AEDC

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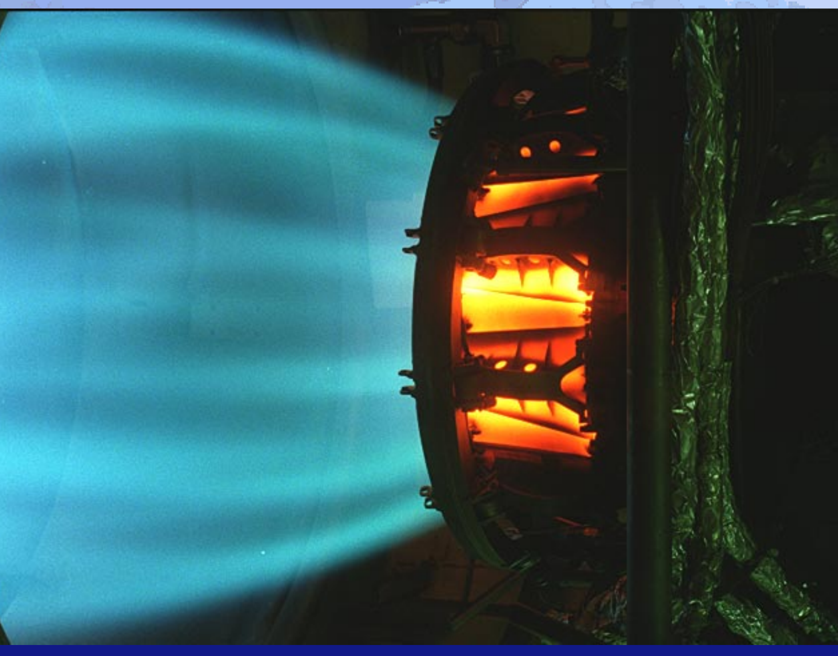
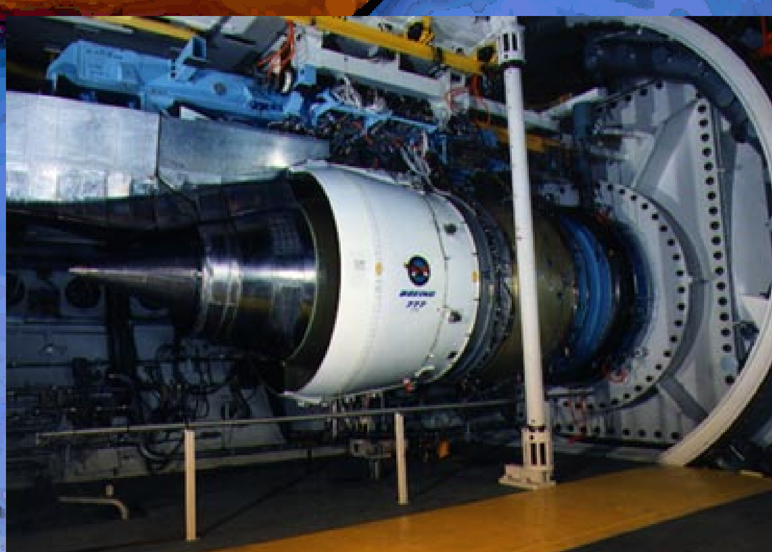
Aeropropulsion Highlights





ARNOLD ENGINEERING DEVELOPMENT CENTER
An Air Force Materiel Command Test Facility

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CATEGORY/EXPERTISE
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- Aircraft/Missile Performance; Stability and Control; Propulsion/Inlet Integration and Compatibility; Store/Stage/Separation, Weapons Carriage; Aero-optics; Signatures; Sub-, Trans-, Super- and Hypersonic

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AEDC/DOP/ -7855/ -5804/ ETF
- Performance, Operability, Durability, Observability and Specialized Testing and Evaluation, Environmental Testing (Simulated Altitude,Temperature Extremes, Emissions, Precipitation and Icing)

ON THE COVER:
Top-General Electric F414 in AEDC’s AeropropulsionTest Cell T-4.
Middle-Pratt & Whitney F119 in AEDC’s Aeropropulsion Test Cell C-1.
Bottom-Pratt & Whitney 4084 is installed AEDC’s Aeropropulsion Test Cell C-2.

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Contents

Commander's Foreword

Sweeping changes continue for the Air Force, touching every corner of the institution and every aspect of how we do business.

Air Force leaders have crafted a revised blueprint, "Global Engagement: A Vision for the 21st Century Air Force," which anticipates rapid projection of small concentrations of highly mobile forces that can be supported within a matter of days anywhere in the world.

Among the core competencies sought by the Air Force are air and space superiority, global attack, rapid global mobility, precision engagement, information superiority and agile combat support.

The Air Force Materiel Command and AEDC are contributing to building and sustaining superior aeropropulsion technologies to support these core competencies. The mission of AEDC is two-fold: To provide our customers with the world's most effective and affordable aerospace ground test and evaluation products and services, and to ensure Arnold Engineering Development Center ground test facilities, technologies and knowledge fully support today's and tomorrow's customers.

This edition of *AEDC Aeropropulsion Highlights* focuses on aeropropulsion testing and evaluation at AEDC.

During fiscal years 1997 and 1998, AEDC's Engine Test Facilities performed numerous tests and evaluations (T&E) of high importance to achieving the Air Force's core competencies and enabling the defense and economic security of the nation. T&E on the Air Force's Pratt & Whitney F119 cleared the engine for the F-22 Initial Flight Release (IFR).

Similarly, the Navy's General Electric F414 engine was tested for F/A-18E/F Limited Production Qualification (LPQ) and Full Production Qualification (FPQ). In addition, detailed planning and cell preparations for T&E of the Joint Strike Fighter (JSF) engines were initiated.

Other recent testing included the fielded F100, F110, TF33, F404 and F402. AEDC conducted Component Improvement Program (CIP) testing on the F110, F404 and F100 engines, and RAM Acceleration Mission Test (AMT) on the F100 Superpacer, the powerplant for F-15 and F-16 fighters.

Engineers also conducted high-altitude testing on the Allison AE3700, which powers the Global Hawk, EMBRAER 145 and the Cessna Citation X.

Testing of large commercial engines for the Boeing 777 and future large military transports continued in the Aeropropulsion System Test Facility with development, FAA operability and certification testing of the Pratt & Whitney PW4090 and PW4098 engines. These are the most powerful turbine engines ever tested at AEDC.

AEDC's Test Cell T-3 continued supporting T&E of high efficiency, low emission combustors for commercial ground power units, using the unique temperature and pressure capabilities of this high Mach number facility.

Col. Michael Heil, AEDC Commander

Construction and checkout of new test cells T-11, T-12, SL-2 and SL-3 continues, adding two small engine and two RAM sea-level test cells as a result of a Base Realignment and Closure Commission decision in 1993.

Team AEDC is committed to providing our customers with the world's most effective and affordable aerospace ground test and evaluation, and to ensuring AEDC ground test facilities, services, technologies and knowledge fully support today's and tomorrow's customers.

The AEDC work force is comprised of military, civilian and contractor personnel.

Sverdrup Technology, Inc., conducts aeropropulsion, aerodynamic, space, and missiles test and evaluation. ACS, a joint venture of CSC, DynCorp and General Physics Corp., provides Center support.

Strategic Overview

Aeropropulsion Vision…to provide best value propulsion test, evaluation and analysis services to mitigate risk in the development and sustainment of aeronautical vehicle propulsion systems.

The AEDC Aeropropulsion Business Area's vision is centered on becoming the Department of Defense's Propulsion Test Center of Excellence. This vision entails consolidating our position as a full-service organization providing aeropropulsion systems development, test, evaluation, and analysis support to engine manufacturers, system program offices and sustainment organizations including logistics centers.

The price and cost of providing developmental test and analysis information to our propulsion test customers will be internationally competitive. Continuous process improvements geared towards reducing development cycle times will enable the achievement of AEDC's strategic objectives by FY01. A more intense process of benchmarking will promote the attainment of enhanced productivity.

Maintaining the proper production and production capability balance ensures investment in infrastructure that not only contributes to improved processes, but also to more efficient operations and maintenance. Consolidation of the ETF A and B Plant Control Rooms not only provides significantly more efficient plant operations, but also tremendously enhances test cell and plant control room operations and safety. Improved connectivity between test support utilities and plants promotes greater flexibility and decreased operational costs. Improved Systems Engineering and Configuration Management practices will complement increased investment in propulsion plant and test cell preventive maintenance, thereby substantially reducing lost test time while driving down unscheduled maintenance.

To becoming DoD's Propulsion Test Center of Choice, we will retain Aeropropulsion Test's characteristic hallmark of customer responsiveness and test program flexibility. This goal also requires significant expansion of test support services in the areas of turboshaft and environmental testing. The ability to attract international test business is facilitated through recognition of best practices and well-established DoD policies accommodating international customers, and compliance with ISO9000 standards.

As a DoD full service propulsion development and sustainment organization, the Aeropropulsion Test area will provide an integrated approach to supplying propulsion customers with best value, risk reduction information services. This is possible through the employment of a test information system that effectively integrates current test data with modeling and simulations, as well as archived test and analysis data. This complementary information will be exchanged near-real time with remote test customers through high-speed virtual linkage with AEDC communications and computer systems and lead test engineers and analysts.

As a Propulsion Test Center of Excellence, it is inadequate to focus only on more efficient production and related process improvements. Long-range planning initiatives under development ensure the future viability of the propulsion test infrastructure. Such planning leads to early insertion of future propulsion test investments in the Test Investment Planning Process (TIPP) Military Construction (MILCON) and Five-Year Plan (POM) submissions. The ETF Sustainment Program promotes the continued use of the 40-year-old, one billion dollar investment in turbine engine test infrastructure. Other planned programs include the incorporation of new capabilities to expand the test envelope for future high technology military systems, such as Uninhabited Aerial Vehicles.

Other long-range technology and investment initiatives help realize the adoption of aeromechanical test techniques that promote better understanding of development issues relating to high-performance engine phenomena, such as High Cycle Fatigue. Better test data acquisition and processing systems capable of near-real time analysis of transient

Col. Dan Pierre,
AEDC Director of Operations

and dynamic engine test data promote this vision. The Integrated Test Information System (ITIS) will provide customers with full-service system development and test support by providing the software "glue" to make all of AEDC's information systems interface with each other.

In response to a customer's request for propulsion system information, ITIS will provide that customer with pertinent archived results from previous tests and simulations. It will permit the customer to view what types of modeling AEDC can perform to support their need. If a test is required, ITIS will allow the customer to plan a test matrix, with requirements capable of being run through facility models and cost models to determine the most efficient way to conduct a test. Other ITIS tools will allow test users to describe the information and data systems requirements, and through the use of models, automate their configuration. ITIS will interface to a 3D physical model of the test cell to show users how the model fits into the test cell and allow the user to virtually "walk" around to see the proposed configuration. Once testing begins, automated control systems will send information to that 3D model, and with a "point and click" interface, the user will be able to see the results of the test on-line at both AEDC and the user's home site. Displays will include trending tools and the ability to compare on-line test results with archived data. Models will be used to perform on-line verification and validation of test data.

Realization of AEDC's Aeropropulsion Business Area vision requires intensive process improvement initiatives to enhance current production (P) and astute investment in production capability (PC) to sustain future operations. This P-PC balance is maintained through the attainment of the four Business Area Targets addressing affordable production, optimizing processes, maintaining and improving plant, and effecting productive and satisfied people. Through adoption of continuous process improvement initiatives, balanced investments of M&R, I&M, MILCON and Technology resources, and sustaining Quality of Life enhancements for our work force, the Aeropropulsion Business Area vision for FY98-04 can be a reality.

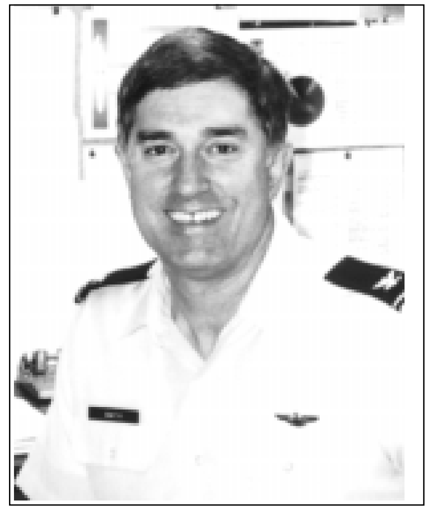
Prioritization of Critical Thrusts

1. Reduce the price and cost of propulsion systems test, evaluation & analysis services.
2. Develop Systems Engineering and Configuration Management tools to facilitate maintenance processes.
3. Secure ETF Sustainment investment resources to extend service life of propulsion test infrastructure.
4. Improve quality of work environment for Aeropropulsion Business Area work force.
5. Enhance fidelity and speed of propulsion data acquisition and processing.
6. Adopt knowledge-based approach for propulsion testing to include development of Integrated Test Information Systems and employment of the Simulation Test & Evaluation Process (STEP).

Arnold Engineering Development Center
Arnold AFB, Tennessee

Strategic Focus

With the many environmental changes in DoD and tightening budget constraints, the Aeropropulsion Business Area's primary focus is reducing cost of engine test services and translating these savings to reduced prices for our customers. Our passion for the next five years will be this focus on Operational Excellence (lowest customer prices) and customer satisfaction.



Col. Charles F. Smith,
AEDC Director of Propulsion Test

Today

To support our "passion" for Operational Excellence, we are investing our resources to provide a balanced test operations and maintenance program, assuring excellent test support while protecting both the test article and the infrastructure. Through benchmarking activities with engine producers and other DoD agencies, we are targeting non-competitive cost areas and business practices and eliminating them. Our metrics indicate our efforts and strategies to date are driving costs down. We are providing the customer increased ability to tailor the specific test services required, focusing strictly on what they need with no frills, thus reducing price and decreasing required test times. Emphasis is also being placed on best practices and compliance with ISO9000 standards. We are adding four economical test cells for RAM Accelerated Mission Test (AMT) of both large and small jet engines as well as testing of tuboshaft engines. Data systems are also being upgraded to improve data acquistion, display capabilities and reliability to reduce down time and cut maintenance costs. A cell upgrade was completed in Test Cell C-2 to reduce installation time when converting from large commercial engines to military engines.

We have seen an increase in our testing for the Navy, as major programs including the F414, F404 and F402 are now being tested at AEDC. The Naval Air Warfare Center in Trenton, N.J., was closed due the 1993 Base Realignment and Closure Commission, and both personnel and test hardware were transferred to the Center. To date we have transferred Test Cell T-11 and T-12 and are constructing the Large Engine Environmental Test Facility to provide our customers with additional testing capabilities.

Future

We are currently engaged in a major base re-engineering effort to increase efficiency of all computer operations as well as facility maintenance, test estimation and management while streamlining all financial management processes—further reducing the price of testing to our customers. Long-range planning initiatives are underway to resize, reshape, modernize and automate the AEDC propulsion infrastructure to reduce costs, increase customer access, reduce cycle times and increase efficiency of all plant operations, thus dramatically reducing overhead costs and, ultimately, customer price. Technology and investment initiatives are being developed to shorten required engine test times and provide data on high-performance engine phenomena such as High Cycle Fatigue. Better test data acquisition and processing systems capable of near-real time analysis of transient and dynamic test data are being developed.

Revitalization

In the area of revitalization, modernization of test facilities to accommodate engine technology advancements and available test automation capabilities is crucial. As we enhance engine performance and robustness during the 21st century, some of the new test capabilities required include production of increased mass airflow at increased temperatures and pressures, advances in exhaust gas management systems, improved integration of analog/digital simulations, enhanced simulations of inlet pressure distortion patterns, advanced RAM Acceleration Mission Test (AMT) methods, and better atmospheric and observable emissions measurement tools.

Commitment

AEDC Aeropropulsion is committed to making the process changes and facility improvements required to reduce price and to offer increased test value for our customers' dollars.

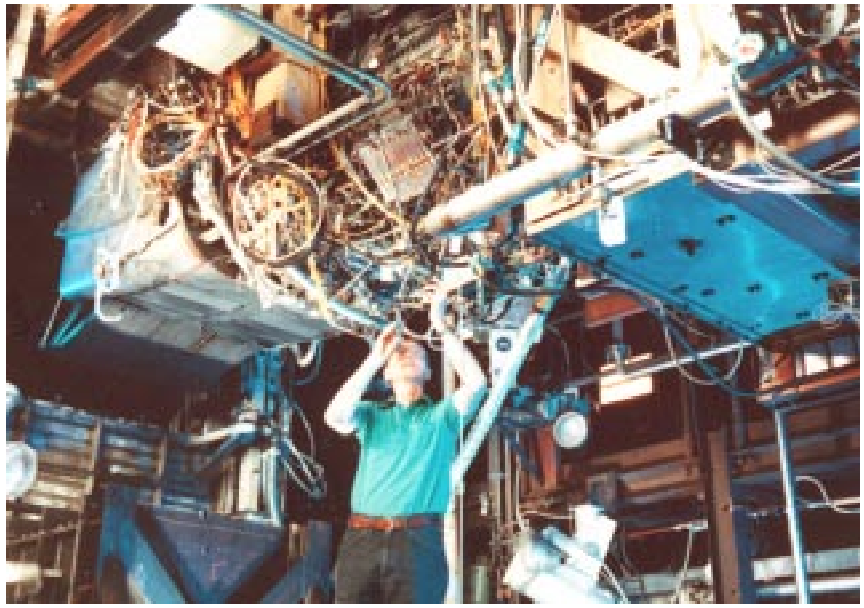
Propulsion Systems Test & Evaluation

Pratt & Whitney F119

AEDC engineers and technicians have been supporting development for the Air Force's next-generation fighter, the F-22 Raptor, since 1988. This support has included the Demonstration and Validation phase of the F-22 program and now focuses on the Engineering and Manufacturing Development (E&MD) phase. The AEDC and Pratt & Whitney team completed another critical phase of support with successful completion of the Preliminary Flight Qualification test in 1997. Through the end of 1998, the engine has completed 3,500 air-on hours of testing at AEDC to support altitude assessment of the engine's performance, operability, aeromechanical and durability characteristics. All planned objectives for this phase of the engine's development were achieved by the AEDC-P&W project team.

During FY97 and continuing into FY98, Pratt & Whitney's F119 E&MD engine underwent testing in AEDC's Propulsion Development Test Cells C-1 and J-2. AEDC supported the F-22 program in evaluating the engine's aeromechanical performance, combustor and augmentor operability, vectored and non-vectored nozzle performance, fan performance, compressor stall margin and air start capability.

The F119 passed an important milestone in 1997 with the successful completion of both an Accelerated Mission Test (AMT) and Preliminary Flight Qualification altitude performance and operability clearance test. "This is a major milestone in the F119 program, putting us on the threshold of F-22 flight testing," said Walter N. Bylciw, Senior Vice President of F-22 flight testing at Pratt & Whitney's Government Engines and Space Propulsion (GESP), which conducts the military engine programs. "Successful completion of these tests are the final engine requirements for flight clearance."



Pratt & Whitney's F119 engine being prepared for testing in the Aeropropulsion Systems Test Facility.

During the AMT, the F119 engine completed 919 TAC cycles simulating more than 300 Air Force combat missions and included more than 13 hours in augmentation and more than 40 hours of hot time. Each cycle involves multiple settings of the engine's thrust vectoring exhaust nozzles, which totaled more than 12,000 vectored transients.

The altitude testing, which verifies engine performance and operability, took the engine to all extremes of the fighter envelope. These extensive test programs included performance and operability testing at 15 different flight conditions, certifying the engine was cleared for flight testing in the F-22.

F-22 flight testing began in September 1997 and continued in the summer of 1998 at the Air Force Flight Test Center at Edwards AFB, Calif. "This has been an outstanding effort by the F-22/F119 team," said Maj. Gen. Robert F. Raggio, former F-22 System Program Director. "We all can be proud of our contributions to the challenging and rewarding development work that is being done in the program."

At the request of Pratt & Whitney, the AEDC team used a new test support system to provide immediate, on-line structural dynamic test results for the latest series of tests. The Center's Computer Assisted Dynamic Data Monitoring and Analysis System (CADDMAS) was used to process and analyze aeromechanical data on-line during the testing, rather than the traditional approach days after the test, allowing completion of testing two months ahead of the original plan. **(See related story on page 32.)** Testing was accomplished in AEDC's C-1 test cell to confirm elimination of vibratory stress levels discovered earlier in the program. During the 10-hour test, the engine was operated at varying altitudes and speeds, exposing it to the maximum pressures and temperatures possible during flight. Vibratory stress levels were taken at two flight conditions through strain gages mounted on the blades and then relayed to CADDMAS.

CADDMAS is a data processing and monitoring system designed by AEDC to gather and analyze test information as it occurs. The system contains multiple parallel data processors linked with personal computers to process data as it's received and to provide engineering information in real time. The CADDMAS provides the user with data analysis cheaper and faster than a mainframe supercomputer.

Through CADDMAS, the stress data were processed and analyzed during the test. Stress level measurements were simultaneously displayed as they were gathered, allowing engineers to compare them to measurements obtained during tests conducted prior to the modified configuration. The on-line analysis provided Pratt & Whitney with immediate confirmation of reduced stress levels in the turbine blades using this configuration.

"Normally data reduction and processing can take several days or weeks to compile and analyze," said Tom Cromer, aeromechanical analysis engineer for Sverdrup Technology, Inc., support contractor for testing at AEDC. "CADDMAS provided our customer immediate on-line proof that the modified configuration worked and gave them confidence to continue with this design."

Engine development and flight test support will continue in AEDC's Test Cells C-1 and J-2 throughout FY98 and FY99. Lockheed's F-22 Raptor is the future replacement for the F-15 Eagle aircraft.

"It is a distinct pleasure to acknowledge the outstanding contributions AEDC has made to the F-22/F119 Program. Without their "can-do" attitude and unsurpassed drive the F119 Engine Program would not have completed testing vital to the overall F-22 program."

Brig. Gen. Michael C. Mushala
F-22 System Program Director

Pratt & Whitney's F119 engine undergoing testing in the Aeropropulsion Systems Test Facility.

General Electric F414-GE-400

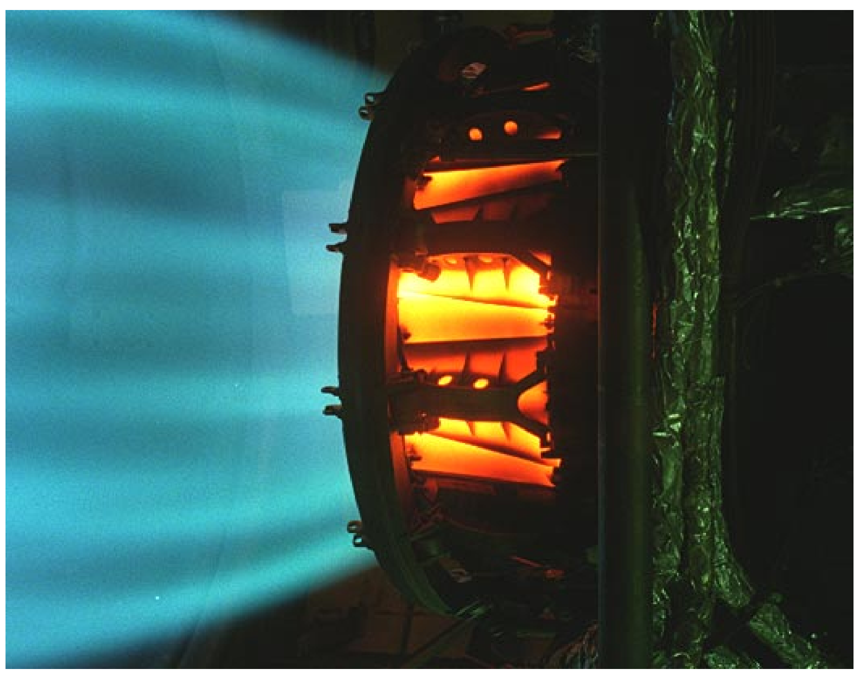
With more than 2,000 hours of altitude testing logged, AEDC engineers continue to test the F414-GE-400, the powerplant for the Navy's F/A-18E/F Super Hornet fighter. The F414 is an advanced derivative of the F/A-18's current F404 engine family. The new engine will have increased thrust, an improved thrust-to-weight ratio of 9:1 and a 3- to 4-percent cruise-specific fuel consumption improvement over the F404-GE-400 engine.

Testing of the F414 began at AEDC in October 1993, only six months after the first F414 was tested at sea level in GE's facilities in Lynn, Mass.

F414 testing at AEDC includes altitude performance, and functional and operability testing. AEDC testing of the F414 was focused on achievement of three specific program milestones: Preliminary Flight Qualification test in May 1995; Limited Production Qualification tests in September 1996; and Full Production Qualification tests in September 1997. Flight testing of the Super Hornet began in November 1995. To speed the F414 test data analysis process, a high-speed link was established with the Navy's facility in Trenton, N.J., allowing the Navy engineers to have "virtual presence" at AEDC, analyzing the data in virtually real time. The same data were displayed at both Trenton and AEDC, allowing the Navy to evaluate the test results and provide test direction much more quickly than using traditional practices.

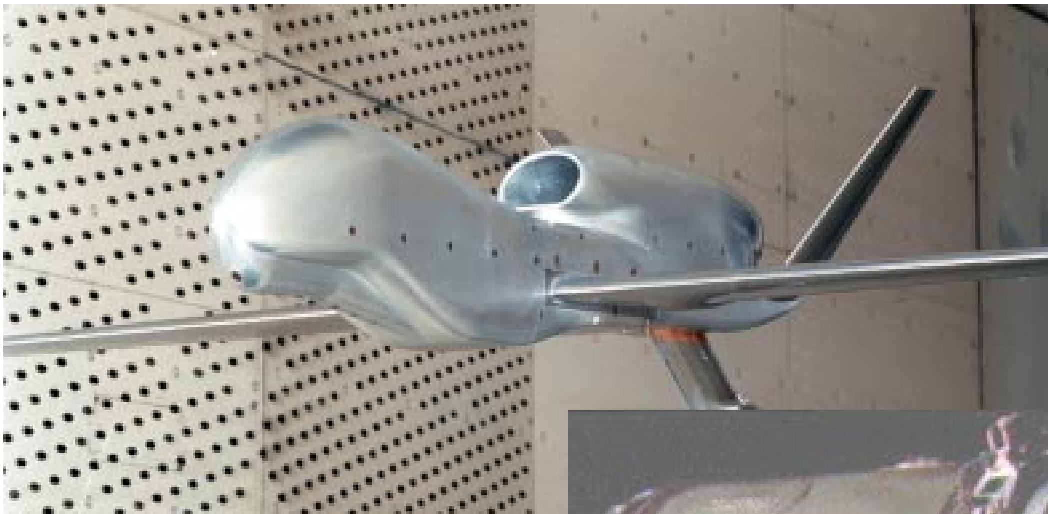
The F414 engine program is the first major Navy aeropropulsion test program conducted at AEDC as a part of the transition of workload from the Navy's engine test facilities.

The Navy's F/A-18 E/F Super Hornet.

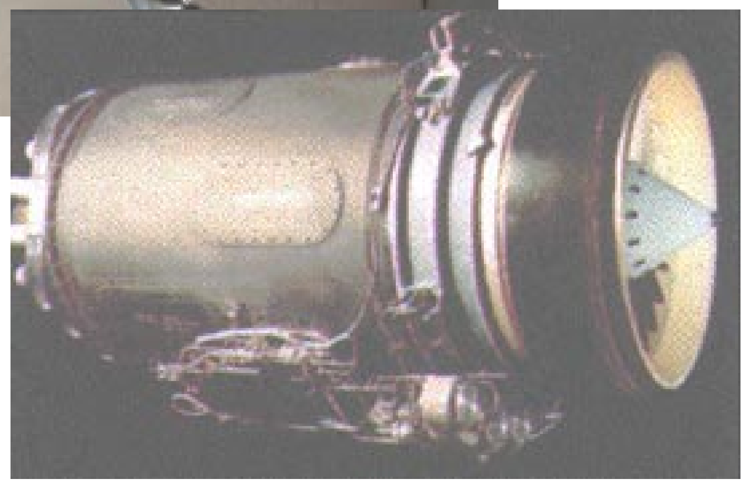


General Electric F414-GE-400 engine undergoing test in AEDC test cell.

Allison AE3007



Global Hawk model as tested in the Center's 16-ft transonic wind tunnel.



The Allison AE3007 is the powerplant for the Global Hawk, an unmanned, very high altitude reconnaissance aerial vehicle, the EMBRAER 145, a 50-passenger regional airliner, and the Citation X, a high-performance business jet. "The AEDC testing supplied the data necessary to define the required design changes Allison will incorporate in the engine to allow the AE3007 to perform well at high altitudes," said Tom Fetterhoff, Air Force project manager for the program. "Prior to this AEDC test, the AE3007 engine had operated at altitudes of slightly over 50,000 feet. The AEDC testing subjected the engine to a simulated altitude of over 70,000 feet. The testing was completed on time, under budget and in a very professional manner. The customer has been extremely happy with our product."

The engine, which produces 7,200 pounds of thrust at sea level and had been qualified at an altitude of 51,000 feet, underwent 69 air-on hours at high altitude in AEDC's Propulsion Development Test Cell T-1. The AE3007 also completed an additional 28 air-on hours of Type IV Fan work in support of the EMBRAER 145 project.

This test program marked the first-time AEDC on-line use of the new Silicon Graphics workstation. It was used during testing to compare engine math models to on-line test data. This assured proper data validity and prevented a loss of air time for repetition of test cases.

The Global Hawk is a state-of-the-art, unmanned high-altitude reconnaissance aerial vehicle. With a 116-ft wingspan and a design take-off gross weight of 24,000 pounds, the Global Hawk is designed to operate at 65,000 feet for periods of 24 hours or more. The Global Hawk will be able to complete missions in hostile environments previously reserved for piloted vehicles, thus keeping the pilots out of harm's way. A model of the Global Hawk aircraft was recently tested in AEDC's 16-foot transonic wind tunnel.

This test has established a basis for future AE3007 AEDC testing, as the Global Hawk project moves into the Full Scale Development phase.

The AE3007 tests re-established Allison as an AEDC test customer. The last AEDC test of an Allison engine, the TF41, took place in 1979.

Rolls Royce F402-RR-408 Pegasus

The F402-RR-408 Pegasus, the powerplant for the AV-8B Harrier II and the second Rolls Royce engine to be tested at AEDC, has undergone approximately 72 air-on hours of altitude performance testing in the Propulsion Development Test Cell J-1 of the Engine Test Facility. The objectives of the test were to assess the engine's altitude performance and to demonstrate AEDC's capabilities to handle this unique vectored-thrust engine.

The Harrier incorporates an innovative swiveling engine-exhaust nozzle design with a lightweight airframe to permit unique maneuvering capabilities unmatched by conventional aircraft.

The Pegasus provides the Harrier II with both lift and propulsive thrust through four swiveling exhaust nozzles which vector engine thrust from horizontal, for conventional flight, to vertical, for landing.

Previously, the F402, which has been in production in various versions for 25 years and has 21,500 pounds of thrust, had been tested in the United States exclusively at the Naval Air Warfare Center at Trenton, N.J. However, as a result of the Base Realignment and Closure Commission, the Trenton facility was closed, and testing was transferred to AEDC.

The AV-8B Harrier II is manufactured by Hawker Siddeley/ McDonnell Douglas for the U.S. Marine Corps to provide fast, effective, close-air support for Corps ground forces and to fly interdiction missions. Its primary function is to attack and destroy surface targets under day and night visual conditions. The fighter is the world's first fully operational short take-off and vertical landing (STOVL) fixed-wing ground-attack aircraft.

AV-8B Harrier in flight.

Rolls Royce F402-RR-408 Pegasus

General Electric F404-GE-402

The first General Electric F404-GE-402 engine to be tested at AEDC was tested in Propulsion Development Test Cell T-2. The F404, the powerplant for the F/A-18C/D Hornet, underwent a test period of about 70 air-on hours spanning an eight-week period. Previously, the F404, which has been in production for 16 years, was tested exclusively at the Naval Air Warfare Center at Trenton, N.J. until the facility was closed and testing was transferred to AEDC.

The purpose of the test was two-fold. The first was to demonstrate the F404 model can be tested at AEDC. Secondly, it was a Component Improvement Program (CIP) test to evaluate the performance improvements incorporated in the afterburner flame holder.

Designed to replace the F-4 Phantom, the F/A-18C/D Hornet is manufactured by McDonnell Douglas Corporation as a multi-mission tactical aircraft. Its primary function is to attack and destroy surface targets, day or night, under all weather conditions.

It also conducts multi-sensor imagery reconnaissance, engages and destroys enemy fighters and provides ground support. The Hornet's maximum speed is Mach 1.8 (1,190 miles per hour.)

Navy F/A-18 "Hornet."

General Electric F404-GE-402 awaiting testing in Test Cell T-2.

Pratt & Whitney F100

AEDC has played a key role for many years in the development and testing of two high-performance fighter aircraft engines, Pratt & Whitney's F100 and General Electric's F110. Recent testing of these engines has focused on support to resolve of problems encountered with engines in the field and Component Improvement Program (CIP) testing on these engines.

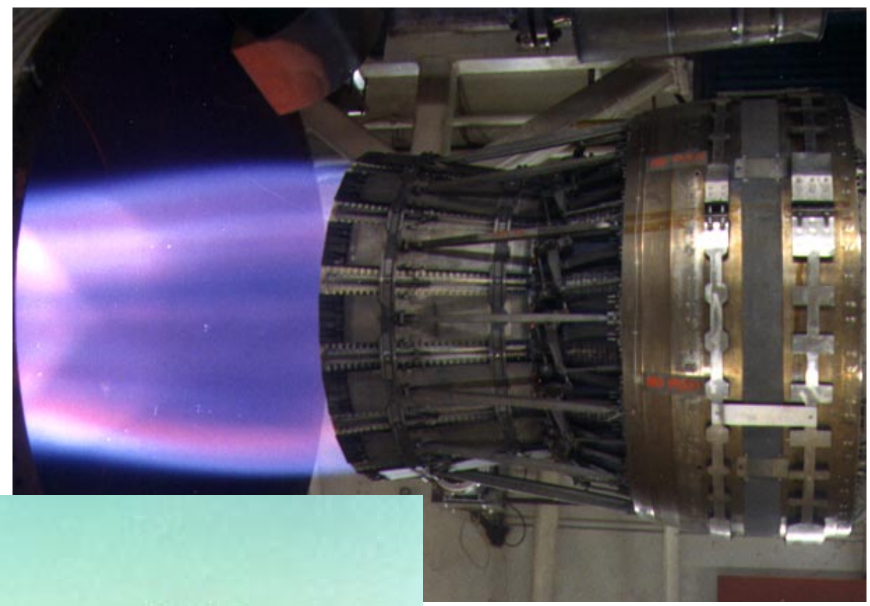
A key part of this testing was for the F100-PW-229, the powerplant for F-15 and F-16 fighters, which marked several firsts for AEDC. This particular F100 was a "Superpacer" engine, a designation for an engine the Air Force has pulled from the line to "lead the fleet" in engine accumulated operational hours .

The engine underwent approximately 100 air-on hours of Accelerated Mission Test (AMT) to determine how the F100 engines will age. This marks the first time a Superpacer engine has been tested at AEDC.

In addition, this test marks the first time a RAM Accelerated Mission Test has been performed in Propulsion Development Test Cell T-1. Engines undergoing RAM AMT are subjected to increased inlet pressure and temperatures to simulate high-speed flight.

In order to accommodate RAM AMT testing in Test Cell T-1, several modifications were made to the cell, including inlet plenum stack-up, engine inlet duct instrumentation layout and other F100-related items to ready the cell.

RAM AMT testing specifications dictate very tight inlet pressure control performance during repeated engine power transients. The pressure control available for Test Cell T-1 utilizes specialized control logic applied to a pair of cell bypass valves to meet the requirements. Also, for the RAM AMT testing in Test Cell T-1, cell pressure requirements allow for idling the exhausting machinery and exhaust directly to atmosphere. This configuration enables the test program to realize a considerable reduction in power utilization and lower program costs during the long duration of RAM AMT testing.



Pratt & Whitney's F100-PW-229 undergoes testing in Test Cell J-2.

Air Force F-15 "Eagle."

General Electric F110

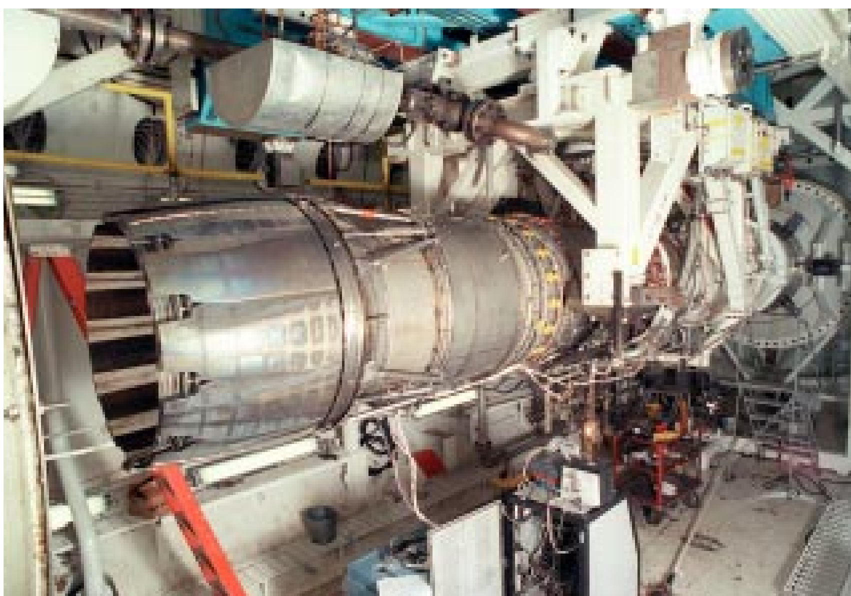
The F110-GE-129 engine, the powerplant for the F-16 C/D Fighting Falcon and the F-15E Eagle, has undergone a variety of testing at AEDC ranging from altitude testing to Component Improvement Program (CIP) testing. The F110-GE-129 has completed 1082 air-on hours of testing at the Center.

The most recent testing, which was conducted in Propulsion Development Test Cell J-1, has been development and qualification testing. The engine features a long-chord blisk (blades integral with the disk) fan and an improved augmentor with a radial design adapted from the F414 engine. Both components have completed substantial factory testing. This test program's primary objective is to qualify at simulated flight conditions the long-chord blisk fan aeromechanically and to gather performance, control, operability and radial augmentor engineering data to support qualification of an F110-GE-129 Field Service Evaluation in 1999.

The F110 engine family, which powers F-16C/Ds for the USAF and for Bahrain, Egypt, Greece, Israel and Turkey, is also powering four of Japan's Mitsubishi F-2 aircraft currently in flight test. Selected by Japan for the F-2, the F110-GE-129 to date has accumulated more than 600 engine flight hours on the test aircraft. AEDC supported engine ground testing and development of this engine for the F-2 in 1994.

General Electric will deliver the first F110-GE-129 production engine kits to Japan in 1998 as the F-2 transitions into a production program. Final assembly of the engines will be handled by Japan's Ishikawajima-Harima Heavy Industries. Support to international engine development programs like the Japanese F110 is an AEDC strategic objective.

A new F110 derivative, the F110-GE-129 EFE, is successfully continuing development and has recently arrived for testing at AEDC.



The General Electric F110-GE-129 is prepared for testing in Test Cell J-2.

Air Force F-16 "Fighting Falcon."

AEDC prepares to test powerplant for Joint Strike Fighter

AEDC will begin testing the competing Joint Strike Fighter (JSF) engine configurations in the fall of 1998. The tests, which will be conducted in Propulsion Development Test Cells J-2 and C-2, will test both the Boeing and Lockheed versions of the F119 JSF engines. Test cell preparation for these tests is underway.

Formerly known as the Joint Advanced Strike Technology (JAST) Program, the JSF program is the Department of Defense's focal point for defining affordable next-generation strike aircraft weapon systems for the Navy, Air Force, Marines and our allies. The focus of the program is affordability — reducing the development cost, production cost and cost of ownership of the JSF family of aircraft. The program is accomplishing this goal by facilitating the Services' development of fully validated, affordable operational requirements and lowering risk by investing in and demonstrating key leveraging technologies and operational concepts prior to the start of Engineering and Manufacturing Development (E&MD) of the JSF in 2001.

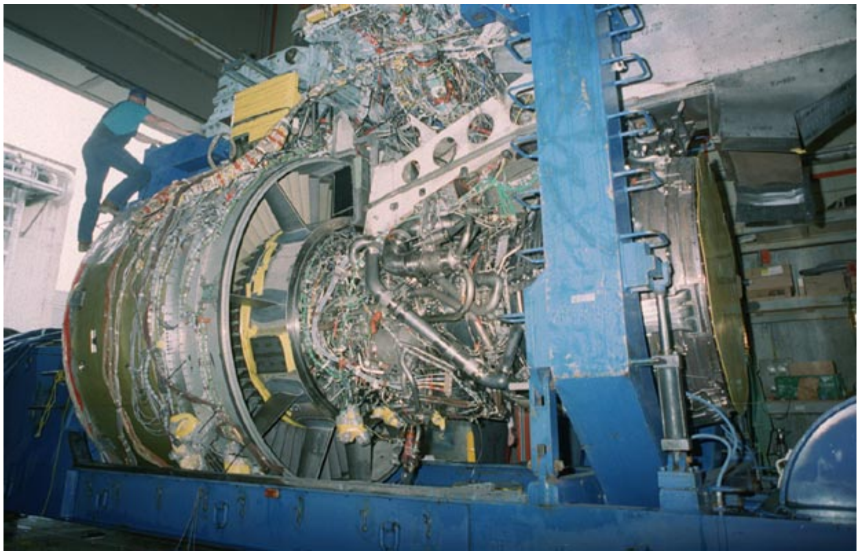
The primary propulsion systems being designed for the JSF Program are derivatives of the F119-PW-100 engine, which also powers the F-22 Raptor. The propulsion system concepts for the Boeing and Lockheed Martin configurations utilize new fan and low-pressure turbine (LPT) designs which will be based on F119 designs, materials and processes.

In FY97, JSF awarded Pratt & Whitney the Propulsion Ground and Flight Demonstration Program contract. This program will provide flight-qualified engines for the JSF Weapon System Contractor (WSC). Concept Demonstration Aircraft (CDA) will continue the definition of the propulsion system for the Preferred Weapon System Concept (PWSC). The AEDC testing will support the Services' selection of an engine-airframe combination for the PWSC.

Artist's drawing of Lockheed's Joint Strike Fighter.

Artist's drawing of Boeing's Joint Strike Fighter.

Pratt & Whitney PW4000 Engine Family



AEDC and Pratt & Whitney personnel prepare a Pratt & Whitney 4098 engine for installation in Test Cell C-2.

In April 1994, the Federal Aviation Administration certified a new engine made by Pratt & Whitney to power Boeing's new 777 aircraft. "All the altitude certification testing for the PW4084 was completed at AEDC. They were an integral part of the certification," said John Guidone, Manager of Engineering Test Operations for Pratt & Whitney.

More than 200 personnel from AEDC were involved in test work for the new engine, one of the most powerful gas turbines ever tested at AEDC. The work was done in the center's Aeropropulsion Systems Test Facility, the only engine test facility in the United States capable of testing the new large engine in the range of altitude and speed conditions it will experience in flight.

Since that time, AEDC thrust records have continued to be broken as a series of more powerful Pratt & Whitney commercial engines for growth versions of the Boeing 777 were tested and certified.

Testing of the PW4090 was completed in May 1996 . The Pratt & Whitney PW4090 engine, with its 90,000 pounds of thrust, is the powerplant for the Boeing 777-200 Increased Gross Weight aircraft; this engine is the same physical size as the PW4084, which powers the 777-200. The PW4084, with its 84,000 pounds of thrust, was tested more than 500 air-on hours at AEDC.

Three entries of the PW4090 engine into the AEDC test facilities provided the necessary engine certification data. Although the second PW4090 was on base for less than two weeks for a single, six-hour test period, several of the engine's key milestones were completed. "I am extremely proud of the AEDC personnel for the effort they have put forth in support of this program," said Tom Fetterhoff, Air Force project manager. "For the second time this fiscal year, the test personnel in ASTF worked around the clock to provide the test support needed to meet program milestones for the PW4090. The first engine was on site only 20 days for a test program consisting of five air periods for a total of 50 air-on hours."

The FAA certification testing was performed in Propulsion Development Test Cell C-2 of the Aeropropulsion Systems Test Facility. Three tests were completed in Test Cell C-2 for the development and certification of the engine. The

Boeing 777 on its first flight is powered by AEDC-tested PW-4084 engines.

FAA awarded engine flight certification in June 1996, and it entered service in March 1997. The PW4090 is the second growth engine model of the PW4000 growth engine series in which AEDC played a major role in flight certification.

The Pratt & Whitney PW4098, the third in the series of PW4000 growth engines to be tested at the Center, is the largest engine tested to date at AEDC. The engine produces 98,000 pounds of thrust and is scheduled to enter revenue service in the second half of FY98. The PW4098, which will power the Boeing 777-300, has undergone combustor development, engine performance and operability development and FAA certification testing at the Center.

The development of the Pratt & Whitney PW4098 combustor was accomplished in Propulsion Development Test Cell T-4. The objective of this test project was to conduct lightoff and blowout testing of the combustor in order to map its performance boundaries. The combustor logged about 24 hours of testing in two testing periods in mid-summer 1997. The PW4098 was first tested at AEDC in the spring of 1997. This test entry accomplished approximately 200 hours of engine performance and development testing.

The PW4098 returned to AEDC in January 1998 to undergo about 140 air-on hours of engine performance and operability development and FAA certification. The testing, accomplished over nine test periods, was completed in Test Cell C-2.

New Test Facilities

Engine Test Cell SL-2 and SL-3

Construction of AEDC's newest test facility, the Large Engine Environmental Test Facility, began in July 1996 and is scheduled to be completed in November 1998. The first customer test is scheduled to begin in early FY99.

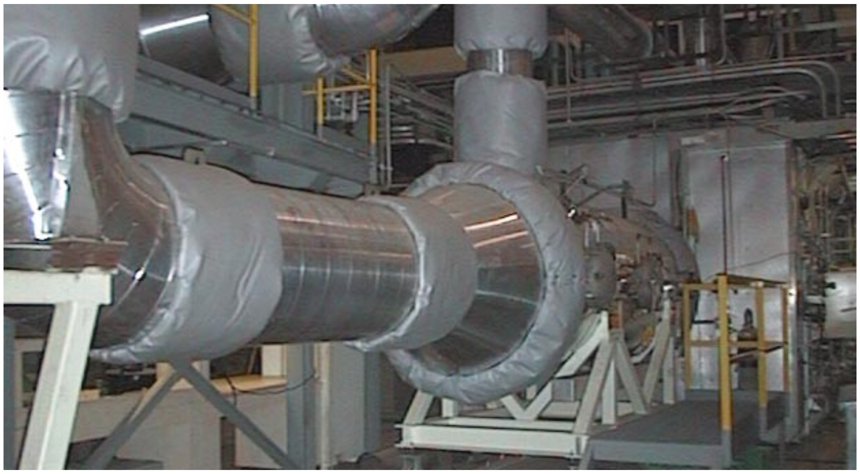
The two test cells housed in the facility, SL-2 and SL-3, are sea-level cells similar to those from the Naval Air Warfare Center Aircraft Division in Trenton, N.J., which was closed as part of the 1993 Base Realignment and Closure Act. The cells, previously known as 1W and 2W in Trenton, were part of Trenton's infrastructure and could not be moved, thus requiring the construction of the new facility and cells at AEDC to complete the transfer of Trenton's 1W and 2W test capabilities.

The facility will also include provisions for inlet ram airflow up to 550 pounds per second at temperatures from -65° to 260°F and air pressures up to 30 pounds per square inch (See rear cover page.). A fuel conditioning system will provide fuel at temperatures from -65° to 260°F. Instrumentation and control systems will be compatible with other AEDC turbine engine test cells.

The addition of these test cells to AEDC's infrastructure provides multiple test capabilities, since the cells are not altitude test cells but do have RAM air capabilities for environmental testing. In addition, the test cells are capable of engine testing under conditions of salt water spray, combined sand and dust, icing, and cold soak start. The new facility will also be able to support engine endurance testing, either with sea-level engine inlet, or with process air from the Aeropropulsion Systems Test Facility.

AEDC's newest test cells SL-2 and SL-3.

Propulsion Development Test Cell T-11



Test Cell T-11 installed in the Engine Test Facility.

Propulsion Development Test Cell T-11, one of AEDC's newest turbine engine test cells, conducted its first air-on periods in early 1997 as a part of the activation of the new test facility. This cell is the first of two test cells being transferred from Naval Air Warfare Center Aircraft Division, Trenton, N.J.

Test cell T-11, known as 5W at NAWCAD-Trenton, was used for cruise missile and other small turbine engine testing for the Navy from 1974 until late 1994. In February 1995, the test cell was removed from the Small Engine Test Area at Trenton and shipped to AEDC. Following cell refurbishment, it was installed in the Engine Test Facility.

The first test was part of a series of "simulator" tests that use a large duct and flow control valve installed in the test cell to simulate changes in engine airflow while the facility is being checked. "This test was a very successful first test period and included vacuum checks, controlling airflow and pressure through the cell and checkout of automatic inlet pressure control," said Kent Lominac, Air Force Trenton Transition program manager. "The new ETF Data Acquisition and Processing System (EDAPS) was also used for the first time to support an air-on test."

The objective of the first engine tests, sponsored by the Naval Air Warfare Center Test Directorate, was to conduct a Specification Performance Verification Test (SPVT) on the F107-WR-402 engine. The F107 engine is the propulsion system for various cruise missile weapon systems, including the Air Launched Cruise Missile (ALCM), Sea Launched Cruise Missile (SLCM) and Ground Launched Cruise Missile (GLCM).

The test plan included at least three engine starts, four conditions for steady-state calibration, two runs for operating line checks and two cell entries during testing. Each air-on period was about six hours.

The first two tests in the program were completed in August and October 1997, with the second half mid-1998.

Propulsion Development Test Cell T-12

The second of AEDC's new test cells and the last cell to be transferred from Trenton has been installed in the Engine Test Facility, and is scheduled for checkout early in FY99. The facility should be ready for its first customer test program in the spring of 1999.

Known as 4W at Trenton, Test Cell T-12 is 20 feet long and 10 feet in diameter and will primarily be used to test turboshaft and turboprop engines. The cell can support a variety of testing for small auxiliary power turboshaft units.

Test Cell T-12 can also provide a unique corrosion testing capability, in which a salt water solution is blown through the engine to assess how it corrodes in a sea environment.

Test Cell T-12 shown completing final installation in the Engine Test Facility.

T&E Applied Technology

Arnold Engineering Development Center is a well-known Test and Evaluation (T&E) center. In order to conduct tests, engineering analyses and technical evaluations, AEDC conducts an in-house applied technology program to develop advanced test facilities, test techniques, diagnostics, and modeling and simulation (M&S) approaches.

Timely development of T&E technology is advanced at AEDC in areas including hypersonics, space, re-entry, aerodynamics, aeropropulsion, rockets and computational support. In each of these areas, the AEDC technology team leverages Center resources with those of outside agencies to meet the ground test technology needs of customers including the Air Force, Navy, NASA, the Army, the Environmental Protection Agency, the Ballistic Missile Defense Organization and others.

Goal

Develop and transition cost-effective, value-added technologies to the Aeropropulsion Business Area.

Objective

Develop and transition product/services to:

- Reduce test cost and cycle time
- Expand T&E capability to meet customer needs
- Reduce risk of test environmental non-compliance events

Desired Outcome

- Reductions in test configuration/maintenance costs using advanced measurement diagnostic and modeling and simulation techniques
- Reduced plant cost and Improved availability using advanced modeling and simulation techniques and improved planning using test optimization techniques
- Reduced test cycle time using:
  - -Automated instrument and data validation diagnostic systems
  - -Wide range fuel flow measurement system
  - -Predictive models
- Expanded test envelope/capability using new test techniques for mission and in-flight test simulations

AEDC focuses its Aeropropulsion technology development efforts in five technical areas:

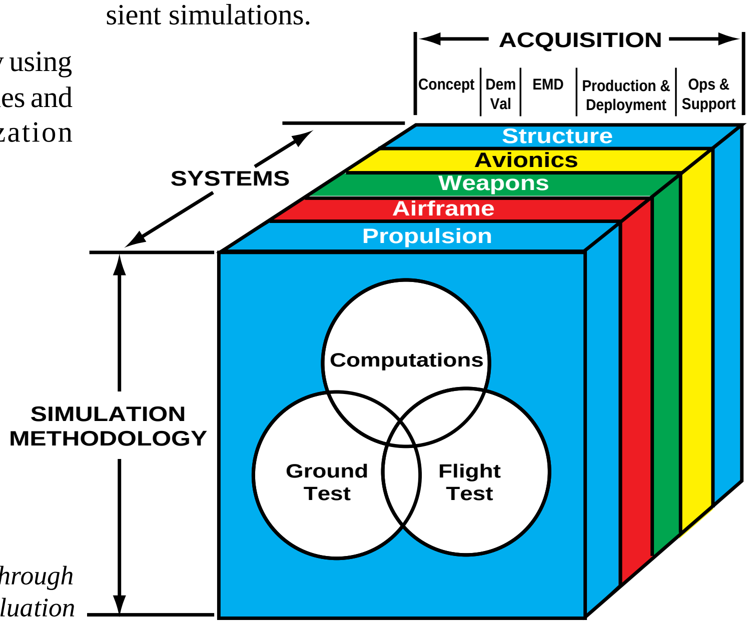
• **MEASUREMENT TECHNIQUES** that include airflow, fuel flow, emissions, pyrometry, infrared optics, engine health monitoring and facility health monitoring.

• **TEST TECHNIQUES** that include airframe/propulsion integration, flight maneuvering simulation , hot-gas ingestion from VSTOL operations and munitions, inlet flow simulation techniques for high cycle fatigue and icing/adverse weather simulation.

• **STRUCTURAL ANALYSIS** that includes real-time component stress mapping, HCF margin and blade life assessment, stress trending test methodology, integrated optical/strain gage diagnostics, on-line, near real time engine component finite element modeling validation and rapid dynamic data processing systems for structural test support.

• **DATA INFORMATION MANAGEMENT** that includes both steady-state and transient, real-time algorithms for automated engine fault and diagnostics, automated test instrument checks, an automated calibration data system, on-line interactive graphics for data validation and networking (ITIS).

• **FACILITY & ENGINE MODELS** that include plant transient control simulations, coupled plant/1-D full engine transient simulations, 3-D engine steady and transient compression system stall modeling, coupled 3-D engine inlet/fan modeling, 3-D augmentor combustion modeling, and 1-D full engine dynamic/transient simulations.



Enhanced Weapon System Acquisition through Integrated Test and Evaluation

MS&A Knowledge-Based Approach

The Air Force F-22 flies for the first time. The propulsion system of this Engineering and Manufacturing Development version of the F-22 Raptor was ground tested at AEDC.

The Aeropropulsion Team has increased its efforts to extend AEDC's value to its customers by using knowledge-based approaches. This concept is wholly consistent with AEDC's mission of using ground test and computational facilities for creating knowledge to guide system decision making and risk management, and to reduce AEDC's system development cost and time.

An aeropropulsion roadmap has been developed to properly transform routine test processes into a knowledge-based approach. This roadmap delineates a number of initiatives in four mutually supporting thrust areas—Integrated Test and Evaluation (IT&E); Modeling, Simulation, and Analysis (MS&A); High Performance Computing and Networking (HPC&N); and Knowledge Archiving (KA).

Integrated Test and Evaluation is the integration and use of ground testing and analysis, mathematical models, simulations and analyses, and flight testing and analyses to provide relevant risk-reducing information. When used to integrate multiple subsystems, including airframe, propulsion, weapons, and avionics, in the weapon system acquisition cycle, AEDC envisions an extension of the IT&E process. Modeling and Simulation is an integral part of a T&E knowledge base, reducing the time and cost for weapon system development. This approach is highly supportive of DoD's Simulation, Test and Evaluation Process (STEP), "a move from a traditional test-fix-test approach to an approach of model first, simulate, then test, and then iterate the test results back into the model." STEP promises a significant reengineering of the Test and Evaluation Process with anticipated and actualized payoffs in program savings, development schedule and productivity, and improved mission performance. The Aeropropulsion Team is supporting the Joint Strike Fighter (JSF) and F-22/F119 programs using this enhanced IT&E process.

MS&A provides invaluable tools for supporting IT&E, optimizing test matrices and designing test support hardware. The AEDC Aeropropulsion Team increasingly uses computational methodologies to support knowledge-based approaches to test, evaluation, and analysis. This includes computational fluid dynamics (CFD), computational structural dynamics (CSD), interdisciplinary computing (IDC) and engineering models. Computational codes continue to be enhanced and streamlined to provide more rapid solutions to more complex aeropropulsion problems. Aeropropulsion modeling capabilities have grown to better address dynamic engine behavior such as surge, rotating stall and inlet distortion, as well as the traditional transient and steady-state behavior. In addition, engine model-based data validation approaches have been demonstrated in a pilot on the F414 and F119 test programs.

The Knowledge Center roadmap has been enhanced in the aeromechanical area by defining a complementary roadmap for coupling turbine engine aerodynamic modeling with engine structural modeling. This joint endeavor between AEDC and AFMC's Air Force Research Laboratory offers a holistic approach to addressing engine high cycle fatigue. Along with the traditional computational fluid dynamic tools, these new turbine engine tools will enhance AEDC's IT&E capabilities. The Aeropropulsion Team has developed a detailed MS&A roadmap outlining key acquisition/test tools considered essential for supporting the AEDC portion of the STEP approach.

High Performance Computing and Networking is a prerequisite for performing high-fidelity computations and identifying solutions for complex engine and test geometries exposed to sophisticated aerothermodynamic environments. Previously, AEDC's customers were forced to accept higher levels of program risk as a result of limited on-base computing power and limited access to remote supercomputers. As a result of a very intensive effort to compete for resources from the DoD's High Performance Computer Modernization Office, AEDC was one of the first test centers to be designated as a Distributed Resource Center. Through FY98, AEDC has received approximately $10 million to expand computational capability fivefold through state-of-the-art super-computer technology, expand archiving capability and provide a high-speed T1 data link to the Defense Research and Engineering Network. Using these modern networking tools, the Aeropropulsion Team has provided test customers at the Navy's Trenton Test Facility, Pratt & Whitney's West Palm and East Hartford facilities, Rolls Royce's Derby facility, and General Electric's Evendale facility real-time access to AEDC test and analysis results, yielding their "virtual presence" in the conduct of testing and analysis.

AEDC archival system capacity has been expanded to over 100 terabytes on-line.

Knowledge archiving is another essential element of the knowledge-based approach to test and evaluation. The ability to integrate stored knowledge with planned and ongoing test programs facilitates more effective program risk management and reduces development cycle time. An increasing number of AEDC customers are requesting AEDC archival services, and under the High Performance Computing Initiative, AEDC archival system capacity has been expanded to over 100 terabytes on-line.

As these thrust areas mature, AEDC will gradually evolve into a comprehensive Knowledge Center—a national source of aeropropulsion knowledge essential to effective decision making and risk management. In this new, broader role, AEDC is positioned to bring even more value to our customers.

AEDC Integrated Test Information System (ITIS)

Propulsion customers have a continuing need to receive information and knowledge of DT&E activities at AEDC as quickly as possible, eventually moving to near-real time information and knowledge transfer. This includes the results of tests in the form of data and the knowledge derived from the data and other test information or metadata which is needed to properly interpret and understand the data and test results. In addition, AEDC seeks to combine data from multiple sources to form a more complete and comprehensive knowledge base for information and knowledge access.

AEDC is pursuing the goal of near-real time access to propulsion test and related information through the Integrated Test Information System (ITIS). The vision of the Integrated Test Information System (ITIS) is to produce an information-age tool providing uniform integrated access, visualization and fusion of diverse test and evaluation data from any source (computational models, ground tests and flight tests).

The conceptual architecture of the ITIS is comprised of the following components:

Integration Infrastructure

Integration infrastructure provides common metadata storage, interobject data communication and data management functions for all other components ("objects") in the system. This infrastructure is expected to be implemented using a combination of commercial-off-the-shelf (COTS) products with some custom software. The focus will be on providing common services which integrate the system components using industry-standard protocols (e.g., CORBA, TCP/IP,...).

Test Project Planning and Preparation

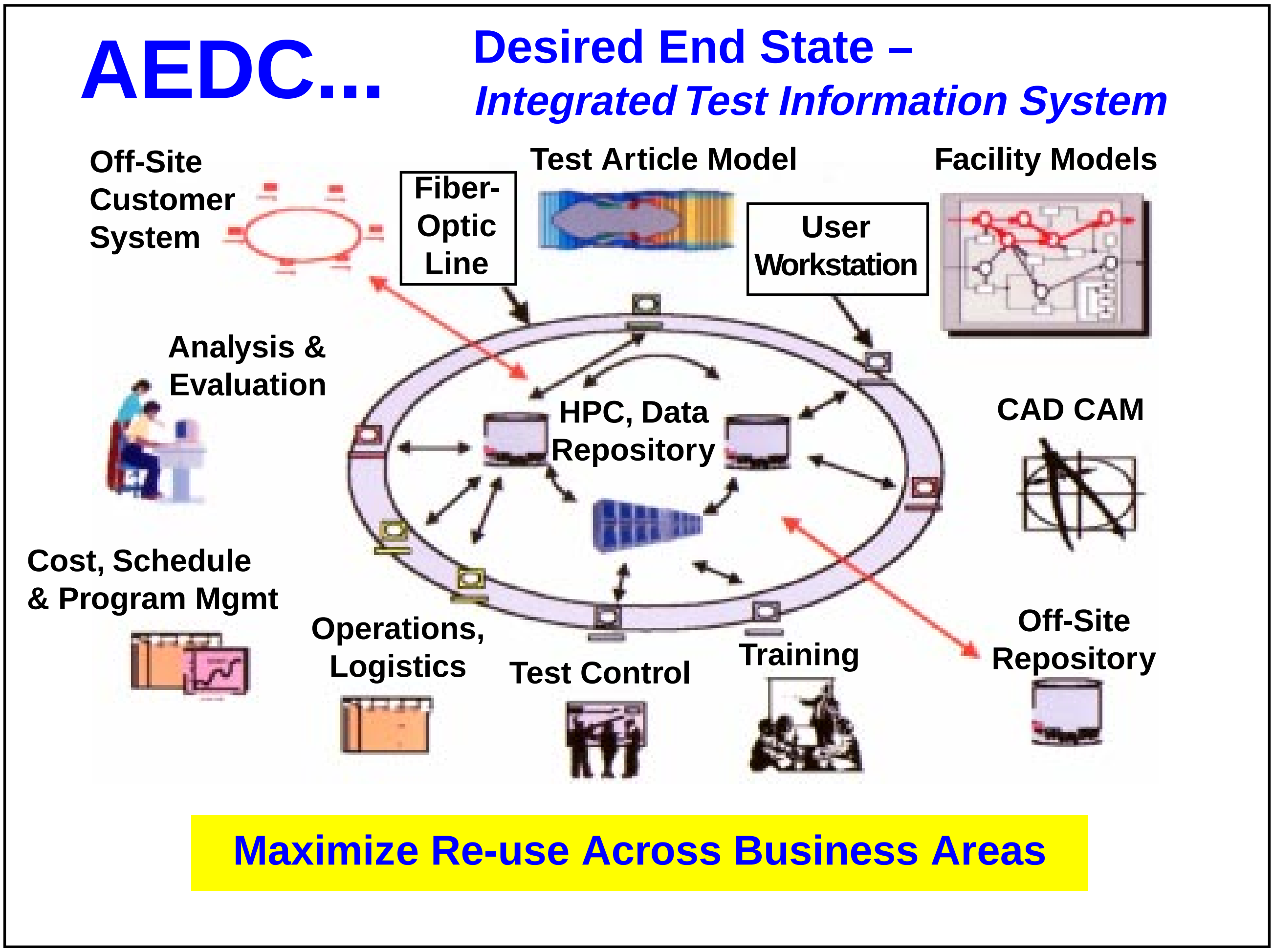
Test project planning and preparation components provide the test project team (customers, managers, engineers, operators, ...) the tools needed to collaboratively plan the scope, cost, schedule, pre-test build-up and experimental design of a test project. Many of these tools must be web-based to provide a collaborative environment for customers outside of (remote to) AEDC. In some cases, legacy tools (e.g., COTS scheduling applications, accounting systems, ...) will be integrated into the ITIS; in other cases, new tools will need to be developed to fulfill a specific need.

Test Execution, Analysis and Reporting

Test execution, analysis and reporting components provide the test team, particularly the engineers and analysts, tools to monitor, visualize, and analyze the test data in near-real time to enable faster and better test conduct. Also, data "fusion" tools will be built to compare and contrast:

- expected performance (from engineering analyses, computational methods or archived test data),
- simulated performance (from archived or on-line experimental test data), and
- actual performance (from flight test data).

This year, demonstration prototypes of "virtual presence" were completed. Archived data sets located on a networked server were visible to other users on the local area network (LAN) using a commercial web browser. In early FY99, the ITIS program intends to expand these prototypes and procure a commercial-off-the-shelf (COTS) product data management (PDM)/Enter-



prise Resource Planning (ERP) class of software for use as integration infrastructure of ITIS. The ITIS PDM will be part of an enterprise-wide solution to test data management at AEDC and will interface to other COTS information management systems on the base (e.g., Metaphase™, Synergen™ and Peoplesoft™).

The key functions of the PDM are expected to include:

- **data linking and association** (ability to create, edit, view and manage all data elements related to a specific test project as a logical whole regardless of physical location of the data),

- **work flow automation** (logically and/or physically moving/routing data elements for review, approval and processing based on type of data element, state of work in process, and roles of test team members),

- **document configuration management** (maintaining a record of multiple revisions/versions of individual data elements which comprise a larger whole project, supporting ISO9001 efforts at AEDC),

- **web-browser publishing/access** (providing secure internet access to all or selected data elements or types of data via a standard HTML browser),

- **ability to be "tightly" integrated with legacy applications** (use the PDM's application programming interface to call or be called by legacy applications to enable customized data processing),

- **highly visual interfaces with Windows look-and-feel** (use easily modifiable templates to create processes and structures to store data and metadata, reduce training time for the casual user, allow infrequent customers to access ITIS without formal training, etc.),

- **efficient data capture and registration** (capturing metadata and test data only once at the earliest appropriate point in the test/business processes and maintaining the data throughout the remainder of the data's life cycle. Data may be entered via keyboard inputs, from embedded attributes of data files, or from other automated data processing interfaces. Registration involves consistent representation of the data and metadata and their associations to each other and appropriate application programs), and

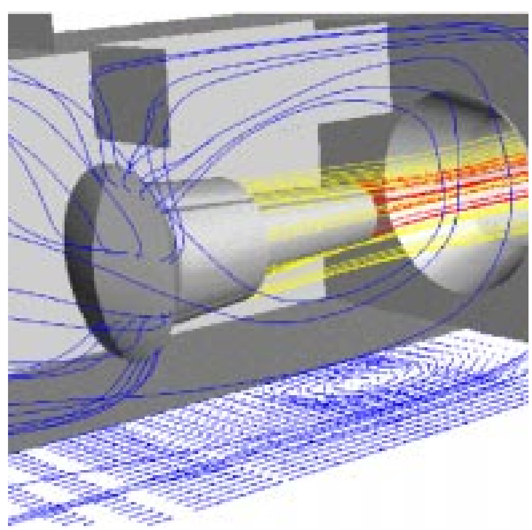
- **intuitive searches for information** (providing easy-to-use interfaces to search through categories, keywords or relationships of metadata describing processes or information).

The ITIS will be implemented in an incremental fashion over approximately the next five years. An initial operational capability is expected within the first 18 months, with incremental deliveries of additional features as the system is further developed and deployed to the test operation business areas at AEDC.

Computational Fluid Dynamics (CFD) Applications

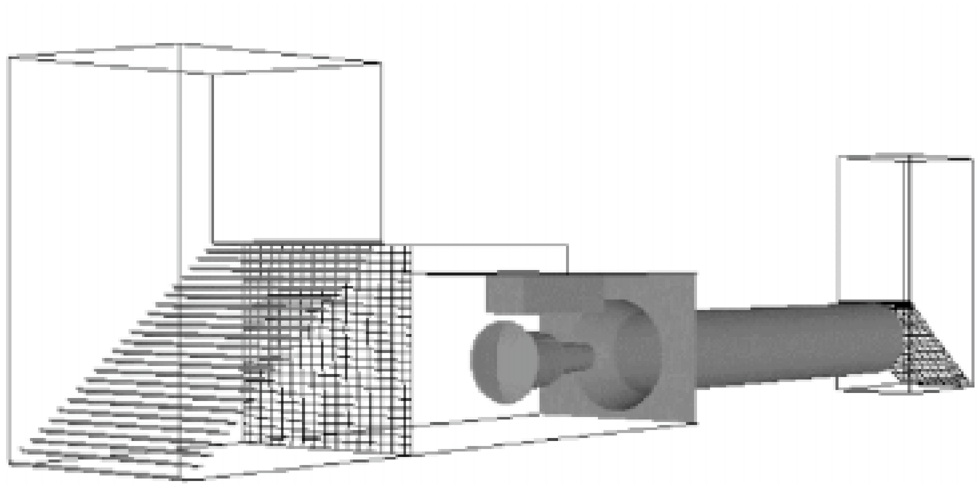
Test engineers don't have a crystal ball to predict test results, but they do have predictions based on a computer simulation technique known as computational fluid dynamics (CFD). Engineers use CFD to supplement the testing AEDC does in flight simulation facilities. CFD simulates air flow and test article behavior under test conditions. By using the principles of CFD, engineers can use computers to formulate and solve mathematical equations governing the flow of fluids such as air over and around such objects as airplanes or turbine engines installed in test cells or in actual flight thereby predicting the behavior of test articles with less actual testing.

The Center is deeply involved in CFD as an integral part of its thrust in Integrated Test and Evaluation (IT&E) methodology to solve complex engineering problems. Although CFD has matured greatly in the last 20 years, it still requires continuous development to further increase the speed at which problems are solved. As with most fast-moving technologies, each increase in speed brings a demand for even faster speeds.



Overview of altitude test facility.

Arnold Center was recently designated a high-performance computing center, and as such, favored for governmental investment in high-performance computers. Computational facilities at AEDC have already received one upgrade. Additional investments, forthcoming in the next few years, will give Arnold Center the equivalent of eight Cray C-90 supercomputers. Twenty percent of this computational horsepower will be available to research centers outside AEDC. University of Tennessee Space Institute (UTSI) will be plugged in as one of the most-favored centers.



Growth in the role that CFD plays in support of propulsion system testing is tied in part to capability enhancements in the following areas:

(1) Low speed/incompressible flow capability,

(2) Multidisciplinary nature of simulation, with emphasis on heat transfer, and

(3) Expanded involvement in analysis of propulsion systems performance.

Key applications of these IT&E tools are provided in the following paragraphs.

Simulation of a turbine engine altitude test cell

The National Project for Applications-oriented Research in CFD (NPARC) Computational Fluid Dynamics code was applied to an existing altitude test cell for a baseline configurations and to several modified configurations in both steady and unsteady mode. NPARC solves the full Navier-Stokes equations using a Beam-Warming or Runge-Kutta finite-difference algorithm. An engine was modeled beginning just upstream of the nozzle throat. The large portion of the test facility was modeled including the test section with its uniform cooling flow, diffuser and the flame chamber.

The objectives of the test were to evaluate (1) the cooling flow distribution within the test section of the Center's engine altitude test facility, (2) the performance of the exhaust diffuser for a turbine engine altitude test cell at low-altitude conditions, and (3) the potential impact on engine exhaust nozzle heating. In addition, engineers were evaluating possible cell modifications to improve cell cooling flow distribution and facility diffuser performance.

An axisymmetric parametric study of steady-state diffuser performance provided insight into the effects of varying the facility exhaust system diffuser configuration. In particular, it was determined that shortening the diffuser on the aft end was an especially efficient means to significantly reduce the pressure rise through the diffuser to improve its performance. An unsteady simulation identified a possible mechanism for the experimentally observed "puffing" phenomena by which hot gases periodically are expelled from the diffuser and have been severe enough to damage instrumentation wiring. "Puffing" has been controlled by increasing the facility cooling airflow which "scrubs" the exterior of the engine exhaust nozzle and consequently reduces the accuracy of the thrust mechanism.

Time and test costs are reduced as a result of a more extensive understanding of the flow field in the vicinity of the engine nozzle and possible sources of cell heating. "Puffing" and its side effects can be avoided by using this technique to vary facility cooling airflow and diffuser size during the test planning phase.

Electronic prototyping of engine test facilities

Electronic prototyping allows quick, accurate simulation of engine installation configurations, concepts variations and interference detection. The objective of this electronic prototyping was to reduce the time required to install a Joint Strike Fighter engine in the test facilities. The Propulsion Development Test Cell C-2 was electronically modeled and an electronic prototype of the JSF Pratt & Whitney-Boeing engine was installed using the tools available in the AEDC CAD/CAM/CAE system.

Parametric design and concurrent engineering methods were combined with AutoCAD Mechanical desktop solids and assembly modeling software to create electronic prototypes of multiple engine installations. Models of the primary test cell infrastructure, engine and engine support hardware were provided by Pratt & Whitney.

The engine inlet ducting provided to AEDC was simulated to support a number of proposed configurations during the concept development cycle.

The results showed that electronic simulation can provide quick, accurate evaluation of multiple installation configurations, reduce duplication of data by working from a shared database and improve the quality of and confidence in the proposed concept.

The "time to test," shortened by the concept development work phase at the same time, increased the accuracy of the concepts evaluated.

On-line Structural Integrity Assessment Using Structural Dynamic Response Analysis Capability (SDRAC)

Development programs for new engine systems are generating significantly greater volumes of dynamic data than ever before. New engine systems are also seeking to extract greater and greater work from each stage of the machine. These factors highlight a need to increase understanding of the structural integrity of each component and to bring understanding to all of the data generated.

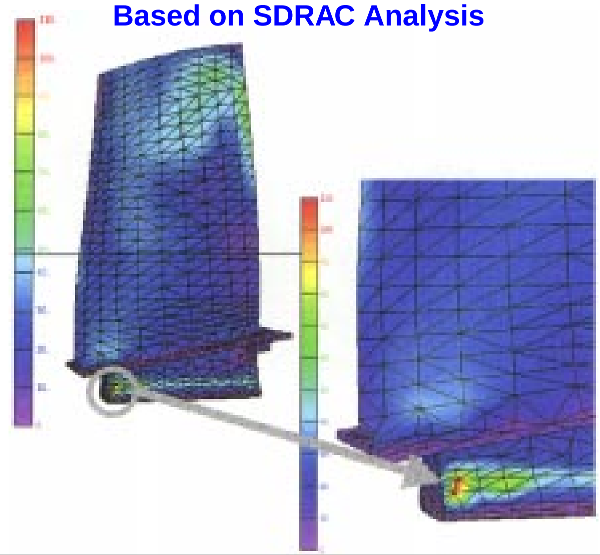
To meet these challenges, AEDC has developed a model-based analysis tool that merges real-time processed dynamic test data with finite element models (FEM) and pretest analysis results. The tool, called the Structural Dynamic Response Analysis Capability (SDRAC), performs this merge, displays the analysis results via an interactive graphical user interface (GUI) and presents an assessment of HCF capability in real time.

SDRAC also features a model modification routine to ensure that the mathematical simulation adequately reflects results from the test. The adequacy of the simulation is displayed via error measures.

SDRAC combines the strengths of state-of-the-art dynamic data processing technology and finite element modeling technology to produce a single tool that permits real-time analysis of the modal characteristics of an engine component and performs fatigue analysis to ensure that newly developed components meet their structural integrity goals.

Significant progress has been made in the area of interactive graphical user interfaces that permit the analyst to tailor the analysis to meet changing needs. Also, significant progress has been made in the area of model modification to ensure that the analytical simulation is of the highest fidelity and accurately reflects the physics of the actual system. All these features work together to ensure that maximum benefit is gained from each structural test and, because the tool operates in real time, to ensure that test costs are kept in check.

High Cycle Fatique (HCF) Margin Contours Based on SDRAC Analysis



A key feature of the SDRAC is the ability to accurately map "numerical" strain gages to the finite element models for direct comparison with test strain data. These numerical strain gages model the size of the strain gage to account for averaging effects present in the test. This results in an "apples-to-apples" comparison of analytical and experimental strain values

Because the gage is modeled numerically and independently of the finite element mesh, it is possible to move the gages around on the model at will. This provides the potential for applying optimization routines to find optimum locations to apply strain gages to accurately sense various modes of interest subject to constraints provided by the engineer. AEDC has developed a tool called BladeOPS for this purpose which can insure that strain gages are placed for optimum detection of modes.

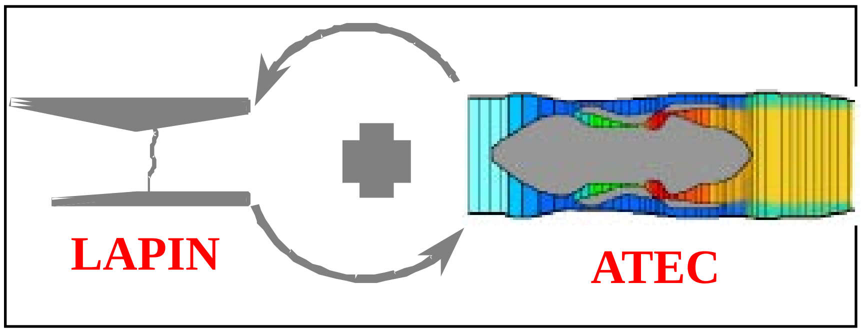
Along this same line, this technology permits the analyst to make a one-time "correction" for the potential misapplication of strain gages within some predetermined application tolerance range. This capability has been implemented into the SDRAC.

Inlet and Engine Computational Capabilities for IT&E

A primary objective of the AEDC integrated test and evaluation (IT&E) mission is centered on integrating airframe and propulsion systems. Airframe-propulsion integration encompasses a number of issues ranging from aircraft stability and control to inlet-engine compatibility. Consequently, the integration involves a wide range of technical disciplines with implications to the T&E environment. Examples include external aerodynamics with the characterization of forces and moments, inlet performance, engine operability, engine performance, controls and structures. To address these disciplines, the T&E process requires the application of a variety of test resources as well as analytical and computational tools. Testing for airframe-propulsion integration, and, in particular, inlet-engine compatibility, generally requires the coupling of component tests conducted in wind tunnels and engine altitude facilities.

Modeling and simulation technology, coupled with the baseline information provided by the current wind tunnel and test cell test procedures, produce a virtual coupling of the wind tunnel facility with the test cell information. The fusion of computational and experimental data will result in an increased level of information available to the tester for system development risk reduction.

AEDC is embarking on a course of action that will provide an engine-inlet performance and operability analysis capability by infusing test and computational capabilities. Steps are being taken that will address the computational tools needed to augment our current test capabilities. CFD codes have been applied to predicting the performance of current-day military aircraft, and three-dimensional engine models are being developed in conjunction with NASA Lewis Research Center to provide the appropriate level of simulation to analyze inlet distortion and engine-inlet interactions. Preliminary engine-inlet combinations have been performed using one-dimensional codes both for the inlet (NASA's LAPIN inlet code) and engine (AEDC's dynamic engine code, ATEC). Through using these 1D codes, insight has been gained into the types of component interactions requiring simulation with the more complex 3D codes being considered for integration.



Because the success of today's aircraft is so dependent on a high level of subsystem integration, the inlet-engine compatibility issue will evolve from an engine operability assurance task to the assurance of system operability, performance and aeromechanical integrity. Because of these trends, the airframe-propulsion integration job is expected to remain a critical component of the aircraft development cycle. Furthermore, the airframe-propulsion test and evaluation business will become even more interdisciplinary to accommodate the additional integration issues that must be addressed.

Turbine Engine Modeling and Simulation--Knowledge-Based Approach through Integrated Test and Evaluation (IT&E)

A primary objective of the AEDC knowledge-based approach is the development of an Integrated Test and Evaluation (IT&E) process. The IT&E process relies upon numerical simulations to provide information that may not be obtained during the testing process. For IT&E to become viable in the gas turbine engine business area, rapid multidimensional, interdisciplinary simulations of the full engine are required for analysis ranging from steady-state performance to highly dynamic events that include inlet distortion, gas ingestion, compressor surge/stall, and combustion instability.

To obtain the desired modeling and simulation capability, a formal alliance has been obtained with the

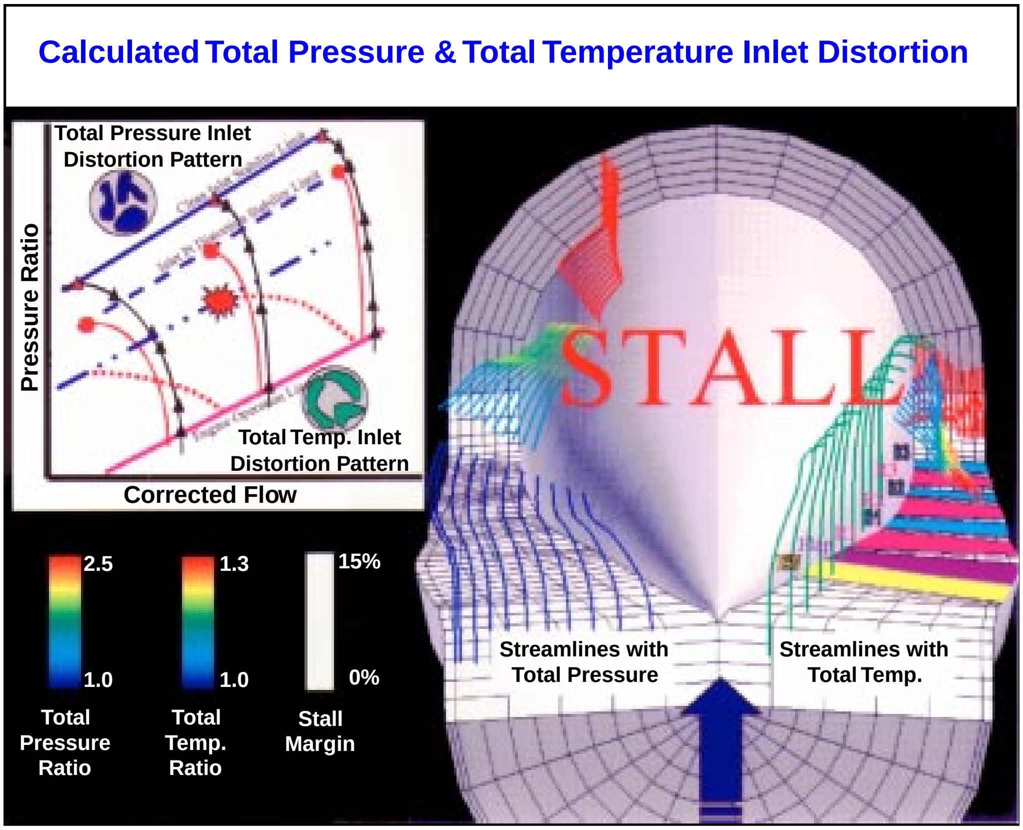
NASA Numerical Propulsion System Simulator (NPSS) program. Many of the objectives of the NPSS program complement AEDC's objectives for Modeling and Simulation. The NPSS program and its goals are outlined below.

The NPSS project's main objective is to develop a common set of numerical simulations for aircraft propulsion systems that would be supported and used by industry and government alike. The vision for NPSS is to be a "numerical test cell' used throughout the design, test and evaluation processes to reduce the amount of costly testing required to develop and certify aircraft propulsion systems. The NPSS program consists of three phases.

Phase I will develop a basic gas turbine engine model capability based upon steady-state and transient cycle code technology and 1D Euler techniques for dynamic events such as surge and time-dependent inlet distortion. Phase I activities are currently centering on the development of the National Cycle Code, NCP, with version 1 expected in September of 1998. Version 2 of NCP will incorporate dynamic modeling capability based upon the AEDC developed DYNTECC and ATEC dynamic 1D compression system and engine models. AEDC personnel will be instrumental in the implementation of this technology into the NCP.

Phase II will center on the development of a three-dimensional gas turbine engine code using Euler equations with turbomachinery source terms and Navier-Stokes equations where required. The 3D code will focus on dynamic engine behavior such as inlet distortion, surge and rotating stall but be capable of analyzing detailed design issues as well. In FY98, the development of a 3D, dual-spool compression system model which will be able to predict the stability margin with both clean inlet and distorted inlet was initiated based upon the AEDC-developed 3D dynamic compression system code, TEACC. The initial operating capability of the dual-spool simulation is expected to be available in early FY99.

Phase III will center on the development of interdisciplinary type codes for the analysis of aerodynamic, aero-structural, and aerothermal issues. AEDC, through an AFOSR sponsor project, is developing a closely coupled aero-structrured interaction code based upon the Lawrence Livermore Laboratory ALE3D code. This capability is envisioned in Phase III of the NPSS program. Again, with a visionary step forward, AEDC is positioning itself to become a major participant in this phase of NPSS.



Planned use of 3D turbine engine model at AEDC in an IT&E role-- reducing test data points to define the operability characteristics of compression systems.

AEDC's past turbine engine modeling and simulation efforts have been focused upon one-dimensional modeling techniques, the NPSS Phase I type models. Investigations into compression system operability and engine operation during the starting process have been made using AEDC dynamic models, DYNTECC and ATEC. Two recent uses of these AEDC models illustrate the usefulness and timeliness of having a dynamic modeling capability available. Both of these examples were conducted within a month of getting resources for the investigations. The quick response was obtained because AEDC had already provided the resources and time in previous years to develop the analysis capability.

• In FY96 a study to determine the potential causes of lower performance and stall margin for ASTF facility exhaust machine E311 was conducted. This machine had been consistently outperformed by its sister machines. Based upon the parametric study conducted with the AEDC dynamic compression system model, DYNTECC, it appears likely that the E311 compressor performance degradation may be caused by some level of inlet pressure distortion, with the possibility of some level of temperature distortion as well. Once compression system instability is encountered, the compressor moves into a rotating stall condition.

• In FY97, a study was conducted to determine the effect of the facility inlet ducting on the instability that an F100 engine undergoes when a destabilizing event occurs. This study was in support of an operability problem because of an F100 fan third-stage redesign to fix a structural problem. Prior to testing, an issue that needed to be resolved was whether the facility inlet needed to be lengthened to simulate an actual F-15 inlet. Based upon the numerical investigation with the DYNTECC code, it was concluded that:

• Test configuration ducting volume has an influence on the operability characteristics of systems tested with that volume.

• Because of the large volumes of facility ducting, a system will exhibit the same operability characteristic whether it uses an 8-ft inlet duct or a 17-ft inlet duct.

• Since inlet ducting at AEDC can be disregarded as a primary influence on system operability, altitude test cells will not require a nonstandard, 17-ft inlet duct in order to evaluate engine operability concerns.

In today's testing environment, problems more complex than one-dimensional models can handle have arisen. Thus, more complex and highly dynamic models are required. Through the alliance with NASA's NPSS program, AEDC is developing a new three-dimensional turbine engine model capable of simulating dynamic behavior such as complex inlet distortion, engine-inlet interaction, aerodynamic-structural interaction and combustion instability. These capabilities will support AEDC by providing the tools necessary to enact the vision of Integrated Test and Evaluation: to reduce test costs and cycle time for our customers.

On-Line Model Based Data Validation Approach

In 1993, a group of AEDC engineers recognized a need to develop more efficient techniques to ensure the accuracy of transient turbine engine performance data. A joint venture formed between AEDC, the DoD High Performance Computing Modernization Office, Vanderbilt University, NASA, and the University of Tennessee Space Institute laid the groundwork for a project to fulfill that need. They began developing a real-time system to simultaneously identify component performance changes and sensor errors occurring during transient engine operation. Real-time identification of the instrumentation problems is of particular emphasis to ensure more productive tests and higher-quality test data.

During a typical year AEDC acquires more than 10,000 hours of test data in the Center's flight simulation facilities. In the past, these data required several weeks

High Performance Computer.

of labor-intensive manual inspection to validate and analyze. The new process, capable of inspecting thousands of measurements, uses a high-performance computer (HPC) to perform more than three billion data-validation instructions per second. The new technology will provide real-time test data validation, allowing customers to make on-line decisions during turbine engine testing.

The group developed a prototype computer code and built a prototype HPC in 1995 using nine interconnected microcomputers. Based on the prototype application's success, the team installed the computer code on a 64-processor HPC as part of the Department of Defense High Performance Computing Modernization Program. The HPC provides an eight-fold increase in computing speed and enables real-time operation.

Using engine cycle-matching principles, the system performs automated data validation, engine condition monitoring and fault identification processes to emulate typical engineering techniques used during test data analysis. Complex mathematical computer models capable of simulating both steady-state and transient engine conditions are used to automate the once lengthy data validation process. High-performance computers are used to perform the many complex computations in real time.

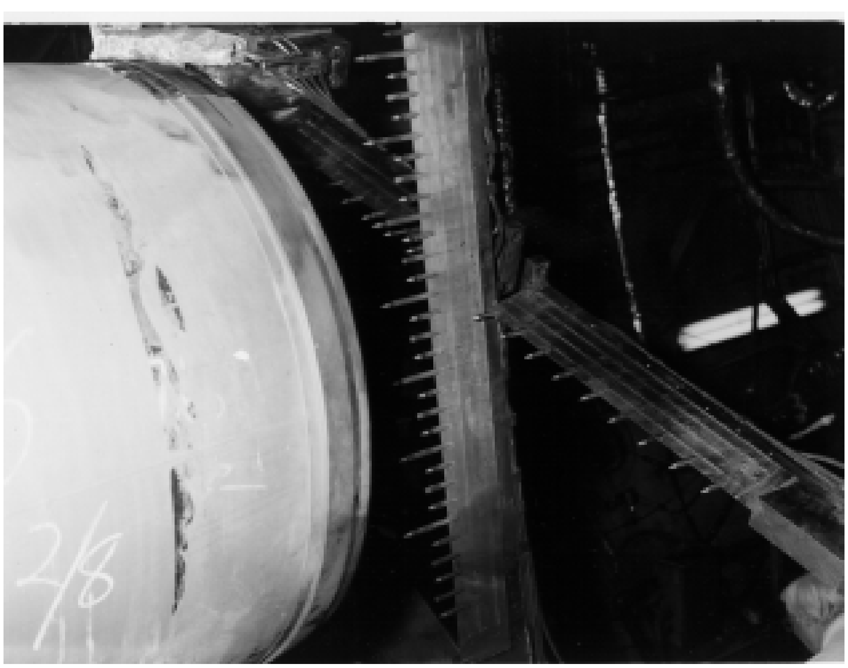
The team evaluated and validated the prototype system using data from two distinctly different turbine engines undergoing ground-test development tests at simulated altitude conditions. The system was successfully in detected sensor failures over a wide range of operating conditions while maintaining a low false alarm rate.

The new system will obtain test data through sensors mounted in the engine and test facility. Transient data gathered through these sensors will be acquired through the new Engine Data Acquisition and Processing System (EDAPS), then transmitted directly to the processors. The EDAPS system can provide up to 500,000 measurements per second to the data validation system. A graphical representation and data analysis will also be available immediately to the user as data are acquired. When a fault is detected, a diagnostic element of the system will provide the relative probability of each possible fault. This in turn supports the test engineers' decisions.

In addition, the new data validation system will minimize data reprocessing required by the current approach. Data will be validated and reduced in a matter of seconds rather than days obviating the waiting period following the test. This new process allows the customer to make necessary test changes while the test continues, saving both time and money.

Full operational capability of the system is scheduled for the year 2001.

Real-Time Emissions Measurements (Gas Sampling)



TF-33 emissions test in ASTF C-2.

Typically, AEDC requirements for real-time emission measurements and analysis is in support of the development of aircraft turbine engines tested at simulated altitude. AEDC has recently provided emissions measurements for various engines, including the F414, F110, TF33 and the Westinghouse Combustor, and for facility assessments like the Aeropropulsion Test Unit (APTU), the AEDC Plant Glycol Assessment, and flammable gas inerting verifications.

For the engine tests, the exhaust gas pressure is subatmospheric, and vacuum pumps are used to flow the sample to the analyzers. Heated sample lines from the probe rake transport the gas to a system of analyzers. SAE standard measurements are made with gas sampling probes. Measured species include CO, CO_2, NO_x, NO, O_2 and unburned hydrocarbons. Several nonintrusive diagnostic systems have also been developed at AEDC for the measurement of the species in the exhaust gas.

Emissions measurements taken during engine tests have met several objectives. On the F414 and F110, the objective was to quantify the performance of various augmentor spray ring and liner configurations. The emissions were required to locate fuel-rich areas in the nozzle and to qualify the local combustion efficiency and fuel-to-air ratio.

For the TF33 engine, AEDC compared the performance of versions of the TF33 engine burning JP-8 to the performance of the same engine burning JP-4 fuel. Emission measurements were made for comparison of emission indices, combustion efficiencies and the smoke number for each engine burning both fuels.

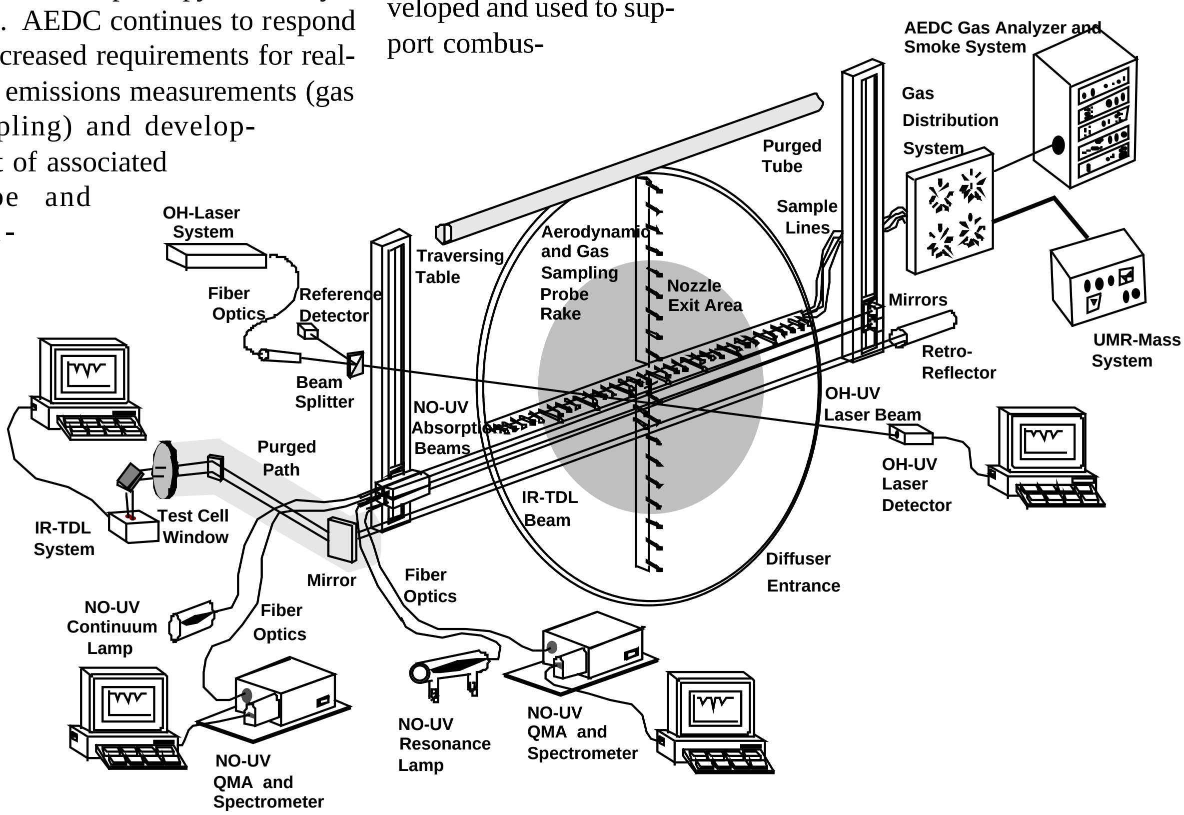
Advanced Instrumentation and Measurement Diagnostics

AEDC continues to develop and enhance existing instrumentation and diagnostic techniques in order to provide state-of-the-art real-time measurement capabilities for customer application requirements. AEDC also provides operational support for customer-owned specialized instrumentation and diagnostic systems used at AEDC during engine tests. Examples of operational support include the non-interference structural measurement system (NSMS), blade tip clearance (BTC) measurements, telemetry systems, and optical pyrometer systems. AEDC continues to respond to increased requirements for real-time emissions measurements (gas sampling) and development of associated probe and sampling technologies for varied and harsh sampling conditions, including combustor and augmentor applications.

Advanced Hi-Temp Probe Development

AEDC has successfully developed and demonstrated gas sampling, pressure, temperature, Mach number/ flow angularity probes and complete rake systems for both combustor and turbine engine exit applications. Probe and rake instrumentation has been successfully developed and used to support combustor rig testing at temperatures approaching 3500°F.

In addition, AEDC has developed intrusive probes for optical viewing inside combustors. The optical probes are inserted directly into combustors and provide direct image information on the combustion processes and on local heating of the combustor. Similar probes have also been used as a conduit for fiber-optic instrumentation to permit application of nonintrusive line-of-sight optical diagnostics in regions that



are not accessible to conventional line-of-sight instrumentation. In such applications emissions/ absorption measurements have been obtained at a "point" using line-of-sight diagnostic techniques that usually integrate the result over the entire line of sight of the instrument. Work is currently in progress to extend these techniques to include spectrally resolved measurements.

AEDC is also currently developing a suite of intrusive emissions and thermodynamic performance probes for use in advanced technology combustors and augmentors. The probes under development will operate and acquire data at temperatures up to 4500°F. The conceptual design of these probes has been completed, and prototype fabrication and design validation testing are planned for early FY99.

Engine Exhaust Gas Characterization

Engine exhaust characterization measurements were conducted at AEDC in support of the NASA Atmospheric Effects of Aviation Program (AEAP). The engine was operated over a range of combustor temperatures and pressures at each of several altitudes, including sea-level static. This provided the atmospheric modeling communities with detailed measurements of altitude cruise emissions, and NASA a set of parametric data for insight into exhaust emission variations as a function of combustor parameters and altitude. Major and minor species concentrations, as well as flow-field kinetics, were characterized for a wide range of engine power settings at sea-level static, 25,000, 30,000, 40,000 and 50,000 ft simulated altitude conditions. Both intrusive (gas sampling) and nonintrusive (optical) measurement techniques were used for gaseous species concentrations and a probe sampling technique was used to characterize aerosols and particulate matter.

The figure on the preceeding page graphically illustrates the relative measurement locations for the optical techniques and probes. The probe rake system was mounted inside the diffuser, and the probe tips were positioned near the nozzle exit plane. Conventional gas sampling techniques provided concentration measurements of NO, NO_2, CO, CO_2, O_2, and total hydrocarbons (THC) and an exhaust plume measure referred to as smoke number. Spatial sampling measurements were made at individual probe sites and spatial averages by "ganging" probe samples within the gas distribution system. Spatial profiles of static temperature and static pressure, determined from Mach number/flow angularity probes, stagnation temperature probes and gas sampling data, were used in the analysis of optical line-of-sight data.

Optical techniques were line-of-sight measurement systems. AEDC provided optical measurements of NO and OH using ultraviolet (UV) resonance absorption techniques. The optical beam was traversed across the plume to provide data for spatial distributions across the plume. Additionally, AEDC used a fixed-position spectrally scanned UV laser absorption system for measurements of OH, and infrared tunable diode laser (TDL) measurement techniques for concentration measurements of NO, NO_2, CO, and H_2O, although not all species were measured simultaneously throughout the test series.

The University of Missouri-Rolla system, referred to as the Mobile Aerosol Sampling System (MASS), was used to provide measurements of total aerosol and nonvolatile aerosol concentration, size distribution and hydration of growth as measured by soluble mass fraction and critical supersaturation spectrum.

Advanced Turbine Sensors

AEDC teams with test customers to develop instrumentation and diagnostic methods and systems to achieve test measurement requirements. Participation in organizations such as the Propulsion Working Group (PIWG) enables AEDC to be current and involved with customer problems and issues. Currently, AEDC is a partner in developing the next-generation NSMS for military applications and is integrally involved in measurements for blade tip clearance (BTC), telemetry and pyrometry. Telemetry allows the transmission of strain-gage data across moving parts without direct wire connections. AEDC is currently partnering with test customers to understand the spectral characteristics of thermal barrier-coated material to aid in the modification or development of optical pyrometry systems for real-time measurements of blades and other surface temperatures inside turbine engines during developmental testing. To support pyrometer development, AEDC has a state-of-the-art laboratory spectral emissivity measurement system, developed under the Small Business Innovative Research (SBIR) program, to characterize the temperature-dependent spectral characteristics of TBC materials. This spectral emissivity measurement system, in conjunction with real-time spectral characterization measurements of TBC materials will potentially enable development of an optical pyrometer system for real-time measurements to identify interference radiation sources inside engines.

Engineers help solve T-3A problems

T-3A Firefly

Since 1995, three T-3A Firefly trainers at the Air Force Academy have crashed, killing six instructors and cadets. The latest incident, which occurred in June 1997, prompted the Air Force to suspend operations of all Firefly pilot-screening flights. The problem, the Air Force believed, was in the fuel-to-air ratio. When the pilot throttled back, the engine would quit, causing the plane to crash. AEDC engineers offered to help isolate the problems by deriving low-rpm mixture ratio from exhaust gas emissions measurements on the T-3As. The project's scope included the quantification of the engine mixture ratio over the range of throttle setting and ambient temperature conditions expected during a typical T-3A flight. Engineers surveyed aircraft located at Waco, Texas, Hondo, Texas and at the Air Force Academy, Colorado Springs, Colo.

The T-3A Firefly, powered by one Textron Lycoming Ltd. AEIO-540-D4A5 engine, is a propeller-driven aircraft. It is used by the Air Force's Air Education and Training command to screen pilot candidates by exposing them to military-style traffic patterns, aerobatics and spins. The aircraft has a fully composite structure, and the fuel is automatically transferred by an engine-driven pump. The emissions sample probe was connected to the bottom of the aircraft. The AEDC mobile emission van was parked within 50 feet of the static aircraft, and a heated sample transport line was connected to a sample probe on the exhaust pipe. The van has both a built-in power system and portable power systems.

All available aircraft, 80 of 110 total, were surveyed, and the general data trend agreed with the Lycoming database. In addition, the measurement system provides a near-real time data acquisition and analysis system, and engineers were able to obtain four times more data than expected. "AEDC provided mixture ratio data as planned and in time to guide the work of the PCE team," said Lt. Col. Holly Conner, project manager, OC-ALC/LKO.

Productivity Enhancements

Test Project Archival System

TPAS was developed in September 1993 and was originally intended to allow permanent archival storage of test project information on a CD-ROM to make access in future years convenient and complete. It has met this need and has been enhanced by storing information during the project using the AEDC local area network (LAN).

Instead of rummaging in a notebook for a test log from weeks ago, it can be quickly displayed on any PC, printed or copied to a local disk for use with other programs. Security procedures built into the AEDC LAN limit access to personnel involved on a particular test program.

The pilot turbine program, involving an F119 Engineering and Manufacturing Development engine test project, was completed in January 1995. TPAS data packages were shipped to the customer and sponsor in February. Just the steady-state print pages alone for this test would have consisted of 250,000 separate pieces of paper and would have filled the bed of a pick-up truck. Using the single TPAS disk and a simple 'point-and-click' technique, the customer can view only the pages he wants without having to flip through unnecessary pages.

By eliminating paper reports and plots, TPAS is not only environmentally friendly, it also reduces shipping and recycling costs as well. In addition to the condensed data feature, the program also provides interaction between multiple test files by allowing the inclusion of numerous test documentation types. The system allows the customer to view digitized photographs, videos and electronic drawings of test articles and configurations. All software necessary for viewing the data is included on the CD as well.

TPAS also allows the user to move to various areas in the program through user-friendly menus, and program links allow integration of the text, graphics, audio, video and test data.

An engineer holds a CD-ROM produced by the Test Project Archival System.

Personnel at the Air Force Flight Test Center (AFFTC), Edwards AFB, were recently introduced to AEDC's TPAS. The AFFTC was impressed by the capability and requested immediate AEDC assistance to establish TPAS at AFFTC to support F-22/F119 propulsion flight testing. AEDC implementation efforts at AFFTC are underway

This single compact disk collection contains a variety of test information, such as project documentation and combined test data, while system software adds multimedia, hypertext and data analysis tools. It gives AEDC customers a powerful single-information source for ground tests conducted at the Center.

Following application of the TPAS approach to the Navy's F414 at AEDC, the TPAS approach has become standard practice for Aeropropulsion T&E programs.

Computer-Assisted Dynamic Data Monitoring and Analysis System

Development and application of Computer-Assisted Dynamic Data Monitoring and Analysis System (CADDMAS), a system that applies computer processing in parallel and reduces customer test data turnaround time from days to seconds, is continuing to advance at AEDC.

CADDMAS is a data processing and monitoring system designed by AEDC to gather and analyze test information as it occurs. It is a multi-channel, real-time parallel processing-based, dynamic data (up to 50 KHz) acquisition and complex data analysis system. The system contains multiple parallel processors linked with personal computers to process data simultaneously with its acquisition to provide engineering information in real-time. The CADDMAS provides the user with real-time data analysis cheaper and faster than a main-frame supercomputer.

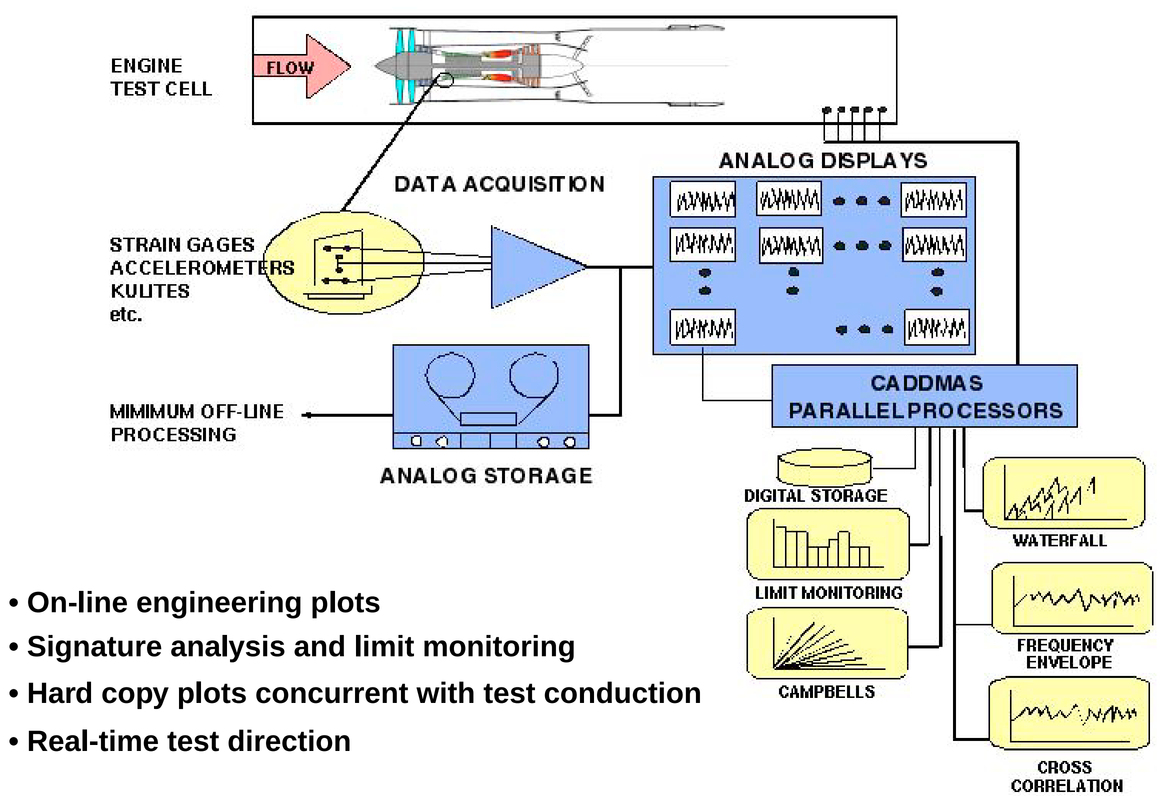
General Electric recently requested AEDC support for use of CADDMAS to perform on-line data analysis for F110-100 and F110-129 engines during F-16 aeromechanical flight testing at Edwards Air Force Base, Calif. This marked the first time a portable CADDMAS has been taken to an off-base site. Its capabilities provided Edwards and GE test engineers with information necessary to make in-flight test decisions.

AEDC engineers have used CADDMAS on base during several programs, including testing of the F119. Through CADDMAS, the accumulated data were processed and analyzed during the test instead of days or weeks afterwards as was typical before CADDMAS was available. Stress level measurements were simultaneously displayed as they were gathered, allowing engineers to compare them to measurements obtained during tests previously conducted on F119 engines. The on-line analysis provided Pratt & Whitney with immediate confirmation of reduced stress levels on the blades using this configuration.

In a typical test application, strain gages are attached to an engine component and connected to a data acquisition system. Each gage represents one data channel to the data processing unit. During system testing, these sensors monitor various conditions such as engine compressor blade vibrations and provide raw (analog) data to the acquisition system. The data are converted to digital form, recorded on magnetic tape and typically stored for later analysis. Previously, a limited number of data channels could be displayed during the test, but only one at a time on a single-channel frequency monitor. Data conversion and production of graphs, plots and tables needed for further analysis took three to 10 days after the test to complete, resulting in little on-line stress knowledge and very limited monitoring capabilities. This severely limited on-line test direction. Final post-test data analysis was not only time-consuming, but also highly labor intensive and costly.

Now, using CADDMAS, data collection, conversion and magnetic storage techniques are the same, but the data processing phase has been streamlined. Once converted to digital format, data are relayed to multiple parallel processors instead of the single-channel frequency monitor. Having 24 data channels as opposed to one, these processors allow the test conductor to view multiple aspects of the test as it occurs. He can then analyze the data as they are received, monitor ongoing test conditions, graphically display situations as they occur, and modify the test plan on-line if necessary.

Data Acquisition and Processing with CADDMAS



Meanwhile the test continues, uninterrupted, and the customer receives the requested data in real time, not within 10 days, saving both time and money and reducing test article risk.

The system's return on investment for AEDC aeromechanical testing alone has been estimated at 7 to 1 over a 10-year period. When the technology development and transition of CADDMAS are complete, the return on investment across the Department of Defense is expected to be orders of magnitude above that for AEDC aeromechanical testing. In addition, avenues for technology transition into private industry are being pursued.

Data Acquisition and Processing Systems

The way AEDC's test facilities acquire, process and distribute data is on the cusp of undergoing a revolutionary change. AEDC Data Acquisition and Processing Systems, or ADAPS, is an instrumentation, control and computer upgrade initiative that establishes common data systems among the Center's test facilities. ADAPS is an effort to create a common architecture and promote reuse of test facility resources.

Historically, each of AEDC's test cells, facilities and plants has had unique computer systems for acquiring, monitoring and processing test data. Not only did this make each unique system expensive and difficult to support, it has limited the opportunity for personnel to work in different test cells.

With ADAPS, AEDC personnel can move between facilities and be familiar with control systems, recognizing common screens and capabilities. Although each test cell may have different requirements and capabilities, the basic operating interface is the same.

The system is designed with significant commercial-off-the-shelf hardware and software and will operate in a Windows™ environment where users "point and click" their way through common screens — something not currently possible in the Center's facility control rooms.

ADAPS uses state-of-the-art computer hardware, software, networks and new control technology to provide customers with unparalleled data processing and display capabilities. On one screen, users view real-time data display, audio, video or information management with interactions with customers and testers in real time. The days of relying on one computer for one application with many steps of tedious processes are gone.

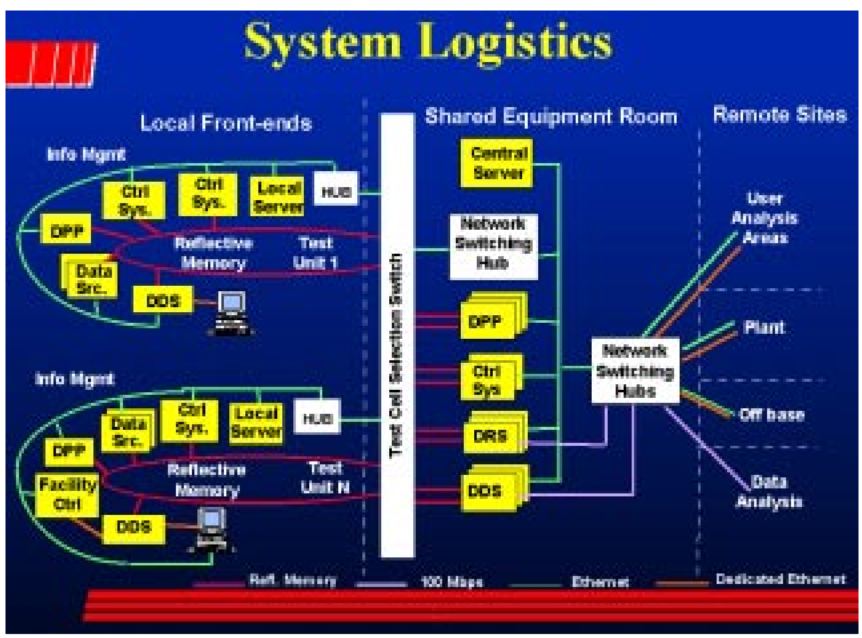
ADAPS will also allow AEDC customers to monitor and interact with test activity from remote sites in near-real time. Test customers can establish ADAPS design and interface configurations at their site and can view test activity while monitoring and analyzing test data from their location as if sitting in an AEDC control room.

In addition to offering ADAPS to AEDC test customers, other DoD and NASA test and evaluation sites are interested in the program. AEDC has shared this knowledge with the Air Force Flight Test Center at Edwards AFB, Calif., Naval Air Warfare Center Aircraft Division at Patuxent River, Md., NASA Langley in Virginia and, most recently, Kennedy Space Center, Fla.

The first test cell at AEDC to implement ADAPS will be Propulsion Development Test Cell T-11. T-11 test cell is under final checkout and was recently transferred from Trenton, N. J. to AEDC.

Feasibility of ADAS has been demonstrated in T-11 and is in transition to 16T, 16S, C1, C2, 4T, VKF, ETF, APTU and the T/J cells.

Future installation of ADAPS will be determined by funding limitations. With ADAPS capability, the ASTF data supply rate will be increased from 40K to 400K samples per second.



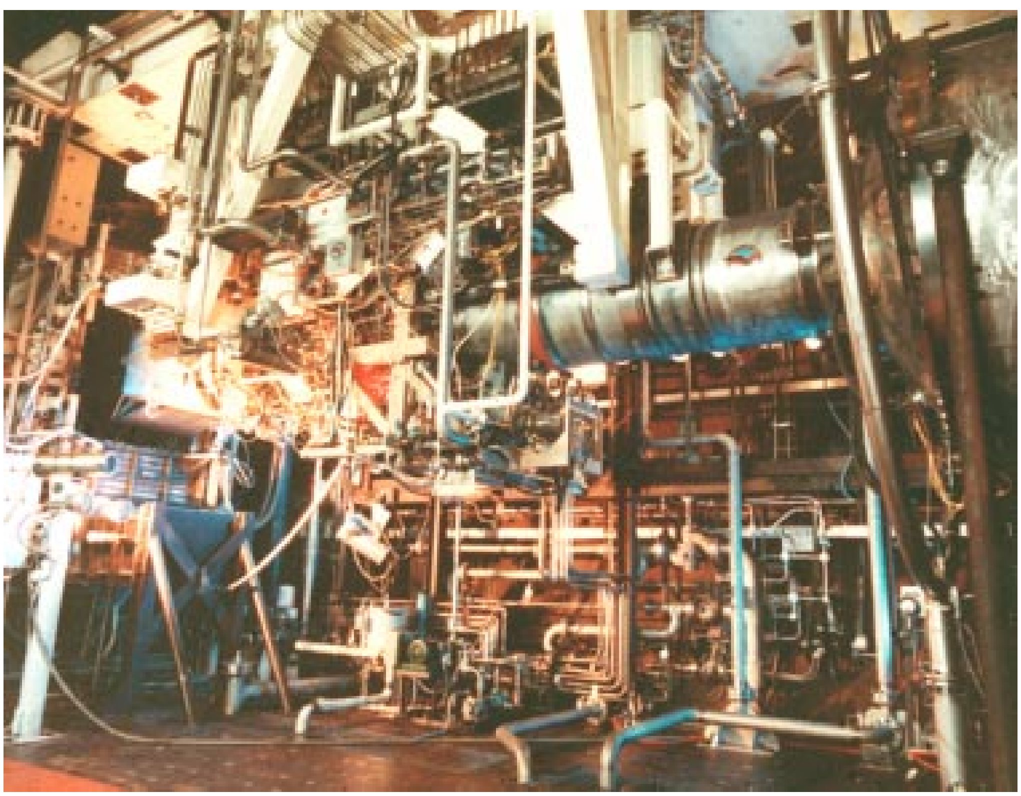
Test cell modified to better serve customers

Propulsion Development Test Cell C-2 has been used in recent years to test large commercial engines for the Boeing 777 aircraft, logging more than 750 air-on test hours for the Pratt &Whitney PW4084, PW4090, PW4098 and the Rolls Royce Trent 800. However, with the birth of the next generation of advanced fighter, the Joint Strike Fighter (JSF), came the need to use Test Cell C-2 for testing its powerplant. With this need also came the challenge of configuring the cell to easily accommodate both types of engines.

Because of ASTF's capability, the two P&W JSF engine designs, one for Boeing and the other for Lockheed, for the JSF will be tested in ASTF. Both contractors have selected derivatives of the Pratt & Whitney F119 engine, the powerplant for the F-22, to power their demonstrator aircraft. The engines will use an F119 engine core, with the nozzle fan and controls tailored to individual aircraft requirements. The JSF engine for the Boeing configuration will be tested in Test Cell C-2, while the engine for the Lockheed configuration will be tested in Test Cell C-1, C-2 and J-2.

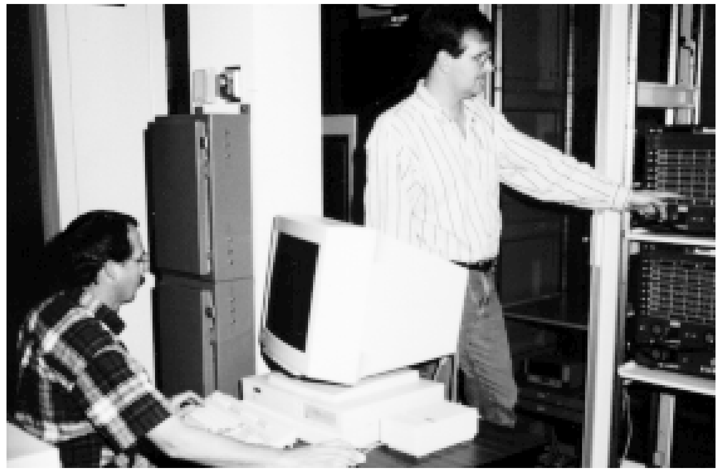
Because both large engine and JSF engine tests are required in Test Cell C-2 during the FY98-FY00 window, modifications to the so-called "test cell neutral configuration" are required to reduce the cycle time between the two types of tests to accommodate all customer requests. Modifications to Test Cell C-2 will reduce the time spent reconfiguring the test cell by about 40 percent (5 weeks) when it is changed from a large engine to a JSF engine installation, thus increasing the C-2's test availability. Test cell modifications will be accomplished incrementally; the initial modification work was completed in February 1997. During the summer of 1997, the test cell was converted to an interim neutral configuration. The final increment of the modification was accomplished in FY98.

The modification is a joint venture between the commercial companies and the government. The commercial companies invest to improve their ability to test, while the government is investing to support future workload. Future test support for the JSF program includes both ASTF test cells in support of the JSF Concept Demonstration Phase from FY98-December FY2000. In addition, EMD altitude development testing is scheduled for November 2002, and EMD altitude qualification testing will follow in March 2003.



Propulsion Development Test Cell C-2

ETF customers receive test data on-line



AEDC personnel work with the ETF customer on-line computer data system.

Only a couple of years ago, Engine Test Facility (ETF) customers had to wait hours, sometimes days, for test data to reach their home sites, causing test schedule delays and financial pressures on test programs.

With all the advancements in information technology, AEDC engineers thought there had to be a better way to link customers to their test data. The outcome of this effort is an on-line analysis system that makes extensive use of new computer workstations and high-speed networks to support turbine and rocket test programs in the ETF.

The initial emphasis for this effort was to improve the customer analysis capability and access to on-line test data. Customer systems were developed in fiscal year 1993 for Pratt & Whitney, West Palm Beach, Fla., and the Navy at Trenton, N.J. In fiscal year 1994, systems were also developed for Rolls-Royce, Derby, England, and General Electric, Evendale, Ohio, and systems to service the Navy at Patuxent River, Naval Air Station, Md., are underway. Subsequent emphasis was placed on developing an improved method for AEDC ETF analysis engineers to provide the required local analysis capability.

The hardware and software for a local AEDC ETF analysis capability was completed in October 1995. The first test program to use the new analysis capability locally was the Allison engine test in Propulsion Development Test Cell T-1. Since then, the concept has been expanded and can support future ETF test programs such as the Trent 800, the Pratt & Whitney F119 and F100, and the General Electric F414 and F101. Expansion to other AEDC test facilities in order to provide a common AEDC test data analysis capability is currently in progress.

Customer analysis areas were developed first because of test data requirements. The F119 engine tests in the Aeropropulsion Systems Test Facility (ASTF) acquired more data than the previous off-site networks could support. Since customers had their own analysis software which could be easily introduced to the workstations provided, only limited software had to be developed to provide a production capability for data transmission and analysis.

In addition, the AEDC-developed software is also based on the open system philosophy using government and industry standards, so it can be easily shared with other government installations with similar needs. The volume of test data dictates a graphical presentation of information, coupled with the capability to retrieve, select, manipulate, recode and recalculate data in an interactive mode. This functional capability is required for both on-line test support and post-test, off-line analysis. In addition to test data analysis, engineers and scientists require a similar functional capability to deal with the problems associated with computational fluid dynamics, technology efforts and other engineering functions.

Off-base data transmission has been expanded to send encrypted data over public networks such as the Internet or Aeronet, making use of the existing infrastructure.

This technical transformation was a result of a team effort with Air Force, contractor and customer personnel to improve the test data analysis process. Customers Hugh Horrocks of Pratt & Whitney and Tom Beck of General Electric praised the effort for reducing test costs by improving test data access times. “Significant efficiency gains as well as reduced travel and lodging costs have been realized in a very short time period,” said Tom Beck, leader of the GE test programs at AEDC.

As far as the Navy is concerned, Jack Walters, AEDC Deputy Director of propulsion and a Navy employee, has indicated Navy test engineers are pleased with the new system and expect to benefit from its use both at AEDC and at the Navy Air Weapons Center at Patuxent River.

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AEDC Test Facilities
(Nominal Values)

ENGINE TEST FACILITY	Test Section Size: Cross Section, ft	Test Section Size: Length, ft	Total Temperature, °R	Speed Range	Pressure Altitude (Nominal), ft	Capacity of Installed Thrust Stand, lb	Primary Use*
Propulsion Development Test Cell T-1	12.3 diam	39 to 57	380 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	30,000	(2) (6) (9)
Propulsion Development Test Cell T-2	12.3 diam	42 to 50.5	380 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	30,000	(2) (6) (9)
Propulsion Development Test Cell T-3	12 diam	15	450 to 1,660	Mach 0 to 4.0	Sea Level to 100,000	20,000	(2) (3) (6) (9) (11)
Propulsion Development Test Cell T-4	12.3 diam	39 to 47.8	380 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	50,000	(2) (6) (9)
Propulsion Development Test Cell T-5 ***	7 diam	17	395 to 660	Mach 0 to 2.0	Sea Level to 80,000	2,000	(2) (6) (9)
Propulsion Development Test Cell T-6 ****	3 diam	18	430 to 760	Mach 0 to 3.0	Sea Level to 90,000	None	(1) (3) (4) (6) (7) (11)
Propulsion Development Test Cell T-7 ***	7 diam	9	395 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	1,000	(2) (6) (9)
Propulsion Development Test Cell J-1	16 diam	65	395 to 1,210	Mach 0 to 3.2	Sea Level to 80,000	50,000	(2) (3) (6) (9)
Propulsion Development Test Cell J-2	20 diam	67.3	395 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	50,000	(2) (3) (6) (9)
Propulsion Development Test Cell J-2A****	18.3 diam	32	(Wall, 144)	Static	450,000	20,000	(1) (5) (11)
Rocket Development Test Cell J-3	12 diam 17 diam	26 High 20, 30, 40 High	– – –	Static	125,000	200,000	(1) (5)
Rocket Development Test Cell J-4	48 diam	82 High	– – –	Static	100,000	500,000	(1) (5) (11)
Rocket Development Test Cell J-5 ***	16 diam	50	– – –	Static	100,000	300,000	(1) (5) (11)
Rocket Development Test Cell J-6	26 diam	62	– – –	Static	100,000	500,000	(1) (5) (11)
Sea Level Test Cell SL-1	24 x 24	50	Ambient	Static	Sea Level	52,500	(2)
Sea Level Test Cell SL-2	24 x 24	57	395 to 720	Mach 0 to 1.1	Sea Level	25,000	(2) (6) (9)
Sea Level Test Cell SL-3	24 x 24	57	395 to 720	Mach 0 to 1.1	Sea Level	25,000	(2) (6) (9)
Propulsion Development Test Cell C-1	28 diam	50 to 85	360 to 1,480	Mach 0 to 3.8	Sea Level to 100,000	100,000	(2) (3) (6) (9)
Propulsion Development Test Cell C-2	28 diam	50 to 85	360 to 1,110	Mach 0 to 3.0	Sea Level to 100,000	100,000	(2) (6) (9)

von KARMAN GAS DYNAMICS FACILITY	Test Section Size, in.	Total Pressure, psia	Total Temperature, °R	Speed Range	Pressure Altitude, ft	Dynamic Pressure, psf	Reynolds No./ft (x10⁶)	Primary Use*
Supersonic Wind Tunnel A	40 x 40	1.5 to 200	530 to 750	Mach 1.5 to 5.5	16,000 to 151,000	53 to 1,780	0.3 to 9.2	(6) (7) (14)
Hypersonic Wind Tunnel B	50 diam	20 to 900	700 to 1,350	Mach 6 to 8	98,000 to 180,000	43 to 590	0.3 to 4.7	(6) (7) (14)
Hypersonic Wind Tunnel C	50 diam	200 to 1,900	1,650 to 1,950	Mach 10	132,000 to 188,000	43 to 430	0.3 to 2.4	(6) (7) (14)
Aerothermal Wind Tunnel C	25 diam Free Jet 25 diam Free Jet	200 to 2,000 20 to 180	1,220 to 1,900 720 to 1,660	Mach 8 Mach 4	95,000 to 149,000 56,000 to 105,000	132 to 1,322 231 to 1,928	0.7 to 7.8 0.2 to 8.1	(6) (7) (13) (6) (7) (13)
Aerodynamic and Propulsion Test Unit (APTU)	32 diam 36 diam 42 diam Free Jet	20 to 160 20 to 300 40 to 300 20 to 240 50 to 300	700 to 1,000 700 to 1,200 700 to 1,300 700 to 1,150 700 to 1,600	Mach 2.20 Mach 2.72 Mach 3.50 Mach 2.55 Mach 4.10	Sea Level to 40,000 10,000 to 70,000 35,000 to 75,000 Sea Level to 65,000 55,000 to 80,000	900 to 7,300 600 to 9,300 650 to 4,800 700 to 8,500 500 to 2,900	3.15 3.16 1.10 2.17 1.6	(1) (3) (4) (6) (7) (9) (11) (12) (13)
Hypervelocity Range/Track G	120 diam	– – –	– – –	To 24,000 fps	Sea Level to 244,000	– – –	– – –	(8) (10)
Hypervelocity Impact Range S1	Target Tank 30 diam	– – –	– – –	To 32,000 fps	Sea Level to 10^5 torr	– – –	– – –	(10)
Bird Impact Range S3	240 x 144	– – –	– – –	200 to 1,400 fps	Sea Level	– – –	– – –	(10)

TUNNEL 9	Contoured Nozzle	Reynolds No./ft (x10⁶)	Supply Pressure Range, atm	Nominal Supply Temp, °R	Usable Run Time, sec
	7	3.7 to 15.8	180 to 815	3,460	1 to 5
	8	8.7 to 55.7	135 to 815	1,660	0.2 to 0.75
	10	0.86 to 21.9	35 to 955	1,810	0.2 to 15
	14	0.072 to 6.2	7 to 1,295	3,160	0.7 to 15
	16.5	2.65 to 3.2	1,295 to 1,430	3,260	3.0 to 3.5

	Nozzle Exit Diameter, in.	Model Enthalpy, Btu/lb	Model Pilot Pressure, atm	Mach Number	Erosion Simulation: Dust Particle Diameter, μm	Erosion Simulation: Dust Velocity, fps	Primary Use*
High Enthalpy Ablation Test Unit (HEAT) H1	1.8 to 3.5	2,000 to 9,000	17 to 95	0.75 to 3.00	70 to 200 Graphite	5,800 to 7,300	(13)
High Enthalpy Ablation Test Unit (HEAT) HR **	1.8 to 3.2	2,000 to 5,200	19 to 77	1.1 - 4.0	– – –	– – –	(13)
High Enthalpy Ablation Test Unit (HEAT) H2	4 - 9.8	0.896 to 2,278	0.14 to 3.4	4.0 to 8.0	– – –	– – –	(7) (13)

	System	Type	Size	Max. Specimen Weight, lb	Max. g	Remarks	Primary Use*
Impact, Vibration, and Acceleration Test Unit ****	Vibration	Electrodynamic Ling A249	30-in. diam	2,800 at 10 g rms	75	30K-lb Max. Sine Force 32K-lb Max. Random Force 5.2 kHz, 1.0 in. Double Amp	(1)
	Shock	Electrodynamic Ling A249	30-in. diam	2,000	– – –	Pulse Shapes: Sawtooth, Half-Sine, etc.	
	Shock	Parallel-Pendulum	– – –	1,000	– – –	Travel, 2 ft	
	Acceleration	Centrifuge	17-ft rad	2,000	30	– – –	

USE LEGEND: * Testing of (1) Rockets, (2) Turbojets (3) Ramjets (4) Missile Base Heating Models, (5) Space Environmental Tests, (6) Aerodynamic Models, (7) Aerothermodynamic Models, (8) Aeroballistic Models, (9) Combined Aerodynamic Inlet and Propulsion System Tests, (10) Impact Studies, (11) Free-Jet Expansion of Rocket Exhaust Plumes, (12) Ablative Materials, (13) Ablative and Erosive Materials, (14) Store/Stage Separation

** Currently Mothballed
*** Standby Status
**** Currently Non-Operational

10/98

AEDC Test Facilities
(Nominal Values)

AEROSPACE CHAMBERS	Test Section Size		Wall Temp., K	Chamber Empty Pressure, torr	Pressure Altitude, miles (1962 U.S. Std Atm)	Thermal Radiation Simulation	Primary Use*
	Cross Section, ft	Length, ft					
Mark I	42	(Vert.) 82	77	10^{-7}	210	Collimated Solar and Programmed Heat Flux	
10V	10	(Vert.) 30	77	10^{-7}	200	Tungsten Lamps	
12V	12	(Vert.) 35	77	10^{-7}	200	8-ft-diam Xenon Solar and Programmed Tungsten Lamps	
7V	7	24	<20	10^{-7}	200	N/A	
FPCC	5	5	<20	10^{-7}	200	N/A	
DWSG	Varies	Varies	<20	N/A	200	N/A	
BRDF	3	5	AMB	10^{-5}	AMB	N/A	(5)
COP	2	3	77	10^{-5}	200	N/A	
SAM	2	15	77	10^{-7}	200	Xenon Lamp	
SMOG	2	1	AMB	10^{-5}	AMB	N/A	
7A	3	5	<20	10^{-7}	200	– – –	
UHV	2	3	<20	10^{-7}	200	N/A	
4 X 10	4	10	<20	10^{-7}	200	– – –	
CROVAC	Varies	1	<20	10^{-7}	200	N/A	

DECADE	10-13k Rad(Si), 10,000 cm^2 target area, 1.5 by 2 m test articles in chamber

PROPULSION WIND TUNNEL FACILITY	Test Section Size		Total Temperature, °R	Speed Range	Pressure Altitude (Nominal), ft	Dynamic Pressure, psf	Reynolds No./ft ($x10^{-6}$)	Primary Use*
	Cross Section, ft	Length, ft						
Propulsion Wind Tunnel 16T	16 x 16	40	540 to 600	Mach 0.06 to 1.6	Sea Level to 90,000	2 to 1,100	0.2 to 6.0	(6) (9) (14)
Propulsion Wind Tunnel 16S ***	16 x 16	40	580 to 1,080	Mach 1.5 to 4.75	45,000 to 155,000	25 to 550	0.1 to 2.4	(6) (7) (9) (14)
Aerodynamic Wind Tunnel 4T	4 x 4	12.5	540 to 600	Mach 0.2 to 2.0	Sea Level to 65,000	20 to 1,400	2.0 to 7.0	(6) (14)

USE LEGEND: * Testing of (1) Rockets, (2) Turbojets (3) Ramjets (4) Missile Base Heating Models, (5) Space Environmental Tests, (6) Aerodynamic Models, (7) Aerothermodynamic Models, (8) Aeroballistic Models, (9) Combined Aerodynamic Inlet and Propulsion System Tests, (10) Impact Studies, (11) Free-Jet Expansion of Rocket Exhaust Plumes, (12) Ablative Materials, (13) Ablative and Erosive Materials, (14) Store/Stage Separation

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