www.arnold.af.mil

Test Facility Guide

Arnold Engineering Development Complex

Arnold AFB, Tenn. 37389
An Air Force Test Center Test Complex

Arnold Engineering Development Complex

OVERVIEW

The Arnold Engineering Development Complex is part of the Air Force Test Center (AFTC). Headquartered at Arnold Air Force Base in Tennessee, the Complex also consists of two geographically separated units - the Hypervelocity Wind Tunnel in Maryland and the National Full-Scale Aerodynamics Complex in California. The five AEDC Combined Test Forces (CTF), listed below, are accountable for customer interface and test planning, execution and reporting.

- Propulsion Wind Tunnel CTF
- Turbine Engine CTF
- Space and Missiles CTF
- Hypervelocity Wind Tunnel 9 CTF
- National Full-Scale Aerodynamics Complex CTF

White Oak, Md.

Moffett Field, Calif.

Table of Contents

AD INEXPLORATA

ARNOLD ENGINEERING DEVELOPMENT COMPLEX

AEDC MISSION

Develop, test and evaluate weapon, propulsion, aerodynamic and space systems at realistic conditions for the nation through modeling, simulation and ground test facilities

AEDC VISION

Be the nation's best value ground test and analysis source for aerospace and defense systems

Arnold AFB, Tenn.

DOING BUSINESS WITH AEDC

AEDC offers extensive test and evaluation capabilities, and our team is focused on providing the best possible data and a positive test experience for our customers. The AEDC test facilities can be used by government, private industry and academia.

The following steps summarize how typical test programs are planned and conducted at AEDC facilities:

1. The customer contacts one of the AEDC representatives listed below to inquire about our testing and evaluation services. Lead time to using AEDC facilities is primarily based on test complexity and can range from two weeks for less complex tests to 24 months for very complex ones.
2. AEDC provides an initial rough order of magnitude (ROM) cost estimate and schedule availability for customer inquiries.
3. If the estimated cost and schedule are acceptable to the customer, AEDC requires that a test request be submitted.
4. AEDC contacts the customer to determine schedule dates and set up the initial pretest meeting. The customer is required to provide AEDC advanced funding for initial project planning and estimating.
5. After the initial pretest meeting, the customer provides a detailed test plan containing the test objectives, scope, schedule, desired test program matrix, test article descriptions, instrumentation, data reduction and analysis requirements. AEDC prepares a statement of capability (SOC) or contract using this information, which will be the formal agreement between AEDC and the customer for test requirements scope, schedule, risks and costs.
6. Once the SOC or contract has been signed, the balance of test funding is required by AEDC to proceed.
7. AEDC Combined Test Force representatives will work closely with the test customer throughout the test planning phase to review and finalize the test plan, test matrix, and data reduction and analysis requirements and prepare the necessary documents to schedule test periods and configure all systems to support testing.
8. The AEDC Customer Service Representative (CSR) assists the customer with getting on-base using the visit authorization letter (VAL) process, accessing AEDC's computers, long distance access when at AEDC, and general AEDC/local area information. Customers are free to contact the CSR at any time with questions.
9. During the testing process, the customer is billed for actual charges and costs for facility operations.
10. Once the test has been completed, AEDC provides analyses and data products as detailed in the SOC or contract.

America's Aerospace Advantage

AEDC Points of Contact

Customer Service Rep	Arnold_CustomerService@us.af.mil	(931) 454-6641
Propulsion Wind Tunnel CTF	Arnold_FlightSystems@us.af.mil	(931) 454-6100/5851
Turbine Engine CTF	Arnold_AeropropulsionSystems@us.af.mil	(931) 454-4522/5155
Space and Missiles CTF	Arnold_SpaceMissileSystems@us.af.mil	(931) 454-7455/6650
Technical Services	Arnold_TechnicalServices@us.af.mil	(931) 454-4511/6876
National Full-Scale Aerodynamic Complex CTF	AEDC.ArnoldNFAC@us.af.mil	(650) 604-5191
Hypervelocity Wind Tunnel 9 CTF	AEDC.Tunnel9@us.af.mil	(301) 394-1750

For assistance or additional information about AEDC, visit our website: www.arnold.af.mil or contact the AEDC Public Affairs Office (931-454-4204)

PROPULSION WIND TUNNEL COMBINED TEST FORCE

The Propulsion Wind Tunnel Combined Test Force at AEDC offers aerodynamic ground-test capabilities from very low subsonic speeds through Mach number 10 in various wind tunnels. These wind tunnels provide essential test and analysis services in support of DoD, national, U.S. industry and international aerospace programs. AEDC operates five active wind tunnels in two primary facilities, the Propulsion Wind Tunnel Facility (PWT) and the von Kármán Gas Dynamics Facility (VKF).

AEDC wind tunnels are used for testing and evaluation in areas including vehicle aerodynamic performance evaluation and validation, weapons integration, inlet/airframe integration, exhaust jet effects and reaction control systems, code validation, proof-of-concept, large- and full-scale component research and development, system integration, acoustics, thermal protection system evaluation, hypersonic flow physics, space launch vehicles, operational propulsion systems and captive flight.

An extensive inventory of instrumentation is available for testing use, including force and moment balances, heat-transfer gauges and electronically scanned pressure modules. AEDC can provide design, fabrication, and calibration services for force and moment balances. AEDC is experienced with other wind tunnel test instrumentation such as model attitude measurement devices, heat-transfer gauges, dynamic pressure transducers, and several flow visualization techniques including pressure-sensitive paint (PSP). In addition, customers can choose to have AEDC design and fabricate their wind tunnel test models to best meet program requirements.

AEDC is a leader in wind tunnel data productivity, and its facilities are continually optimized through targeted investment and maintenance to provide customers with the highest quality aerodynamic data. With decades of experience testing and analyzing the nation's flying weapons systems, our team can provide program development experience to your system. Our engineers are highly trained and experienced in wind tunnel tests and associated analyses and use standardized, configuration-controlled test processes to ensure high-quality, high-fidelity, and accurate test results. Careful test planning and coordination with test customers ensures that test objectives are met and that testing is streamlined and efficient. Our engineers and analysts can also assist sponsoring DoD organizations in pre-MS A planning activities, activities supporting Milestone B decisions, activities in support of Milestone C and beyond and integration of T&E activities and results throughout the system lifecycle to help ensure program success.

AEDC wind tunnel test sections are some of the largest in the world for the speed ranges they provide, capable of accommodating moderate- to large-scale models to limit scalability issues and increase the fidelity and quality of simulation.

Wind Tunnel Test Facility Capabilities

Tunnel	Test Section Size		Speed Range (Mach No.)	Reynolds No. Range (million per ft)	Dynamic Pressure (psf)	Total Pressure	Total Temperature (º F)	Pressure Altitude (nominal, K ft)
	Cross Section (ft)	Length* (ft)						
Propulsion Wind Tunnel 16T	16 x 16	40	0.05 - 1.6	0.03 - 7.2	0.35 - 1161	200 - 3950 (psf)	80 - 140	Sea Level - 86
Propulsion Wind Tunnel 16S†	16 x 16	40	1.5 - 4.75	0.1 - 2.4	25 - 564	200 - 1900 (psf)	120 - 580	43 - 154
Aerodynamic Wind Tunnel 4T	4 x 4	12.5	0.05 - 2.46	0.02 - 7.1	0.17 - 1465	100 - 3400 (psf)	80 - 140	Sea Level - 115
Supersonic Wind Tunnel A	3.3 x 3.3	9	1.5 - 5.5	0.3 - 8.5	50 - 1750	3 - 195 (psi)	90 - 280	17 - 152
Hypersonic Wind Tunnel B	4.17 diam	9	6 or 8	0.40 - 5.2	66 - 620	40 - 900 (psi)	290 - 890	100 - 162
Hypersonic Wind Tunnel C	4.17 diam	9	10	0.3 - 3.0	48 - 475	200 - 2000 (psi)	1220 - 1700	130 - 180
High Re. No. Wind Tunnel C	2.08 diam free jet	3	8	0.5 - 7.9	132 - 1256	200 - 1900 (psi)	760 - 1440	97 - 147
Aerothermal Wind Tunnel C	2.08 diam free jet	3	4	0.3 - 7.1	212 - 2018	20 - 190 (psi)	290 - 1440	56 - 106

* Nominal test section length dimensions are shown. The actual model lengths that can be tested depend on Mach number and should be coordinated with the AEDC test engineering staff.

† Inactive

Propulsion Wind Tunnel 16T

Propulsion Wind Tunnel 16T provides flight vehicle developers with the aerodynamic, propulsion integration, and weapons integration test capabilities needed for accurate prediction of system performance. Large-scale models can be accommodated in the 16-ft square by 40-ft long test section and can be tested at Mach numbers from 0.05 to 1.60. Pressure in the test section can be varied to simulate unit Reynolds numbers from approximately 0.03 to 7.2 million per foot or altitude conditions from sea level to 86,000 ft. Air-breathing engine and rocket testing can also be performed in Tunnel16T using a scavenging system to remove exhaust from the flow stream.

Wind tunnel models can be supported in a variety of ways including a High Angle-of-Attack System (HAAS) for evaluating extreme flight attitudes and a Captive Trajectory Support (CTS) system for weapons integration testing. Other testing support services include utilities such as supplying high-pressure air to the test models for simulation of jet exhaust or control jets. A fuel system is also available for engine testing.

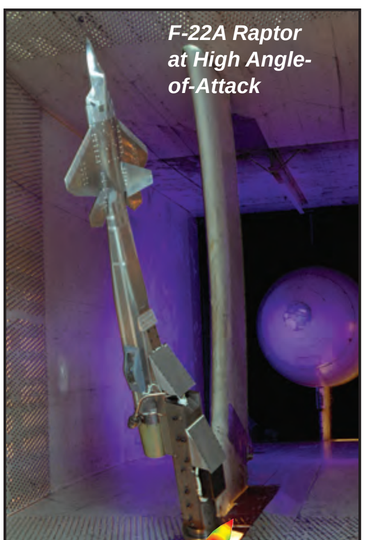
Tunnel 16T provides world-class test productivity by using automated and integrated test process controls. Modern steady-state and high-speed data systems with real-time displays and multichannel remote controls are available. High-rate continuous-sweep data acquisition is routinely acquired to provide a more complete assessment of model aerodynamics and related effects during test. Other data needs will be met as established through communication with the test customer.

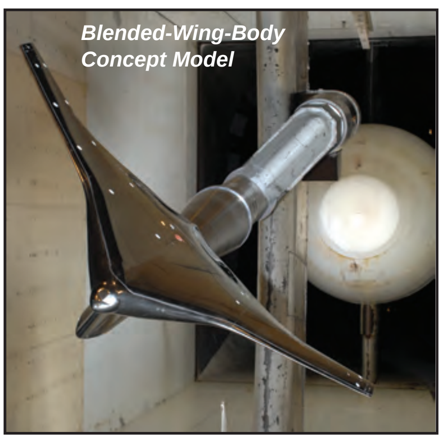
One example of AEDC's continuous improvements in test technologies has been the development of the pressure-sensitive paint (PSP) data acquisition system that provides full-time, 360-deg model coverage. This system allows engineers to acquire and evaluate global surface pressure data on wind tunnel models using a special paint whose luminescence is a function of the local test article surface pressures.

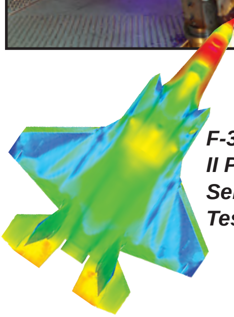
Major aircraft development programs, such as the recent Lockheed Martin F-35 Lightning II and Boeing's F/A-18E/F Super Hornet, have selected Tunnel 16T as a primary aerodynamic test data supplier. Other high-performance military aircraft, such as the B-2A Spirit stealth bomber and the RQ-4 Global Hawk unmanned aerial vehicle, have undergone extensive testing in Tunnel 16T, as have space vehicles such as the DoD's Evolved Expendable Launch Vehicle (EELV), the NASA Space Shuttle, NASA Ares, and research vehicles such as the Blended-Wing-Body or the X-33 reusable launch vehicle.

Tunnel 16T has supported almost every major DoD and government flight vehicle program of the past 55 years, and our customers include both domestic and foreign, private industry and academia.


F/A-18 E/F Store Separation

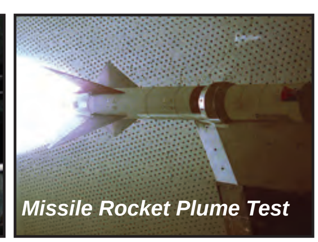

F-22A Raptor at High Angle-of-Attack


Blended-Wing-Body Concept Model


F-35 Lightning II Pressure-Sensitive Paint Test Results


Standard Model Test


Full-Scale JASSM Cruise Missile Test


Missile Rocket Plume Test

Transonic Wind Tunnel 4T

AEDC's 4-ft transonic wind tunnel (4T) is a versatile, continuous-flow, mid-size test facility that can be used for a variety of aerodynamic test needs. Used primarily in conducting small-scale aerodynamic and store separation testing, the tunnel has a 4.0- by 4.0- by 12.5-ft test section. The transonic designation indicates its primary use for testing at near-sonic airspeeds; however, its Mach number capability extends from 0.05 to 2.46. Tunnel 4T can simulate altitudes from sea level to 115,000 ft and provide Reynolds numbers up to approximately 7.1 million/ft.

Although Tunnel 4T is primarily used in conducting small-scale aerodynamic and store separation testing, a variety of test types, many of which can be applied simultaneously during a single test entry, are available. Tunnel 4T has been used to conduct specialized testing such as material testing, and our engineers can develop specialized test techniques to meet the unique test needs of our customers.

Supporting systems include modern, state-of-the-art, steady-state and high-speed data systems with automated test process controls for high test productivity similar to Tunnel 16T. A limited pressure-sensitive paint (PSP) system is available. Wind tunnel models are supported using a remotely actuated, high-angle, sting-support pitch and roll system for aerodynamic testing. Pressurized air can be routed to the test models for simulation of control jets. A sidewall mounting system with a manually actuated support is available for aerodynamic testing of large panels. A recently redesigned six-degree-of-freedom Captive Trajectory System (CTS) with increased range-of-motion and load bearing capability is available for store separation testing.

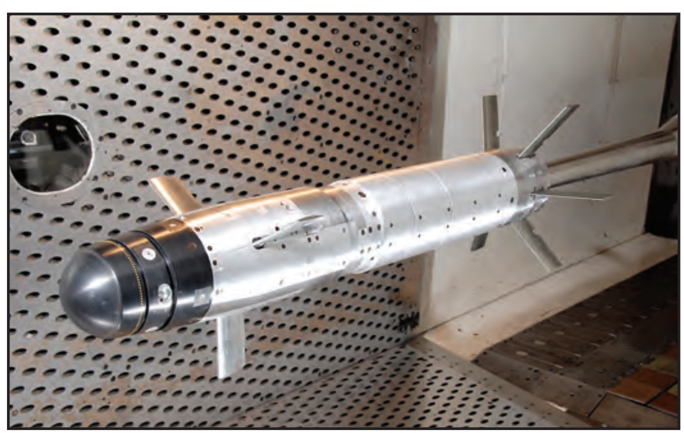
Tunnel 4T has supported almost every major national flight vehicle development program and has been used recently for weapons integration testing on several fighters such as the multi-service F-35 Lightning II, F-22A Raptor, F/A-18C Hornet, F-14 Tomcat, F-15 Eagle, and F-16 Fighting Falcon. The tunnel has also been used to test large vehicles such as the B-1 Lancer and has provided Space Shuttle material testing. Customers include domestic and foreign governments, and private industry.

F-35 Lightning II Store Separation

Additional Test Types

- Stability and Control
- Captive Loads
- Acoustics
- Static and Dynamic Pressures
- Flow Visualization (Shadowgraph, Laser Vapor Sheet, Doppler Global Velocimetry, Particle Image Velocimetry, Background-Oriented Schlieren)
- Pressure-Sensitive Paint
- Oil Flow
- Freestream
- Aerodynamic Grid
- Flow-Field Probe
- Captive Trajectory

Tailless Aircraft Concept



Mid-Range Munition

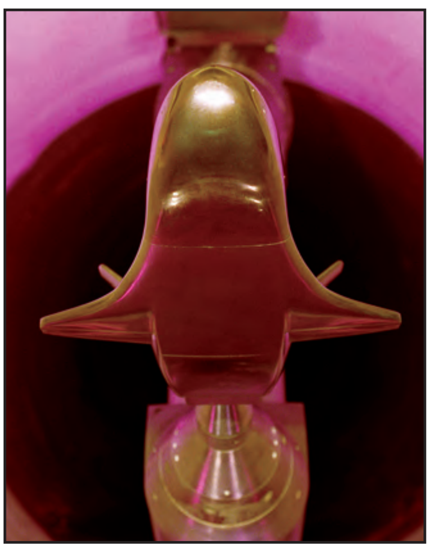
Wind Tunnels A/B/C

The Von Kármán Gas Dynamics Facility (VKF) is comprised of a supersonic wind tunnel (Tunnel A) and two hypersonic wind tunnels (Tunnels B and C). These tunnels provide high-quality flow in the Mach number 1.5 to 10 flight regime and operate as variable-density, continuous-flow units. Tunnels A, B, and C offer large test sections (40 to 50 in.) for aerodynamic testing and have unique operating capabilities.

The tunnels are used extensively to obtain large aerodynamic and aerothermodynamic databases to develop supersonic and hypersonic flight vehicles. Customers use these facilities to conduct testing for static stability, pressure loads, jet interaction, store separation and vehicle staging, heat transfer, inlet integration, material sampling, thermal mapping, and dynamic stability, including forced and free oscillation.

The VKF tunnels have several unique features. Tunnel A has a computer-controlled, continuous-curvature nozzle that can vary Mach number from 1.5 to 5.5. In addition, Tunnels B (Mach 6 and 8) and C (Mach 4, 8 and 10) are the only operational hypersonic T&E facilities with continuous-flow capabilities. The Mach number 4 Tunnel C configuration can match true flight conditions from 56,000 to 105,000 ft. Tunnel C offers an aerothermal environment for testing materials proposed for use on space vehicles and aircraft. This one-of-a-kind hypersonic wind tunnel can subject flight hardware to a combination of aerodynamic and thermodynamic effects up to 1440ºF to study how materials respond to the combined effects of external heating, internal heat conduction, and pressure loading. Each tunnel is also equipped with a unique model injection system to allow reconfiguration of test articles during air-on operation, resulting in high data productivity for obtaining aerodynamic databases. Special photographic techniques are used in the tunnels to visualize shock waves and heating patterns.

Virtually every high-speed flight vehicle has required testing in Tunnels A, B and C, from reentry and tactical vehicles and space capsules to the X-planes and winged vehicles. Extensive testing in Tunnels A, B and C has also been performed on the NASA Space Transport System, Ares, National Aerospace Plane, X-37 orbital test vehicle, X-43 reusable launch vehicle and Atlas space launch vehicle.

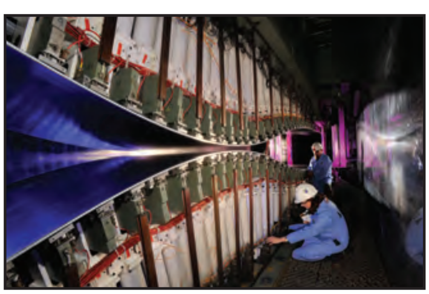


X-37 Aerodynamic Test in Tunnel B

Control Jet Interaction Test Tunnel B

Color Schlieren of Space Shuttle Booster Separation Test in Tunnel A

Ares Heat Transfer in Tunnel B



Tunnel A Flexible Nozzle

NASA Space Shuttle Material Test Tunnel C

Fully-Resuable Access to Space Technology Proof-of-Concept Launch Vehicle in Tunnel A

HYPERVELOCITY WIND TUNNEL 9 COMBINED TEST FORCE

Hypervelocity Wind Tunnel 9 Combined Test Force an AEDC site located at White Oak, Md. near Silver Spring, provides aerodynamic simulation critical to the development of hypersonic systems and hypersonic vehicle technologies.

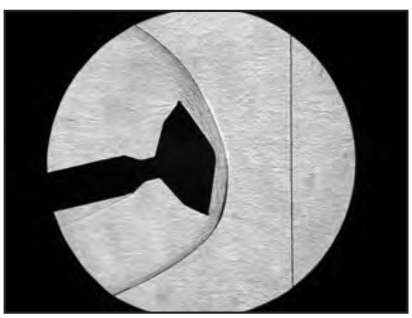
The facility supports testing for Air Force, Navy, Army, Missile Defense Agency and NASA programs, as well as advanced hypersonic technologies such as wave-rider-type vehicles, scramjets inlets and transatmospheric space planes.

Tunnel 9 is the primary high Mach number and high Reynolds number facility for hypersonic ground testing and the validation of computational simulations for the Air Force and DoD. Noteworthy advantages of Tunnel 9 over other facilities include a unique storage heater with pressures up to 1,900 atm and temperatures up to 3,650ºR. Axisymmetric contoured nozzles for Mach 6.7, 8, 10 and 14 operation are also available.

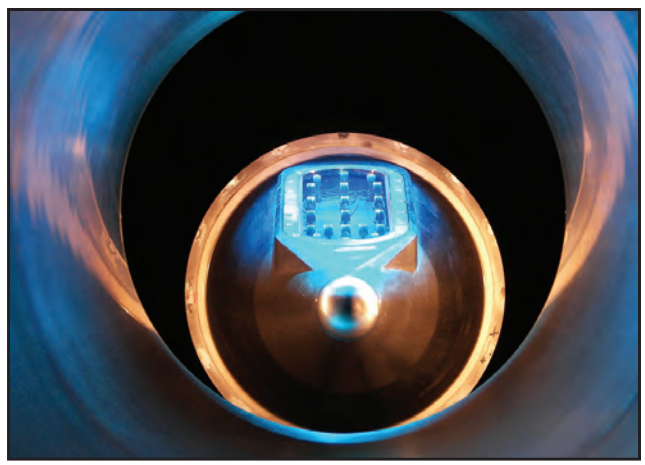
When compared to other hypervelocity facilities, which have run times of a few milliseconds, the long test times available in Tunnel 9, typically on the order of 1 sec (up to 15 sec), provide higher productivity by allowing for parametric variation such as an angle-of-attack sweep or flow survey during a single run. The 5-ft-diam (1.5 m) test cell accommodates large-scale heavily instrumented test articles.

The combination of operational range, long test times and a large test cell makes Tunnel 9 the highest Reynolds number, largest scale ground-test facility in the world, capable of simultaneously collecting continuous pitch-polar static force and moment, pressure and heat-transfer data during each run. Having the capability to test at flight-matched Reynolds numbers provides a significant risk reduction for the design and evaluation of hypersonic systems.

Tunnel 9 provides a useful and cost-effective environment for research and development test and evaluation (RDT&E) as well as for investigating the complex physics associated with hypersonic science and technology (S&T). Past testing includes aerodynamic, aerothermal, seeker window thermal-structural and aero-optic, shroud removal, hypersonic inlet, fundamental flow physics and computational fluid dynamics (CFD) validation experiments.



Schlieren Photo of NASA Mars Science Laboratory



Terminal High Altitude Area Defense (THAAD) Seeker Aerothermal Test

Wind Tunnel Test Facility Capabilities

Tunnel	Test Section Size: Cross Section (ft)	Test Section Size: Length* (ft)	Speed Range (Mach No.)	Reynolds No. Range (million per ft)	Dynamic Pressure (psf)	Total Pressure	Total Temperature (º F)	Pressure Altitude (nominal, K ft)
Hypervelocity Wind Tunnel 9 (Hypersonic)	2.9 diam free jet	9	8	4 - 48	960 - 11,300	1000 - 12,500 (psi)	1100 - 1200	Sea Level - 65
	5 diam	12	10	0.5 - 20	95 - 4000	300 - 14,000 (psi)	1200 - 1350	39 - 111
	5 diam	12	14	0.05 - 3.6	8 - 900	100 - 19,000	1750 - 2800	82 - 173
Hypervelocity Wind Tunnel 9 (Aerothermal)	11.3 (in) diam free jet	6	6.7	4 - 7.6	3540 - 6850	2600 - 5500	2100 - 2900	52 - 67

* Nominal test section length dimensions are shown. The actual model lengths that can be tested depend on Mach number and should be coordinated with the AEDC test engineering staff.

NATIONAL FULL-SCALE AERODYNAMICS COMPLEX COMBINED TEST FORCE

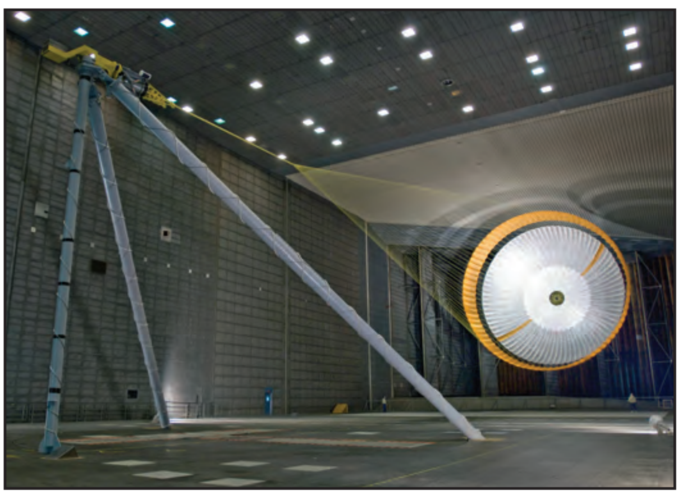
The National Full-Scale Aerodynamics Complex (NFAC) wind tunnel facility, located at Moffett Field, in Mountain View, Calif., is managed and operated by AEDC. This facility is composed of two large test sections and a common, six-fan drive system. A wide range of available support systems combine with this unique facility to allow the successful completion of aerodynamic experiments that cannot be achieved anywhere else. Additionally, each of the test sections is acoustically lined for acoustic testing.

The 40- by 80-ft wind tunnel circuit, originally constructed in the 1940s, is now capable of providing test velocities up to 300 knots and Reynolds numbers up to 3 million/ft. The 80- by 120-ft open-circuit leg was added and a new fan drive system was installed in the 1980s. The 80- by 120-ft test section is the world's largest wind tunnel and is capable of testing a full-size Boeing 737 at velocities up to 100 knots at nominal unit Reynolds numbers of 1.1 million/ft.

A system of moveable vanes can be positioned so that air is either drawn through the 80- by 120-ft test section and exhausted into the atmosphere, or driven around the closed circuit through the 40- by 80-ft test section. A passive air exchange system is utilized in the 40 by 80 circuit to keep air temperatures below 125ºF.

The new fan drive system is composed of six variable-pitch fans, each 40 ft in diameter, arranged in two rows of three. Each fan has 15 laminated wood blades and is powered by a 22,500 hp electric motor. The six fans rotate together at 180 rpm drawing 106 MW of electricity at full power while moving more than 60 tons of air per second.

Unique test-specific requirements are explored with each customer to guide the experiment design, and new systems are integrated into the facility as needed. Utility support systems that have been used for testing powered vehicles and components include variable-frequency electrical power, hydraulic power units, cooling water, 150- and 400-Hz electrical power and jet fuel systems. Rotor test beds incorporating electric motors and rotor balance systems are available for testing complete rotor and hub systems independent of the flight vehicle.



JPL Mars Science Laboratory Parachute Testing

NASA/Army UH-60 Individual Blade Control Test on the Large Rotor Test Apparatus (LRTA)

National Full-Scale Aerodynamics Complex Capabilities

Tunnel	Test Section Size		Speed Range (Mach No.)	Reynolds No. Range (million per ft)	Dynamic Pressure (psf)	Total Pressure	Total Temperature (º F)	Pressure Altitude (nominal, K ft)
	Cross Section (ft)	Length* (ft)						
National Full-Scale Aerodynamics Complex	40 x 80	80	0 - 300 knots	<3	0 - 262			Sea Level
	80 x 120	190	0 - 100 knots	<1.1	0 - 34			Sea Level

* Nominal test section length dimensions are shown. The actual model lengths that can be tested depend on Mach number and should be coordinated with the AEDC test engineering staff.

TURBINE ENGINE COMBINED TEST FORCE

The Turbine Engine Combined Test Force at AEDC is responsible for propulsion testing in the Engine Test Facility (ETF) test cells, which are used for development and evaluation testing of turbine-based propulsion systems for advanced aircraft. These test cells provide essential test and evaluation services in support of DoD, U.S. industry, and international programs. AEDC operates eight active test cells for atmospheric inlet and altitude testing.

AEDC test cells are used for testing and evaluation in areas including performance, operability, aeromechanical, icing, corrosion, inlet pressure distortion, inlet temperature distortion, accelerated mission testing (AMT), engine-inlet dynamics, mission simulations, and engine component testing. Test cells are available in a range of sizes to meet customer needs. AEDC has the right test cell for virtually any requirement, whether the test article is a small cruise missile engine or a large turbofan engine for the airline industry.

The ETF contains instrumentation and controls infrastructure to acquire measurements from an extensive variety of instrumentation used in turbine engine testing. The various sensors available can support the requirements of both production and development engines. Measurement capabilities include force, fuel flows, airflows, high-frequency-response pressures, displacement, acceleration, digitally-scanned temperatures, digitally-scanned pressures and high-speed digital video. Measurement capabilities in the various test cells range from 600 channels to over 3,000, with parameter recording options from 1 sample per second up to 156,250 samples per second. Control capabilities include up to 500 channels of control input/output using programmable logic controllers. Open- and closed-loop control functions can be monitored while testing and are merged in real time with instrumentation data. AEDC can provide exacting calibration services for force, fuel flow, and pressure measurements. Spectral structural analysis equipment provides real-time engine component health monitoring in conjunction with steady-state and transient data. Our systems can be modified to accommodate the customer's digital or analog systems.

AEDC is a recognized leader in propulsion testing and our capabilities are constantly improved through targeted investment to provide customers with the highest quality data and analysis results. With five decades of experience, our specialists in ground testing can provide unrivaled assistance to your team, from pretest planning through posttest analysis and evaluation. Our careful test planning and coordination with test customers ensures that test objectives are met and testing is streamlined and efficient. Our engineers and analysts can also assist sponsoring DoD organizations in pre-MS A planning activities, activities supporting Milestone B decisions, activities in support of Milestone C and beyond and integration of T&E activities and results throughout the system lifecycle to help ensure program success.

Engine Test Facility Capabilities

	Test Section Size		Nominal Capability Range			
Propulsion Development Test Cell	Cross Section	Length (ft)	Speed Range	Total Temperature (ºF)	Pressure Altitude (Nominal, ft)	Axial Thrust Capacity (lb)
Test Cell C-1	28 diam (ft)	45	Mach 0 - 2.3	-60 - 350	Sea Level - 75,000	100,000
Test Cell C-2	28 diam (ft)	47	Mach 0 - 2.3	-60 - 350	Sea Level - 75,000	100,000
Test Cell J-1	16 diam (ft)	44	Mach 0 - 3.2	-60 - 720	Sea Level - 75,000	70,000
Test Cell J-2	20 diam (ft)	46	Mach 0 - 2.6	-60 -450	Sea Level - 75,000	50,000
Test Cell SL-2	24 x 24 (ft)	60	Mach 0 - 1.4	-15 - 260	Sea Level	70,000
Test Cell SL-3	24 x 24 (ft)	60	Mach 0 - 1.4	-15 - 260	Sea Level	70,000
Test Cell T-3	12 diam (ft)	15	Mach 0 - 3.6	-80 - 1,000	Sea Level - 100,000	20,000
Test Cell T-4	12 diam (ft)	47	Mach 0 - 2.5	-40 - 400	Sea Level - 75,000	50,000
				(ºR)		On-Condition Run Time (sec)
APTU / Supersonic	42 diam (in) 42 diam (in)		Mach 3.1 Mach 4.3	1460 max 2300 max	21,000 - 54,000 63,700 - 88,400	120 max 240 max
APTU / Hypersonic	42 diam (in) 42 diam (in) 42 diam (in)		Mach 5.2 Mach 6.3 Mach 7.2	2650 max 3233 max 4700 max	54,500 - 96,400 76,000 - 105,000 88,000 - 110,000	120 max 90 max 60 max

NOTE 1: Expanded capability is available with custom upgrades to test cells.

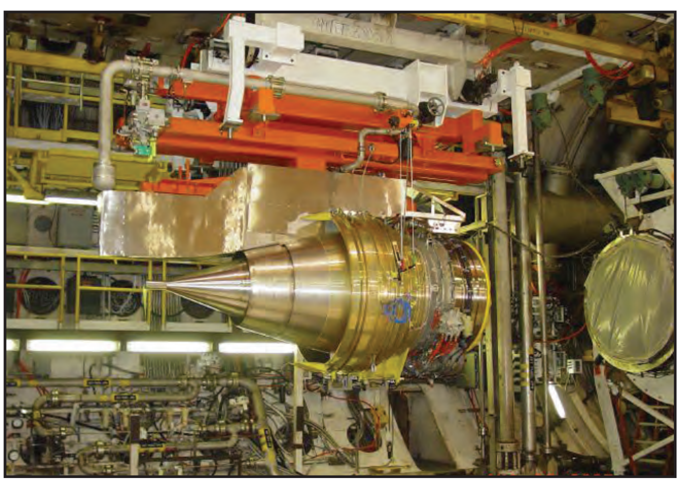
NOTE 2: Maximum performance values (temperature, speed, and altitude) do not occur simultaneously. Comparison of specific test points to cell capability will be required to ascertain feasibility.

Test Cells C-1 and C-2

Altitude Test Cells C-1 and C-2 comprise the Aeropropulsion Systems Test Facility (ASTF). This is a unique national asset designed to test large military and commercial engines in true mission environments. ASTF is part of the Engine Test Facility and has helped establish AEDC as the USAF center of expertise in turbine engine testing. C-1 and C-2 are each 28 ft in diameter and approximately 45 ft in length. Each cell is capable of testing up to Mach 2.3 and simulating altitudes of up to 75,000 ft. Either cell can provide engine inlet temperatures of up to 350º F and accommodate engines producing up to 100,000 lb of thrust.

C-1 is normally used to conduct performance testing of large augmented turbine engines. C-2 can also be used to test large augmented turbine engines, but it has recently been used for performance testing of large turbofan engines. Aeromechanical testing, vectored-thrust testing, icing testing and inlet pressure distortion testing may also be accomplished in ASTF.

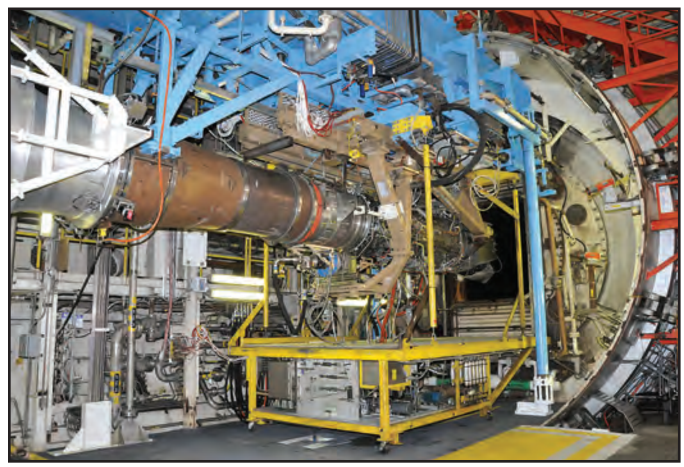
The F135 Engine for the F-35 Lightning II Aircraft Installed in C-1



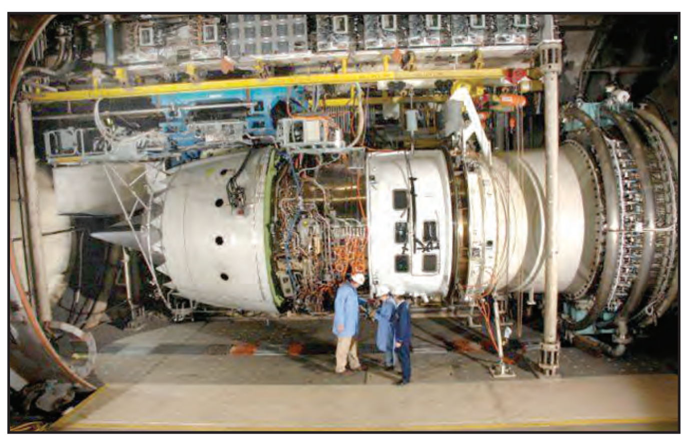
The XF7-10 Engine for the Japanese P-1 being Installed in C-2

Support systems in both cells include state-of-the-art digital steady-state and transient data acquisition systems capable of recording up to 3,500 parameters. Multiple remotely operated venturis and a multileg fuel system allow each test cell to make accurate measurements of engine airflow and fuel flow over the full range of engine operation. C-1 provides a multicomponent thrust system for the measurement of side forces up to 15,000 lb and vertical forces of up to 50,000 lb. This allows the determination of axial thrust as well as pitch and roll moments. C-2 provides axial thrust measurement and also has the capability of conducting icing testing at altitude, including the capability of transiently varying liquid water content and droplet size during a single cloud simulation.

In recent years, C-1 has principally tested F119 engines for the F-22A aircraft and F135 engines for the F-35 aircraft. C-2 has tested various large turbofan engines such as the Trent 900 and GP7200 for the Airbus A380, the PW6000 for the Airbus A318, the Trent 1000 for the Boeing 787, the XF7-10 for the Japanese P-1 and the BR725 for the Gulfstream G650.



The F119 Engine for the F-22A Raptor Installed in C-1



The Rolls-Royce Trent 1000 Engine for the Boeing 787 Installed in C-2

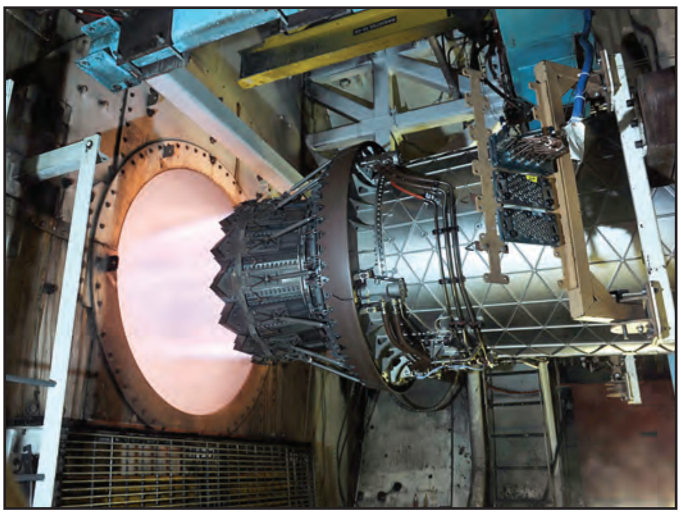
Test Cells J-1 and J-2

Test Cells J-1 and J-2 are altitude test cells sized for medium and large turbine engine testing. The cells are similar in capability to cells C-1 and C-2, but smaller in size. The cells are each approximately 44 ft in length, but J-1 is 16 ft in diameter while J-2 has a diameter of 20 ft. Both J-1 and J-2 are capable of simulating altitudes up to 75,000 ft and testing up to Mach 3.2 and Mach 2.6, respectively. J-1 and J-2 can provide engine inlet temperatures of up to 450ºF; however, J-1 can attain 720ºF with facility modifications. J-1 can accommodate engines that produce up to 70,000 lb of thrust, while J-2 is sized for engines that produce up to 50,000 lb of thrust.

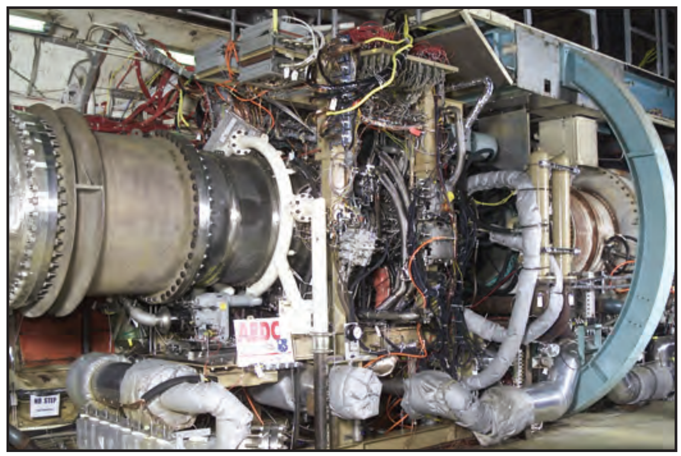
J-1 is normally used to conduct performance, aeromechanical and operability testing of medium augmented turbine engines, while J-2 is typically used for similar testing of larger augmented turbine engines. Core testing may also be accomplished in J-1.

Support systems in both cells include state-of-the-art digital steady-state and transient data acquisition systems capable of recording up to 2,600 parameters in J-1 and 3,500 parameters in J-2. Multiple remotely operated venturis and a multileg fuel system allow each test cell to make accurate measurements of engine airflow and fuel flow over the full range of engine operation. Both cells are also equipped with axial thrust stands allowing for accurate thrust measurement.

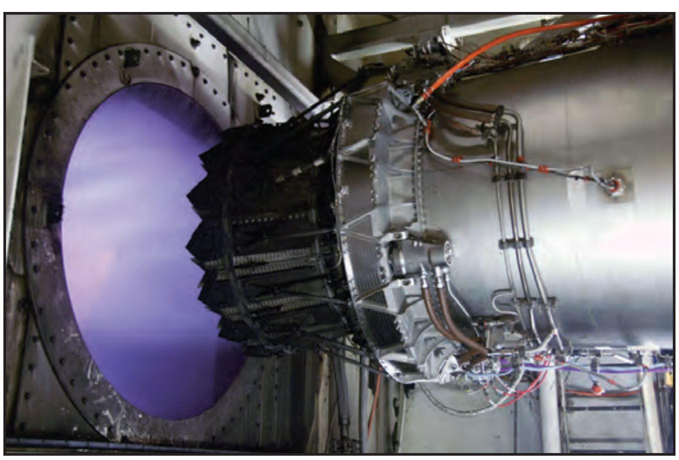
In recent years, J-1 has tested the F100 for the F-15 and F-16; the F110 for the F-16; the F118 for the B-2 and U-2; the F101 for the B-1B; and performed core testing on the Advanced Turbine Engine Gas Generator (ATEGG). J-2 has also tested the F110, F118 and F101 engines, as well as the F119 engine for the F-22A and the F135 and F136 engines for the F-35.



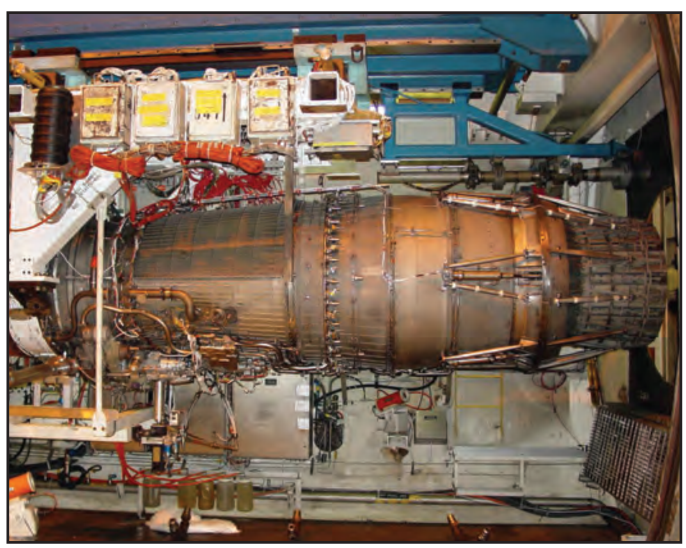
The F135 Engine for the F-35 being Tested in Test Cell J-2



The Advanced Turbine Engine Gas Generator (ATEGG) Installed in J-1 for Core Testing



The F136 Engine for the F-35 being Tested in J-2



The F101 Engine for the B-1B Bomber Installed in J-1

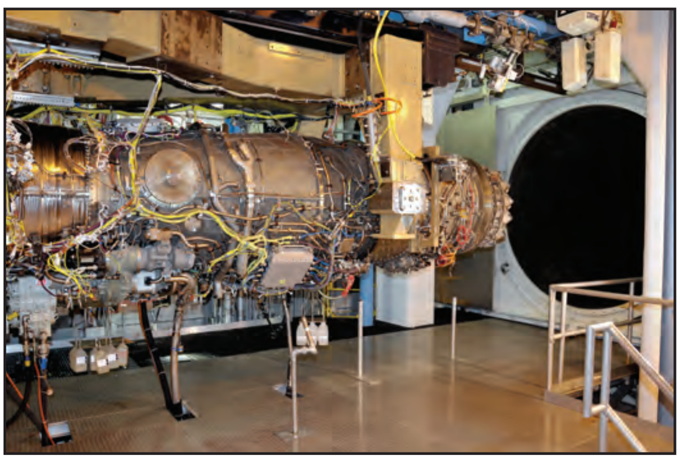
Sea Level Test Cells SL-2 and SL-3

Sea-Level Test Cells SL-2 and SL-3 provide the capability to economically conduct durability testing on large augmented turbine engines at near-sea-level conditions (1000 ft altitude) by eliminating the cost of running inlet and exhaust plant machinery. The cells are each approximately 24 ft in height and width and 60 ft in length. In addition to running ambient pressure inlet conditions, they also provide the capability of using the ETF plant to run ram conditions (inlet pressures above ambient), allowing testing at up to Mach 1.4 when necessary to achieve test objectives. Inlet temperature capability extends from ambient to 120ºF when running in the atmospheric inlet mode and from -15 to 260ºF in RAM mode. Both cells can accommodate engines that produce up to 70,000 lb of thrust.

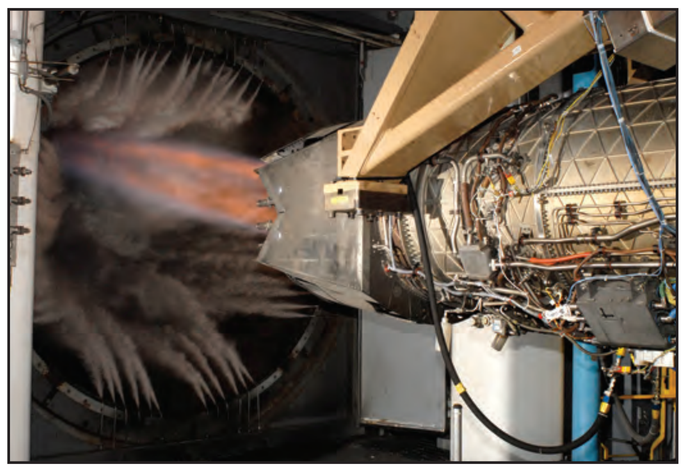
These sea-level cells are normally used for Accelerated Mission Testing (AMT). These tests evaluate engine durability and performance retention by repeatedly simulating the types of missions the engine will fly in service. The RAM capability allows interspersed testing of atmospheric inlet and RAM AMT during a single test program and eliminates the expense of engine removal and installation into another facility. In addition to a more accurate representation of engine use, it saves the customer time and money by allowing the testing to be done with a single engine installation. Since atmospheric inlet testing in SL-2 or SL-3 does not require the plant machinery, test scheduling becomes very flexible, allowing rapid completion of test objectives.

Support systems in both cells include state-of-the-art digital steady-state and transient data acquisition systems capable of recording up to 1,500 parameters in SL-2 and 2,200 parameters in SL-3. Bellmouths and multileg fuel systems allow both test cells to make accurate measurements of engine airflow and fuel flow over the full range of engine operation. Both cells are equipped with axial thrust stands allowing for accurate thrust measurement. Additionally, SL-3 is equipped to perform specialized testing such as corrosion testing.

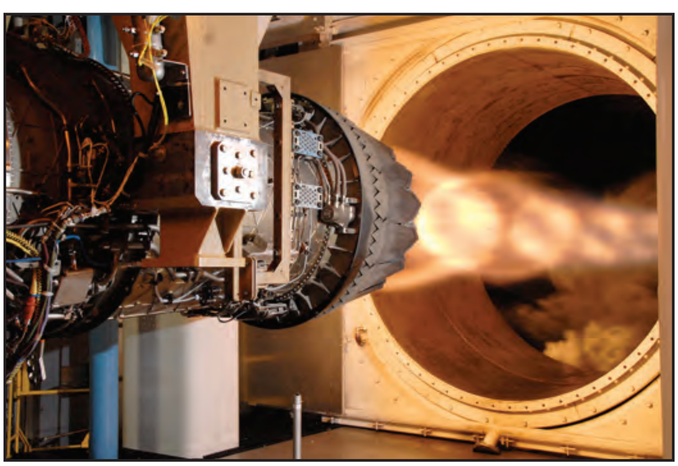
In recent years, SL-2 has tested the F100 engine for the F-15 and F-16 and the F119 engine for the F-22A. SL-3 has also tested the F100 engine, as well as the F135 engine for the F-35.



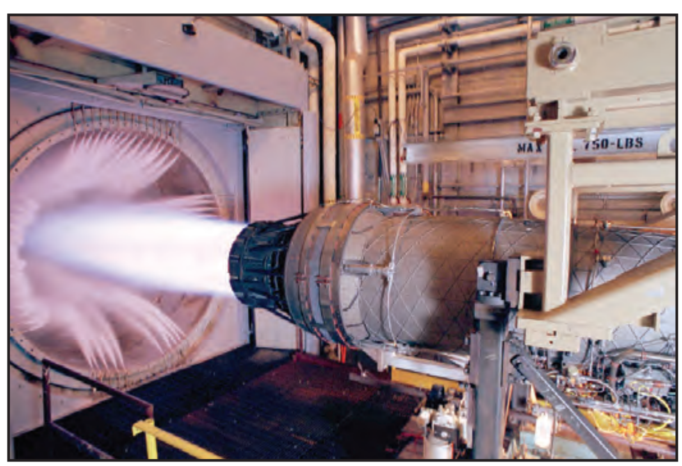
The F135 Engine for the F-35 Lightning II installed in SL-3



The F119 Engine for the F-22A Raptor being Tested in SL-2



The F135 Engine for the F-35 Lightning II being Tested in SL-3

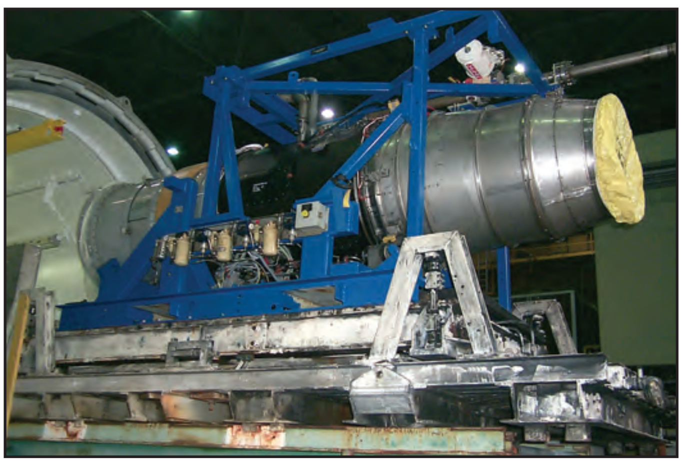


The F100 Engine for the F-15 and F-16 being Tested in SL-2

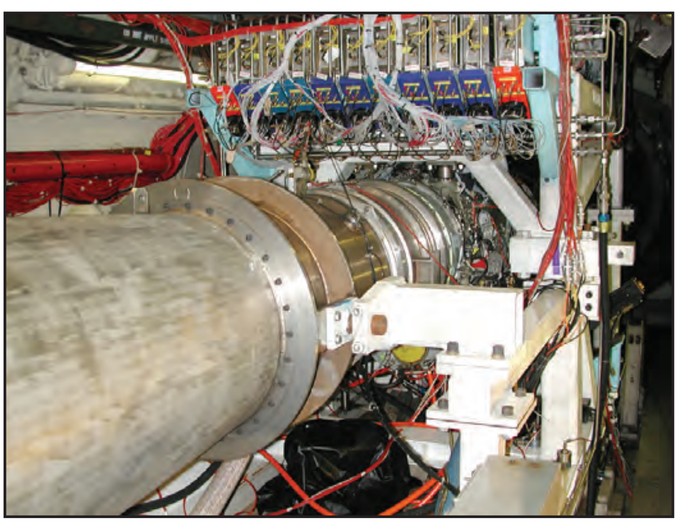
Test Cells T-3 and T-4

Altitude Test Cells T-3 and T-4 are diverse test cells with multiple test applications for testing small and medium turbine engines and cruise missile engines. Their sizes and capabilities are varied to accommodate a range of test articles. T-3 is 12 ft in diameter and 15 ft in length, and T-4 is 12 ft in diameter and 47 ft in length. T-4 is capable of testing at altitudes of 75,000 ft and Mach numbers of 2.5, while T-3 can simulate altitudes up to 100,000 ft and Mach numbers of up to 3.6. The maximum inlet temperature capabilities are 400ºF for T-4 and 1,000ºF for T-3. T-3 and T-4 can accommodate engines producing up to 20,000 and 50,000 lb of thrust, respectively.

These cells are used for a variety of types of testing. T-3 is used for high Mach number turbine engine and cruise missile engine testing; T-4 is normally used for performance and operability testing of medium turbine engines. These two cells are not in continuous use at AEDC. Some activation time may be required prior to use.



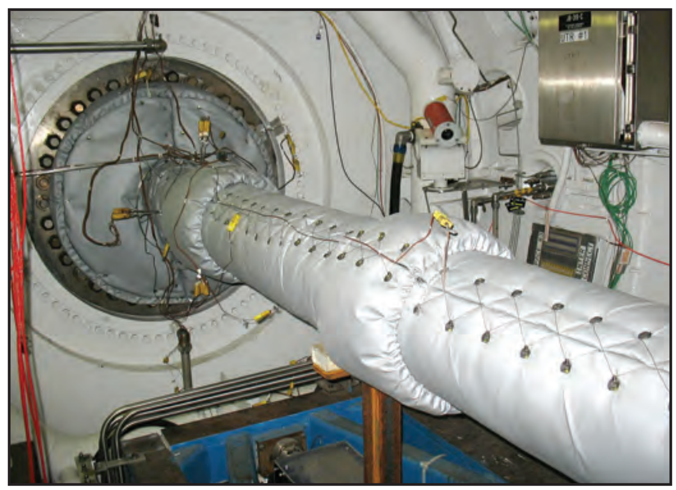
The AE3007H Engine for the RQ-4 Global Hawk being Installed in T-4.



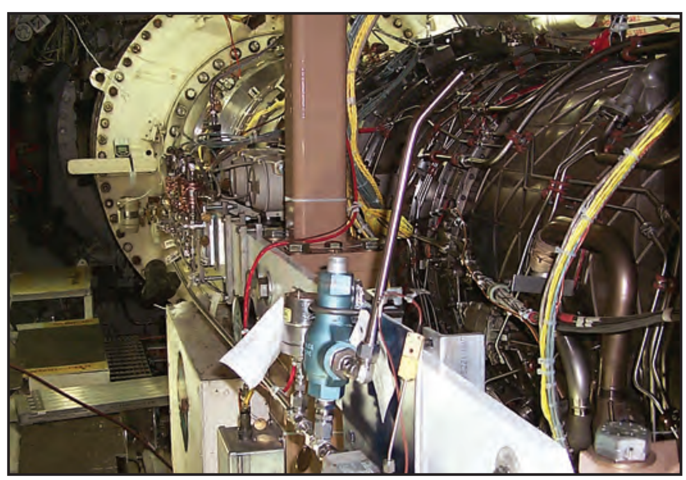
The F405 Engine for the T-45A Installed in T-4

Support systems include steady-state and transient data acquisition systems capable of recording up to 1,100 parameters in T-3 and 1,500 parameters in T-4. Venturis and/or calibrated bellmouths and multileg fuel systems allow each test cell to make accurate measurements of engine airflow and fuel flow over the full range of engine operation. T-3 is equipped with a multicomponent thrust stand, while T-4 is equipped with an axial thrust stand.

In recent years, T-3 has performed combustor rig testing for Westinghouse and supersonic flight conditions for advanced engine designs, and T-4 has tested the F100 engine for the F-15 and F-16, the F414 engine for the F/A-18E/F, the AE3007H engine for the Global Hawk and the F405 for the T-45A. The F107-WR402A engine for the JASSM-ER, the F415 engine for the Tactical Tomahawk cruise missile, the F107 engine for the BGM-109G cruise missile, the F112 engine for the ALCM, the JETEC engine demonstrator, and accomplished combustor segment testing for the F135 engine for the F-35 have all been tested in ETF and can be accommodated in T-3 or T-4 test cells.



Insulation Blankets to Reduce Test Cell Heat Load in T-3



The F100 Engine Installed in T-4

Aerodynamic and Propulsion Test Unit

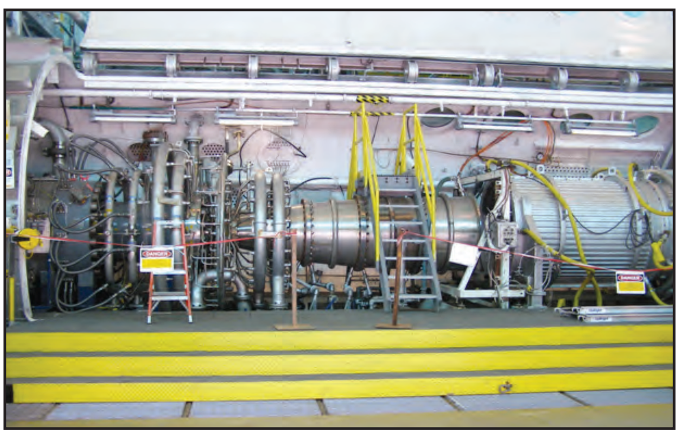
The Aerodynamic and Propulsion Test Unit (APTU) is a blow-down, true temperature and pressure test facility designed for testing the performance, operability, and durability of supersonic and hypersonic missile scale flight system hardware including propulsion systems and materials. APTU can test in either freejet or direct connect configurations.

The test environment at APTU is supplied by the Combustion Air Heater (CAH). The CAH, installed in 2004, burns isobutane fuel in a flow of high pressure air and oxygen to provide a test medium with an oxygen mole content equivalent to air. APTU can operate over a range of total pressure from less than 100 psia to 2,800 psia (6.8 atm to 190.5 atm) and a range of total temperature from 1,000ºR to 4,700ºR (556 K to 2,611 K). Though it has been cleared for operations up to Mach 6.75, it is capable of generating test conditions near Mach 8 with an appropriate nozzle. Five fixed area ratio converging / diverging freejet nozzles are currently available to produce test conditions from Mach 3.1 to Mach 7.2. All five nozzles have an exit diameter of 42 inches (1067 mm). Test medium enthalpy levels varying from Mach 2.9 to Mach 7.4 have been obtained with the CAH and these nozzles. Test durations, while dependent on the specific test condition being simulated and the test article under test, are normally on the order of two minutes, excluding facility startup and shutdown.

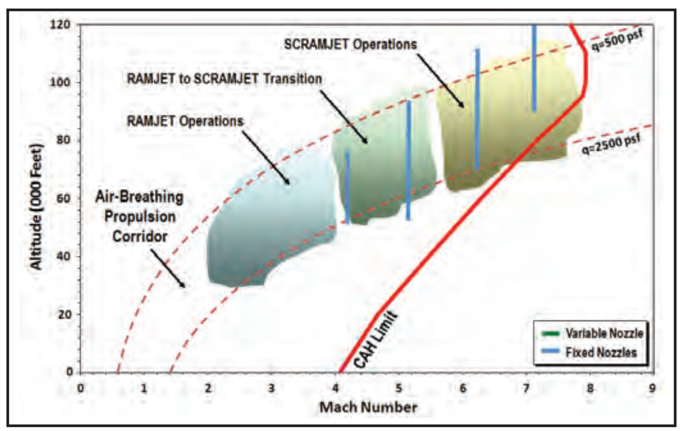
The supersonic and hypersonic flight conditions generated by the facility are controlled by the newly installed Facility Control System (FCS). The FCS has demonstrated control of the various key parameters to within half of a percent of set point during steady state operation. Transients representing altitude variations at rates representative of those obtainable with a flight system have been demonstrated to within two percent of set point.

Other utility systems are available in the test cell area to support customer test needs. The APTU data system can collect over 600 channels of pressure, temperature, and voltage data from user tests. High pressure water at flow rates greater than 300 lbm/sec (136 kg/sec) at pressures as high as 2000 psia (136 atm) is available. A six component thrust stand is available, with a maximum thrust load capability of +/- 5000 lbf (22.4 kN). Exhaust pumping is provided by an air ejector system, so expulsion of test article hardware from the test cell can occur without concern for an exhaust plant downstream of APTU.

The APTU provides customers with a much needed ground-test capability for the acquisition of transitional Mach number flight conditions to better develop operational high-speed and hypersonic flight systems.

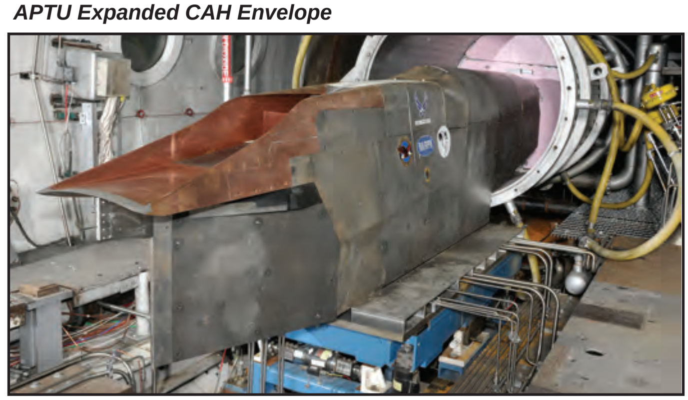


CAH with Freejet Nozzle Installed



APTU Expanded CAH Envelope

CAH Nozzle Exit Characterization with Hypersonic Calibration Rake



DARPA FaCET Test Article Installation

SPACE AND MISSILES COMBINED TEST FORCE

The Space and Missiles Combined Test Force at AEDC is responsible for ground testing space and missile weapon systems. The CTF provides lethality, rocket propulsion, aerothermal, supersonic, hypersonic, and space test and evaluation services. The Complex coordinates testing and evaluation in 19 facilities that support the development of tactical missile interceptors, ballistic missiles, launch vehicles, reentry materials, hypersonic air vehicles, space sensors, and satellite systems. Additionally, the Space and Missiles CTF is chartered with collecting and maintaining the nation's largest archive of missile and rocket hard-body and plume signature data in the Advanced Missile Signature Center (AMSC).

Space testing capabilities include evaluating infrared and visible sensor performance, mission simulation and other hardware-in-the-loop activities. AEDC performs testing for space systems in a thermal/vacuum environment from component level to full-scale, flight-qualified systems. For component scale hardware, testing to simulate full spectrum space environments is available and includes contamination, solar, atomic oxygen, outgassing, radiation and other effects. For combined effects of natural conditions, self-induced hazards, and hostile threats on full-scale systems or subsystems; our newest capability in the Space Threat Assessment Testbed (STAT) can provide analysis leading to the development of operational Tactics, Techniques, and Procedures (TTPs) for satellite systems.

Space and Missiles Test Facility Capabilities

Lethality	Facility	Projectile Size (in. diam)	Launch Velocity (ft/sec)	Projectile Mass (lbs)	Pressure Altitude (ft)	Run Time (shot/day)
Ballistic Ranges -	Range G	3.3	4900 - 22,700	1.0 - 13.2	Sea Level - 225,000	1
Hypervelocity and	Range G	4.0	4900 - 19,700	1.0 - 13.2	Sea Level - 225,000	1
Impact/Lethality	Range G	8.0	5600 - 17,100	13.2 - 44.1	Sea Level - 225,000	1
Erosion	Range I	2.5	4900 - 22,100	0.7 - 8.8	Sea Level - 225,000	1
	Range S1	0.3 - 0.75	4900 - 26,200	0.018 - 0.820 (oz)	Sea Level - 300,000	2
	Range S3	7.0	131 - 2300	3.3 - 55.1	Sea Level	2

Rocket Propulsion	Facility	Test Section Size	Thrust Stand (lb)	Pressure Altitude (ft)	Cell Temp Control (ºF)	Run Time (min)
Solid Propellant	Cell J-6	26 ft diam x 62 ft long	5000 - 500,000	up to 100,000	15 - 110	1 - 6 min
Liquid Propellant	Cell J-4†	48 ft diam x 82 ft high	5000 - 500,000	up to 100,000		5 min

Aerothermal	**Facility**	**Nozzle Exit (in.)**	**Mach No.**	**Stagnation Enthalpy (Btu/lbm)**	**Pressure Atmos**	**Mass flow (lbm/sec)**	**Run Time (min)**
High Enthalpy	H1	0.75 - 3.0	1.8 - 3.5	600 - 8500	<120	0.5 - 8	1 - 2
Ablations	H2	5.0 - 42.0	3.4 - 8.3	1200 - 5500	<120	2 - 10	3 - 30
Erosion	H3	1.2 - 4.5	1.8 - 3.5	600 - 8500	<150	3 - 25	1 - 2
	Tunnel 9*	11.3	6.7	900 - 925	52 - 67	18 - 37	3 - 6
	Tunnel C*	25	4, 8	170 - 480	1 - 130	0.6 - 55	Continuous

Space Sensor	Facility	Environmental Conditions	Run Time	Image Sources
Sensor Calibration	7V	sensor: ambient - 15K, 10^{-7} torr	Continuous	2 Independently Moving Precision Blackbody Targets - 500 K
Characterization		background: 15K, 10^{-7} torr		Dynamic Complex Scenes - IR Arrays, 512 x 512, 45 Hz, 1◦ x 1◦ FOV
3-Color Sensor HWIL	10V	15K, 10^{-7} torr	Continuous	2 Independently Moving Precision Blackbody Targets - 800 K 2 IR Arrays, 512 x 512, 45 Hz; 1 Visible Array, 1024 x 1024, 45 Hz Closed-loop HWIL

Space Environments	Facility	Test Section Size	Wall T, Altitude P	Environmental Capabilities
Combined Space	STAT	fits 2.5 ft x 2.5 ft x 2.5 ft test article	80 K, 10^{-6} torr P	Combined effects of natural/self-induced/ man-made threat sources: Natural - Protons [30-150 KeV, 10^2 to 10^8 p+/cm^2/sec]** Electrons [20-100 KeV, 5x10^2 to 5x10^8 e-/cm^2/sec]** Solar [120-2500 nm photons at 1 sun (±20%)] Atomic oxygen [5 eV, 1x10^{10} to 2x10^{12} 0/cm^2/sec]** Self-induced - thruster ions, material outgassing, spacecraft charging
Combined Space	CCOSE	fits 2" diam x 1/2" thick test article	ambient T, 10^{-6} torr P	electrons, protons, ions, atomic oxygen, 120-2500 nm solar
X-ray Environment	MBS	2.5 ft diam target area	ambient T, 10^{-6} torr P	Cold (5 KeV) or Hot (1-2 MeV) X-Ray
Electric Propulsion (<50kW)	12V	12 ft diam x 35 ft tall	15K, 10^{-7} torr P	10^6 torr L/sec Xenon pumping capacity

Signature Measurement	Facility	Spectral Bands (µm)	Equipment	Calibration
AMSC	Rapid Deployment Team	0.250-12	10 Radiometers, ~20 Imagers, 4 spectrometers, 4 Tracking Mounts	NIST Traceable Engineering Units

† Inactive
* See Flight Systems section for additional information.
** Higher fluxes available with smaller test volumes

Ballistic Ranges G, I, S1 and S3

Hypervelocity Ballistic Range G is used to conduct kinetic energy lethality and impact phenomenology tests. The Range G launcher is the largest two-stage, light-gas gun system in the United States that provides unequalled "soft launch" (minimized acceleration loading) capability to launch extremely high-fidelity missile simulations at hypervelocity speeds. Quarter-scale testing is available at velocities from 4,900 to 23,000 ft/sec (1.5- to 7-km/sec). Recent improvements have extended the range of capabilities to projectiles near half scale of actual interceptors.

The Range G launcher is capable of launching various types of projectiles at velocities up to 23,000 ft/sec (7.0 km/sec). Projectiles up to 8.0 in. (203 mm) in diameter are launched into a 10-ft (3-m)-diameter, 930-ft (283.5-m)-long instrumented tank that can be maintained at pressure altitude from sea level to 225,000 ft. Three sizes of interchangeable barrels; 3.3 in. (84 mm), 4 in. (102 mm), and 8 in. (203 mm), are available for use on the Range G launcher. A four-rail guidance system can be mated to the barrel in order to guide the projectile close to the target and provide increased hit-point accuracy.

The 3.3-in. (84-mm)-diam launch tube is typically used to support one-fourth scale testing (projectile and target one-fourth the size of the full-scale system), but in order to meet the lethality test requirements of missile defense programs, AEDC has developed the capability to launch larger scale projectiles up to 8 in. (203 mm) at higher velocities than those previously achievable at any ground-test facility. With this capability, AEDC is able to provide a greater level of projectile and target fidelity for tests conducted with two-stage light-gas guns.

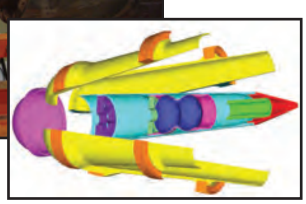
The primary challenge in designing projectiles for gun range lethality testing is to develop a geometrically scaled projectile that matches the axial and radial mass distribution of the actual missile and is able to withstand the acceleration loads experienced during gun launch. The use of 3-D finite-element analysis software (ABAQUS) coupled with the AEDC light-gas gun code provides a seamless projectile design capability.

In addition to the unique capability to duplicate, at subscale, the lethality of missile impacts, the range has for many years served the ground-test community in other areas of hypersonic research. This unique ability to duplicate real flight, although at subscale, makes it the ideal facility for a variety of testing requirements such as, aerodynamic, boundary-layer studies, aerothermal heating assessments, wake physics, material phenomenology and hypersonic plasma mitigation studies. All of this capability comes at a very low cost when compared to flight test.

Other Range Capabilities

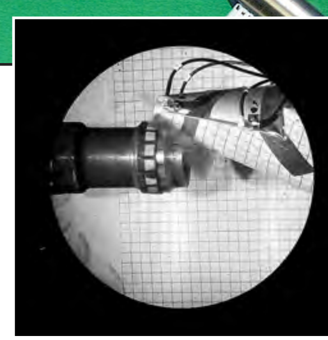
Three other ranges are available at AEDC.

- Range I is similar to, but smaller than, Range G.
- Range S1 is a two-stage, 0.75-in. lab gun similar to Range G.
- Range S3 is a 7-in., single-stage gun previously used for bird-strike impact testing of aircraft canopies.



High-Fidelity, Large-Scale Lethality Testing in Range G and CAD Drawing of the Model

Above: High-Fidelity Projectile and Sabot



Right: Lethality Ground-Based Missile Defense Test

Rocket Development Test Cell J-6

The J-6 Facility provides ground-test simulations for solid-propellant rocket motors. J-6 has been used mainly for aging and surveillance and in testing of stages II and III for both Minuteman and Peacekeeper ICBMs. Additionally, J-6 has supported ORBUS and CASTOR® 30 as well as STAR37 motor qualification testing for the Air Force's Global Positioning Satellite (GPS) constellation. AEDC has unique test capabilities for testing rocket propulsion systems with high-performance/high-area-ratio nozzles and those requiring altitude start and restart, stage separation and spin testing. J-6 is the largest of its kind in the world and provides the only altitude test capability for large solid-propellent rocket propulsion systems in the United States. Ambient (sea-level) testing of rocket propulsion systems designed for high-altitude operations can compromise engine performance data and potentially jeopardize the structural integrity of the exhaust nozzle. Ground testing under simulated altitude conditions in J-6 includes carefully controlled test environments with extensive instrumentation and photographic coverage to validate the operability and performance of a test article.

The J-6 digital data acquisition system is designed to acquire up to 500,000 samples/sec. Testing can also include an extensive array of sophisticated rocket diagnostic instruments obtainable only in a ground-test configuration. State-of-the-art techniques such as wide-band infrared and ultraviolet radiometric coverage, emission/absorption detection, laser-induced fluorescence, plume surveys and real-time radiography are applications available for use in J-6 testing.

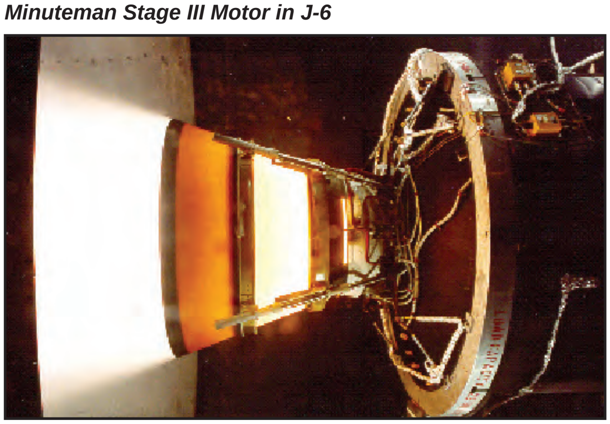
J-6 is designed to test large Class 1.3 or 1.1 (detonable) solid-propellant rocket motors weighing up to 100,000 lb. Measuring 26 ft in diameter by 62 ft long, the horizontally oriented test cell is capable of testing rocket motors at simulated altitudes up to 100,000 ft. The temperature conditioning system can maintain the test cell at an air temperature within the range of 15 to 110ºF (±5ºF) from motor installation until prefire pumpdown to altitude conditions.

J-6 supports long-duration altitude tests of high-area-ratio nozzle including extendible nozzle deployment operation with dynamic loads, thermal ignition tests, stage separation testing, heat transfer, postheat soaking and failure analysis. This facility can be used to test many different types of motors with large quantities or advanced mixes of propellants. The facility is equipped with three interchangeable diffusers that can ensure minimal blowback at shutdown while accommodating thrust ranges from 5,000 to 500,000 lbf. The test cell is connected to a 250-ft-diam by 100-ft-high concrete dehumidification chamber that collects, cools and conditions the resulting rocket exhaust products.

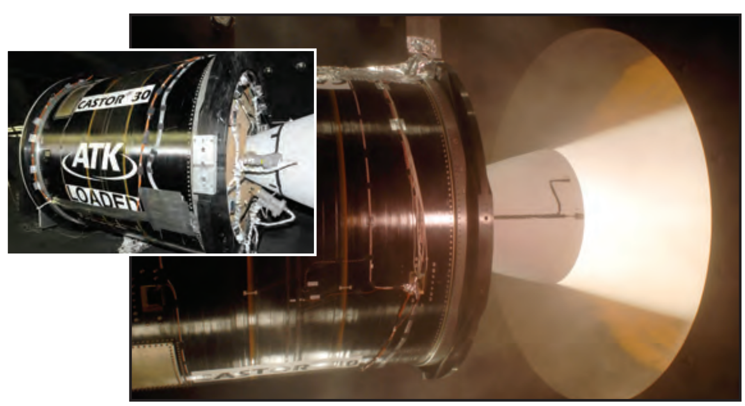
Minuteman Stage III Motor in J-6

Additional Unique J-6 Capabilities

- An exhaust plant with steam systems provides simulated altitude and soft shutdown to prevent blowback on the test article.
- Thrust measurement up to 500,000 lbf with 0.25% uncertainty
- A spin rig which can spin motors up to 90 rpm
- Certified to test class 1.1 explosive classified rocket motors



Peacekeeper Stage II Altitude Test Firing in J-6



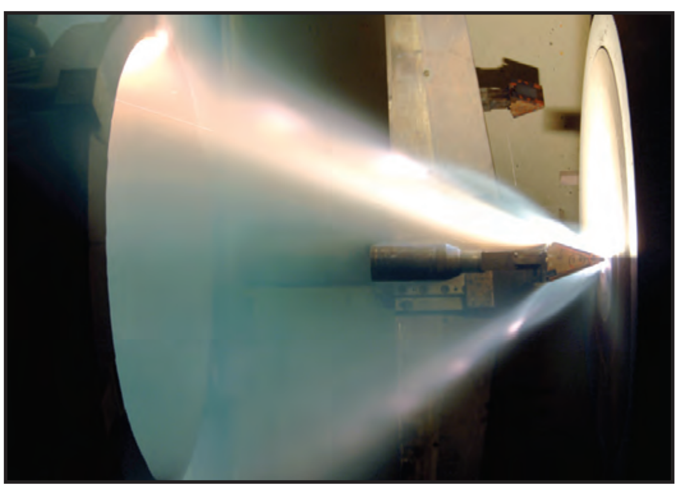
ATK's CASTOR® 30 was Ground Tested in J-6.

Arc Heaters H1, H2 and H3

The AEDC arc heater facility is used to provide high-enthalpy test environments to test materials and other means of thermal protection. The AEDC arc-heated test facilities include two high-pressure, segmented arc heaters (H1 and H3) and one Huels arc heater (H2). Both types utilize an arc discharge to heat air to temperatures up to 13,000ºR. The combination of high-enthalpy test gas and high plenum pressure makes possible heat flux simulations representative of flight at speeds in excess of Mach 20 at high dynamic pressures.

The 30-MW H1 Test Unit is an advanced performance arc-heated facility providing high-pressure, high-enthalpy test conditions for qualification of thermal protection materials, nosetips, and electromagnetic apertures and structures for hypersonic missiles, space access systems, and reentry vehicles. The unique segmented construction allows the arc to be held at a fixed length to optimize heater efficiency, total enthalpy at high pressure, and flow uniformity. Normal operating conditions for the heater are about 20,000 V and 1200 amp, providing heater chamber pressures up to 120 atm at high stagnation enthalpies. The H1 test cell is equipped with a multiple-strut, programmable rotary model injection system capable of positioning one to seven test models sequentially into the test freejet for preset dwell times.

The 45-MW H2 Test Unit is an arc-heated aerothermal tunnel providing high-enthalpy flow at high Mach numbers and dynamic pressures simulating hypersonic flight at pressure up to 120 atm. H2 utilizes an N-4 Huels type arc heater to generate high-temperature, high-pressure air for expansion through a hypersonic nozzle into the evacuated test cell. The combination of the arc heater driver, various nozzle/throat combinations, the evacuated test cell, and the exhauster makes possible high-enthalpy flows at Mach numbers from 3.4 to 8.3.

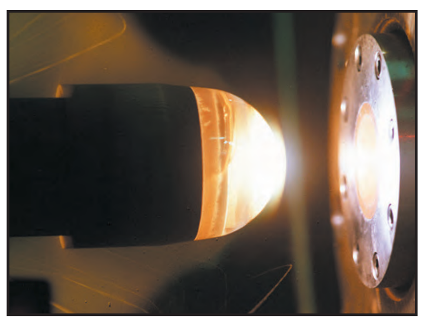


Materials Test for the NASA Orion Crew Exploration Vehicle

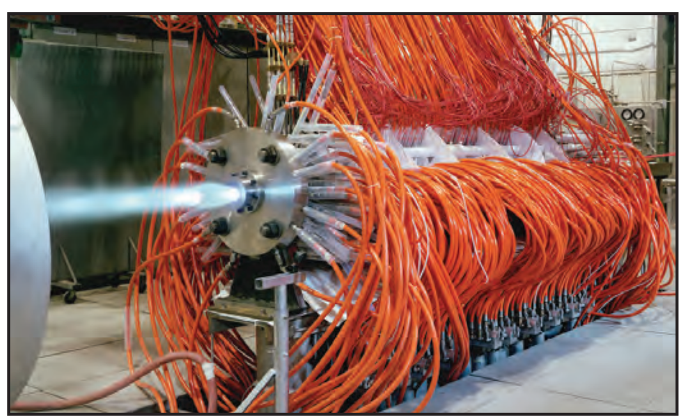
The 70-MW H3 arc heater was developed to provide a large, high-pressure arc facility with sufficient size and performance for testing of full- and large-scale missile and reentry samples and structures. H3 is a 12-module, 50% geometric scale-up of the H1 segmented arc heater and is designed to operate at over twice the available power level and mass flow of H1, with operational pressure up to 150 atm.

Typical Test Techniques

- Steady-state ablation testing of nosetip materials
- Nosetip boundary-layer transition tests during which the nosetip is subjected to a Reynolds number variation of a factor of five during the run
- Wedge tests where two-dimensional material samples are exposed to various pressure/heat-transfer rate combinations
- Combined ablation/erosion tests using graphite dust particles accelerated in the arc heater to high velocity
- Cooling-effectiveness tests on actively-cooled electromagnetic apertures or transpiration-cooled nosetips
- Hot transmission testing of antenna window materials



Leading-Edge Model in H2 Tunnel



H3 Arc Heater Firing

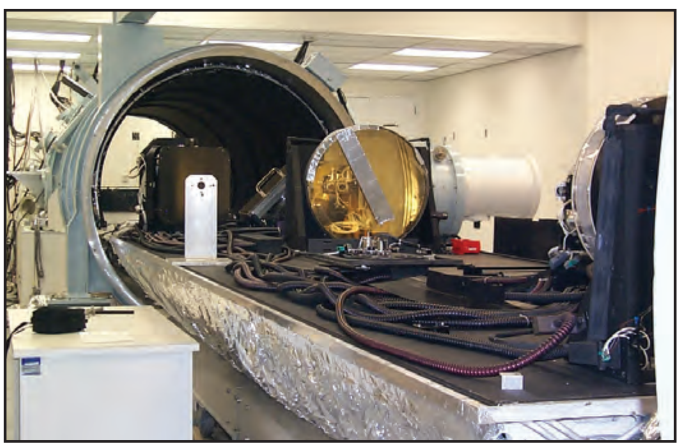
Space Environmental Chambers

The AEDC 7V (7-ft diam by 21-ft long) and 10V (10-ft diam by 30-ft long) sensor chambers are part of a state-of-the-art space environment simulation test facility designed to test interceptors and surveillance sensors. These chambers are configured to provide complete characterization and radiometric calibration of visible and infrared (IR) sensors. This includes all categories of sensor characterization (flood, point, polarized source, spectral calibration and mission simulation). An assortment of source systems allows evaluation of sensor performance over a wide range of target conditions. Current generation sensor arrays mounted in the chambers provide independent source and background evaluation and target position. Both chambers are cooled using gaseous helium shrouds with an optically clean vacuum system. 7V is in a Class 1,000 Clean Room, while 10V is in a Class 10,000 Clean Room. A 300,000-lb seismic mass allows vibration isolation of the optical bench and all optical elements in 10V. A radiometric calibration system allows for accurate calibration of source systems that is traceable to the National Institute of Standards and Technology (NIST).

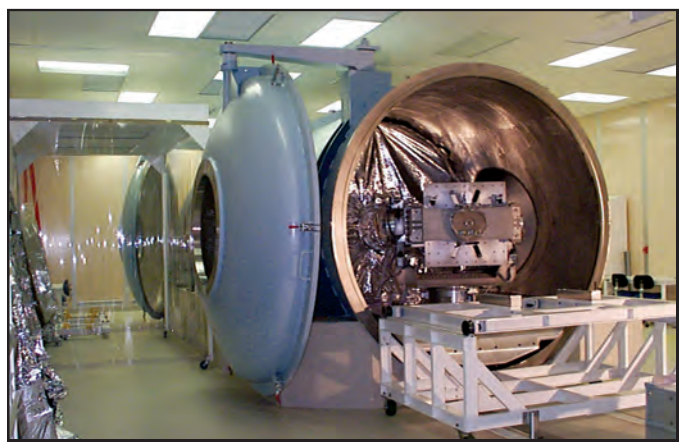
7V provides the unique capability to test sensor systems in a flight-representative temperature and pressure environment (either aircraft or space conditions) while simultaneously maintaining a different target representative environment (e.g., space). 7V has also been used to test UAV subsystems, such as tactical communication radios, in flight-representative environments.

The 10V Chamber sensor test facility features a high-fidelity target system containing multiple independent point-source systems to simulate target acquisition and tracking operations. An IR scene projection system is used to simulate objects in the sensor's field-of-view and provides simulation of the terminal phase of the interceptor mission. A visible projection system is used to simulate star shots and objects that appear in the visible spectrum. The 10V Chamber is configured to provide end-to-end closed-loop mission simulation capability for interceptor and surveillance sensor systems, providing simulation of the sensor mission from launch to intercept.

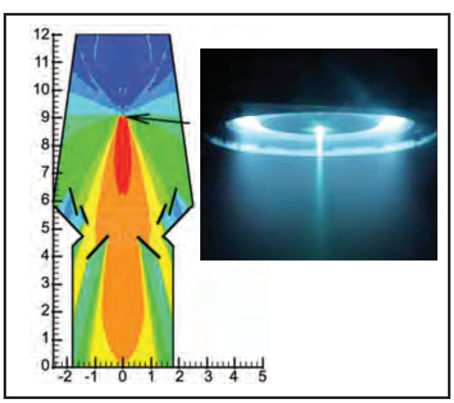
The 12V Chamber is a 12-ft-diam by 35-ft-high



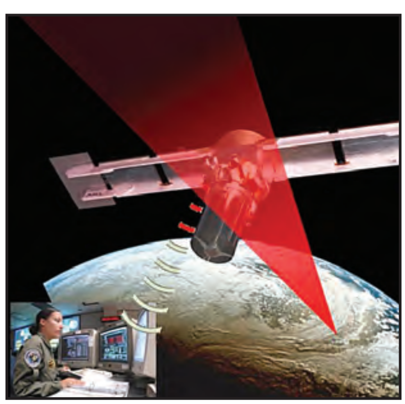
7V Sensor Test Chamber



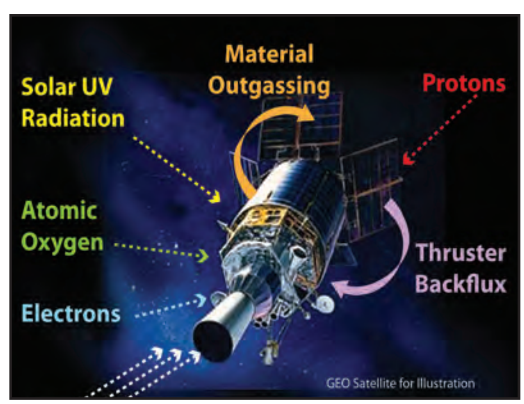
10V Sensor Test Chamber



Computational Model and Results of 12V Vacuum Chamber Electric Propulsion Test



Combined Environment, Threat and SOC Concept



Spacecraft Environment for STAT

thermal vacuum test facility. The facility has its own nitrogen thermal shroud and an optional gaseous helium liner that can be cooled to 10° K. The chamber is currently configured for high-power electric propulsion (EP) thruster plume analysis and integration effects.

The Space Threat Assessment Testbed (STAT) can evaluate space systems and subsystems in natural environments subjected to hazards and threats while simulating various orbits. The STAT chamber is contained in a class 10,000 clean room. STAT delivers a combined research and development test environment approach for simulating a mission environment with natural space sources (solar, proton, electron, atomic oxygen), self-induced hazard sources (ions to simulate electric thrusters, outgassing, spacecraft charging) and man-made threat sources.

Advanced Missile Signature Center

The Advanced Missile Signature Center (AMSC) is a national facility supporting the Missile Defense Agency (MDA), Defense Intelligence Agencies (DIA) and other DoD programs with analysis, modeling, measurement, archival and distribution services. The AMSC archives include target, threat and battlespace environment signatures for missiles and other vehicles. Staff expertise and supporting infrastructure are primarily focused on tactical and ballistic missile ultraviolet, visible and infrared plume signatures. These capabilities are leveraged to also address signatures associated with missile postburnout and reentry, celestial and terrestrial backgrounds, scene generation and other battlefield targets such as mortars, small arms fire and fixed and rotary wing aircraft.

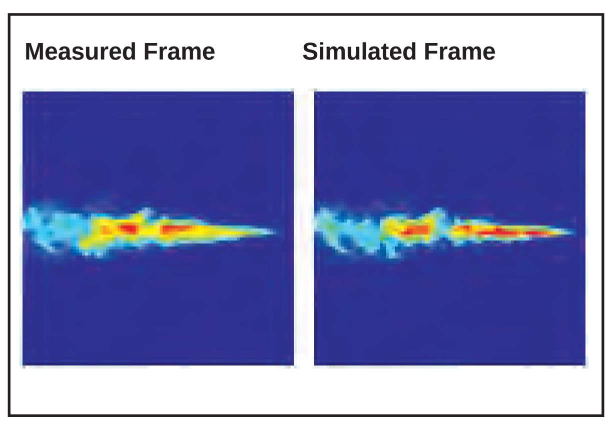
AMSC experts use state-of-the-art instrumentation and infrastructure to collect temporal, spectral and spatial signatures during static, launch, sled and free flight tests on test ranges in and outside the USA. Sensors are calibrated to National Institute of Standards and Technology (NIST) pedigree and deployed for expert digital data collection, processing, analysis and quick-look products.

Measurement capabilities are complemented by the development and enhancement of computational tools for data processing, data analyses and physics-based modeling. AMSC maintains expertise in various image processing and analysis tools and government standard modeling and simulation codes to exploit measured data and confidently extrapolate to signatures in the flight envelope that are not readily measured. This extrapolation process anchors the modeled signatures to measured data. Thousands of modeled signatures are then coupled with an AMSC processing methodology to generate a hypercube of high-fidelity flight envelope signatures that are readily accessible for real-time, hardware-in-the-loop applications.

The AMSC efficiently manages digital data, documents and other nondigital media such as film and video at multiple classification levels. All documents are converted to softcopy text searchable form for information search and retrieval. For key digital data sets, primary data and metadata are merged into a common standard archive format that permits data recipients to quickly access and exploit data content. Film and video media in 16-, 35- and 70-mm film formats and all of the major video formats can be digitized, and image processing tools can be applied to further exploit collected data. Catalogs and certain program data sets are also available through access-controlled websites.

EO-IR Instrumentation Deployed for Static Test

Infrared Image During Launch



Measured and Simulated Tactical Missile Plumes

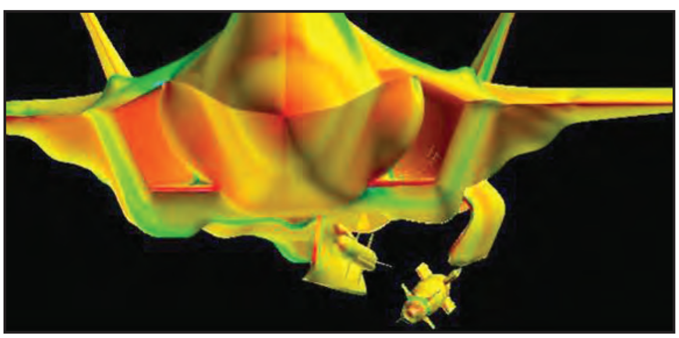
TEST TECHNOLOGY BRANCH

The Arnold Engineering Development Complex supports a robust and versatile Test Technology Branch focused on three primary disciplines in support of the CTFs and integrated test and evaluation processes: Modeling and Simulation (M&S), Instrumentation and Diagnostics (I&D) and Facility and Testing Technology (F&TT). A team of engineers, scientists, craft and support personnel provide expertise to develop, adapt and apply complex computational models, nonconventional diagnostic systems, advanced facility capabilities, test techniques and engineering-level facility models to address customer testing and AEDC facility infrastructure requirements.

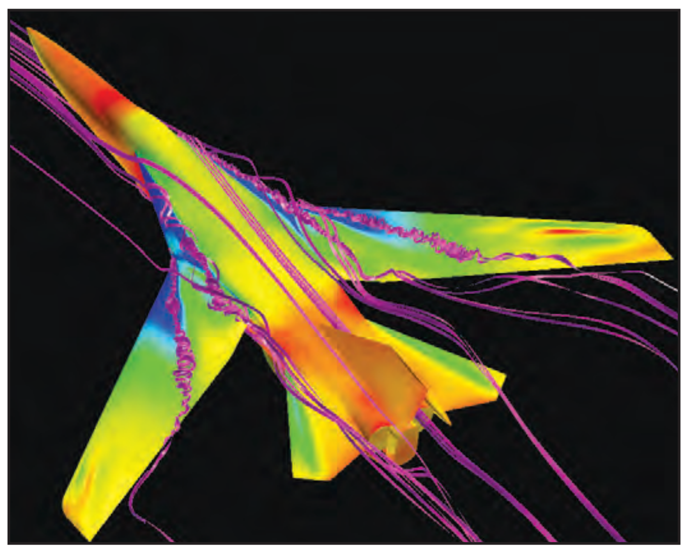
The goal of the M&S focus area is to provide validated, computationally efficient tools that can be transitioned to support test engineers in their efforts to optimize test matrices and test facility configurations, including placement of critical diagnostic instrumentation. Posttest computational fluid dynamic (CFD) simulations provide insight for diagnosing and correcting data anomalies and extrapolating ground-test data to flight scenarios. To this end, we are key players in the High Performance Computing Modernization Office development and application of the Computational Research and Engineering Acquisition Tools and Environments - Air Vehicle (CREATE-AV) computational tools.

Aerodynamic flow models predict environments surrounding complex aerodynamic vehicles. Interactions of the freestream flow with control surfaces and the separation of stores from aircraft bays and pylons are significant aerodynamic concerns addressed by CFD methodologies. Physics-based CFD models are also applied to predict internal flow streams passing through turbine engine rotating components and to simulate highly energetic combustion phenomena occurring inside propulsion systems. Specialized facility models predict the thermo/fluid dynamic behavior of ground-test facilities and provide insight for optimizing facility operations.

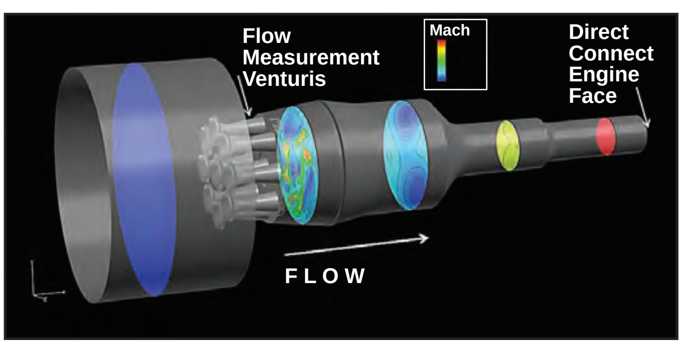
The goal of the I&D focus area is to provide AEDC test engineers and customers with state-of-the art diagnostic techniques which minimize measurement uncertainties, reduce diagnostic hardware interferences with interrogated flow environments and provide high-resolution, real-time measurements in complex and demanding test environments. The high-quality measurements are used to validate numerical models, guide model improvements and enhancements and provide test customers with unique insights into test article behavior.



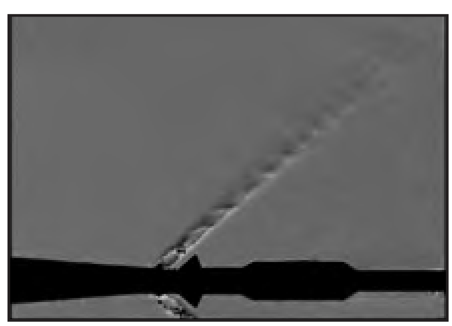
F-35 Weapon's Bay Store Release



Computed Flow Field About the Standard Check Model Configuration

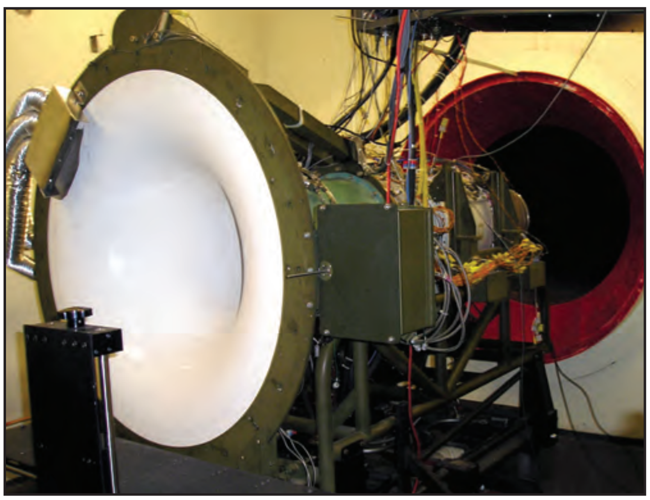


J-1 Turbine Engine Test Facility Venturi Flow Analysis

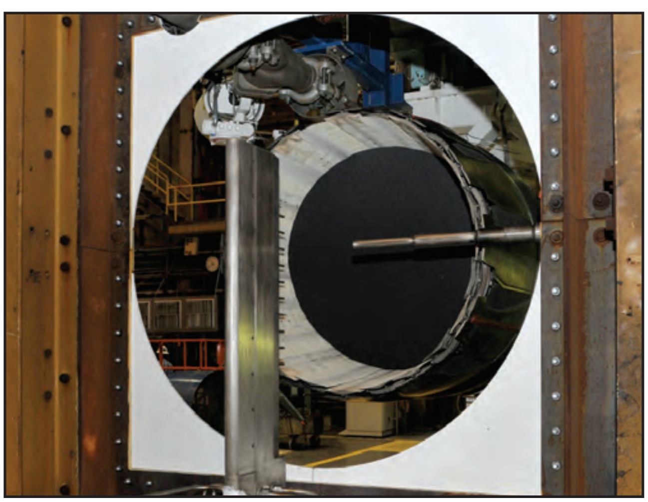


Background Oriented Schlieren (BOS) CEV Data Obtained in 16T

Both intrusive and nonintrusive techniques are being developed and used to acquire quantitative, spatially resolved flow-field measurements and qualitative flow visualization across the full spectrum of test environments. Significant ongoing efforts are focused on innovative designs, fabrication techniques and stringent calibration requirements of specialized probe systems for applications in harsh environments. Currently, diagnostic probes have been used successfully to quantify Mach number, temperature, pressure and flow angularity in high-enthalpy flow streams, including Mach numbers approaching 7. Probe sampling systems have been developed which chemically quench flow samples entering the probe in order to quantify both gaseous and particulate species. Innovative probe designs and state-of-the-art fabrication techniques have been developed for embedding miniaturized cameras and Micro Electro Mechanical Systems sensors within the probe tips, allowing visualization of combustion phenomena occurring inside turbine engine combustion chambers and augmentor components. Improvements in probe design for survivability at higher temperatures, pressures and Mach number conditions continue to be addressed.



Collaborative Test of the Honeywell F109 Engine at the USAFA Test Stand to Measure Engine Response to Swirl



F-T Fuels Emissions Rake and High-Speed AB Camera from Inside Diffuser in J-1

Nonintrusive optical diagnostic systems are being developed and applied to quantify and visualize flow environments inside AEDC test cells. Specialized active optical techniques which stimulate and measure exhaust emission features have been successfully demonstrated. These measurements are used to derive spatially resolved flow-field properties including temperature, multiple velocity components and chemical specie concentrations. In addition, characterizations of qualitative and quantitative flow structures are obtained through the development and implementation of techniques such as laser sheet visualization, Background Oriented Schlieren (BOS), Particle Image Velocimetry (PIV) and Planar Doppler Velocimetry (PDV). These techniques have been successfully demonstrated for monitoring test facility flow quality and for acquisition of flow-field properties on a noninterference basis. Capabilities are being developed to support measurement of global heat transfer, aero-optic effects on laser beam quality, and for other emerging diagnostic needs.

The goal of the F&TT focus area is to work enhancements closely with test engineers in developing and demonstrating specialized simulation hardware, facility systems and ground-test methodologies to address the challenges of providing realistic flight simulation conditions and efficient ground testing capabilities.

The scope of technology efforts supporting F&TT includes development and improvements of test facility systems and engineering-level facility models for the Propulsion, Aerodynamic and Space and Missile areas. Specifically, this focus area supports identification of required technology development to support future test facility requirements and address T&E deficiencies, analysis of facility performance and durability issues and the development of advanced test methodology concepts.

In summary, the Applied Technology and Analysis Program combines technical expertise in M&S, I&D and F&TT to support the Integrated Test and Evaluation (IT&E) process at AEDC. AEDC maintains dedicated technology investments to enhance these capabilities to support challenging requirements and address identified shortfalls in order to minimize technical risks and uncertainties associated with ground testing and data integration and analysis.

Evaluation of Arc Heater Anode and Cathode Coatings on Wear

TEST SUPPORT SERVICES

In addition to extensive test and evaluation capabilities, AEDC can provide a full range of other services for its customers.

AEDC understands that confidentiality of customer test and evaluation information is paramount, so AEDC has an active security program. AEDC can perform sensitive DoD testing and provide test preparation areas, test facilities, control rooms and data systems that are secure.

AEDC's precision machine shop has a full complement of skilled machinists and a complete range of modern machines, from conventional to six-axis computer-numerically controlled (CNC), as well as electrical discharge machine tools. Heat treatment, chemical cleaning and welding facilities are also available. The machine shop maintains coordinate measuring equipment for precise measurement of complex contours to allow 100% inspection and recording of all dimensions.

The Metallurgical/Nondestructive Evaluation Laboratory provides metallurgical test and evaluation services including stress and tensile strength testing, welder certifications, radiographic inspections, and other nondestructive test services. The Chemical Laboratory provides chemical analysis of various components including fuels, oils, soils, liquid-rocket propellants, exhaust gases, water and various other liquids and gases.

AEDC maintains the Precision Measurement Equipment Laboratory (PMEL), which is certified by the Air Force Metrology and Calibration (AFMETCAL). The PMEL provides calibration of test measurement instrumentation such as voltage measurement, pressure, temperature and dewpoint standards at the appropriate intervals to ensure measurements that are traceable to the National Institute of Standards and Technology (NIST).

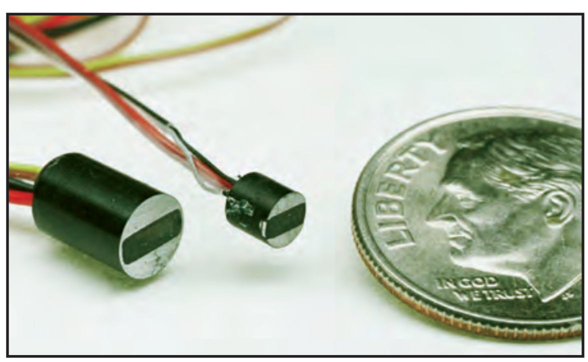
The Aerothermodynamic Measurement Laboratory (ATML) provides technical expertise, analytical tools and calibration/characterization facilities for applied research in aerothermal test measurement techniques. ATML services include specialization in heat transfer and transient temperature measurement for application to space and atmospheric high-speed flight models. Specialized instrumentation is designed, fabricated, calibrated and installed in supersonic and hypersonic test articles and facilities.

High-performance computing (HPC) computational resources are provided to support customers with time-critical mission support via rapid data analysis and the capability to computationally test high-fidelity physics models in a shorter time, thus saving resources. HPC computers are primarily used to provide computational fluid dynamics (CFD) solutions to customer requests and to develop numerical algorithm and physics modeling improvements.

Chemical Lab

Fabrication of Precision Instrumentation

Metallurgical/Nondestructive Evaluation Lab



Sensor Fabrication and Assembly Capabilities of the ATML

Arnold Engineering Development Complex