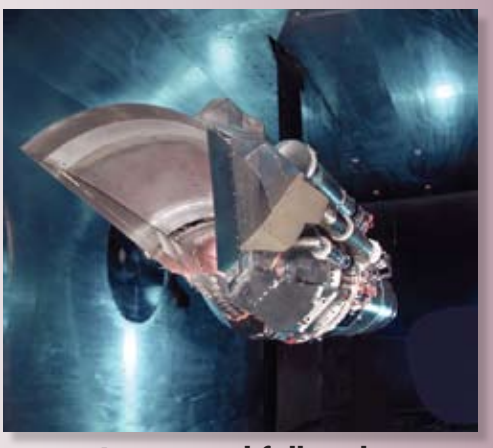


Wind Tunnels

NASA GRC operates and maintains several wind tunnels in accordance with its commitment to researching innovative propulsion technologies and flight safety. Spanning the operating speed range of 0 to Mach 7, the wind tunnels offer unique aerodynamic and propulsion test capabilities to support the diverse needs of our customers.

The wind tunnels have developed the capabilities, systems, and expertise to execute tests in areas such as basic flow physics, code validation, proof-of-concept, small-scale component research, icing protection systems development and certification, inlet/airframe integration, large- and full-scale component research and development, system integration, acoustics, aerodynamic force and moment, short takeoff and vertical landing, space launch vehicles, propulsion systems (live burning), and nontraditional wind tunnel activities. These tests have been efficiently and effectively conducted for NASA, other Government agencies, academia and commercial corporations in the aeronautics and space communities. Detailed facility test capabilities information is available on page 41.

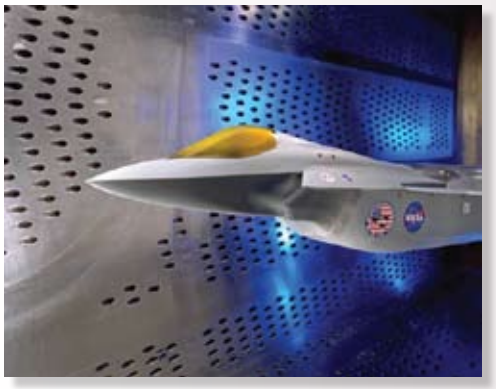
Ice protection system development and certification



Large- and full-scale component/system testing

Aerodynamic and acoustic testing

Basic research and proof-of-concept and code validation



Inlet/airframe integration testing

Hypersonic testing

Icing Research Tunnel (IRT)

The IRT is one of the world's largest refrigerated wind tunnels dedicated to the study of aircraft icing.

The IRT is GRC's oldest and busiest facility. Built at the end of World War II to solve aircraft icing problems, the IRT has been in continuous operation since 1944. In this facility, natural icing conditions are duplicated to test and study the effects of in-flight icing on actual full-size aircraft components and models of aircraft, including helicopters. The IRT has played a substantial role in developing, testing, and certifying methods to prevent ice buildup and develop next-generation ice protection systems for military and commercial aircraft.

A variety of tests are performed in the IRT including

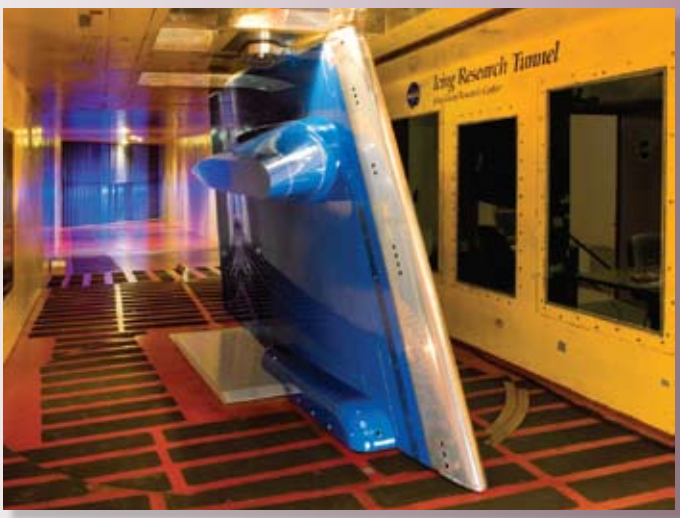
- Ice protection system development and certification
- Fundamental studies of icing physics
- Icing prediction validation
- Investigation of de-icing and anti-icing fluids for use on ground and on aircraft
- Icing Code Validation

The IRT can simulate actual flying conditions by providing airspeeds ranging from 50 to 350 kts and air temperatures as low as –40 °C, controllable to within 0.5 °C. A uniform test section icing cloud approximately 4.5 ft high by 6 ft wide can be created. Detailed analysis and electronic storage of ice shape data in addition to a wide variety of data collection and observation methods are used. Permanent casting and physical tracing of ice formation are also created for extended study.

With over 50 years of knowledge and experience in the icing arena, GRC has collaborated with the Federal Aviation Administration and industry to improve current capabilities in ice shape simulation and identify shape features most critical for evaluation of aircraft performance. This research is directed at understanding the physical process underlying the ice accretion processing including phenomena associated with super-cooled large-droplet ice accretion.

Bell 609 Spinner inlet icing test

General atomics test



Boeing P8 wing section

9- by 15-Foot Low-Speed Wind Tunnel (9×15 LSWT)

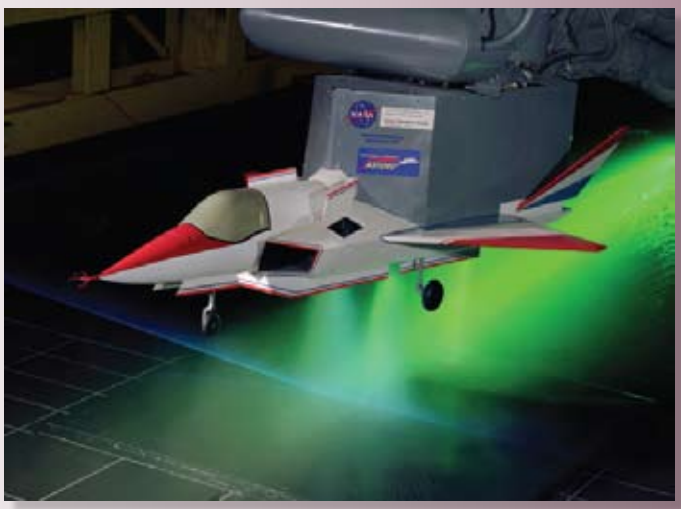
The 9×15 LSWT is the most utilized low-speed propulsion acoustic facility in the world and is the only national facility that can simulate takeoff, approach, and landing in a continuous subsonic flow wind-tunnel environment.

The 9×15 LSWT is used to test large-scale hardware in a continuous flow, calibrated subsonic airstream. Providing airspeeds from 0 to 175 mph, the test section can be configured to support both aerodynamic and acoustic testing of a variety of models.

With the ever-increasing demand for reducing aircraft noise, the 9×15 LSWT has the unique and nationally recognized ability to evaluate the aerodynamic performance and acoustic characteristics of fans, nozzles, inlets, and propellers. The test section is acoustically treated and equipped with microphones linked to a dynamic data system to allow acoustic research at frequencies as low as 250 Hz. A series of drive rig systems are available to power ducted engine fan models and unducted "open rotor" models for performance and acoustic testing. A unique "rotor-alone nacelle" test capability allows isolation of fan-alone noise by elimination of the outlet guide vanes. The 9×15 LSWT also has the ability to investigate hot gas reingestion of advanced short takeoff and vertical landing (STOVL) concepts.

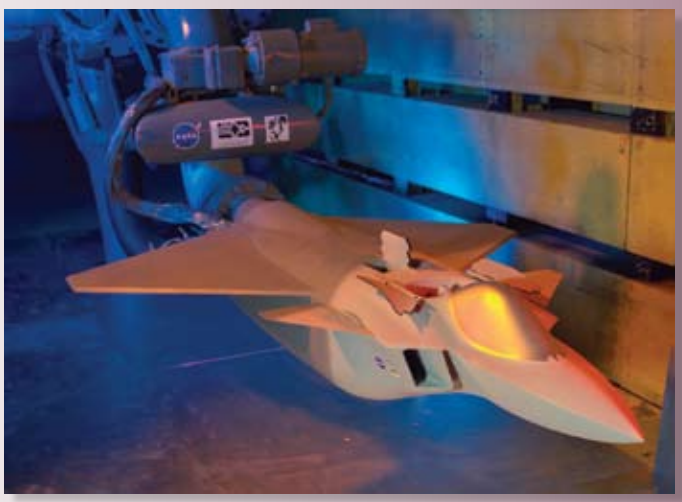
Support systems include steady-state and dynamic data acquisition systems with real-time data displays, infrared imaging, sheet lasers, Laser Doppler Velocimetry, pressure- and temperature-sensitive paint, heated high-pressure air, exhaust, and hydraulics.

The 9×15 LSWT has supported research on a variety of commercial aircraft propulsion systems, the High-Speed Research program, the Joint Strike Fighter program, and other military STOVL aircraft applications.



STOVL hot gas ingestion model

Rotor-alone nacelle system installation



Lockheed Martin inlet/airframe integration model

8- by 6-Foot Supersonic Wind Tunnel (8×6 SWT)

The 8×6 SWT is NASA's only transonic wind tunnel with propulsion test capabilities, providing test section speeds of Mach 0.25 to 2.0.

The 8×6 SWT provides researchers the opportunity to explore the subsonic, transonic, and supersonic speed range in a calibrated test section. The 8×6 SWT supports research of advanced aircraft concepts and components, engines for high-speed aircraft, and launch vehicle concepts.

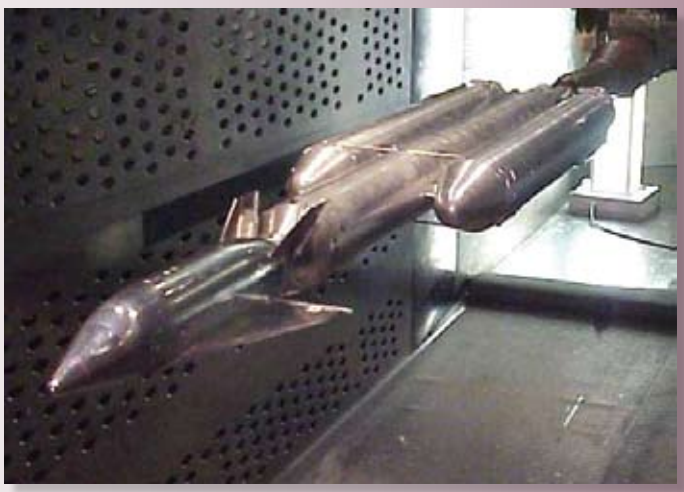
The 8×6 SWT can operate in either an aerodynamic cycle (for testing the aerodynamic performance of components, such as inlets, nozzles, and propellers or integrated systems) or in a propulsion cycle (for testing live engines or propulsion systems). The 8×6 SWT is also equipped to accommodate force and moment scale models.

Support systems include steady-state and dynamic data acquisition systems with real-time displays, heated pressure air, exhaust, pressure- and temperature-sensitive paint, hydraulics, Schlieren, supersonic and transonic strut mounts, and gaseous hydrogen. An assortment of test hardware is available to support our customer's test needs.

With a history of testing that includes the space shuttle, the National Aerospace Plane, and the Joint Strike Fighter, and an active role in support of NASA, DOD, other Government agencies and commercial corporation programs, the 8×6 SWT is prepared to provide technically proficient and cost-effective wind tunnel testing to meet and exceed customer requirements.

Live burning test of National Aerospace Plane nozzle

Joint Strike Fighter model



Space transportation system

10- by 10-Foot Supersonic Wind Tunnel (10×10 SWT)

The 10×10 SWT is the largest wind tunnel at NASA GRC, providing test section speeds of Mach 2.0 to 3.5.

The 10×10 SWT, also called the *Abe Silverstein Supersonic Wind Tunnel,* is the largest wind tunnel at GRC, specifically designed to test supersonic aerodynamic and propulsion components such as inlets and nozzles, integrated propulsion systems, full-scale jet and rocket engines, and launch vehicle concepts.

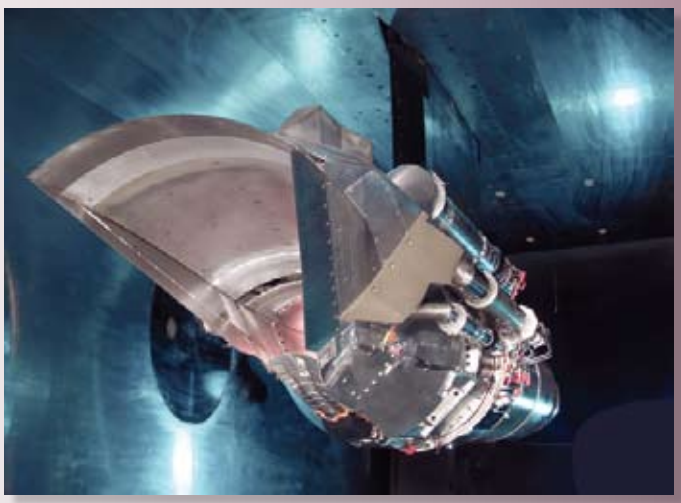
The 10×10 SWT can operate as either a closed-loop (aerodynamic cycle) or open-loop (propulsion cycle) system and can reach test section speeds ranging from Mach 2.0 to 3.5. Recent upgrades allow the facility to operate subsonically from 0 to Mach 0.36. The test section, 10 ft high by 10 ft wide by 40 ft long, can accommodate large-scale models and some full-scale engines and aircraft components. Recent programs have supported a wide variety of test types, from aerodynamic force and moment tests to live burning propulsion system tests.

The 10×10 SWT is supported by steady-state and dynamic data acquisition systems with real-time displays, high-pressure air, exhaust, hydraulics, liquid jet fuels, and gaseous hydrogen and oxygen. An assortment of test hardware is available to support our customer's test needs. Advanced optical instrumentation such as standard focused Schlieren systems, sheet lasers, pressure- and temperature-sensitive paint, high-speed video, and partial image velocimetry (PIV) are also employed.

The 10×10 SWT has contributed to fundamental aeropropulsion technology research and vehicle-focused research programs such as the space shuttle, the High-Speed Civil Transport, and the National Aerospace Plane (NASP) and Joint Strike Fighter (JSF). It continues to contribute in areas such as sonic boom mitigation, propulsion system and component evaluation, engine and airframe integration, launch vehicle systems, and entry, descent, and landing technical development for parachutes and inflatable decelerators.

NASA Glenn/NASA Langley load-comparison tests

Rocket-Based Combined-Cycle (RBCC) test



Parametric Inlet test

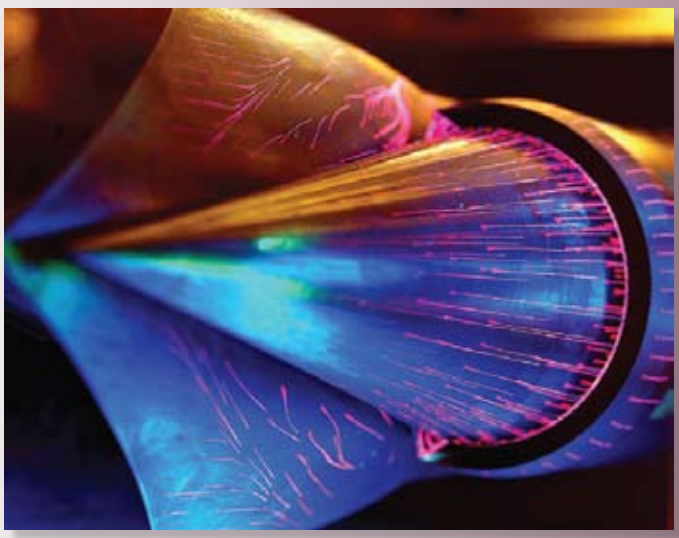
1- by 1-Foot Supersonic Wind Tunnel (1×1 SWT)

The 1×1 SWT is an excellent low-cost testing tool for small-scale research, simulating speeds ranging from Mach 1.3 to 6.0.

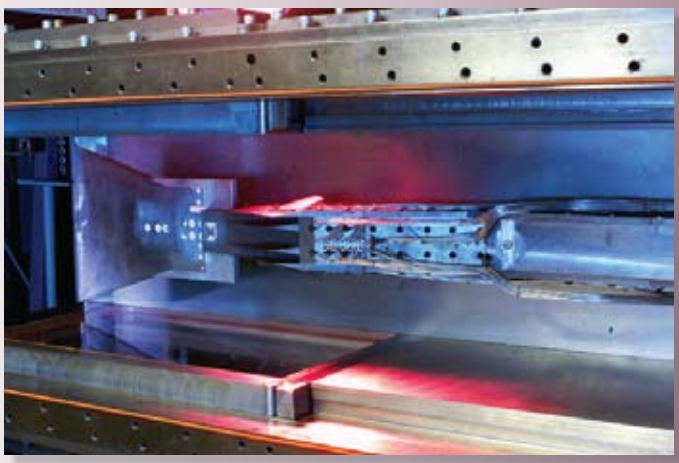
The 1×1 SWT specializes in conducting fundamental research in supersonic and hypersonic fluid mechanics, supersonic-vehicle-focused research, and detailed benchmark-quality experiments for computational fluid dynamic code validation. With the facilities unique capabilities, expert staff, and efficiency the 1×1 SWT offers the supersonic research community an excellent low-cost testing tool for small-scale research.

The 1×1 SWT can provide continuous tunnel operation at 10 discrete airspeeds between Mach 1.3 and 6.0. One of the biggest advantages of testing in the 1×1 SWT is that researchers can conduct early proof-of-concept tests; if an outcome is promising, they can scale up their models for testing in larger tunnels, thus avoiding the immediate cost of full-scale modeling and testing. Another advantage is the up-close viewing of conditions in the tunnel. Test articles can be mounted on any of the four walls of the test section, which can be configured to provide a variety of instrumented plates and optical-quality glass panels.

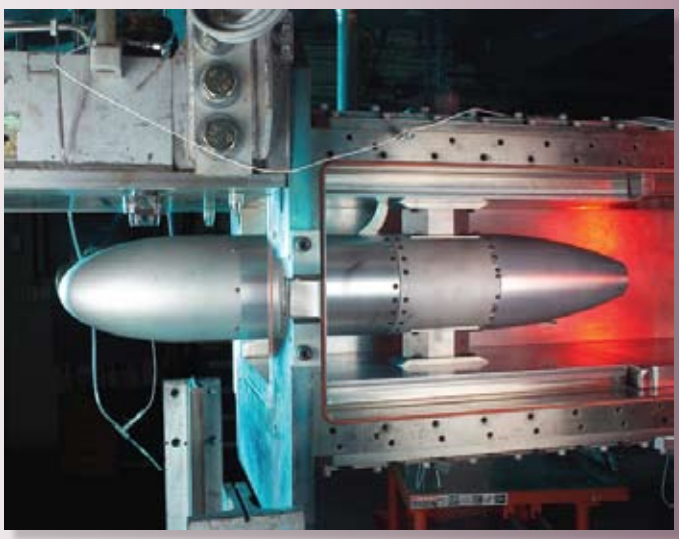
Specialized support systems are available such as exhaust, high-pressure air, model hydraulics, and probe actuation systems. Flow can be visualized with the use of Schlieren, a sheet-laser system, or blue Zyglo and black lights. Quantitative flow-field measurements can be made with a two-component laser Doppler velocimeter.



Oil flow visualization on the GTX inlet test rig



Integrated System Test of Air-Breathing Rocket (ISTAR) inlet testing



Pulsed ejector wave propagation test rig

Hypersonic Tunnel Facility (HTF)

The HTF tests large-scale hypersonic air-breathing propulsion systems.

Originally designed to test nuclear thermal rocket nozzles, the HTF located at Glenn's Plum Brook Station is a hypersonic (Mach 5, 6, and 7) blow-down, nonvitiated (clean air) wind tunnel capable of testing large-scale propulsion systems at true enthalpy flight conditions. Located on 6,400 acres, the test site has a generous exclusion zone that allows for high-energy, high-risk testing.

HTF testing in direct-connect mode

The HTF contains a large experimental infrastructure that can be readily configured to meet a variety of ground test applications including megawatt-level thermal heating, cooling, and electrical systems and large-capacity gas storage. Enhancements to provide direct-connect testing of large-scale combustors at hypersonic flow conditions are underway. Test articles can experience multiple gas flow inputs up to 220 lb/sec at temperatures and pressures up to 3,600 R and 1,200 psig and altitude conditions up to 120,000 ft.

Hypersonic testing

The HTF is equipped to test large-scale propulsion systems and flight-rated structures at hypersonic conditions. The primary performance differentiator between the HTF and other hypersonic facilities is that it uses nonvitiated (clean air) flow whereas traditional hypersonic facilities utilize a combustion process to generate high enthalpy conditions required to simulate hypersonic flows. The HTF generates these conditions by flowing clean nitrogen gas through a 3-MW graphite core storage heater. This heated nitrogen is then mixed with ambient temperature oxygen and ambient temperature nitrogen to yield a flow of synthetic (true composition) clean air at the requisite stagnation temperature. A single-stage steam ejector is used to exhaust the facility flow and provide altitude simulation. Propulsion testing in a facility with nonvitiated (clean air) flow most closely represents the actual flight conditions and minimizes potential errors between ground test results and true flight performance.

The facility is also unique due to its large scale. The test section can accommodate test articles that are up to 14 feet in length. The facility's size along with its long run duration allow for full systems testing of large-scale flight-rated structures and propulsion systems. This ability to test near full-scale systems minimizes the potential scaling errors associated with ground testing at hypersonic conditions. In addition, the HTF contains the Agency's only large-scale nonreacting heater core that could be used in the development of future nuclear thermal propulsion systems. This 3-MW heater is fully operational and is staffed by a crew that is fully trained in its use and operation. The facility has an additional 10 MW of power available at the site to meet any other high-energy testing requirements.

Flight Research

The Flight Research Building is home to many unique and innovative aircraft, including the Learjet Model 25, the S–3B, the T–34C, and the Twin Otter.

NASA GRC uses a high-performance *Learjet Model 25* as an economic testbed for a wide variety of remote-sensing applications and other diverse technologies. The Learjet is capable of carrying up to four researchers 1,200 miles at an altitude of 45,000 ft while traveling at 0.80 Mach. The aircraft has been extensively modified to support numerous research programs and has viewing ports on both sides, as well as a 22- by 19-in. downward-looking nadir port and two zenith ports.

NASA GRC's extensively modified *DeHaviland DHC–6 Twin Otter* is primarily used by programs interested in flying below 16,000 ft at speeds below 140 knots. This aircraft has hard points on both wings and numerous openings to mount instruments and can be flown with the aft doors off to allow a 4- by 4-ft outside view from the cabin.

The *S–3B Viking* was built as a carrier-based anti-submarine platform. The S–3B is perfectly suited for long-range missions down low and slow, but is also capable up to 40,000 ft and speeds up to 0.79 Mach. It has heated bomb-bays that can be opened in flight, various instrument mounting locations, and two wing-mounted hard points.

The *T–34C Mentor* is an inexpensive platform, which is well suited to carry small instrument packages over 500 nautical miles up to an altitude of 25,000 ft. The aircraft has an internal downward-looking nadir port, which has been used to fly a small hyper-spectral imager. It is the platform of choice for those looking to quickly fly and prove their unmanned aerial vehicle (UAV)-sized instruments in the Federal Aviation Administration (FAA)-controlled airspace. *Detailed aircraft information is available on page 42.*

Learjet Model 25 aircraft

DeHaviland DHC–6 Twin Otter aircraft

S–3B Viking aircraft

T–34C Mentor aircraft

Microgravity

For over 40 years, GRC has played a major role in planning, directing, and implementing space experiments in technology and microgravity science. The focus of microgravity research is to conduct scientific and technology development studies to enhance the understanding of the role of gravity on physical phenomena including combustion, fluid physics, material science, biotechnology, etc., enabling new technology for future space missions and expanding our scientific knowledge for terrestrial applications.

Microgravity, a condition of relative near weightlessness, can only be achieved on Earth by putting an object in a state of free fall. Drop towers and aircraft, flying a parabolic trajectory, are used by NASA to create microgravity environments lasting from 2.2 to 22 sec. One of the most significant and substantial areas of microgravity includes the design, buildup, testing, and integration of hardware for long-duration experiments to be conducted aboard the International Space Station. The success of many of NASA's space flight experiments is due in part to the ability to test space experiment concepts and hardware here on Earth in the 2.2-Second Drop Tower and Zero Gravity Research Facility. *Detailed facility test capabilities information is available on page 43.*

2.2-Second Drop Tower

One of NASA's most heavily utilized microgravity facilities is the 2.2-Second Drop Tower. It provides 2.2 sec of low gravity as the experiment hardware is allowed to free fall a distance of 24 m, before it is safely stopped in an airbag. Due to the simplicity of this facility, up to 12 drops per day can be conducted at an extremely low cost. Experiments measuring 96 by 84 by 40 cm and weighing up to 159 kg can be accommodated in the 2.2-Second Drop Tower. Properly designed drop tower experiment packages can also be integrated into the Zero Gravity Research Facility drop vehicles or flown aboard NASA low-gravity aircraft, should additional low gravity time be required. The drop tower is used to study combustion, fluid physics, and biotechnology phenomena in low gravity. This research has applications in spacecraft fire safety, materials flammability, fire detection and suppression, propellant management, and space medical devices. The facility has supported the development of space experiments for the Apollo program, space shuttle, and International Space Station. Among the first tests ever conducted at the 2.2-Second Drop Tower were fluid physics experiment supporting the Apollo space program.

Downward view

Drag shield installation

General purpose combustion rig

Zero Gravity Research Facility (Zero-G)

The Zero-G Research Facility is the largest facility of its kind in the world and continues to be the Nation's most modern research tool for exploring weightlessness or microgravity, here on Earth.

The Zero-G is NASA's premier facility for conducting ground-based microgravity research. Operational since 1966, it is one of two drop towers located at NASA GRC. The facility was built during the Space Race Era of the 1960s and was originally built to support research and development of space flight components and fluid systems in a weightless or microgravity environment. Today, the facility is used by investigators from around the world to study the effects of microgravity on physical phenomena such as combustion, fluid physics, biotechnology, and materials science.

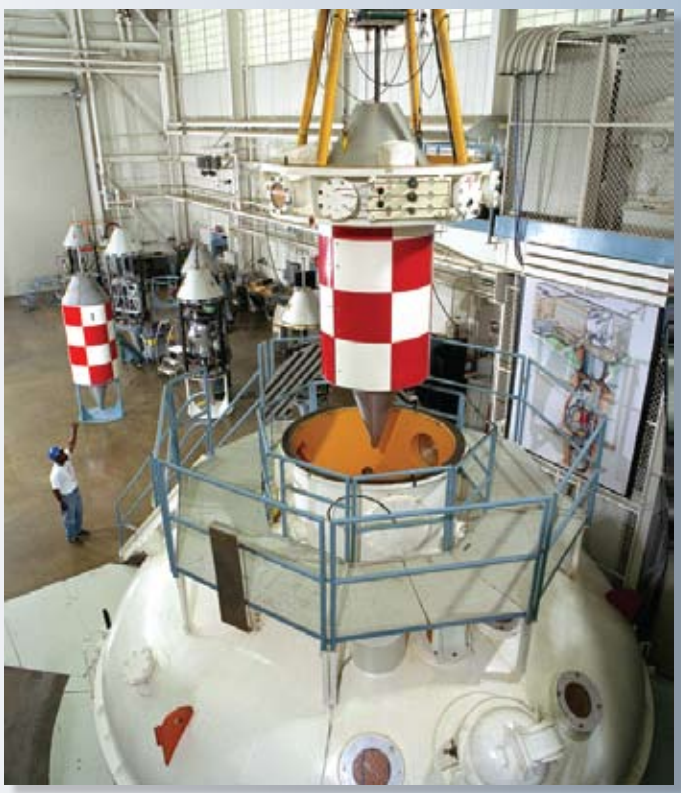
Microgravity, a condition of relative near weightlessness, can only be achieved on Earth by putting an object in a state of free fall. In the Zero-G, experiments free fall 132 m and are weightless for 5.18 sec during the fall. The free fall is conducted inside of a 143-m steel vacuum chamber. Evacuating the chamber to a pressure of 0.01 torr reduces the acceleration, due to aerodynamic drag, on the freely falling experiment vehicle to less than 0.00001 g.

A variety of tests are performed in the Zero-G including

- Fundamental scientific studies of combustion, fluid physics, biotechnology, and material science
- Feasibility of experiment concepts proposed for long-duration microgravity experiments
- Development and testing of International Space Station experiment hardware
- Deployment of hardware during free fall in a vacuum environment

NASA GRC plays a major role in planning, directing, and implementing space experiments in technology and microgravity science. The Zero-G allows experimenters to quickly perform microgravity research, test space experiment concepts, and develop space flight hardware at a small fraction of the cost of conducting these tests in space.

Retrieving a drop vehicle after a test



Positioning drop vehicle on top of the vacuum chamber

Chemical Propulsion and Propellant Handling

Chemical propulsion has provided the heavy lifting required for NASA to travel into space. Whether it is to reach Earth orbit, to escape the gravitational pull of the Moon, or to lift a manned vehicle into low Earth orbit, chemical propulsion has provided the thrust required. As NASA pursues new space exploration initiatives, the development of new technologies are required. Propellants with higher energy densities, zero cryogenic propellant boiloff for extended interplanetary missions, production of in situ propellants for return trips from Mars, materials that can endure high temperatures with less weight, and demonstration of chemical rockets under deep space conditions are just a sampling of the issues that GRC's personnel and facilities are prepared to address. Detailed facility test capabilities information is available on pages 44 and 45.

The Spacecraft Propulsion Research Facility (B–2) offers a complete "test-as-you-fly" environment to thoroughly ground test flight hardware and reduce the likelihood of costly in-flight failures.

The Research Combustion Laboratory (RCL) Altitude Combustion Stand (ACS), Small Multi-Purpose Research Facility (SMiRF), and the Cryogenic Test Complex (CTC) have been influential in supporting the space industry by collaborating with NASA and engine research partners to develop and research safer propellants for future space missions.

Research Combustion Laboratory

Altitude Combustion Stand

Spacecraft Propulsion Research Facility

Small Multi-Purpose Research Facility

Spacecraft Propulsion Research Facility (B–2)

The B–2 offers a complete "test-as-you-fly" environment to thoroughly ground test flight hardware and reduce the likelihood of costly in-flight failures.

NASA's B–2 is the world's only facility capable of testing full-scale upper-stage launch vehicles and rocket engines under simulated high-altitude conditions. The engines or vehicle can be exposed for indefinite periods to low ambient pressures, low background temperatures, and dynamic solar heating, simulating the environment the hardware will encounter during orbital or interplanetary travel. Vehicle engine systems producing up to 100,000 lb of thrust can be fired for either single or multiple burn missions, utilizing either cryogenic or storable fuels or oxidizers. The facility infrastructure is capable of being modified to test engine systems that can produce 400,000 lb of thrust. Engine exhaust conditions can be controlled to simulate a launch ascent profile. In addition, altitude conditions can be maintained before, during, and after the test firing.

The B–2 also serves as a standalone thermal/vacuum test facility. It represents the Agency's third largest space environment simulation test facility and as such has been used to test a variety of large space hardware. The versatile 38- by 62-ft chamber provides a maximum test specimen envelope of 33 ft in diameter and 55 ft in height. It is capable of maintaining 10^{-7} torr pressures using ten 35-in. diffusion pumps backed by Roots blowers and Stokes mechanical pumps. A copper cryoshroud lines the inner surfaces of the chamber and provides 1.2 MW of heat rejection. Convenient access to the chamber is through a 27-ft-diameter top port, along with two personnel doors at lower levels in the facility.

The B–2 has performed tests on equipment such as small research engines, high-altitude balloon payloads, Mars rover airbag balloon landing and deployment systems, and spacecraft photovoltaic arrays. The B–2 facility is located at NASA's Plum Brook Station in Sandusky, Ohio.

McDonnell Douglas Delta 3 Rocket Engine test

Flight Solar Panel test

Research Combustion Laboratory (RCL)

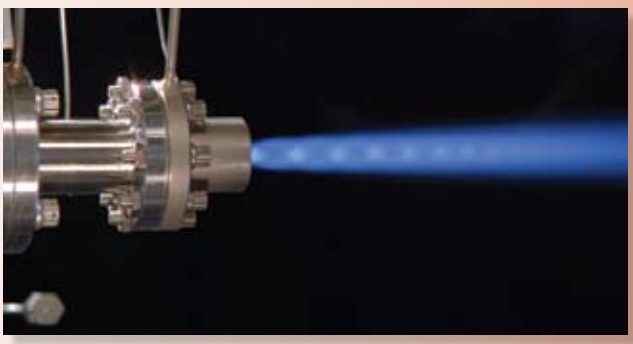
The RCL develops advanced propulsion concepts and evaluates safer propellants for launch vehicles and spacecraft thrusters and advanced ignition systems for next-generation launch vehicles.

The RCL consists of a suite of flexible test cells, including five sea-level combustion stands, three altitude combustion stands, the *Heated Tube Facility* (HTF) for studying heat transfer properties of fuels, and two test cells for studying advanced fuel cells. The RCL provides a safe environment for testing aviation and chemical rocket propellants, including liquid and gaseous hydrogen, oxygen, and methane- and kerosene-based fuels.

A variety of tests are performed in the RCL including altitude performance testing, chemical rocket ignition systems, high-temperature thermal testing, sea-level testing of chemical rocket engine components, fuel cell and electrolyzer components, and regenerative fuel cell systems. The RCL has evaluated safer propellants for space shuttle thrusters, ignition systems for next-generation launch vehicles, and lightweight high-temperature materials for aeronautics and space applications.

The *Small Multi-Purpose Research Facility* (SMiRF) evaluates the performance of the thermal protection systems required to provide long-term storage (up to 10 years) of cryogenic propellants in space. The SMiRF provides the ability to simulate space, high altitudes, and launch pressure environments; conduct calorimetry tests on prototype insulation systems; and safely handle gaseous and cryogenic propellants. The SMiRF features a 72- by 100-in. diffusion-pumped high-vacuum chamber with a cold wall capable of simulating the thermal cycle of a lunar day. The facility's pumping system is augmented with mechanical pumps that are capable of matching a launch pressure profile.

The *Altitude Combustion Stand* (ACS) facility provides a system to test combustion components at a simulated altitude. The facility is equipped with an axial thrust stand, gaseous and cryogenic liquid propellant feed systems, water-cooled diffuser, data acquisition system, facility control system, spray cooler, and multistage vacuum ejector systems. Construction of this facility was completed in 2008 and engine testing began in 2009. The facility can accommodate engines from up to 2,000 lb force thrust and combustion chamber pressure to 1,000 psia. Depending on the size, engines can be fired at sea level or into a test tank that is evacuated to a simulated altitude up to 110,000 ft.



Flametube test (RCL—Cell 21)

Cooled-panel nozzle extension test (RCL—Cell 22)

Cryocooler preparation for zero boiloff test (SMiRF)

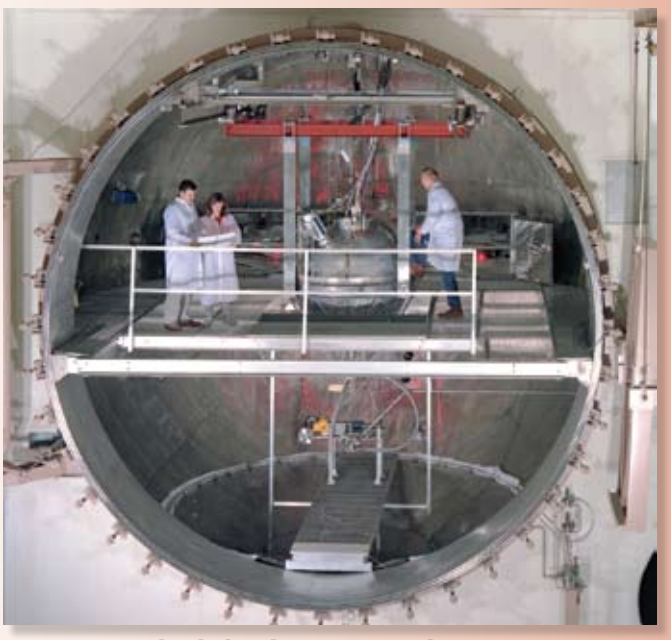
Altitude Combustion Stand test

Cryogenic Test Complex (CTC)

The CTC supports research of cryogenic propellants and is a testbed for mechanical equipment with cryogenic propellants. Propellant densification and condition of cryogenic propellants is also a focus.

Cryogenic Test Complex

The CTC encompasses the vacuum chamber of the Cryogenic Propellant Tank Research Facility (K-Site), as well as a new state-of-the-art Cryogenic Component Laboratory (CCL) for research, development, and qualification of cryogenic materials, components, and systems. CTC buildings and systems are ideally suited for high-energy, high-risk research on cryogenic systems utilizing liquid hydrogen, oxygen, and nitrogen. Testing includes chilldown: seal, bearing, and turbopump tests; fluid densification; and thermal-vacuum testing of spacecraft subsystems, sensors, probes, tanks, and insulation. The CTC is located at Glenn Research Center's Plum Brook Station in Sandusky, Ohio.



Slush hydrogen production

The K-Site is a 25-ft-diameter high vacuum space environment test chamber with a 20-ft-diameter door. The design and construction of this facility allows large-scale liquid hydrogen (LH_2) experiments to be conducted safely. Control and data systems are located in a separate remote building, and electrical control systems include explosion-proof hardware. K-Site also features a removable LH_2/LN_2 cryogenic cold wall, which can simulate deep space temperatures down to –423 °F; vacuum-jacketed LH_2 piping and chamber penetrations; a hydraulic shaker system; and a vacuum-jacketed LH_2 dump line and burnoff stack to handle accidental LH_2 spills inside the chamber. K-Site plays an essential role in the development of advanced insulation systems and on-orbit fluid transfer techniques for flight-weight cryogenic fuel tanks and insulation systems. The facility also includes an 800-gal slush hydrogen batch production plant and a 200-gal small-scale propellant densification system.

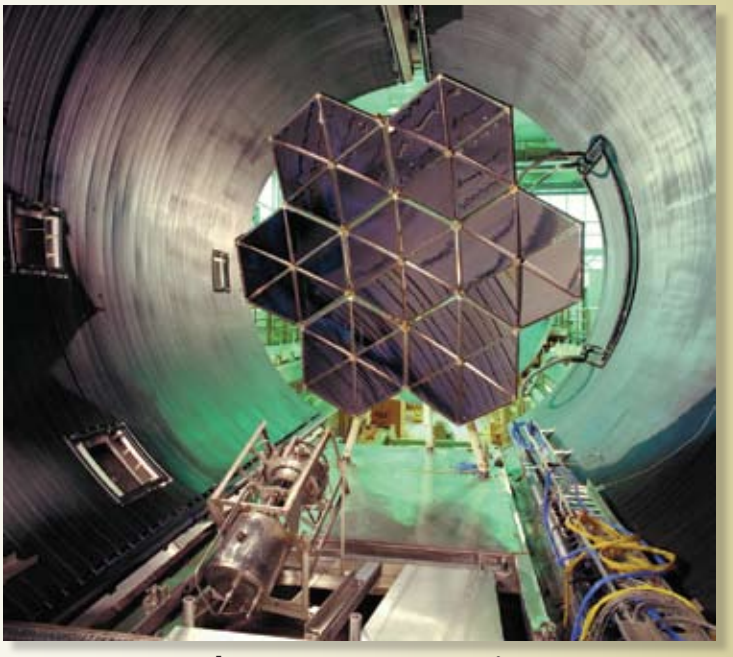
CCLs include test cells with extensive LH_2 and liquid oxygen (LOx) handling capabilities. Two test cells support small-scale testing of turbomachinery components such as bearings, seals, and related equipment under cryogenic operating conditions. Cell 1 is designed to provide LOx or LH_2 at conditions up to 1,250 psig and 75 gpm by means of multiple-stage cryogenic pumps. The pumps are fed from a 3,000-gal supply dewar. Cell 2 is designed to provide LH_2 from a 1,300-gal dewar at pressures up to 1,250 psi. The CCL also provides capabilities for the densification and conditioning of cryogenic propellants. All test activities at the CCL are conducted from a remote 7,500-sq-ft control room equipped with high-speed data acquisition system. The CCL is supported by an extensive infrastructure of both liquid and gaseous storage of hydrogen, oxygen, nitrogen, and helium.

Electric Power and Propulsion

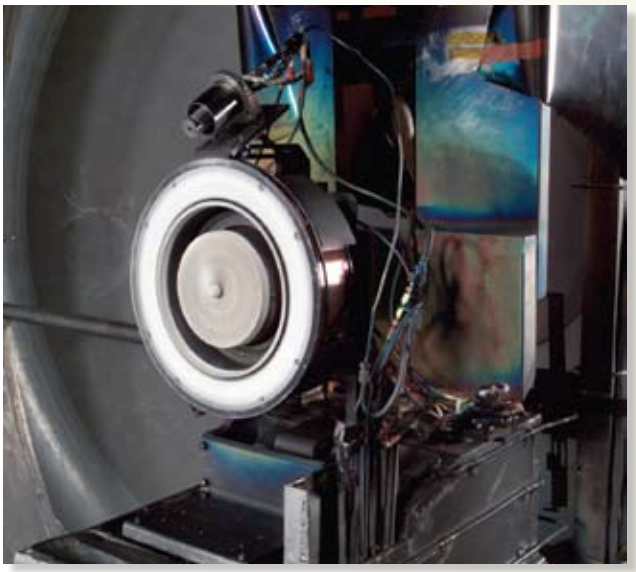
To fulfill the Nation's desire to investigate the heavens and conduct operations in space, NASA must develop technologies that operate under the unique environment of space. Loss of atmosphere, temperature extremes, space plasma, and atomic oxygen degradation are just some of the unique attributes of space, which must be considered in the design and development of spacecraft. GRC has a suite of facilities that are prepared to address these concerns, including the Space Power Facility (SPF), Electric Propulsion Laboratory (EPL), and the Electric Propulsion Research Building (EPRB).

Although no facility can fully simulate all the conditions of space, GRC's facilities can tackle challenges such as simulating the landing of a Mars rover; developing new power and propulsion technologies for interplanetary and other planetary travel; validating ISS flight hardware; or qualifying an upper-stage thruster for delivering satellites into geosynchronous orbits by replicating specific attributes of space. GRC maintains 23 thermal vacuum facilities with diameters greater than 3 ft. Thermal vacuum facilities principally focus on the space environmental effects from the loss of atmosphere and temperature extremes. Detailed facility test capabilities information is available on page 46.

Ion engine test



Solar concentrator testing



Hall thruster testing

Solar sail test in SPF

Electric Propulsion Laboratory (EPL)

The EPL develops and tests spacecraft power and propulsion technologies for space missions that enable NASA to conduct presently nonviable planetary missions and provide the space community with less costly, more effective orbital space missions.

The EPL features two very large space environment simulation chambers (VF–5 and VF–6); 10 intermediate simulation chambers that are suitable for testing subassemblies or components; several bell jars for development and testing of small-scale components; and support areas including an electronics shop, machine shop, clean room, and office space.

The EPL's space simulation chambers have been enhanced to support the unique requirements of electric propulsion and power system testing. VF–5 is the leading testbed for electric propulsion. VF–5's vacuum pumping system can pump condensible gases (3.5 million liters/sec) with its 40.0 m^2 of 20 K helium cryopanels or noncondensible gases (250,000 liters/sec) using baffled, cryotrapped diffusion pumps.

VF–6 supports a diverse range of space simulation environmental testing. A solar simulator provides 1.2 solar constants on a 5-m-diameter target or 11 solar constants on a 30-cm target with a low subtense angle specifically designed to support solar concentrator testing. A liquid nitrogen cold shroud simulates the cold temperatures of space. Its 900,000 liter/sec pumping speed, and 25 ft diameter by 70 ft length and unique thermal capabilities supports a large variety of testing.

Several of the chambers have multiple air-locked access ports. These ports allow several tests to be conducted simultaneously in each chamber without cycling the chamber back to atmospheric pressure during introduction or removal of test hardware. Portable, task-specific shrouds are available for both VF–5 and VF–6. Conditioned direct current (dc) power is supplied to VF–5, VF–6, and VF–12 for powering ion, Hall, and magnetoplasmadynamic (MPD) thrusters. All thermal vacuum facilities run autonomously.

NEXT ion engine test

VF–6 solar simulator

VF–5 test chamber

Electric Propulsion Research Building (EPRB)

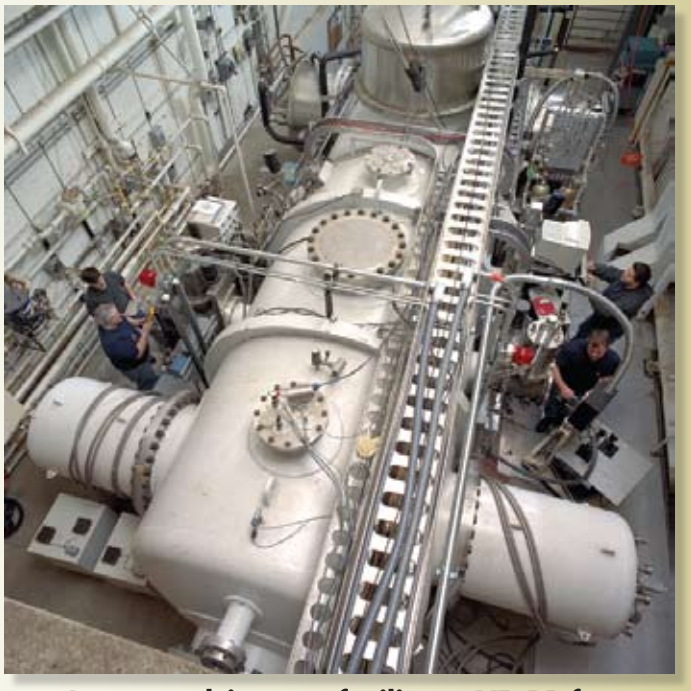
The EPRB works in synergy with NASA GRC's world-class facilities by developing and validating electric propulsion technologies at the component and conceptual levels.

The research cornerstone of the EPRB is its suite of space simulation chambers. EPRB chambers, ranging in size from benchtop bell jars to 3-m-diameter tanks, are equipped with various pumping systems (cryopumps, diffusion pumps, oil-free pumping trains, and high-throughput Roots blowers), depending upon the specific requirements of a test program.

Facilities of particular note are VF–11 and VF–16 ion engine testbeds; VF–1 250-kJ capacitor bank, which is especially suited for conducting fundamental research on high-powered thrusters such as the MPD thruster; VF–9's capability to produce atomic oxygen; and VF–7, which is surrounded by 1-ft-thick concrete. VF–7 is an excellent testbed for conducting research where safety is a concern, such as research on thrusters using hydrogen as a propellant or thrusters that produce plasmas through radiofrequency generation.

In addition, the EPRB has over 20,000 sq ft of specialty labs and buildup and machine shop areas. The EPRB works synergistically with other larger vacuum facilities located at GRC. Research that is initiated in the EPRB on the concept or component level often leads to higher fidelity tests in facilities such as VF–5 (very high pumping speed), VF–6 (unique in its solar simulator capabilities and electric propulsion features), or the Space Power Facility (SPF) (the world's largest vacuum chamber). This process ensures that these world-class facilities are effectively utilized and that research is done in the most cost-effective manner possible.

Thermal vacuum environmental testbed at VF–10



Ion propulsion test facility at VF–11 for developmental tests

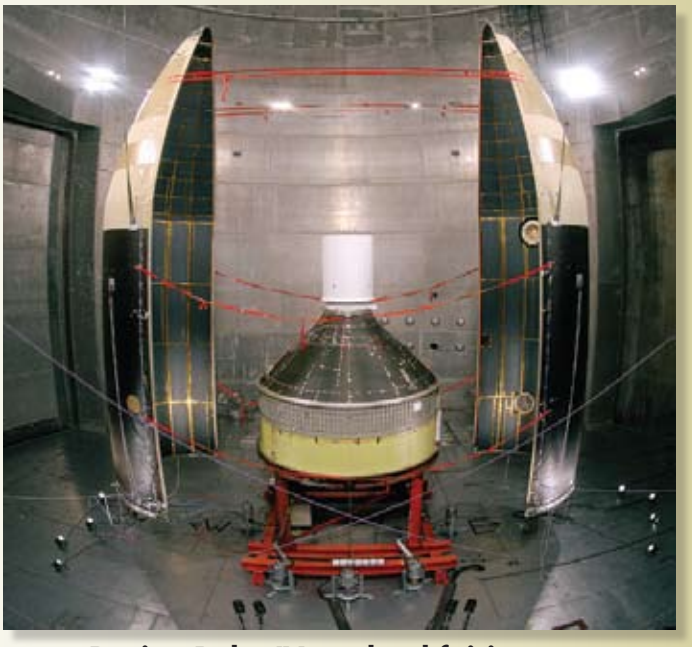
Space Power Facility (SPF)

The SPF, the world's largest space environmental simulation chamber, provides the capability to test large spacecraft in a thermal vacuum environment. Due to its unique size and capabilities, SPF has frequently been the only viable test facility for not only national programs but also international customers.

The SPF houses a 100-ft-diameter by 122-ft-high thermal vacuum chamber. The SPF was designed and constructed to test both nuclear and nonnuclear space hardware in a simulated space environment; however, only nonnuclear tests have been performed throughout its history. The vacuum chamber can sustain high vacuum (10^{-6} torr) with either ten 48-inch diameter cryopumps with vacuum isolation valves or sixteen 48-inch diffusion pumps with liquid-nitrogen-cooled-baffles. The thermal environment can be provided with test-specific cold shrouds, fed by either liquid nitrogen or by a variable temperature (–250 °F to ambient) gaseous nitrogen recirculating system; a 4-MW quartz heat lamp array; and a 400-kW solar arc lamp.

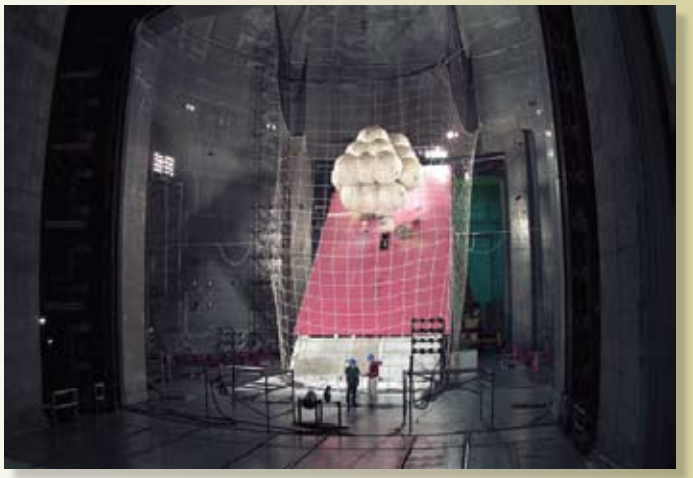
The SPF's ability to handle large equipment is supported by a 20-ton crane installed inside the vacuum chamber, two adjacent 150- by 75-ft high bay areas augmented with 25-ton bridge cranes, and two 50- by 50-ft doors leading directly into the chamber from the individual high bay areas. The chamber floor is designed to withstand a load of 300 tons.

As a result of its size, the SPF has been the facility of choice for several test programs, including high-energy experiments, rocket-faring separation tests, Mars lander system tests, and International Space Station hardware tests. The SPF is located at NASA GRC's Plum Brook Station in Sandusky, Ohio.



Boeing Delta IV payload fairing test

ISS radiator deployment test



Mars exploration rover landing system test

Power Systems Facility (PSF)

The PSF provides an exceptional platform to not only test and verify today's space power systems, but also to design, develop, and test components and systems for new technologies.

The PSF supports the design, development, assembly, and testing of space power components and systems that include the International Space Station, satellites, next-generation launch vehicles, and space-based power systems. The PSF houses testbeds where experienced scientists and engineers verify critical concepts, test prototype hardware and software, and validate systems in real-time simulations under actual loading and operating conditions. Testing capabilities include flywheel systems and components, battery systems, fuel cells, alternating current (ac) power sources, electrical actuators, and power management and distribution hardware and software.

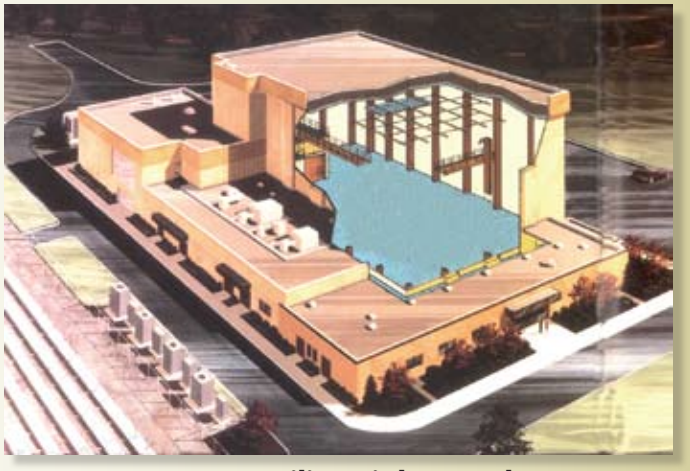
The PSF provides a 5,000-sq-ft, class100,000 clean room. This 60-ft high bay area is also clean room capable. A series of trenches provide the means to easily connect the various test areas in order to support system-level testing of large power systems. Two test cells are surrounded by blast-resistant walls for supporting high-energy testing. An underground spin pit provides high-speed flywheel capability. A 1,600-sq-ft raised floor area provides a laboratory environment to support power management and distribution systems development.

The Constellation Electrical Power Laboratory is used to develop and test the Orion and other spacecraft power systems. The Ares Thrust Vector Control Laboratory (TVC Lab) provides developmental test data supporting the design of the Ares vehicle thrust vector control system.

The TVC Lab contains a one-axis and a two-axis test stand. The one-axis stand supports the testing of a single steering actuator in a computer-controlled kinematic load environment. The one-axis stand can accommodate a wide variety of actuators and be programmed to replicate the flight dynamics of various vehicles. The two-axis stand duplicates the Ares-I Upper Stage Main Propulsion Module.

Constellation Electrical Power Laboratory

Ares Thrust Vector Control Laboratory



Power Systems Facility High Bay Clean Room

The Telescience Support Center (TSC) is also located in the PSF. The TSC is a facility that provides the capability to execute ground support operations of on-orbit International Space Station (ISS) payloads and other space missions. TSC capabilities are provided in coordination with the Marshall Space Flight Center (MSFC) Payload Operations and Integration Center (POIC), the Johnson Space Center (JSC) Mission Control Center in Houston (MCC–H), and other remote ground control facilities.

Fuel Cell Test Facilities

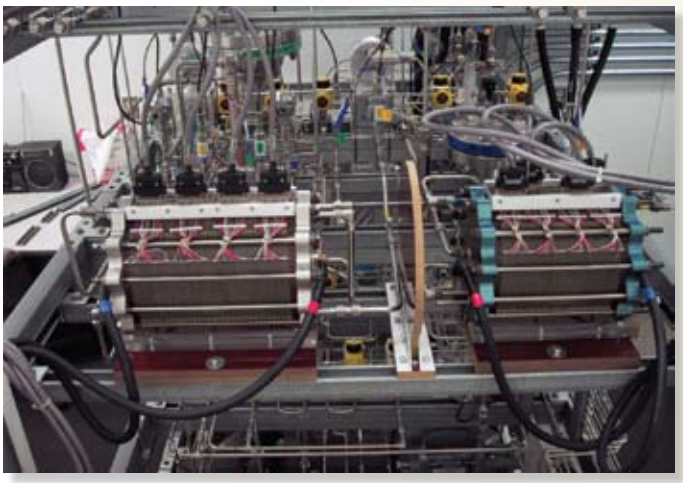
Several test laboratories at the GRC support fuel cell research for space and aeronautics applications. Research focuses primarily on hydrogen/oxygen and hydrogen/air fuel cells.

Fuel Cells Test Laboratory

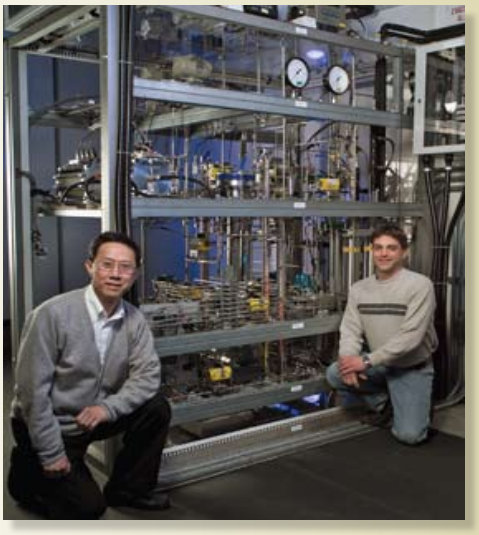
Building 334 control room

The Fuel Cells Test Laboratory, located in building 334, is the most recent addition to these capabilities. The building contains three test cells supplied with hydrogen, oxygen, and nitrogen gases from 2,400 psig tube trailers. In addition, a compressed air system provides 190 psig of air to support air/hydrogen fuel cell tests. The test cells are designed as class I, division 2 hazardous locations for hydrogen uses and are operated from a common remote control room. Each cell can support fuel cell tests at power levels up to 125 kW. Continuous, long-duration testing lasting for several days can be performed. A programmable logic controller (PLC)-based control system monitors and controls test operation, and a LabView®-based data acquisition system records system parameters several times per second.

The Regenerative Fuel Cell Test Rig, located in building 135, is a closed-loop system designed to study energy storage and power generation using an electrolyzer to generate hydrogen and oxygen from water and a fuel cell to recombine the gases and generate power. Applications might ultimately include high-altitude, solar-powered aircraft for Earth observation, reconnaissance, and telecommunications. The facility has the capability to simulate complete day/night power cycles with a 5-kW hydrogen/oxygen PEM (proton exchange membrane) fuel cell and a 15-kW PEM electrolyzer. Supporting tests for fuel cell and electrolyzer components used in the regenerative rig are conducted in cell 24C of the Research Combustion Laboratory (RCL).



Fuel Cell and Electrolyzer in Regenerative Fuel Cell Rig



Regenerative Fuel Cell test rig

Research and Technology Laboratories

Research and Technology laboratories support a wide range of NASA GRC research and development testing. This section only highlights a few of the areas in materials, structures, communications, and instrumentation and controls.

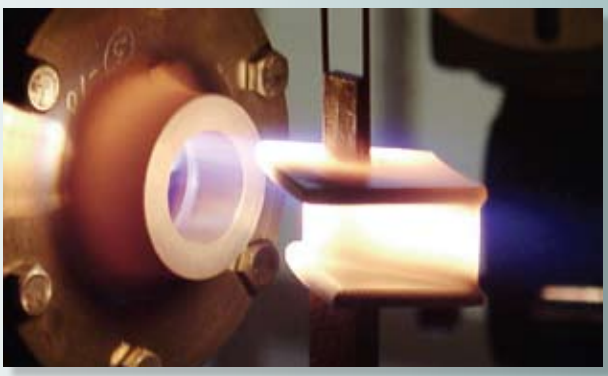
Structures and Materials

NASA GRC provides an extensive variety of laboratories, processing and testing facilities, and advanced characterization capabilities to support both the analytical and experimental studies of advanced aerospace materials and structures to meet the most demanding needs of future aerospace propulsion and power systems. Processing, testing, and characterization facilities for developing new material compositions and evaluating their performance behavior and lifetime versus the application requirements are available for the study of advanced, high-temperature metal, ceramic, and polymeric materials and their composite systems. Developing an understanding of the interrelationships among processing, nanostructure/microstructure, and processing as they pertain to targeted applications are key to advancing the development of all of the material classes studied.

Advanced processing techniques, such as alloy melting, solidification and heat-treating furnaces, hot-isostatic presses, and welding are used for metals development work while various processing laboratories, laser float-zone fiber growth, and fiber winder equipment support the development of structural and functional ceramics and ceramic composite materials. Other specialized equipment is available for polymers synthesis and processing, including such capabilities as prepreg winders, presses, and autoclaves. Testing and characterization equipment is available to evaluate each of the materials types developed. These include multiple test stands for measuring single and multi-axial tensile, creep, and fatigue test equipment to determine mechanical behavior at high temperatures, in air and vacuum, and at varying pressure levels. To determine the material durability in simulated-propulsion and power application environments, the behavior of these advanced materials following exposure to the high temperatures, pressures, high-velocity gaseous environments they must endure, high heat flux lasers, several combustion burner rigs, and plasma spray and physical vapor deposition systems. A large variety of equipment and instrumentation is available to determine the physical properties and characterize the chemical compositions and microstructural properties of advanced materials, along with several other types of specialized materials characterization tools and methods. Examples include field-emission scanning and transmission electron microscopes, atomic force microscope, nuclear magnetic resonance facilities, analytical chemistry and spectroscopy laboratories, a high-temperature mass

Test rig used to evaluate the fatigue properties of research materials

Ballistic impact rig for the study of impact resistance and structural energy absorbing mechanisms



Mach 0.3 burner rig thermal barrier coating test

spectroscopy laboratory, and electrical and optical property measurement equipment.

Facilities to support computational and experimental mechanics of high-temperature monolithic and composite materials, including studies of fatigue and fracture, failure assessment and mechanical and benchmark testing to validate the computational tools developed within the group. Benchmark experimental testing in aeroelasticity, active and passive damping, vibration control, rotor dynamics, ballistic impact mechanics and energy-absorbing structures, and ultra-high power density electric motors are performed. Testing capabilities to evaluate advanced mechanical drive system concepts, gear dynamics and durability, thermal and structural seals for space structures, terramechanics, and lubricants to protect structural materials from friction and wear are in place. Development of validated analytical, computational, and experimental technologies for materials, structures, and mechanical systems helps assure the integrity, durability, and reliability of future aerospace propulsion and power systems.

Communications Technology

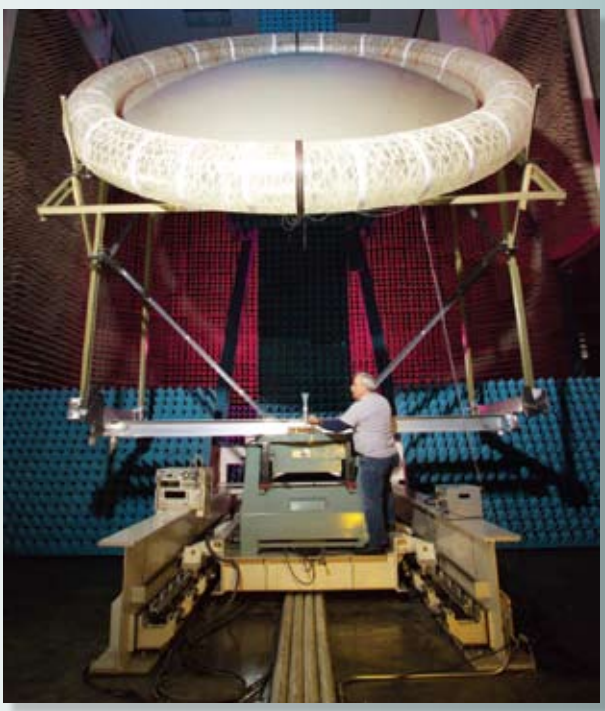
Communications facilities provide capabilities for research and development of advanced space and aeronautical communication concepts, architectures, components, and systems. Advanced research and technology development enables new capabilities for robust, mobile, and high data rate links between spacecraft, aircraft, satellites, and Earth stations. Test facilities and research laboratories for modeling, simulation, design, development, and testing of end-to-end communications systems and networks are available including microwave antenna characterization, high-power traveling wave tube amplifiers, software-defined radios, mobile networking, radiofrequency propagation, cryogenic microwave electronics, secure digital data links, and communication satellite Earth stations.

Instrumentation and Controls

GRC conducts basic and applied research on advanced instrumentation and controls technologies for aerospace propulsion and power applications. Advanced research to enable intelligent systems for aerospace applications includes harsh environment sensors; high-temperature, high-power electronics; microelectromechanical and nanoelectromechanical systems; high data-rate optical instrumentation; active and intelligent control; and health monitoring, diagnostics, and management. These research areas address Agency challenges to develop aerospace systems with reduced size and weight, and increased functionality and intelligence for future NASA missions in aeronautics; economical space transportation; and pioneering space exploration.

Automated eight-spool filament winder supports ceramic matrix composite design

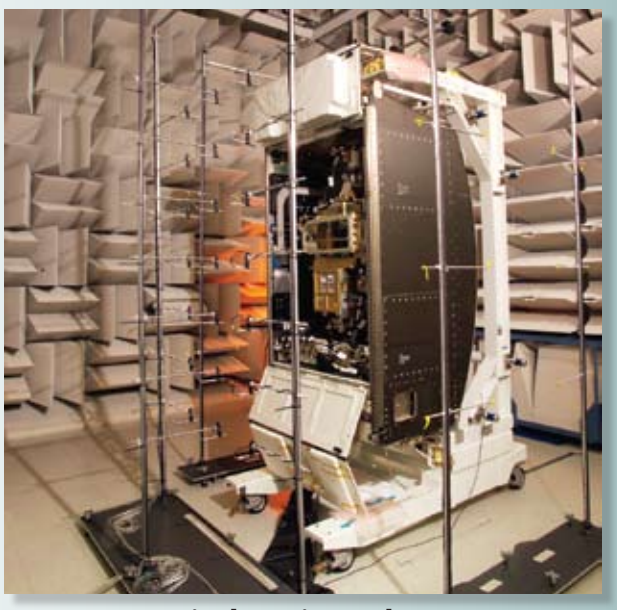
Deep reactive ion etching tool for micromachining of SiC in class 100 clean room



4 × 6 Meter Inflatable Membrane Antennae test in the Near-Field Antenna test facility

Development and Verification Laboratories

Several environmental laboratories provide developmental and verification testing to help developers of space flight hardware meet NASA's requirements that limit emissions and susceptibility to acoustic, structural, and electronic interference.



Acoustical Testing Laboratory

The Acoustical Testing Laboratory (ATL) provides acoustic emission testing and low-noise design services, particularly for space flight hardware that must meet NASA's acoustic emission requirements. A convertible hemianechoic test chamber has interior dimensions of 21 by 17 by 17 ft (high) in anechoic configuration, which provides an ideal environment for developmental testing on small noise source components as well as full-scale verification testing of flight hardware. The ATL's data acquisition system provides real-time one-third octave band and fast Fourier transform (FFT) measurements as well as a variety of specialized diagnostic techniques, including scanning sound intensity. The ATL has been accredited by the National Institute of Standards and Technology.

Fluids and Combustion Facility Combustion Integrated Rack, Ground Integration Unit, Modal Test in SDL

The Structural Dynamics Laboratory (SDL) performs structural dynamic testing to verify the survivability of a component or assembly when exposed to vibration stress screening or a controlled simulation of the actual flight or service vibration environment. Environmental stress screening, or workmanship vibration, is used to identify latent manufacturing defects of components prior to being incorporated into larger assemblies. Vibration testing is also used to verify design margins of assemblies and characterize the internal dynamic responses of a test article.

The Microgravity Emissions Laboratory (MEL) provides testing support for simulation and verification of the International Space Station microgravity environment. The MEL utilizes a low-frequency acceleration measurement system for the characterization of rigid body inertial forces generated by various operating components of the International Space Station (ISS). The facility is unique in that 6-degrees-of-freedom inertial forces can simultaneously be characterized for operating the test article. Vibratory disturbance levels can be measured for engineering or flight-level hardware.

The Electromagnetic Interference (EMI) Laboratory offers several services including analysis of hardware requirements and specification comparisons, consultation during the design and prefabrication phases, electronic component testing, specialized test procedures for unique hardware requirements, intermediate testing as the design progresses, testing of materials for shielding effectiveness, frequency response tests of networks and filters, final qualification testing of experiments in flight configuration, and testing at customer locations for items too large to fit in the EMI Laboratory's shield rooms.

Structural testing is performed to verify the structural integrity of space flight and ground test hardware. Testing in the Structural Static Laboratory (SSL) is also performed to verify the finite element analysis by measuring stiffness and induced stress at points in a test article. A structural test can be used to verify the modes of failure of a design when exposed to simulated service loads. The modes of failure include but are not limited to the following: leak before burst, buckling, ultimate failure, yield, or excessive deflection. The test lab is also outfitted with a tensile test machine that can be used to develop mechanical properties, at up to 1,300 °F, in metallic coupons, composite coupons, adhesive joints, and weld joints. A high-temperature laser extensometer can be used to give accurate strain data tensile testing at elevated temperatures.

Information Technology Laboratories

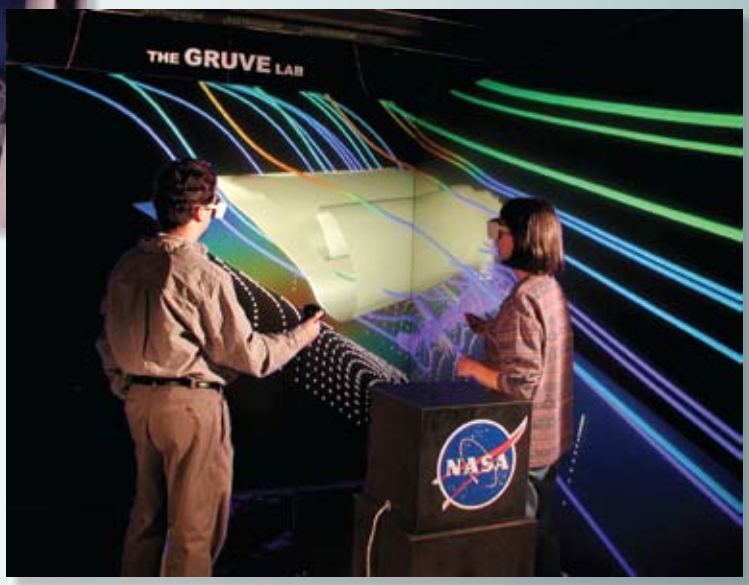
Information Technology Laboratories are developing new ways for researchers to acquire, explore, and analyze data.

The Advanced Computational Concepts Laboratory (ACCL) is a flexible, application-oriented environment for adapting emerging network and computing architectures, and advanced programming techniques, which could enhance future NASA GRC production capabilities. Current efforts involve exploring hybrid computing with graphics processors to accelerate scientific codes, and the integration of discrete workstation clusters to create reconfigurable high-performance computing systems that respond to the changing demands and priorities of various groups and projects.

GRC's Graphic and VISualization (G–VIS) and Glenn Reconfigurable User-interface and Virtual reality Exploration (GRUVE) laboratories are companion facilities that provide advanced computer imaging and scientific visualization services to the NASA research community. The G–VIS lab specializes in developing custom data visualization techniques and houses the latest computer graphics and multimedia technologies and display systems. The GRUVE lab is built around a reconfigurable, fully immersive walk-in virtual reality facility consisting of three large 8- by 8-ft rear-projection screens on which are displayed computer-generated stereoscopic images. Both custom-designed and commercial software provide a wide array of applications to NASA scientists and engineers.

Though the G–VIS and GRUVE labs are used predominantly for analysis of data obtained either by computer simulation or from one of NASA GRC's research test facilities, both labs have served as unique display environments for program advocacy, outreach, and education. In addition, NASA GRC has partnered with various groups in the local community to make these facilities accessible for tasks ranging from medical imaging to digital art.

Advanced Computational Concepts Laboratory (ACCL)



Glenn Reconfigurable User-interface and Virtual reality Exploration (GRUVE) laboratory

Facility Test Capabilities

Central Process System (CPS)

The CPS provides the required pressurized air and exhaust services from two equipment buildings via a complex piping network to the aeropropulsion facilities. The equipment used to create the air pressures, flows, and conditions includes motor-driven compressors, exhausters, turboexpanders, chillers, air dehydrators, cooling tower systems, and various other types of support equipment. The CPS distributes 300,000 hp of energy through over 23,000 ft of piping to the more than 100 test cells located throughout GRC.

Central air equipment building

Operators utilizing the state-of-the-art Central Process System Distributed Control (CPSDC) monitor and control all the systems within the CPS including the high-voltage substations and variable frequency drive systems. Central Control and equipment building staff precisely regulate and monitor the delivery of air services to the test cells where test cell operators fine tune the flows to meet the requirements. The configuration of the CPS allows for a tremendous amount of flexibility and quick response to the changing requirements and customer needs.

System	Building	
	Engine Research	Central Air Equipment
10-psig refrigerated air	One 75-lb/s turboexpander, –70 °F outlet temperature	Three 133-lb/s turboexpander, –90 °F outlet temperature
40-psig combustion air	Two 38-lb/s compressors	Four 120-lb/s compressors
125-psig shop air service	Four 3-lb/s compressors	————
150-psig combustion air	Two 38-lb/s compressors	Two 192-lb/s compressors
450-psig combustion air	Two 38-lb/s compressors	One 38-lb/s compressor
1,250-psig combustion air	One 38-lb/s compressor	————
Altitude exhaust	————	Eight exhausters with flow rates of 520 to 220-lb/s at pressures of 900 to 100 psfa (55,000 ft max. altitude)
Atmospheric exhaust	Two 69,000-cfm blower fans at 8-in. water	————

Aeronautics Facility Test Capabilities

Engine Components

AAPL

Capabilities	Nozzle Acoustic Test Rig (NATR)	Small Hot Jet Acoustic Rig (SHJAR)
Free-jet tunnel speed, Mach	up to 0.35	N/A
Tunnel diameter, in.	53	N/A
Nozzle pressure ratio, max.	4.5	8.0
Nozzle exhaust temperature, max.	1,400 °F	1,300 °F
Thrust measurement, max.	2,000 lbf	100 lbf
Fuels	Natural gas	Gaseous H_2
Compressed air services		
150 psig	130 lbm/sec	6.0 lbm/sec
450 psig	30 lbm/sec (heated)	N/A

ERB, ASCR, and ECRL

Combustor Facilities					
Facility	**Test emphasis**	**Max. pressure, psig**	**Max. airflow, lb/sec**	**Nonvitiated heated air, °F**	**Max. exhaust temp., °F**
CE–5B–1	Sector	60 to 275	2 to 12	500 to 1,350	3,200
CE–5B–2	Flametube	60 to 400	0.6 to 5	500 to 1,350	3,200
CE–9B–A	Sector	120 to 450	5 to 30	750 to 1,100	3,400
CE–9B–B	Flametube	120 to 450	1 to 15	750 to 1,100	3,400
ASCR Leg 1	Sector	50 to 900	3 to 50	500 to 1,200	3,400
ASCR Leg 2	Flametube	50 to 900	1 to 10	500 to 1,200	3,400
ECRL–1B	Augmentors	5 to 150	5 to 60	100 to 625	1,900

Compressor Facilities				
Testing Parameters	**W–1A Low-Speed Compressor Facility**	**W–7 Multistage Compressor/ Fan Facility**	**W–8 Single-Stage Axial Compressor Facility**	**CE–18 Small Engine Components Compressor Facility**
Inlet air pressure	atmospheric	atm to 20 psig	5 to 20 psia	ATM to 40 psig
Inlet air temp.	ambient	–30 to 100 °F	ambient	–20 to ambient
Inlet airflow	66 to 32 lb/s	95 lb/s	100 lb/s max.	60 lb/s max
atm exhaust	0.8 psid blowers	0.8 psid blowers	0.8 psid blowers	14.7 psid
Alt. exhaust	20 to 26 in. Hg	26 in. Hg vacuum	26 in. Hg vacuum	20 to 26 in. Hg
Rotor speed	1,920/1,050 rpm	18,700 rpm	20,600 rpm max.	60,000 rpm max.
Rotor size	60/48 in.	20 to 22 in.	22 in.	8 to 20 in.
Drive motor	1,500 hp	15,000 hp	7,000 hp max	6,000 hp

Aeronautics Facility Test Capabilities

Engine

PSL and ECRL

Capabilities	**Propulsion Systems Laboratory**	**Engine Components Research Laboratory Cell 2B**
Test cell size	24 diam. by 39 ft (length)	Cell 60- by 25-ft wide Chamber 6- by 6-ft wide
Simulated altitude	5,000 to 90,000 ft	5,000 to 45,000 ft or ground level
Simulated flight speed Mach no. PSL–3 PSL–4 PSL–4 (free jet with heater)	Mach no. to 3.0 to 4.0 to 6.0	1.6 (theoretical)
Maximum inlet mass flow PSL–3 and PSL–4 (at 55 psia) PSL–4 (at 165 psia)	 480 lbm/s 380 lbm/s	12 lbm/sec
Inlet total temperature PSL–3 PSL–4	 –60 to 600 °F –90 to 1,100 °F	Ambient
Maximum exhaust mass flow	750 lbm/s	35 lbm/s
Core testing capability 180 psia 425 psia 425 psi 465 psi	 25 lbm/s at 1,375 °F 10 lbm/s at 1,100 °F 73 lbm/s at 450 °F 39 lbm/s at 1,200 °F	
Cooling air (mass flow) 100 lb/s	55, 165, and 450 (psia)	5 lbm/sec at 150 psig 3 lbm/sec at 450 psig
Thrust measurement Axial Vertical Lateral	 50,000 lbf 15,000 lbf 15,000 lbf	600 ft lb at 21,000 rpm
Fuel systems	Jet A, JP–4, JP–5, or JP–8 Hydrogen	Jet A, JP–4, JP–5, or JP–8 Hydrogen
Fuel flow rate at 65 psia	200 gpm	5 gpm at 40 psig

Aeronautics Facility Test Capabilities

Wind Tunnels

Wind Tunnels—IRT

Test section dimensions, ft Height Width Length	 6 9 20
Liquid water content, LWC, g/m^3	0.2 to 3.0
Drop size, MVD, μm	15 to 50
Uniform icing cloud dimensions, ft	4.5 by 6
Cloud uniformity, percent LWC	±20
Test section air velocity, kts	50 to 350
Test section total temperature, °C	–40 to 5
Simulated engine flow lb/s	1 to 85
Heated auxiliary air (bleed simulation) (at 900 °F and 120 psig), lb/s	1

Wind Tunnels—10×10, 9×15, 8×6, 1×1, and *HTF

	10×10 Supersonic		9×15 Low Speed	8×6 Supersonic	1×1 Supersonic	*HTF Hypersonic
	Aerodynamic Cycle	Propulsion Cycle				
Test section speed, Mach	0 to 0.36 and 2.0 to 3.5		0 to 0.23 (0 to 150 kts) (0 to175 mph)	0.0 to 0.1 and 0.25 to 2.0	1.3,1.6, 2.0, 2.5, 2.8, 3.0, 3.5, 4.0, 5.0, 5.5, 6.0	5,6,7
Simulated alt., ft	50,000 to 154,000	57,000 to 77,000	Sea level	1,000 to 35,000	11,000 to 115,000	68,000 to 120,000
Test section Reynolds No./per ft.	0.12×10^6 to 3.4×10^6	2.2×10^6 to 2.7×10^6	0 to 1.4×10^6	3.6×10^6 to 4.8×10^6	0.4×10^6 to 16.5×10^6	0.97×10^6 to 2.3×10^6
Dynamic pressure, lbf/ft^2	20 to 720	500 to 600	0 to 72	200 to 1,340	80 to 1,750	300 to 2,200
Test section total temperature, °R	540 to 750	520 to 1,140	Ambient to 550	520 to 720	520 to 1,100	2,200 to 3,900
Auxiliary air supply At 40 psig At 150 psig At 450 psig Model exhaust	—— —— 12 lb/s 20 lb/s at 2 psia		(Heated) 30 lbm/s 30 lbm/s 30 lbm/s variable	30 lbm/s 30 lbm/s 30 lbm/s variable	—— 2 lbm/s 8 lbm/s ——	——
High-pressure air (2,600 psig) storage, scf	981,000		981,000	981,000	——	675,000 GN_2 at 4,500 psi 386,000 GO_2 at 2,200 psi
Fuels	Liquid jet fuel Gaseous H_2 and O_2		Gaseous Hydrogen	Gaseous Hydrogen	——	Liquid jet fuel Gaseous H_2 and O_2 Natural gas

*Plum Brook Facility

Aeronautics Facility Test Capabilities

Flight Research

Flight Research—Quick Reference Data

Learjet Model 25 Aircraft			
Pilots	2	Electrical Power Configuration Capability	115 volts ac 60 and 400 Hz + 28 volts dc
Researchers	4		
Max. speed	350 KIAS (.81 Mach)	View ports/mounts	Top has two 12-in. ports, plus both sides and bottom
Range	1,200 nautical miles		
Ceiling	45,000 ft	Internal capacity	Standard racks mount to seat rails
Gross weight	15,000 lb		
Useful load	@ 6,500 lb*		
*Fuel/crew/research equipment and other restrictions may reduce this figure.			
S–3B Viking Aircraft			
Pilots	1 to 2	Electrical Power Configuration Capability	115 volts ac 60 and 400 Hz + 28 volts dc
Researchers	2 to 3		
Max. speed	450 KIAS (.79 Mach)	External capacity	Two wing mounts, two heated bomb bays (28 by 90 in.), and an aft sensor area
Range	@ 2,300 nautical miles		
Ceiling	40,000 ft		
Gross weight	52,500 lb		
Useful load	@ 25,000 lb*	Internal capacity	Avionics Bay (79 by 90 in.)
*Fuel/crew/research equipment and other restrictions may reduce this figure.			
DHC–6 Twin Otter Aircraft			
Pilots	1 to 2	Electrical Power Configuration Capability	115 volts ac 60 and 400 Hz + 28 volts dc
Researchers	1 to 3		
Max. speed	140 KIAS	External capacity	Five wing hard mounts plus numerous other small fuselage mounts
Range	@ 400 nautical miles		
Ceiling	16,000 ft	Internal capacity	Large cabin area with standard racks mounted to seat rails, removable cargo doors, and an overhead hatch
Gross weight	11,000 lb		
Useful load	@ 5,500 lb*		
*Fuel/crew/research equipment and other restrictions may reduce this figure.			
T–34C Mentor Aircraft			
Pilots	1	Electrical Power Capability	28 volts dc 40 amps
Researchers	1		
Max. speed	280 KIAS	View ports/mounts	Internal nadir port
Range	650 nautical miles		
Ceiling	25,000 ft	Internal capacity	Baggage area nadir/opening
Gross weight	4,400 lb		
Useful load	@ 400 lb*		
*Fuel/crew/research equipment and other restrictions may reduce this figure.			

Space Facility Test Capabilities

Microgravity

2.2-Second Drop Tower and Zero Gravity

Capabilities	**2.2-Second Drop Tower**	**Zero Gravity**
Microgravity duration	2.2 sec	5.18 sec
Free-fall distance	24 meters	132 meters
Gravitational acceleration	0.0001 g	<0.00001 g
Mean deceleration	15 g	35 g
Peak deceleration	20 to 30 g	65 g
Vacuum level	N/A	0.01 torr
Vacuum chamber length	N/A	143 meters
Vacuum chamber diameter	N/A	6 meters
Drop Vehicle Capabilities Payload diameter Payload height Payload weight	- - - 0.84 meters Up to 159 kg	Up to 1 meter Up to 1.6 meters Up to 455 kg
Number of tests per day	Up to 12	2

Space Facility Test Capabilities

Chemical Propulsion and Propellant Handling

RCL

Combustion and Cryogenics Space Facilities					
Propellants	RCL–11	RCL–21	RCL–22	RCL–31/32	ACS
GH_2 (scf)	70,000	140,000	140,000	70,000	140,000
LH_2 (gallons)	n/a	25	n/a	200	200
GOx (scf)	60,000	60,000	60,000	60,000	60,000
LOx (gallons)	n/a	5	n/a	50	200
HC (gallons)	n/a	8	n/a	100	100
Ethanol (gallons)	0.5	8	n/a	100	n/a
Supply pressure, psi					
GH_2	2,400	2,400	2,400	2,400	2,400
LH_2	n/a	1,800	n/a	1,800	1,800
GOx	2,400	2,400	2,400	2,400	2,400
LOx	n/a	1,800	n/a	1,800	1,800
HC	n/a	1,000	n/a	1,800	1,800
Ethanol	n/a	1,000	n/a		
Maximum flow (lb/sec)					
GH_2	0.022	0.3	2.0	3.0	3.0
LH_2	n/a	0.25	n/a	1.0	1.5
GOx	0.08	1.0	4.0	4.0	7.0
LOx	n/a	2.0	n/a	7.0	7.0
Ethanol		0.1			
Other capabilities					
Max. thrust, lbf	50	300	2,000	2,000	2,000
Altitude, ft	95,000	95,000	n/a	n/a	110,000

Space Facility Test Capabilities

Chemical Propulsion and Propellant Handling

RCL Continued

Test Cell	Features
RCL–11	Conducts performance and life tests in both steady-state, long-duration, and pulse modes. Instrumented or optically accessible hardware, two-color pyrometry for high-temperature measurement, and laser-based diagnostic systems (Rayleigh, Raman, LIF, color Schlieren)
RCL–21	Low-flow facility used to test ignition systems and subscale propulsion concepts and to study pulse detonation engine phenomena. Gaseous or liquid oxygen is used with fuels including hydrogen, methane, carbon monoxide, ethanol, liquid hydrocarbons, and gelled or metallized fuels.
RCL–22	Used for high-temperature thermal testing of advanced rocket engine materials. Capable of gaseous hydrogen and oxygen flows over a wide mixture ratio range. Water-cooled engine hardware provides various chamber pressures.
RCL–24	Provides testing of fuel cell and electrolyzer components. Gaseous hydrogen and oxygen are supplied at controlled humidification levels ranging from zero to fully saturated.
RCL–31 and RCL–32	Provide gaseous and liquid oxygen, hydrogen, and kerosene fuels to test strands. Test article cooling can utilize water, liquid hydrogen, or gaseous hydrogen. An adjacent room supports laser-based optical diagnostic equipment.
ACS	Altitude testing of combustion components up to 2,000 lb thrust and 1,000 psia chamber pressures with thrust measurement capabilities. Cost-effective, self-contained, nitrogen-driven vacuum ejector system for rapid chamber pump down and quick turnaround.
B135	Conducts testing of a regenerative fuel cell system as an energy storage device. Waste heat from electrochemical reactions and fuel cell load are dissipated by forced air. It provides an exclusion zone and outdoor oxygen and hydrogen storage tanks. The control room is located 750 ft away via optical links.
CCL–7	Used as a low-cost small-scale screening facility for concept and component testing. Has the ability to perform cryogenic propellant transfer and vent flow tests. Test operations are conducted from a remote control room.
SMiRF	Features a 72- by 100-in. diffusion pumped high vacuum chamber with cold wall. Provides environment to test cryogenic propellant handling and storage concepts, components, and technology.

CTC

Capabilities
28,000-gal liquid oxygen storage capability
3,000-gal liquid oxygen transfer capability at pressures up to 250 psig
50 gal per minute liquid oxygen flow capability at pressures up to 800 psig via dual centrifugal pumps
75 gal per minute liquid oxygen flow capability at pressures up to 1,250 psig via twin piston reciprocating pump
42,000-gal liquid hydrogen storage capability
1,300-gal liquid hydrogen transfer capability at pressures up to 1,250 psig
13,000-gal liquid nitrogen storage capability
502,000 scf of high-pressure GN_2 storage with delivery rates up to 2.0 lbm/sec for driving pumps, turbines, and other equipment
110,000 scf of high-pressure GH_2 storage
140,000 scf of high-pressure GHe storage

Space Facility Test Capabilities

Electric Power and Propulsion

Vacuum Facilities—PSF, SPF, EPL, EPRB, and Zero-G

Vacuum facility	Dimensions (diam. by length)	Vacuum system	No load pressure, Torr	Pumping speed liter/sec, air	Features
VF–1	5 by15 ft long	(2) 35-in. ODP	3×10^{-7}	40,000	250–kJ capacitor bank 2-msec pulse duration >30-MW pulsed power
VF–2	3.5 by 7 ft long	Turbopump	1×10^{-6}	1,950	
VF–3	5 by 15 ft long	(4) 35-in. ODP	4×10^{-7}	80,000	Multiple test ports
VF–5	15 by 60 ft long Access: 13 by 30 ft long	Cryopanel 750 W at 20 K, 33.5 m^2 of He surface Diffusion Pumps (20) 32-in. pumps, –50 °F traps	1×10^{-7}	3,500,000 (cryo) 250,000 ODP	Leading testbed for electric propulsion thrusters, multiple test ports including 6-ft test port, and flight/qualification testing
VF–6	25 by 70 ft long	(12) 54-in. nude cryotube	5×10^{-7}	900,000	Solar simulation 1.2 solar constant 5-m diam. subtense angle <1° Mercury orbit 30 cm (9) 30-kW xenon lamps
VF–7	10 by 15 ft long	(6) 32-in. diffusion pumps	1×10^{-7}	125,000	
VF–8	5 by 15 ft long	(4) 35-in. ODP	4×10^{-7}	120,000	Portable cold wall for thrusters, multiple test ports. Gaseous feed systems H_2, N_2, N_2H_3
VF–9	2 ft wide by 5 ft long by 8 ft high	Roots blower pumps	1×10^{-3}	3,000 cfm	Atomic oxygen production facility
VF–10	40 by 60 in. long	Turbopump	8×10^{-7}	1,950	Cold wall 35 in. diam. by 40 in. long Control: –250 to 300 °F or (–320 °F)
VF–11	7.25 by 27 ft long	(3) 48-in. cryotubs (4) 36-in. cryotubs	1×10^{-7}	270,000	
VF–12	10 by 30 ft Access: 10 ft by 16 ft	Cryopanels 350 W at 20 K panel temp.	8×10^{-8}	1,000,000	
VF–13	5 by 11.5 ft	20-in. cryopump and turbopump	4×10^{-7}	10,500	Rapid turnaround with valved pumping system
VF–14	22 by 22 by 36 in.	Turbopump	5×10^{-7}	1,000	
VF–15	30 by 18 in.	Turbopump	5×10^{-6}	1,600	High temperature testing
VF–16	10 by 25 ft long	(10) 48-in. cryotubs	7×10^{-8}	500,000	Electrostatic propulsion test facility and supports long-duration testing
VF–19	6 by 9.5 ft	(4) 10-in. ODP	5×10^{-7}	5,300	Space plasma test facility
VF–20	71 by 72 in.	36-in. cryotub	1×10^{-6}	30,000	Space plasma test facility; thermal shroud available upon request
VF–21	36 by 60 in.	10-in. cryopump	1×10^{-6}	4,000	Horizontal turntable
VF–54	18 by 36 in.	10-in. diffusion pump	1×10^{-6}	1,200	
VF–55	18 by 36 in.	Turbopump with dry scroll pump	5×10^{-7}	1,000	
VF–56	18 by 36 in.	Turbopump	5×10^{-6}	400	
VF–62	10 by 30 in.	10-in. cryotub	5×10^{-6}	4,000	
VF–65	18 by 36 in.	10-in. turbopump	1×10^{-6}		
VF–67	3.33 by 10 ft	20-in. cryotub	9×10^{-7}	10,000	Full LN_2 flooded thermal shroud
CW–19	7 by 10 ft	(2) 35-in ODP with dual baffles of LN_2 and water	5×10^{-7}	25,000	
Zero-G	20 by 470 ft	Roots blowers and stokes pump	5×10^{-3}	21,000	Deployment of hardware during free fall at vacuum or altitude
*SPF	100 by 122 ft	(10) 52-in. cryopumps (16) 48-in. ODP	1×10^{-6}	1,300,000	World's largest vacuum chamber thermal simulation; large test article handling very low vibration environment
*B–2	38 by 62 ft	(10) 32-in. ODP	5×10^{-7}	350,000	Hot-firing thermal simulation; hazardous test capability, altitude simulation, and 27-ft test port
*K-Site	25 ft diam.	(4) 35-in. ODP	5×10^{-7}	150,000	Hazardous test capability and thermal shroud vibration testing

**Plum Brook Facilities*

Data Acquisition

NASA GRC uses state-of-the-art computing resources to support today's dynamically changing facilities' test requirements providing the highest quality data and support to ensure cost-effective testing.

Glenn has developed an integrated hardware and software system to support aeronautical facility test needs. This steady-state system, called Escort, provides real-time data acquisition, limit checking, analysis, and display. The facility system acquires, converts, analyzes, and displays steady-state data on graphical and alphanumeric displays with rates up to twice per second. The base functions of Escort are

- Data acquisition of facility instrumentation (up to 2,000 channels) that includes, but is not limited to, thermocouples, pressure transducers, force balances, speed pickups, accelerometers, positions, electronically scanned pressure (ESP) systems, as well as custom systems
- Real-time performance calculations (including iterative calculations) using sampled data
- Online real-time graphical and alphanumeric displays of all sampled and calculated parameters
- Integration with model controls to automate the test matrix to increase the rate of data capture
- Remote Escort data displays at the customer site are supported

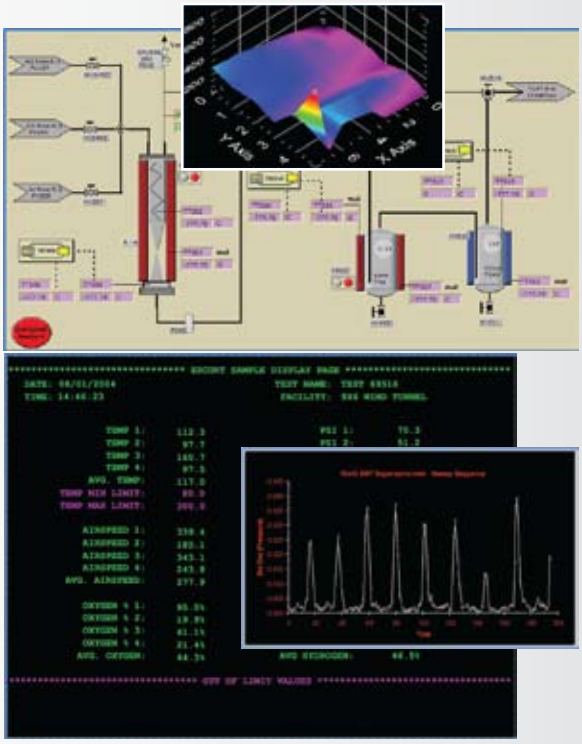
Dynamic and transient data is acquired with systems tuned to meet specific facility and test article needs. These systems vary from facility to facility. Systems range from less than a dozen channels to more than a hundred per system. Scan rates of a few hundred samples per second to 200,000 of samples per second are supported.

Industry standard, as well as customer-specific data formats can be provided. Based on customer's requirements, real-time displays can be generated. Acquired data can be transferred to the customer's computer and analyzed using their programs.

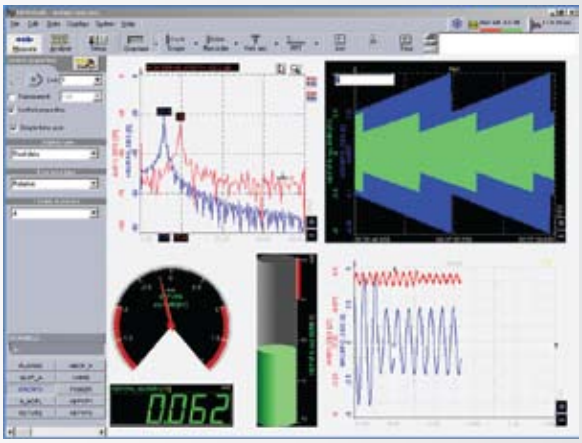
Imaging Services

Located onsite, the Imaging Technology Center (ITC) provides high-quality professional imaging services to GRC's facilities and laboratories.

During a test, the ITC is available to provide high-speed and ultra-high-speed video and film-based services, thermal infrared imaging, high-definition and conventional video, and scientific photography. Other services include onsite photographic printing, CD/DVD authoring, file-format conversion, image analysis, and image archiving.



Steady-state data displays



Dynamic data displays

Imaging Technology Center

Doing Business With NASA Glenn

Our unique test facilities offer superior customer service and state-of-the-art testing capabilities. Test facilities are available for use by private industry, government, and academia. We are committed to providing the highest quality engineering, technical, and testing services at the lowest possible cost.

For additional information on NASA Glenn Research Center Test Facilities, visit the Web site: http://facilities.grc.nasa.gov/ or contact 216–433–5731.

The next steps summarize a typical test process at NASA GRC facilities:

1. Customers contact facility manager directly (contact list is provided below or call 216–433–5731). The facility manager is the primary point of contact for test facilities and will provide information about capabilities and the ability to support specific test requirements, scheduling, and cost.
2. Customers provide test requirements containing information such as test conditions, number of test runs, number of configurations, special instrumentation, and/or systems needed. To assist potential customers, a Test Request Form is available online at http://facilities.grc.nasa.gov/
3. Facility managers will coordinate with appropriate support organizations to assess test requests and provide customers with a cost estimate.
4. If test can be supported and customer is interested in pursuing test, then both parties will need to enter into a Space Act Agreement. The agreement will cover areas such as responsibilities, scheduling, and milestones, financial obligations, liabilities, and data rights.
5. A kickoff meeting and pretest meetings will be held as needed to coordinate the test requirements with the customer.
6. After test completion, actual test cost will be reconciled per Space Act Agreement.

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For additional testing information contact 216–433–5731