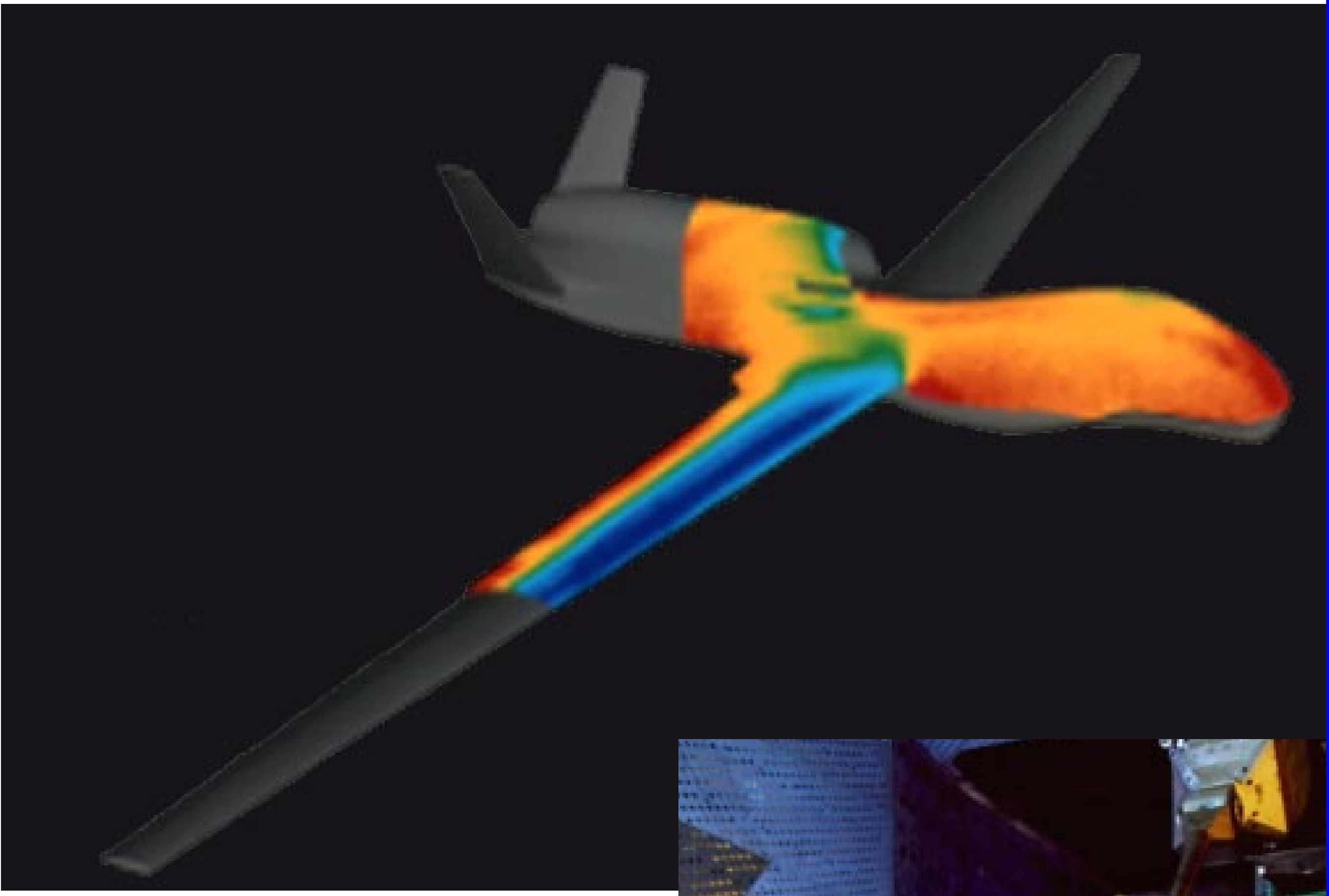
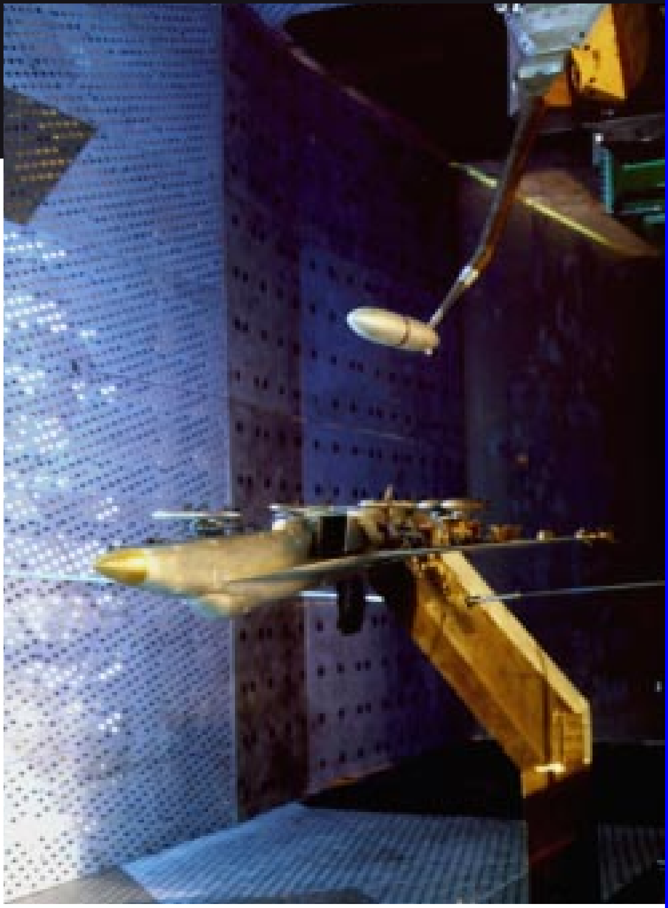
AEDC

Trisonics

TEST HIGHLIGHTS





ARNOLD ENGINEERING DEVELOPMENT CENTER
An Air Force Materiel Command Test Center

ON THE COVER:

Top: A computer-generated image of pressure-sensitive paint devised pressure distribution for the Teledyne Ryan Aeronautical Tier 2 Plus unmanned reconnaissance aircraft.

Bottom, left: A model of the Teledyne Ryan Aeronautical Tier 2 Plus unmanned reconnaissance aircraft undergoes tests in the AEDC 16-ft Transonic Wind Tunnel.

Bottom, right: A test in the AEDC 16-ft Transonic Wind Tunnel simulates separation of a 480-gal. fuel tank from a wind tunnel model of the Navy F/A-18-E/F aircraft.

Program Points of Contact

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CATEGORY Point of Contact	Office Symbol	Phone	Fax	**EXPERTISE**
Aircraft Systems				
AEDC	DOF	-7721	-3339	Aircraft/missile performance, stability, and control; propulsion/inlet integration and compatibility; store/stage/separation; weapons carriage; aero-optics; signatures
Aeropropulsion Systems				
AEDC	DOP	-5305	-7205	Performance, operability, and observability of solid- and liquid-propellant rocket systems at altitude; performance, operability, observability, and specialized testing of turbine systems; environmental testing (temperatures, precipitation, and icing)
Space & Missile Systems				
AEDC	DOS	-5599	-3526	Sensors; nuclear weapons effects; contamination; thermal vacuum; infrared signatures; space dynamics; aerothermal material; hypervelocity impact ablation and erosion; wake physics; bird impact
Technology				
AEDC	DOT	-6523	-3559	Develop new facility concepts and instrumentation; develop new test and analysis techniques
Mission Support				
AEDC	SDC	-5856		Small and large machining; fabrication; welding; chemical and metallurgical laboratory services

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Electronic version of ***Test Highlights*** is available on the AEDC World Wide Web home page at http:/www.arnold.af.mil/

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Contents

Commander's Foreword

This *Trisonics* edition of AEDC Test Highlights focuses on aerodynamic testing and associated analysis and evaluation in AEDC's transonic, supersonic, and hypersonic wind tunnel facilities.

Several themes distinguish the aerodynamic test and evaluation effort during the January 1996 - September 1997 period; namely, interservice support to the Navy's F/A-18E/F fighter development, support to commercial development of the Boeing 747MD, and support to international programs such as the Japanese HOPE vehicle.

Although AEDC has a long history of testing and evaluating weapons systems for the Department of Defense, the center's dedication to interservice cooperation, commercial, and international program support reached new heights during fiscal 1996-97. For example, support to the Navy F/A-18E/F program accounted for about 50 percent of the workload in the 16-foot Transonic Wind Tunnel (16T), up significantly from the previous year. The tests helped validate aerodynamic loads predictions and demonstrated how munitions, missiles, and fuel tanks will separate from the aircraft during flight, a critical step in the design and development of the fighter.

The Boeing Commercial Airplane Group completed a 58-day test in 16T. Based on experiences gained from a benchmarking test of the 767 aircraft in 16T, Boeing chose AEDC to meet its critical wind tunnel testing requirements for accelerated development of a proposed new version of the 747. The test was a major milestone for the AEDC/ Boeing Commercial Group Alliance. The customer praised AEDC for exceeding expectations of efficiency in producing high quality data. AEDC and Boeing teamed during test preparations to develop several process improvements which significantly shortened the test cycle time. These process improvements continue to benefit current test projects.

Other tests have supported the Joint Air to Surface Standoff Munition (JASSM) and the Joint Strike Fighter (JSF) programs.

Tests in the 4-foot Transonic Wind Tunnel (4T) have supported stores integration work for F-15E, F-16, and AV-8B aircraft, and the Air Force's next generation fighter, the F-22. Tests have supported the Joint Direct Attack Munition (JDAM) program, as well as other air-to-ground and air-to-air systems.

In the hypersonic wind tunnels (Tunnels A, B, and C), significant portions of the test load involved international, commercial, and interservice programs. Thirty-six percent of the Fiscal 96-97 test load supported the Japanese HOPE vehicle and the hypersonic ground test capability development at National Aerospace Laboratory (NAL) of Japan. The HOPE is an unmanned, winged space vehicle being developed by NAL. Mitsubishi Heavy Industries (MHI), Ltd. is the contractor responsible for ground test experiments to acquire aerodynamic and aerothermal data for the vehicle.

Working with Science Applications International Corp. (SAIC), which is working under contract to to MHI, AEDC successfully

Col. Robert W. Chedister
Commander

planned and conducted four wind tunnel tests in Tunnels B and C at Mach numbers of 6, 8, and 10. These tests included aerodynamic stability and control, reaction control system (RCS), aerothermal, and boundary-layer experiments.

Another 30 percent of the test load in Tunnels A, B, and C supported the Navy Standard Missile program (NSM), with additional significant wind tunnel test support provided to the U. S. Army and NASA. In fact, less than 7 percent of the test load in Tunnels A, B, and C was in support to U. S. Air Force programs.

In the past, extensive interservice, commercial, and international support would be the exception; however, in today's environment of declining defense budgets, it is quickly becoming the rule.

Near-term plans for facility upgrades include an $85-million, multi-year Propulsion Wind Tunnel (PWT) Sustainment

Program to include upgrading the main drive, acquiring a second atmospheric drier, replacing a computer system, and improving the airflow quality in the 16-foot Supersonic Wind Tunnel (16S).

Test and evaluation (T&E) tools include not only the wind tunnel facilities themselves, but also computational capabilities and databases, including computational fluid dynamics (CFD) codes, aeroprediction methodologies, and the skilled personnel needed to effectively utilize those tools.

Significant contributions in the above areas have employed, to varying degrees, the extensive test capabilities, computational codes, and modeling/simulation tools available in the trisonics facilities at the center.

The nature of flight testing is inherently risky and costly. To mitigate these risks, AEDC is continuing the use of a process of Integrated Test and Evaluation (IT&E). It reduces development risk, both fiscal and schedule, by exploiting the expertise of both the customer and the center. The process capitalizes on the detailed knowledge of the customer and his product and the test experience at AEDC.

An integrated, "knowledge-based" approach to development, test, and evaluation is expected to pay off by reducing the overall cost of flight vehicle system development through improving the quality of ground test information, increasing modeling and simulation accuracy and fidelity, reducing the number of ground test entries and the duration of individual tests required, and reducing flight test costs by addressing appropriate flight test issues in a ground test environment. Improved AEDC capabilities will increase customer satisfaction, reduce test and evaluation costs, and increase utilization of those capabilities by both national and international programs through productivity, efficiency, and quality enhancements.

The wind tunnel facilities at AEDC have been called upon to handle many of the most complex and important test programs conducted anywhere in the world.

The center's reputation for delivering quality, high-volume data to its customers continues to be recognized within the aerospace systems development community. As such, "Team AEDC" has earned an international reputation for delivering quality test results to its customers.

While it would be easy for us to grow complacent and rest on the accolades of the past, we must continue pressing forward to meet the needs of our customers into the 21st century. It's not what we've done yesterday or today that matters, it is what we'll accomplish in the future.

Arnold Engineering Development Center
Arnold AFB, Tennessee

Integrated Test & Evaluation

With increasing emphasis on streamlining the acquisition process, ground test centers like AEDC are re-evaluating their roles in the development of aerospace systems.

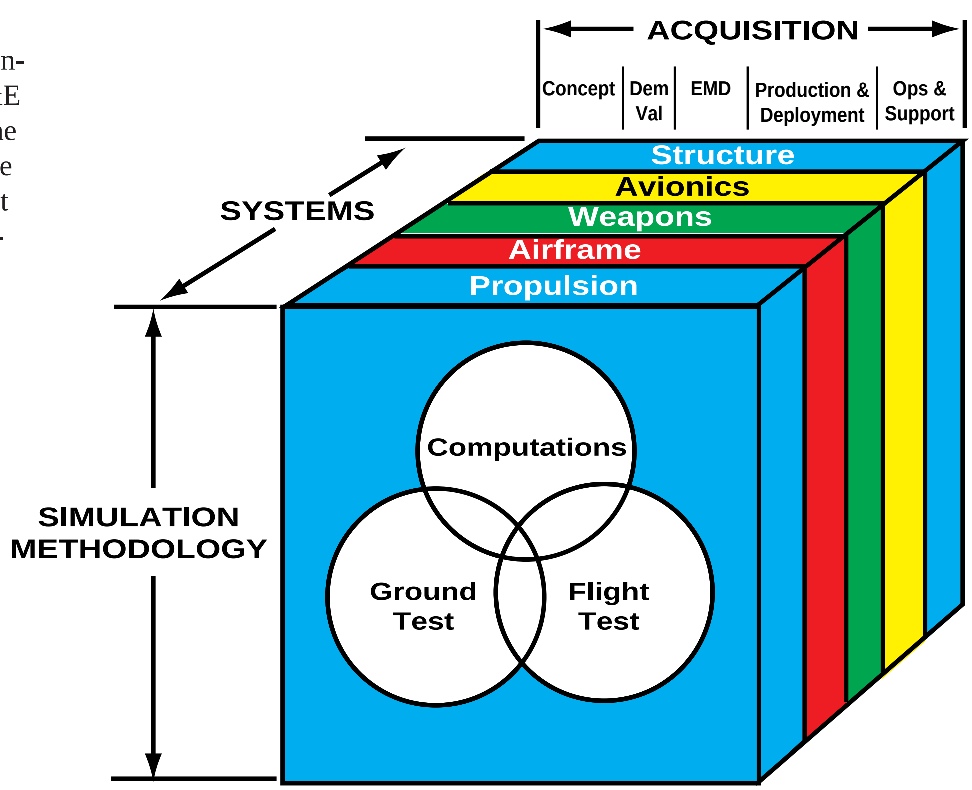
Instead of the traditional role of merely providing data from ground test facilities, the new emphasis challenges the Center to become a team member that provides ***knowledge for risk management and decision making*** during the development and operation of an aerospace system.

As a key link in the transition from a laboratory or design concept to an operational system, the capabilities of a ground test center can provide a tremendous opportunity to reduce the time and cost involved in flight vehicle system development. AEDC has aggressively accepted the challenge, and has developed an ***Integrated Test and Evaluation*** (IT&E) approach to support aerospace system development efforts.

A multi-dimensional conceptual model of the IT&E approach is illustrated in the accompanying figure. In the simplest sense, IT&E might only involve the use of computer modeling tools (such as computational fluid dynamics or engineering methods prediction codes) to augment or correct aerodynamic test data acquired in a wind tunnel However, integrating the modeling and simulation (M&S) tools directly with ground *and* flight tests enables one to design a better ground test program, validate the ground test results, extrapolate the results to flight conditions, and assist in decision making for a more efficient or effective flight test program.

Looking at the second dimension of the conceptual model, IT&E takes on a more important role when used to integrate airframe, propulsion system, weapons, avionics, and other flight vehicle subsystems. Without IT&E, the airframe would be developed and the engine added serially. Moreover, the weapons would likely be added "after the fact." Consequently, one might be well into the flight test program before serious integration problems became apparent. Fortunately, as illustrated by examples in this document, it is possible today to apply the IT&E approach, involving concurrent ground tests of multiple flight vehicle subsystems, to accelerate and improve the integration of those subsystems before flight.

If one looks into the future, the application of multi-disciplined computational methods and powerful computing capabilities, in concert with an IT&E approach, will make it possible to simulate and evaluate the aerodynamics, aeroacoustics, structural response, heat transfer characteristics, store separation qualities, and electromagnetic or stealth characteristics of a vehicle prior to flight. Thus, through the judicious application of a carefully planned and implemented IT&E program, the realization of an optimally-integrated flight vehicle will be virtually assured before its maiden flight.



Military Testing

Navy Aircrew Common Ejection Seat

The Department of Defense has placed a high priority on the development of new ejection seat technologies to reduce injuries to pilots during an aircraft ejection. Recent congressional legislation and Department of Defense policies have relaxed weight requirements to accept military pilots weighing from 100 to 245 lb. In October, 1994, a study was initiated to identify Navy Aircrew Common Ejection Seat (NACES) modifications that might be needed to reduce the risk of ejection injury for the new pilot population.

Navy Aircrew Common Ejection Seat

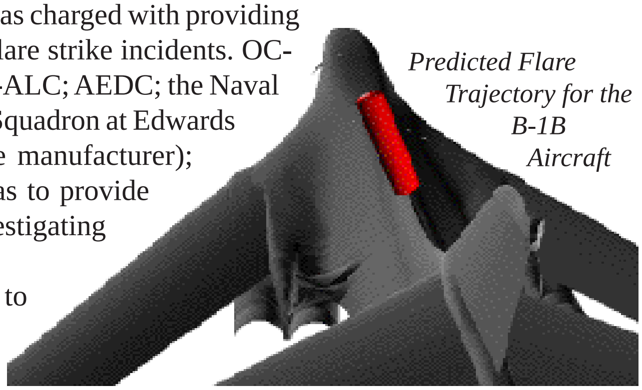
In September, 1997, a full-scale NACES seat, manufactured by Martin Baker Aircraft, Ltd. (Higher Denham, England) and modified for the wind tunnel environment, was tested in the AEDC 16-foot Transonic Wind Tunnel (16T). The test was designed to characterize NACES aerodynamics with occupants of various sizes and weights. Mannequins representing a 5th percentile female, and a 95th percentile male were each tested in the NACES. Force and pressure data were obtained for two seat/occupant configurations at free-stream Mach numbers from 0.3 to 1.5. The seat pitch angle was varied from -13 to 57 deg, and the seat sideslip angle was varied from -3.5 to 30 deg for each configuration.

Martin Baker will use aerodynamic coefficients obtained during the wind tunnel test to develop an aerodynamic database for a numerical simulation of the NACES that will be used to evaluate candidate modifications to the seat.

B-1B Flare Separation Analysis

During routine training missions, the B-1B aircraft experienced several incidents of Infrared Counter Measures (flares) striking the aircraft tail surfaces when the flares were released during maneuvering flight.

The Oklahoma City Air Logistics Center (OC-ALC) was charged with providing a solution that would limit or eliminate further aircraft/flare strike incidents. OC-ALC assembled an investigating team consisting of: OC-ALC; AEDC; the Naval Air Warfare Center at Pt. Mugu, CA; the 419 Flight Test Squadron at Edwards AFB; OGDEN-ALC at Hill AFB,UT; Tracor (the flare manufacturer); Rockwell; and Boeing. The AEDC role on the team was to provide analytical support as needed to the remainder of the investigating team.



Predicted Flare Trajectory for the B-1B Aircraft

A major flight test program was planned by the team to determine the envelope of flight conditions for which flare strikes were likely. Using state-of-the-art aero-prediction and trajectory generation codes, AEDC personnel produced flare trajectory predictions for a variety of aircraft flight conditions and maneuvers. The predictions were then used to narrow the flight test envelope and perform flight test risk assessments. Flight test data were acquired and were used to validate the AEDC predictions.

The AEDC flare trajectory prediction contribution was highly successful. Because of the demonstrated accuracy of the trajectory predictions, a major portion of the flight test program was eliminated, resulting in a cost saving to the flight test program of approximately $500,000.

AEDC personnel briefed B-1B operational units on the test and analysis results, and presented procedures to reduce or eliminate the probability of future aircraft/flare strikes. In addition, a plan was enacted to retrofit B-1B aircraft with improved Tracor flares designed to reduce the likelihood of future aircraft/flare strikes.

Helicopter Armament Store Separation Simulation and Computer Aided Store Separation Analysis System

A simulation capability was developed at AEDC that can be used to predict and analyze the trajectories of weapons and other stores when released from rotary-wing aircraft in flight. The simulation, known as the Helicopter Armament Store Separation (HASS) program, offers benefits to weapon certification processes for many tri-service rotary-wing aircraft.

The simulation development effort was designed to make use of existing AEDC technology in the areas of trajectory prediction, miss distance, and collision detection for traditional fixed-wing aircraft, while expanding the technology to include helicopters. An existing AEDC trajectory generation program, used routinely for wind tunnel store separation analysis work, was modified to accept the aerodynamic definition of a flow field surrounding a maneuvering helicopter from an existing U.S. Army Evasive Maneuver Criteria Evaluation Program. Miss-distance determination and collision detection were calculated using an existing AEDC fixed-wing clearance code.

The simulation was validated by comparing predicted trajectories with measured flight test trajectories for stores released from UH-60 Blackhawk, SH-60 Seahawk, OH-58 Kiowa, and AH-64 Apache helicopters in flight. Flight test trajectory measurements were made available by a Computer Aided Store Separation Analysis System (CASSAS), which can determine store six-degree-of-freedom (6-DOF) position information from digital flight test images. Good comparison results provided confidence in the validity of the simulation. The results revealed that great attention must be given to the accuracy of store math models used in the simulation, and the physical properties for each individual store must be accurately known. The results also revealed that the initiation time for each flight test separation trajectory must be accurately established to ensure that predictions and measurements are compared on a common time-line basis.

Predicted Launch of AGM-114 (Hellfire) Missile from UH-60A (Blackhawk).

F-15E Ballistic Accuracy Improvement

The F-15E Ballistic Accuracy Improvement (BAI) project was commissioned by the Air Force F-15E Weapon System Accuracy Team (WSAT) to improve the unguided bomb delivery accuracy of the F-15E Strike Eagle aircraft. The goals of the project were to: a) collect wind tunnel test data for future weapon-separation-effects (WSE) coefficient generation; and b) develop an improved WSE algorithm for the F-15E aircraft.

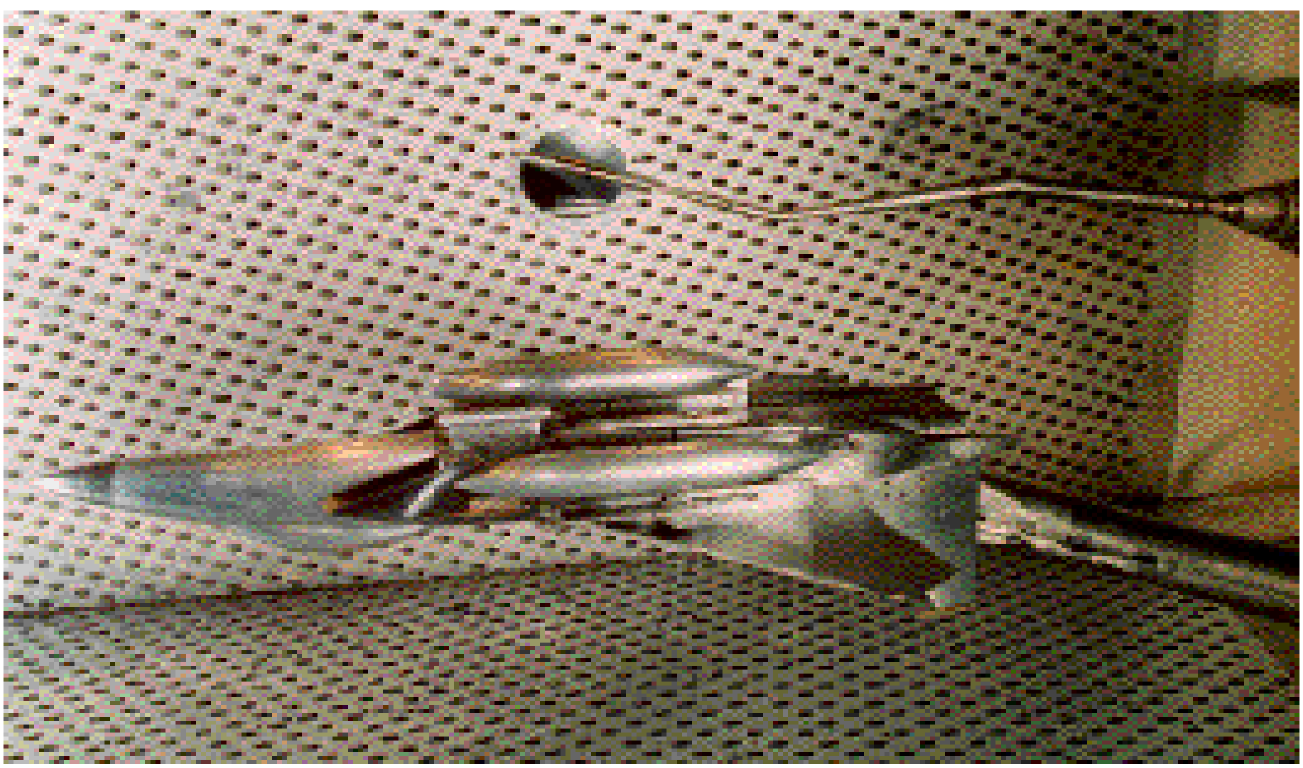
To support the first objective, a series of six captive trajectory support (CTS) tests was conducted in the AEDC 4-ft Transonic (4T) aerodynamic wind tunnel over a 19 month period ending in August 1995. The CTS tests included the collection of grid survey and trajectory aerodynamic data. Five-percent scale models were used in the tests. Flow-field aerodynamic data and large-scale weapon free-stream data were collected for 39 F-15E aircraft weapon loadout configurations. Thus, an extensive wind tunnel test database was established to support the future development of F-15E WSE coefficients for aircraft weapon loadouts not currently certified for flight. The database will permit the analytic determination of WSE coefficients at less than one tenth the cost of flight tests.

The second objective was to develop an improved F-15E aircraft operational flight program (OFP) WSE algorithm. The WSE algorithm compensates for the influence of the aircraft on weapon ballistic trajectories by varying the weapon release times. The baseline OFP for the BAI project was F-15E OFP 2367.

The WSE algorithm development process employed successive regression analyses of F-15E Mk-82 low drag general purpose (LDGP) bomb ballistic trajectories. The regression studies measured the ability of various combinations of aerodynamic and inertial parameters to curve fit the influence of the aircraft aerodynamic flow field and inertial state on the ballistic trajectories of Mk-82 bombs released from the aircraft.

The AEDC algorithm, when applied to F-15E conformal fuel tank weapon station pairs, was predicted to provide a 1-7 mrad reduction in the error of predicting the down-range impact point of unguided bombs, and up to a 68-percent reduction in the predicted circular error probable when compared to the baseline F-15E OFP 2367 WSE algorithm.

Because of the successful completion of the two BAI project objectives, a weapon separation aerodynamic database and improved WSE algorithm are available to provide the F-15E aircraft with enhanced unguided bomb delivery accuracy.



A model of the Air Force F-15E Strike Eagle undergoes store separation testing in AEDC's 4-ft Transonic Wind Tunnel.

F-22 Integrated Test & Evaluation (IT&E) Validation

Over the years, AEDC has invested resources to develop computational tools that complement its wind tunnel testing capabilities. The tools, in conjunction with the unique combination of test facilities and experienced analysts resident at AEDC, have permitted the establishment of the Integrated Test and Evaluation (IT&E) concept described on page 4.

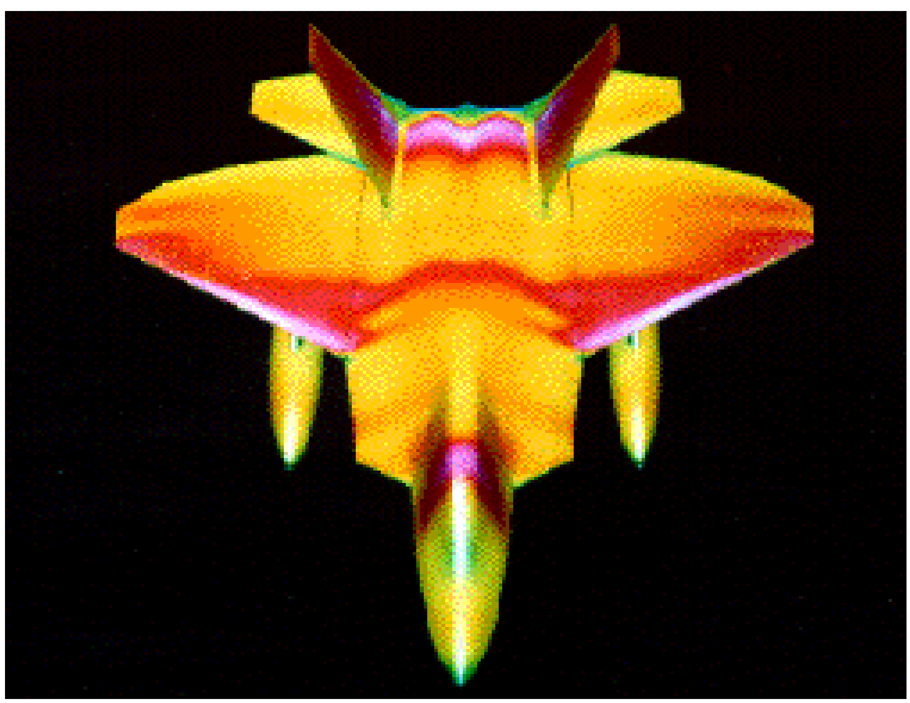
In fiscal year 1992, an F-22 weapons integration team was established to determine the separation characteristics of fuel tank/pylons, launched and jettisoned missiles, and jettisoned pylon/missile clusters when released from the F-22 aircraft. With the participation of Lockheed Fort Worth, the F-22 System Program Office (SPO), and AEDC, an ambitious IT&E plan was established to synergistically combine computations directly with wind tunnel test results to maximize test and evaluation efficiency.

The IT&E approach was used to address issues associated with the separation of fuel tanks and weapons from the F-22 aircraft. Separation of the fuel tank and its pylon from the aircraft was of particular interest because, in addition to the requirement for safe separation of the tank/pylon from the aircraft, there was an additional requirement to determine the reaction loads on the wing at the rear tank/pylon attachment point. The loads information would be used to support wing structural design decisions.

Computational methods were used to predict the separation trajectory of the fuel tank/pylon assembly when released from the aircraft, as well as the reaction loads on the wing. A detailed validation process was applied to provide confidence in the results of the computational methods. Validation was accomplished by comparing 30 TGP-predicted fuel tank/pylon trajectories with trajectories produced in the wind tunnel using a captive trajectory support (CTS) test technique and a free-drop test technique. The free-drop test data were acquired using a photographic data acquisition system and a newly-developed onboard accelerometer/telemetry data acquisition system. The TGP-predicted trajectory data compared well with the wind tunnel CTS data, the free-drop photographic data, and the free-drop telemetry data. The good correlation validated the IT&E approach that was initiated in fiscal year 1992. In addition, the validated approach provided confidence in the ability to extend ground simulation results to flight conditions.

Another challenge facing the F-22 program was the launch of missiles from the internal weapons bays of the aircraft. In addition to launch during normal flight, there was a requirement to launch the missiles during a rolling pull-up maneuver. Successful simulation of missile lanches during the rolling pull-up maneuver required that two specific problems be solved. The first problem involved the development and modeling of the kinematic equations of motion for a new restrained tank/pylon pivoting mechanism under development by Lockheed Martin. The second problem involved the development and modeling of the kinematics of an arbitrarily-maneuvering aircraft in a standard AEDC six degree of freedom trajectory generation program (TGP). Both problems were solved, and the needed separation trajectories were produced.

Using the IT&E approach, the F-22 aircraft store separation process was investigated and clearly understood. In addition, significant test cost savings to the F-22 program were realized.



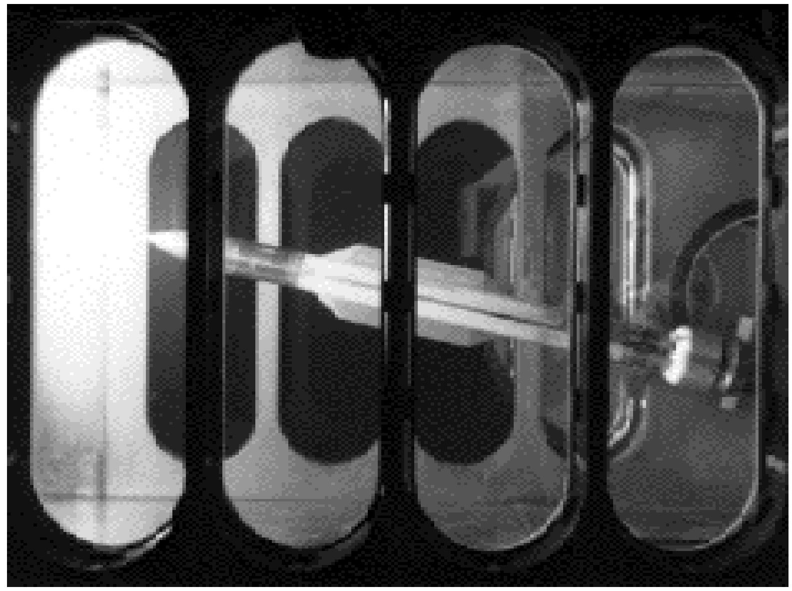
CFD image of F-22 aircraft with external fuel tanks.

Navy Standard Missile

Since June, 1996, a series of AEDC wind tunnel tests have been performed on the Area-Wide Navy Standard Missile (NSM) Block IV-A missile and the Theatre-Wide Navy Aegis Lightweight Exo-Atmospheric Projectile (LEAP) missile.

The NSM Block IV-A missile is the primary surface-launched endo-atmospheric defense system for the Navy. The Aegis LEAP missile is a high-performance missile system consisting of the NSM Block IV-A missile with an added third stage to provide additional velocity. In addition, the Aegis LEAP missile carries an exo-atmospheric kill vehicle.

For both missile configurations, wind tunnel tests were performed to simulate boost, booster separation, and upper-stage phases of flight.



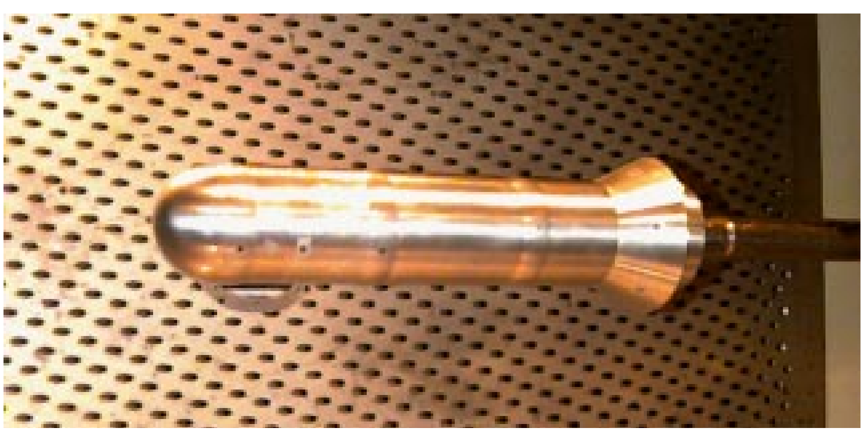
Navy Standard Missile in AEDC Hypersonic Wind Tunnel

Combined Static-Stability, Spin-Damping and Magnus Testing

Spin-damping and Magnus dynamic effects are important when determining targeting accuracy of missiles, artillery rounds, and re-entry vehicles. However, because of limited budgets and the high priority to acquire static-stability and drag performance data during wind tunnel test entries, the dynamic parameters have often been estimated rather than measured. Therefore, to enhance wind tunnel testing utility, the traditional force-and-moment, spin-damping, and Magnus measurement techniques at AEDC were re-engineered to provide the capability to determine roll-damping coefficient, Magnus force and moment coefficients, and six static force and moment coefficients simultaneously.

The effectiveness of the re-engineered test technique was demonstrated during a recent test of the Small Low-cost Interceptor Device (SLID) in the AEDC 4-ft Transonic Wind Tunnel (4T). The test was performed for Rockwell Autonetics and Missile System Division, Duluth, GA. Although the 9/8-scale SLID model was rolled at a relatively low spin rate of 2,400 rpm, rates exceeding 18,000 rpm have been obtained for other models supported by the same hardware. The design maximum spin rate for the system is 25,000 rpm.

Static-stability and control coefficients obtained for the SLID model using spinning and non-spinning test techniques were compared and agreed to within measurement uncertainty levels. Thus, the new test technique produced static-stability, drag, spin-damping, and Magnus coefficient data at a test cost equivalent to that previously required to acquire spin-damping and Magnus coefficients alone.



Spin test hardware in 4-ft Transonic (4T) Wind Tunnel

AEDC Helps Validate Aero-Optical Performance of Advanced Infrared Search and Track System

Wind tunnel testing of the Lockheed Martin Advanced Infrared Search and Track (IRST) system took place in the AEDC 16-ft Transonic Wind Tunnel (16T).

A predecessor, the Lockheed Martin AN/AAS-42 IRST, was originally built for the U.S. Navy F-14D Tomcat. The Air Force was interested in the IRST look-down capability, and its ability to detect targets in heavy clutter. Therefore, a contract was awarded to the company in 1992 to develop an Advanced IRST design that would expand on the capabilities of the existing AN/AAS-42. The contract required that the window of the IRST be tested under "real world" conditions; hence, the wind tunnel test at AEDC.

The Advanced IRST sensor complements the aircraft's onboard tactical radar, providing the aircrew with the flexibility to meet a demanding counter-air mission. According to an article in "Vision," the internal newsletter of Lockheed Martin Electronics and Missiles Company, an IRST system works by detecting two types of hot emissions: those emanating from aircraft exhaust plumes and those emanating from aircraft leading edges, heated by the movement of the aircraft through the atmosphere.

The current IRST system has a multi-paned window, a sensor, and processing electronics. The window, according to Lockheed Martin engineers, is the key technology challenge. It must support the optical requirements of the sensor, while minimizing the impact to the low-observable characteristics of an aircraft such as the F-22. The IRST system is embedded in the chin section of the F-22 to retain the supersonic cruise and low-observable characteristics of the aircraft. Such a window has never before been produced.

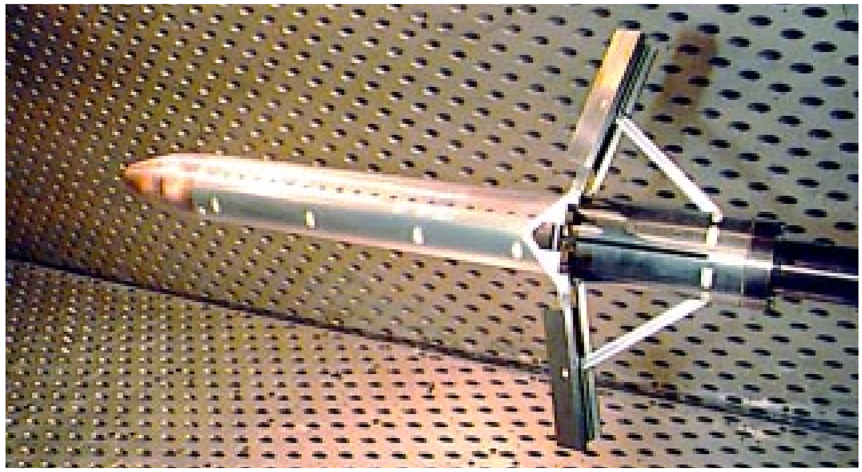
The objective of the wind tunnel test was to validate aero-optical performance of the IRST system for the F-22 aircraft, and also to verify the aero-thermal environment surrounding the aircraft. The IRST system was mounted on a full-scale model of an F-22 aircraft forebody in the wind tunnel. Optical sources were mounted at various positions in the wind tunnel, such that they could be viewed by the IRST sensor.

Successful wind tunnel testing required that flight conditions be precisely duplicated, including airflow temperature, pressure, and density. Sensor aperture diameter and wavelength characteristics were also duplicated.

Data from the test are being analyzed to help ensure that the IRST design will meet stringent requirements set by the Advanced IRST program. With the successful completion of the test and analysis, the major risk elements of the Advanced IRST will have been demonstrated, and a baseline design will have been established for use by the Air Force.

AEDC personnel clean the window containing the sensor for an Advanced Infrared Search and Track system on an F-22 aircraft model.

Aero-Cooling Test of FOTD/IDECM in Tunnel 4T



Fiber Optic Towed Decoy in AEDC's 4-ft Transonic Wind Tunnel (4T).

Heat generated by the equipment enclosed in an electronic countermeasures (ECM) pod must be dissipated to the pod's surroundings in order to avoid damage to, and consequent operational failure of, the ECM onboard electronics. In the case of a towed ECM decoy, all heat generated within the device must be transferred to the airstream through which it passes (aero-cooling).

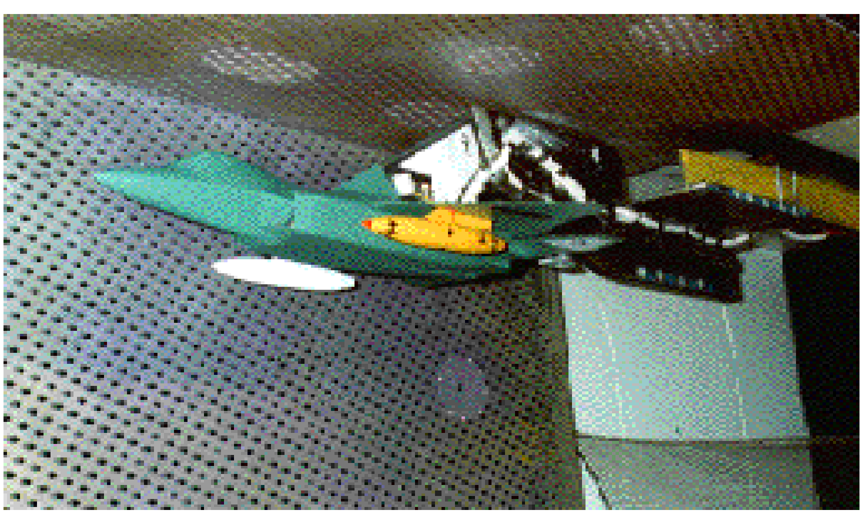
An aero-cooling test of the Fiber Optic Towed Decoy (FOTD)/Integrated Defensive Electronic Counter-Measures (IDECM) store was conducted in the AEDC 4-ft Transonic Wind Tunnel 4T to determine if aero-cooling could provide sufficient cooling to allow the decoy to sustain operations throughout multiple aircraft performance envelopes (airspeed and altitude ranges). Test conditions included altitudes from 0 to 80,000 ft, Mach numbers from 0.2 to 2.0, angles of attack from 0 to 10 deg. and roll angles from -90 to 180 deg. The test was the first heat transfer test to be conducted in Tunnel 4T.

The store model was designed and built by Lockheed-Sanders, Nashua, NH, and contained 27 heaters capable of maintaining a model surface temperature of about 300°F. Seventy five heat transfer (Schmidt-Boelter) gages, arranged on the model in three rows, were designed, built, and installed by AEDC personnel. The gages sensed the heat flux from the model and provided the data needed to determine heat transfer coefficients.

F-22 Store Separation Testing

A store separation wind tunnel test program helped determine the safe separation jettison envelope for 600-gallon fuel tanks and missiles carried on F-22 aircraft. During a jettison event, the 600-gallon tank and pylon, or missile cluster and pylon, separates as a single unit from the aircraft.

To improve separation characteristics and reduce wing loading during the separation event, Lockheed-Martin engineers developed a new pivoting hook release mechanism for F-22 aircraft wing stations. AEDC engineers modeled the equations of motion required to describe the mechanical operation of the hook mechanism during separation and incorporated the equations into the trajectory simulation software for the test program. During the test, captive trajectory and free-stream data were acquired at Mach numbers from 0.4 to 1.5 using 1/15-scale models and the captive trajectory support (CTS) system. Other test variables included 23 aircraft loading configurations, aircraft model angles of attack from 1 to 15 deg, and simulated pressure altitudes from sea level to 50,000 ft. Additional separation testing with the F-22 aircraft is planned in fiscal 1998.



F-22 store separation test in AEDC's 4-ft Transonic Wind Tunnel (4T).

Navy F/A-18E/F Store Separation Wind Tunnel Testing

A series of wind tunnel tests was conducted in the AEDC 16-ft Transonic Propulsion Wind Tunnel (16T) to determine the separation characteristics of stores released from the F/A-18E/F aircraft.

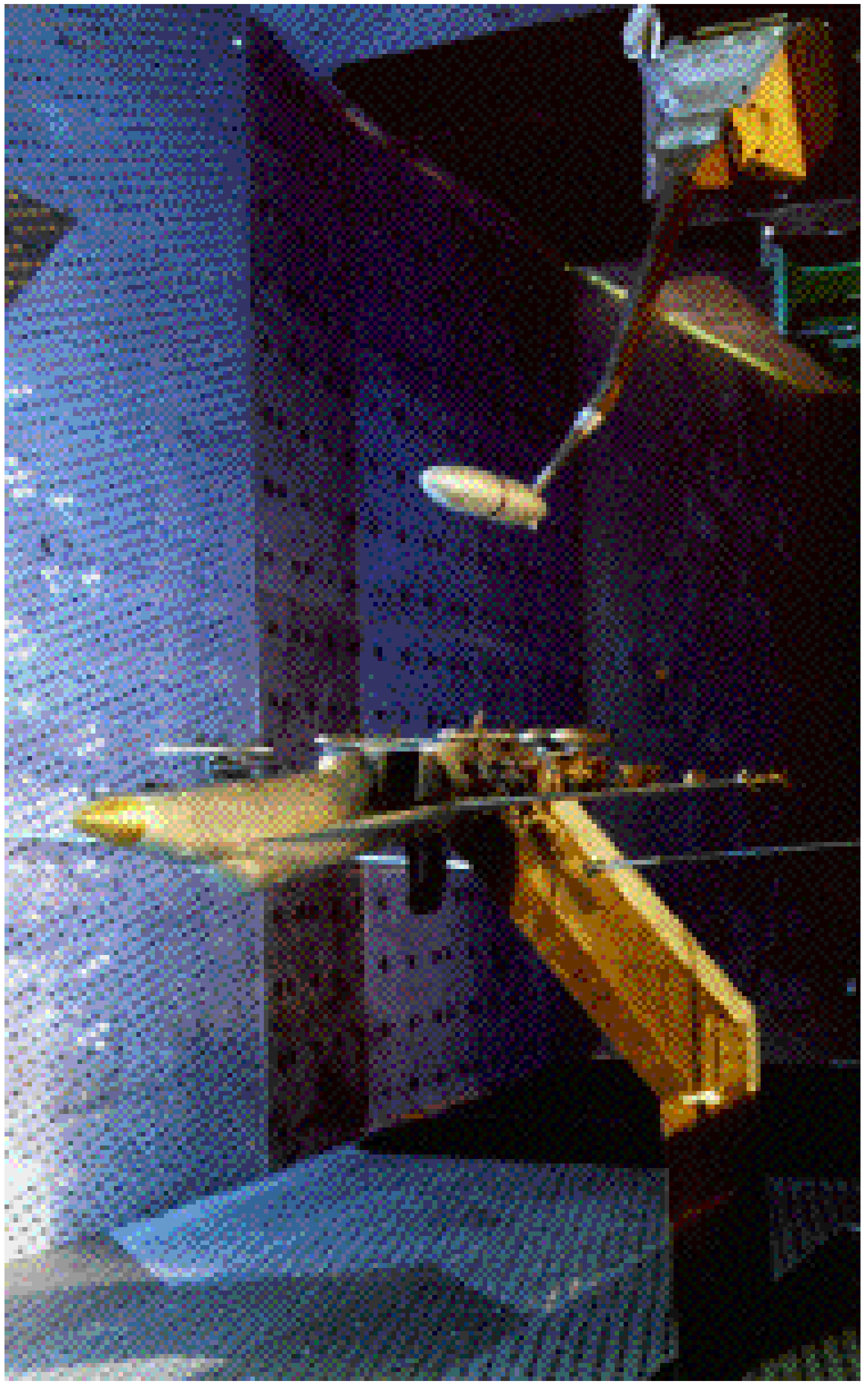
Since the first test in July 1993, data for 40 store types released from hundreds of aircraft store loadout configurations have been evaluated using the captive trajectory support (CTS) system in almost 3,800 test occupancy hours of wind tunnel testing.

Initial wind tunnel test results revealed an adverse aircraft flowfield environment that was detrimental to store separation goals. To better understand the complex aircraft flow field, the region beneath the aircraft was surveyed using a Mach-flow-angularity three-probe pressure rake. Using probe survey and captive trajectory test data, an aircraft modification was developed by the customer to improve store separation characteristics.

Following selection of the desired aircraft modification, an aggressive wind tunnel testing program was conducted at AEDC, encompassing 15 store types and 29 aircraft store loadout configurations, to support the start of a weapons separation flight test program in February 1997.

During the period from June 1996 to March 1997, 1,375 hrs of wind tunnel testing were completed in three test entries in Tunnel 16T. Additional testing was accomplished to determine the effects of wind tunnel model support sting, flight test cameras, and aircraft sideslip on store trajectories.

Ballistic trajectory analyses were performed at AEDC during the wind tunnel testing effort to predict store ground impact patterns for the baseline and modified aircraft configurations, thereby providing assurance that the selected aircraft modification was improving, and not degrading, aircraft bombing accuracy.



F/A-F18 E/F wind tunnel model in AEDC's 16-ft Transonic Wind Tunnel (16T).

F/A-18E/F store separation flight test results show good agreement with the wind tunnel store separation trajectories. Heightened customer confidence in the wind tunnel data allowed flight testing at selected flight conditions to be reduced or completely eliminated. In addition, the flight test camera effects data acquired at AEDC increased customer awareness of camera effects, and directly impacted camera positioning on the F/A-18E/F aircraft for each flight test.

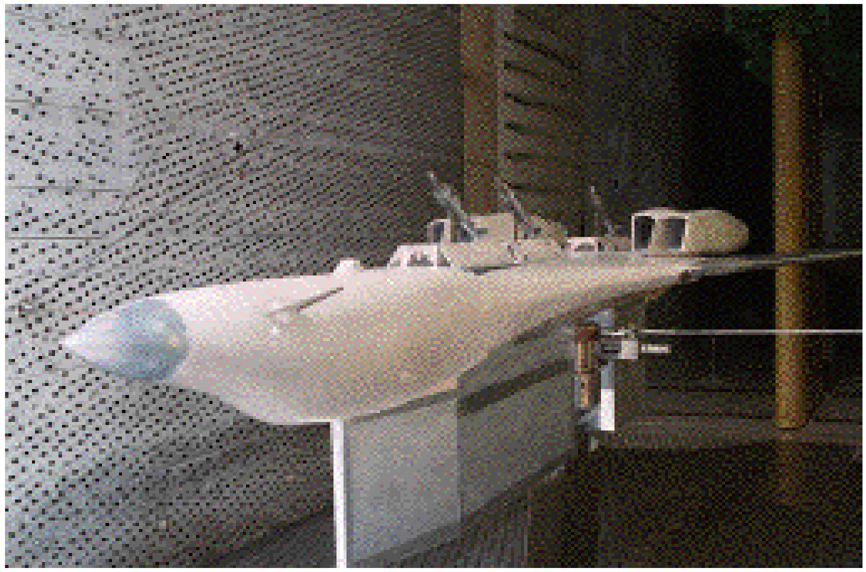
B-1B Conventional Weapons Upgrade

The B-1B aircraft was initially developed for nuclear weapons carriage capability. However, with the end of the Cold War, the role of the B-1B aircraft shifted dramatically to that of a conventional bomber. Consequently, a Conventional Weapons Upgrade Program (CWUP) was initiated to certify the B-1B for carriage and release of conventional weapons. A series of wind tunnel tests was begun at AEDC to support the emerging conventional mission of the B-1B aircraft system.

The series of wind tunnel tests was begun in November 1993. The tests were conducted with 10-percent scale models supported in the tunnel airflow. The aircraft model was mounted to a pitch table below the tunnel floor, permitting aircraft angle of attack to be remotely set. The store models were mounted to the Captive Trajectory Support (CTS) mechanism, permitting full six-degree-of-freedom motion of the store model.

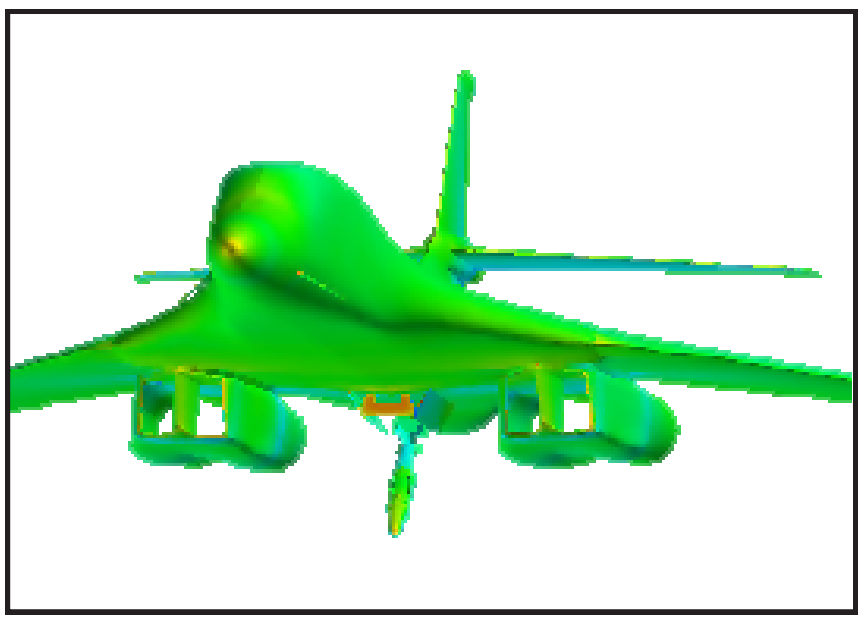
The first test investigated the separation characteristics of the Cluster Bomb Unit (CBU)-89 store when released from the internal weapons bays of the B-1B aircraft. Each of the three aircraft weapons bays was equipped with 10-carry modules, permitting the aircraft to carry and release a total of 30 CBU-89 stores.

In the second test, separation characteristics were determined for Mk-82 LDGP and Mk-82 AIR stores. The objective of the third test was to provide data required to support safe-separation certification for carriage and release of the Joint Standoff Weapon (JSOW) and the Mk-65 mine from the B-1B aircraft throughout the entire air-to-ground/water weapons release envelope. Test conditions included Mach numbers from 0.7 to 1.2.



B-1B wind tunnel model in AEDC's 16-ft Transonic Wind Tunnel (16T).

Trajectory predictions based on the wind tunnel data were performed prior to flight testing. Careful analysis of predicted store motion and trajectory trends permitted the customer to begin safe-separation envelope expansion at a Mach number of 0.85 instead of 0.7, thereby reducing considerably the number of flight test sorties (and monetary cost) required to certify safe separation of the stores from the aircraft. In addition, ballistic trajectory simulations based on the wind tunnel data were conducted at AEDC to predict the effect of the aircraft flow field on store impact points on the ground. The flow-field effects, predicted to be small, were confirmed during subsequent flight tests.



CFD image of B-1B aircraft dropping a conventional store.

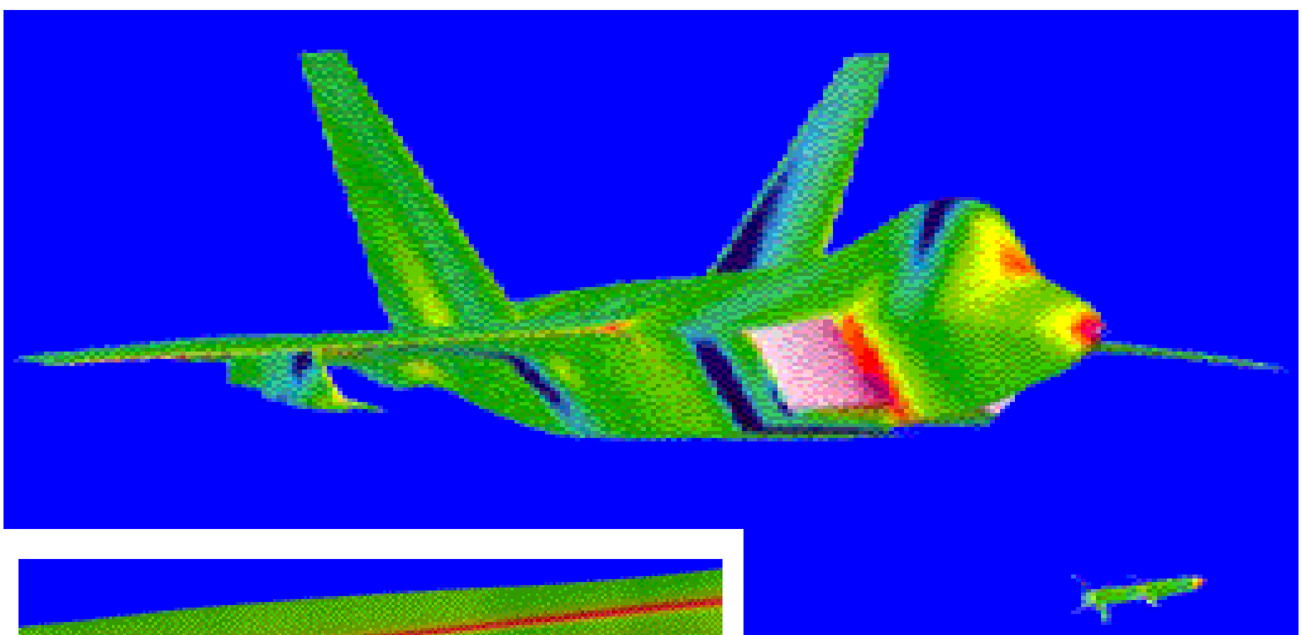
Rail-Launched Missile from a Maneuvering Aircraft

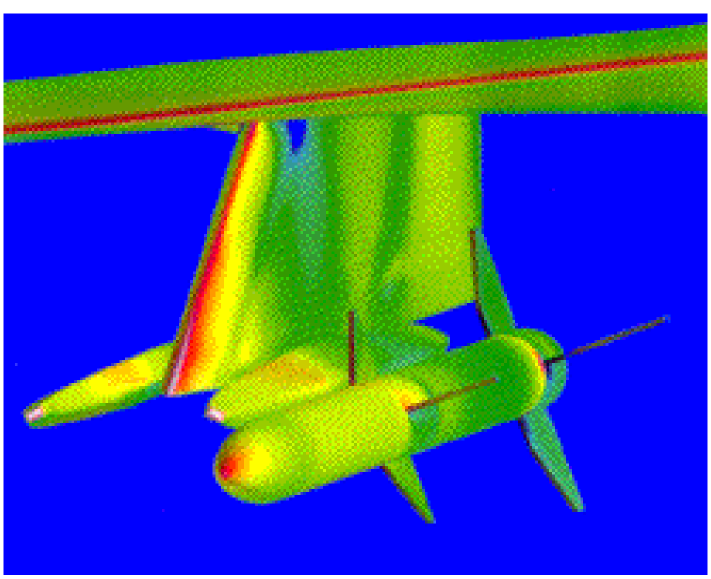
The requirement to launch a missile from a maneuvering aircraft introduces the possibility of missile plume ingestion by the launching aircraft and potential engine stall. To study such phenomena, the Air Force Office of Scientific Research (AFOSR) sponsored an effort at AEDC to apply an existing AEDC computational fluid dynamics (CFD) store separation capability to the plume ingestion problem.

New CFD capabilities developed under the AFOSR-funded effort included: a six-degree-of-freedom trajectory program with the ability to model constrained motion (rail launch) with an accelerating reference frame; plume visualization techniques; and techniques to computationally simulate a reacting plume by using hot air.

Two CFD computations were produced. The first CFD computation simulated the launch of an AIM-7 missile with plume from a non-maneuvering aircraft. The computation was a Navier-Stokes simulation using 1.6 million grid points and consuming 1,500 central processor hours on a Convex 4640 computer. The rocket plume was simulated with a hot air jet. Jet stagnation conditions were tuned to match those for a reacting rocket motor. The plume was visualized as a constant-temperature surface. Flight conditions included a Mach number of 0.9 and a free-stream Reynolds number of 3.6 million per foot.

The second CFD computation simulated the launch of an AIM-120 missile without plume from an F-22 aircraft while undergoing a steady aircraft roll rate of 100 deg per second. The CFD computation was an inviscid solution using 2.7 million grid points and consuming 190 central processor hours. Flight conditions included a Mach number of 0.9 and a free-stream Reynolds number of 3.6 million per foot.





A computer model of F-22 aircraft launching missile.

Ripple Launch Computational Capability

The challenge to certify stores for safe release from an aircraft and accurate delivery to the target presents a difficult and expensive technical problem. Technical approaches have traditionally involved wind tunnel testing, engineering analyses, and flight testing.

While traditional test and analysis approaches have been successful and continue to be essential, the advent of practical time-accurate computational fluid dynamics (CFD) techniques offers a new alternative that can reduce testing costs and permit the evaluation of complex separation events.

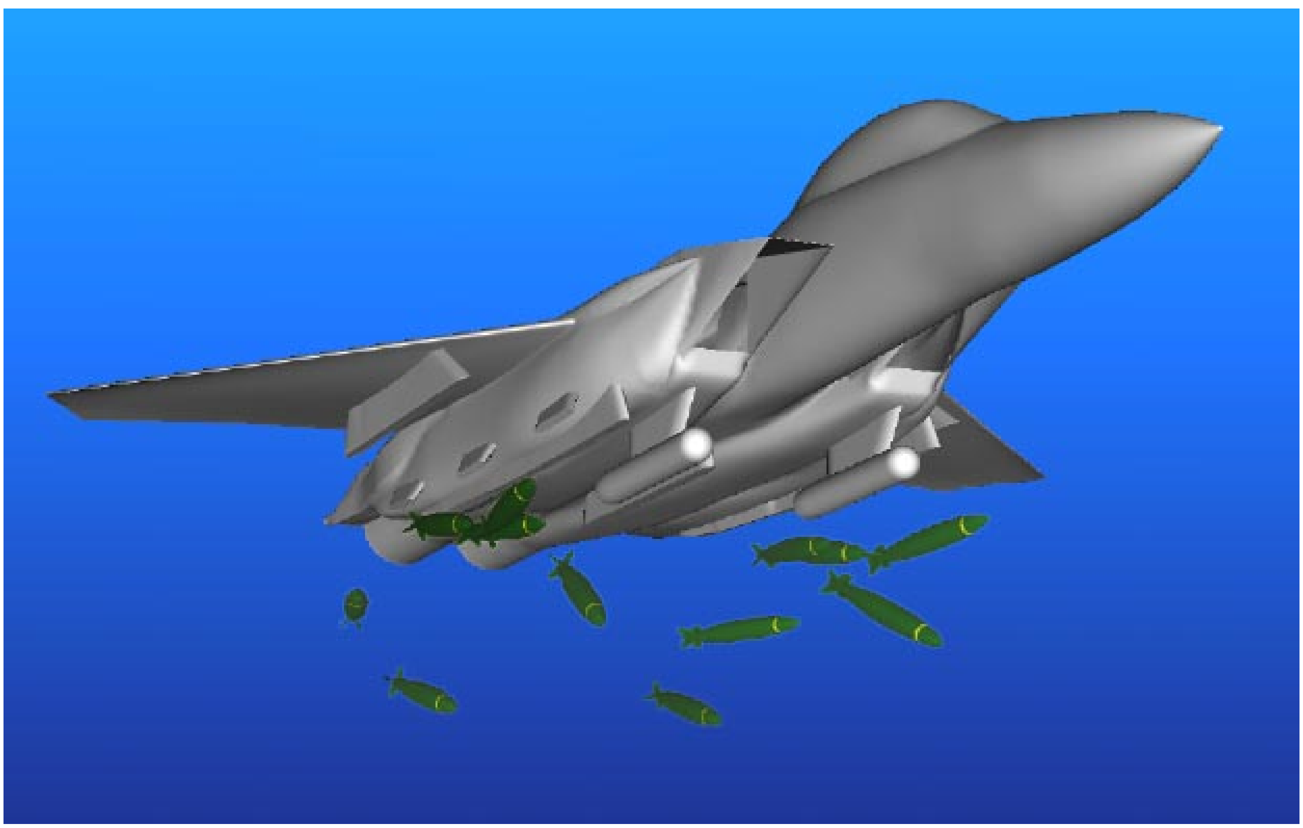
Under the sponsorship of the Air Force Office of Scientific Research (AFOSR), AEDC engineers accomplished a demonstration simulation of the release of six Mk-82 munitions from an F-15E aircraft. The objective of the demonstration was to advance the CFD state-of-the-art beyond the then-current capability of releasing a single store from a simple wing model.

The CFD simulation procedure involved computing an inviscid steady-state flow field over the F-15E aircraft with the six Mk-82 stores at their carriage positions. Using the computed aerodynamic loads and a six-degree-of-freedom trajectory program, the first released store was moved by a small time increment. The entire flow field and loads were then recomputed and the store moved again. The process was accomplished repeatedly and simultaneously for each store after its respective release time. The simulation was continued to 0.3 sec of full-scale flight time, with all six bombs away.

The grid system for the complete 7-body simulation consisted of approximately 4 million grid points. Flight conditions included a Mach number of 0.98, 1.1-deg aircraft angle of attack, and zero aircraft yaw angle. The simulation was qualitatively validated by comparison to an engineering simulation that used wind tunnel data.

This first "ripple launch" simulation required 2,400 central processor hours and about a calendar year on a Cray® C-90 computer. Because of the computational turn-around time, the simulation led directly to the pursuit of an upgrade to the CFD flow solver. The upgrade reduced the computational time by a factor of approximately 100.

Because of the AEDC effort under AFOSR funding, the CFD simulation of a multiple-store release is now a practical reality.



A Computational Fluid Dynamics Model of an F-15E Strike Eagle separating six Mk-82 bombs.

Missile Staging Simulation

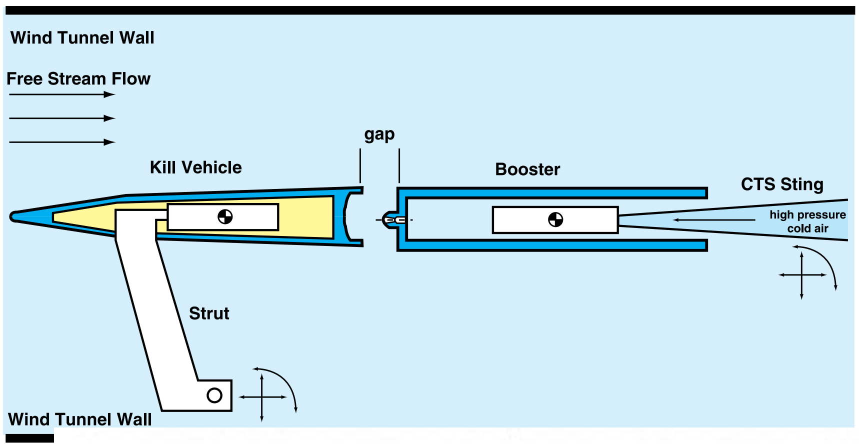
Interceptors designed to stop incoming re-entry vehicles are typically multistage vehicles. Because of the effect of stage separation on vehicle dynamics, the stage separation process can be an important aspect that determines the success or failure of the intended intercept.

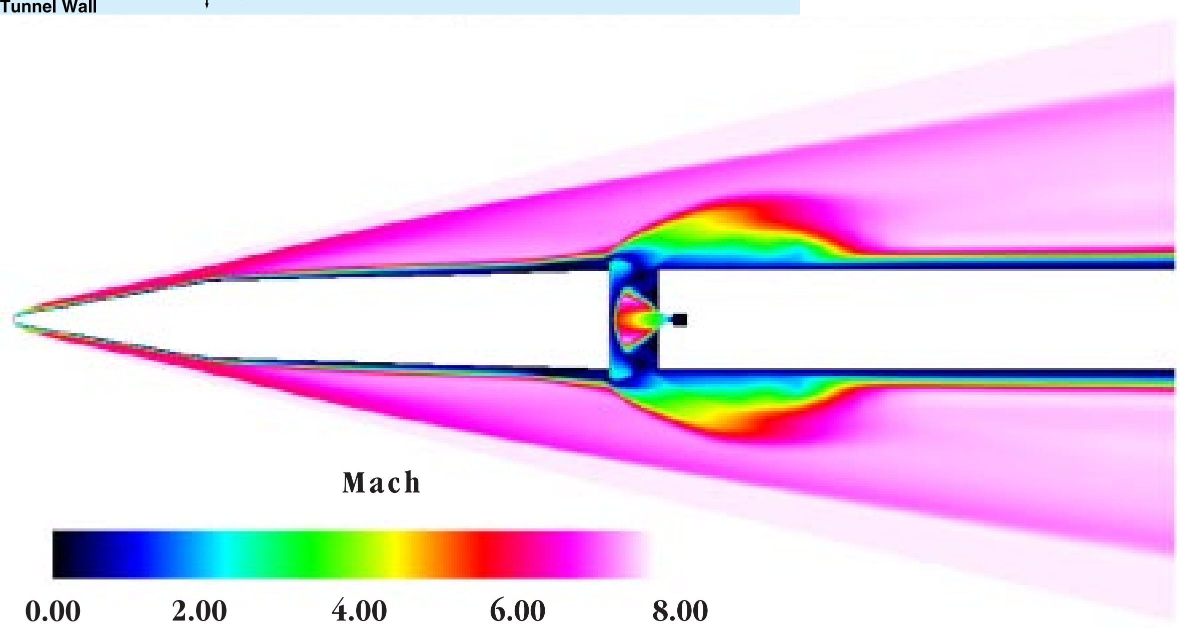
Stage separation is frequently accomplished by igniting a rocket motor located between the kill vehicle and the booster stage. Knowledge of the aerodynamic loads encountered during the dynamic staging process is necessary to evaluate vehicle performance.

Such loads data are normally acquired in a hypersonic wind tunnel test in which the stages are supported at various fixed positions relative to one another while force measurements are made. The test technique also uses pressurized cold gas to simulate the hot gas of the separation motor. Recently, the validity of using static force measurements and cold gas flow to simulate a dynamic, hot-gas situation was investigated.

To assess the validity of the wind tunnel test technique, a series of computational fluid dynamics (CFD) solutions were generated. The approach used a previously untried extension of an AEDC time-accurate-CFD-based store separation technology. The effort was sponsored by the Air Force Office of Scientific Research (AFOSR). Computations were made for a two-stage vehicle with an unpowered kill vehicle and a separation motor in the booster stage. Flight conditions included a Mach number of 8 and a base-diameter Reynolds number of 3 million. The CFD solutions were based on an assumption of axisymmetric flow, and required a grid size of approximately 110,000 grid points. The CFD static and dynamic solutions were computed for both cold- and hot-flow rocket motors.

The CFD static computations were found to agree well with the loads measured in the wind tunnel. Further more, the computations indicated that both the dynamic and hot-flow solutions agreed well with the wind-tunnel-measured static, cold-gas loads except at very small stage separation distances. Thus, it was concluded that the wind tunnel test technique was valid, although a computational correction at small inter-stage gap distances might be beneficial.





A computer-generated model of a two-stage vehicle separation.

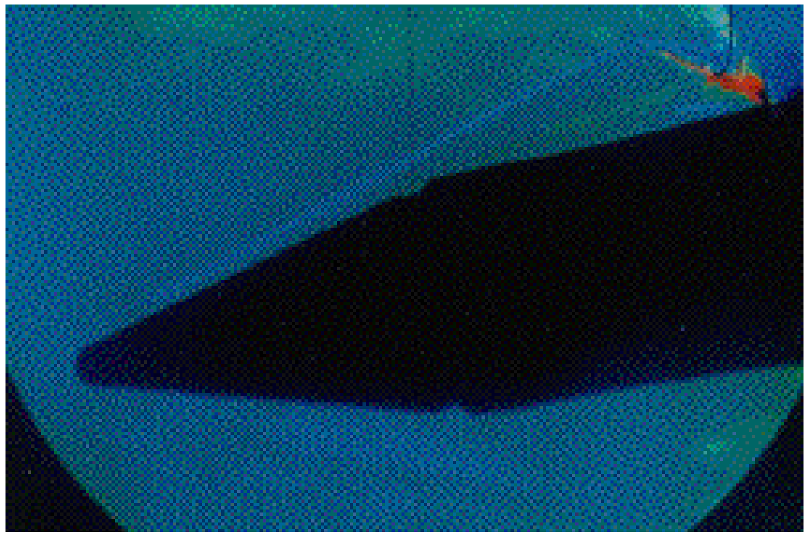
Jet-Interaction

During recent years, increased interest in the development of anti-ballistic missile systems has led to increased emphasis on understanding the effects of control system jets on the aerodynamic flow field surrounding a missile (i.e., jet interaction). Although jet interaction (JI) tests have been conducted at AEDC since the 1960s, recent interest in anti-ballistic missile systems has fueled an increase in JI testing at AEDC. Jet-interaction tests are routinely performed in the supersonic and hypersonic wind tunnels at AEDC.

A Jl test installation is typically comprised of a model with one or more lateral jets, a gas supply line routed forward through the model support sting, a mass flow and pressure controller, and a gas supply source located outside the wind tunnel. During the test, the jets are operated. The jet flow interacts with the tunnel airflow passing over the model. The airflow interaction is characterized using a variety of measurement techniques.

For convenience, air is commonly used as the test gas. However, other gases can be used, including: argon, helium, CO_2, N_2, and SF6. Small solid- and liquid-propellant jet thrusters have also been tested.

Some newly-proposed Theater Ballistic Missile Defense vehicle designs utilize an external gas such as helium for vehicle window cooling. Testing the main jet gas and the cooling jet gas simultaneously is important because of possible interaction of the cooling gas on the vehicle boundary layer and flow field, and subsequent effects on control system effectiveness.



Color Schlieren of BMDO Theater High Altitude Area Defense Missile (THAAD) Jet-Interaction Effects Evaluation on Kill Vehicle Stability and Drag in AEDC Hypersonic Wind Tunnels B.

Ballistic Trajectory Simulation Process

Accurate delivery of unguided munitions by modern strike aircraft requires that an aircraft onboard targeting computer accurately predict where stores released by the aircraft will impact the ground.

The targeting computer predicts the ground impact point by producing a trajectory solution that accounts for store free-flight ballistic drag characteristics and the effects of the aircraft flow field on the store ballistic trajectory.

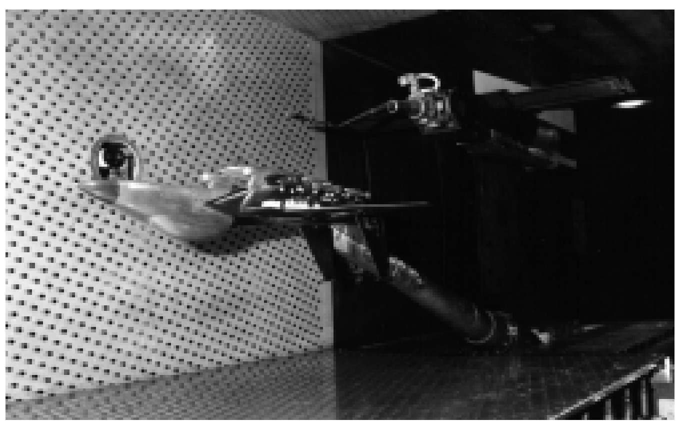
Currently, calibration of an aircraft targeting algorithm for flow-field effects is based on flight test data acquired during many (perhaps hundreds of) flight test sorties. Because monetary and schedule costs associated with flight testing can be quite high, a store ballistic trajectory simulation process was developed at AEDC that permits store ballistic trajectories to be simulated on the ground using ground testing and analytical data sources, thereby reducing reliance on data from expensive and time-consuming flight tests.

The process was verified by comparing simulated ballistic trajectories with 434 flight test ballistic trajectories of a 500-lb-class Mk-82 LDGP bomb when released from an F-I5E aircraft in flight. Initial conditions for each simulated trajectory were identical to measured initial conditions for each respective flight test trajectory.

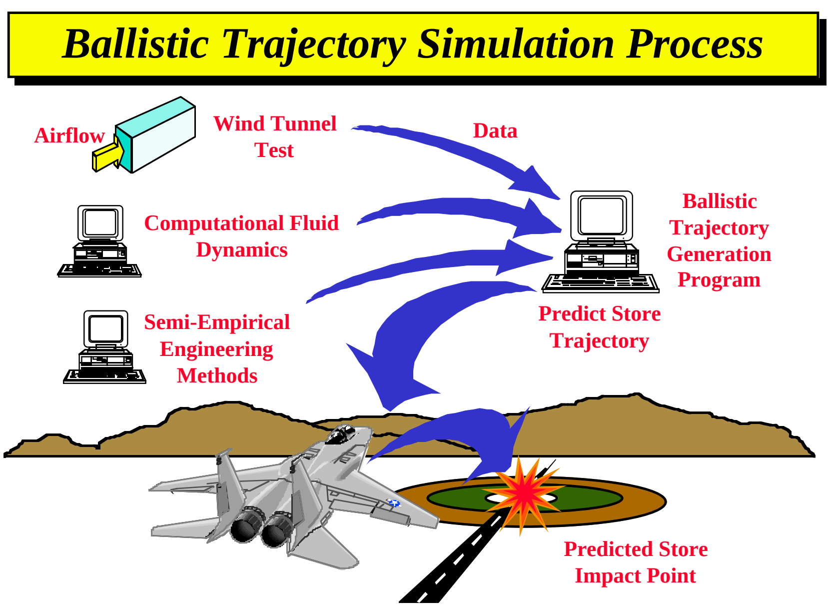
Aircraft flight conditions at the instant of store release included Mach numbers from 0.60 to 0.96, aircraft lift load factors from 0.6 to 4.6 g, aircraft altitudes from 2974 to 8961 ft mean sea level (MSL), and aircraft dive angles from -33 (lofted delivery) to 46 (dive delivery) deg. Mean time of fall for the trajectories was 7.20 sec.

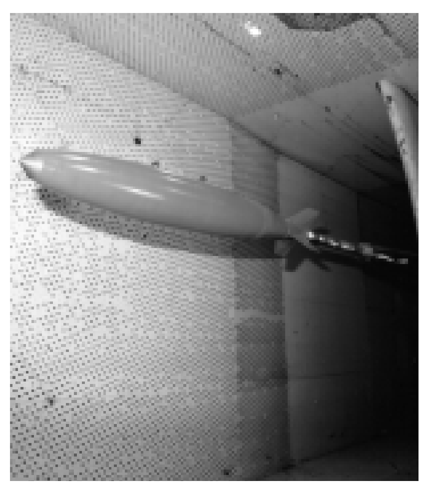
Differences between simulated ballistic trajectories and their respective flight test ballistic trajectories averaged 0.45 mrad in the downrange direction and -0.39 mrad in the crossrange direction, indicating that the simulation produced trajectories that were, on average, 0.45 mrad long of, and 0.39 mrad to the left of, their respective flight test trajectories.

Based on the comparison results, as well as statistical and other tests of the results, the ballistic trajectory simulation process was shown to produce a valid simulation of the flight dynamics of a store when released from an aircraft in flight, thereby establishing an alternative to the use of flight test data for calibration of the flow-field effects portion of an aircraft onboard targeting algorithm.



Five-percent scale F-15E aircraft and Mk-82 LDGP store models in the AEDC 4-ft Transonic Aerodynmic Wind Tunnel (4T).





Full-scale Mk-82 LDGP store in AEDC's 16-ft Transonic Wind Tunnel (16T).

Commercial/NASA

X-33 Reusable Launch Vehicle

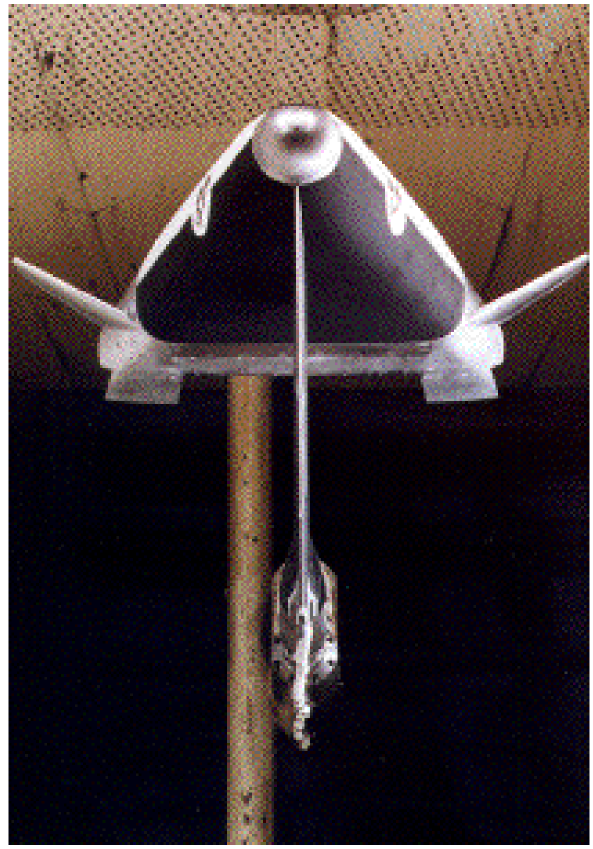
On July 2, 1996, NASA selected Lockheed Martin Skunk Works (LMSW) to build the X-33 spaceplane, a prototype Reusable Launch Vehicle (RLV) designed to offer affordable commercial access to space.

Lockheed Martin Skunk Works (LMSW) conducted wind tunnel tests in the AEDC 16-ft transonic (16T) and supersonic (16S) wind tunnels to determine jet exhaust plume effects on X-33 vehicle stability and control at transonic and supersonic Mach numbers. A 7.75-percent scale model of the X-33 was used for the tests.

The jet exhaust was simulated by flowing high-pressure air at ambient temperature through the four engine exhaust nozzles on the model. The high-pressure airflow rate was varied from 0 to 23 lbm/sec to simulate operating nozzle pressure ratios of the X-33 propulsion system.

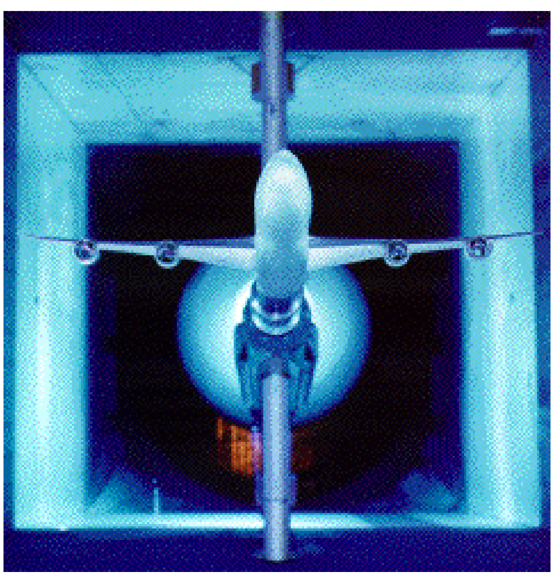
Force and pressure data were obtained for several model configurations at free-stream Mach numbers from 0.3 to 1.5 in Tunnel 16T, and at Mach numbers from 1.6 to 2.3 in Tunnel 16S. Configuration variables included nozzle vector angles, control surface deflections, and a simulated support sting.

The first flight test of the LMSW X-33 is planned to occur in early 1999. If flights of the prototype are successful, the full-scale RLV could be carrying payloads to space in 2006.



A 7.75-percent scale model of Lockheed Martin Skunk Works' X-33 in AEDC's 16-ft Transonic Wind Tunnel (16T).

Boeing Continues Commercial Testing



A model of Boeing's proposed stretched 747 commercial aircraft is tested in the AEDC 16-ft Transonic Wind Tunnel (16T).

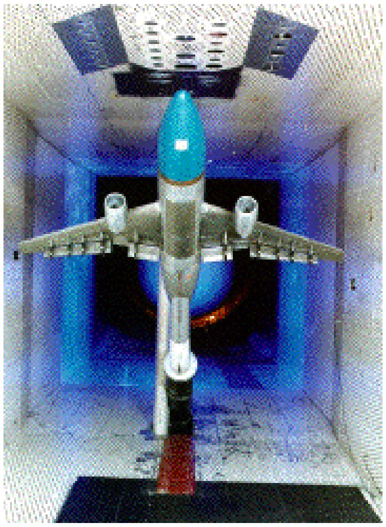
The Boeing Commercial Airplane Group completed a 58-day test of a new commercial aircraft in the AEDC 16-ft Transonic Wind Tunnel (16T). The test was a milestone for the AEDC/Boeing Commercial Group Alliance. The customer praised AEDC for exceeding its expectations of efficiency in producing high quality data.

Based on experiences gained during a previous benchmarking test of a 767 aircraft in Tunnel 16T, Boeing chose AEDC to meet its critical wind tunnel testing requirements for accelerated development of a proposed new version of the 747 aircraft. AEDC and Boeing teamed during test preparations to develop several process improvements which significantly shortened test cycle time. These process improvements continue to benefit current and future test projects.

An appropriate mix of commercial and military testing benefits all AEDC customers by maintaining a strong, talented work force in world-class test facilities.

International

AEDC and DRA Collaborate to Benchmark Wind Tunnels



A British A300-B2 Airbus model undergoes wind tunnel testing in the AEDC 16-ft Transonic Wind Tunnel (16T).

Although during its 46-year history AEDC has primarily tested aerospace vehicles for the military and NASA, the Center has recently begun testing commercial aircraft. A 1/13th-scale Airbus A300-B2 aircraft model was tested in the AEDC 16-ft Transonic Wind Tunnel as part of a collaborative effort to benchmark wind tunnel test facilities in the United States and Great Britain.

The primary purpose of the test was to demonstrate the feasibility of testing the same aircraft model in the British Defence Research Agency (DRA) low speed 5-meter wind tunnel and in the AEDC 16-ft Transonic (high speed) Wind Tunnel. The tunnels complement each other to cover the operating envelope of most military and commercial aircraft and are considered to be world-class facilities in their respective operating envelopes.

Additional benchmarking test data were acquired when the DRA tested an AEDC-supplied 1/4-scale F-16A aircraft model in their 5-meter wind tunnel in 1997. Results from the benchmarking effort will be documented in a forthcoming joint AEDC-DRA technical paper.

Test Capabilities

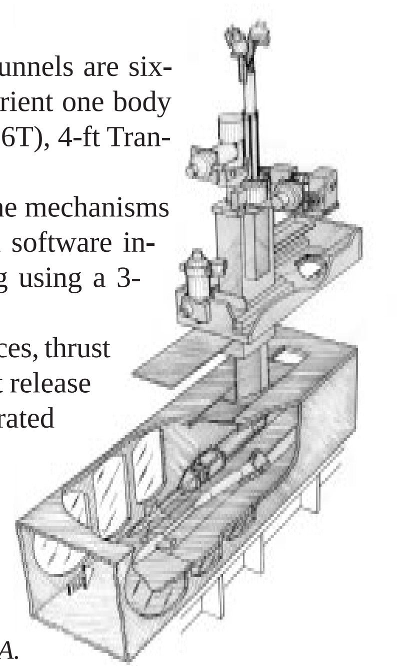
CTS

The captive trajectory support (CTS) systems used in the AEDC wind tunnels are six-degree-of-freedom computer-controlled mechanisms used to position and orient one body relative to another. They are available in the 16-ft Transonic Wind Tunnel (16T), 4-ft Transonic Wind Tunnel (4T), and in the Hypersonic Tunnels A/B/C.

In Tunnels 16T and 4T at transonic and low supersonic Mach numbers, the mechanisms are used primarily in store separation test programs. Available application software includes: captive trajectory; aerodynamic grid; and flow-field grid mapping using a 3-probe Mach-flow angularity rake.

Standard options in the trajectory software include simulation of ejector forces, thrust forces, pullup and pushover aircraft maneuvers, and restrained motion (pivot release and down-the-rail missile motion). Store autopilot algorithms can be incorporated on an as-need basis.

During captive trajectory and aerodynamic grid tests, aerodynamic data can be obtained simultaneously both for the CTS model and for metric store models mounted at the carriage position on the aircraft model.



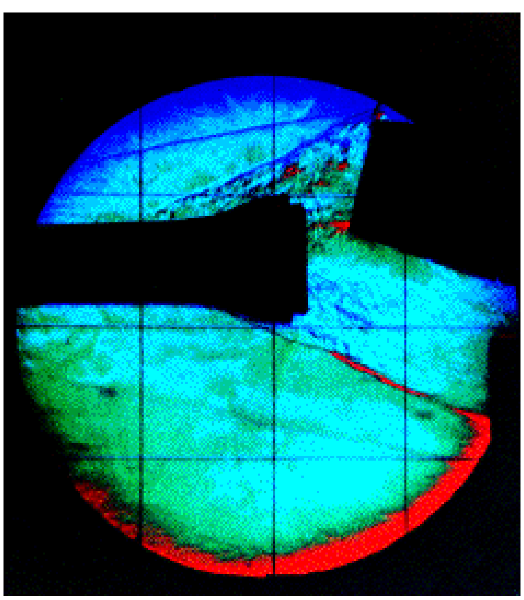
Artist's rendering of the VKF/CTS installed in AEDC Hypersonic Tunnel A.

Stage Separation Testing

AEDC has developed capabilities that are unique in the nation for supporting design of aerospace vehicles which separate or stage in flight.

Tests which simulate a separation event in a vehicle flight plan can be performed in the von Karman Gas Dynamics Facility (VKF) at AEDC using the captive trajectory support (CTS) system. The CTS is a unique six degree-of-freedom computer-controlled motion/positioning system.

Applications for the system in the supersonic and hypersonic test units in the VKF include tandem and in-line staging simulation. Exhaust or control jets on either stage of the separating vehicle can also be simulated. Typically, one of the stages (the parent) of the model is supported by the tunnel support mechanism, while the other staging model (the store) is supported by the CTS mechanism. Separation of the staged model is thus simulated by moving the store model with the CTS mechanism.



Force and moment measurements, static and transient model surface pressures, model surface heat transfer, and control surface loads can all be measured while simulating the staging event. Data may be recorded in two modes. In the grid mode, the desired data are recorded with the store at predetermined points in space, with the store and parent at predetermined attitudes. Such data may be used to develop a math model to predict flight trajectories or determine a safe separation envelope, or assess design modifications after appropriate modification to the data set.

In the trajectory mode, the store is placed in the un-staged position, and the data system is initiated. Static stability measurements for the store, in conjunction with the physical characteristics of the flight vehicle, are used to numerically integrate the equations of motion over a discreet time period. New model attitudes and positions are then calculated for the end of this time

Test Highlights
Trisonics

period. The store is set to the calculated attitudes and positions, and the process is repeated until a separation trajectory has been simulated in the tunnel. Such data can be used to determine a safe separation envelope and to validate performance models developed from grid data.

The VKF CTS mechanism may also be used for simulation air-launched weapons separation and for flow-field mapping.

Dynamic Drop

When the motion of a released store precludes trajectories of sufficient length to establish safe separation (e.g., rapid pitch down or tumbling motion), the Dynamic Drop test technique can be used. The free-falling store motion is captured on high-speed motion picture film from which the trajectory excursions are determined.

Accelerometer telemetry packages may be mounted internal to the drop store models, and acceleration and rate information recorded during the separation event if the store models are sufficiently large to accept the package and proper dynamic scaling can be maintained.

Virtual Flight Testing

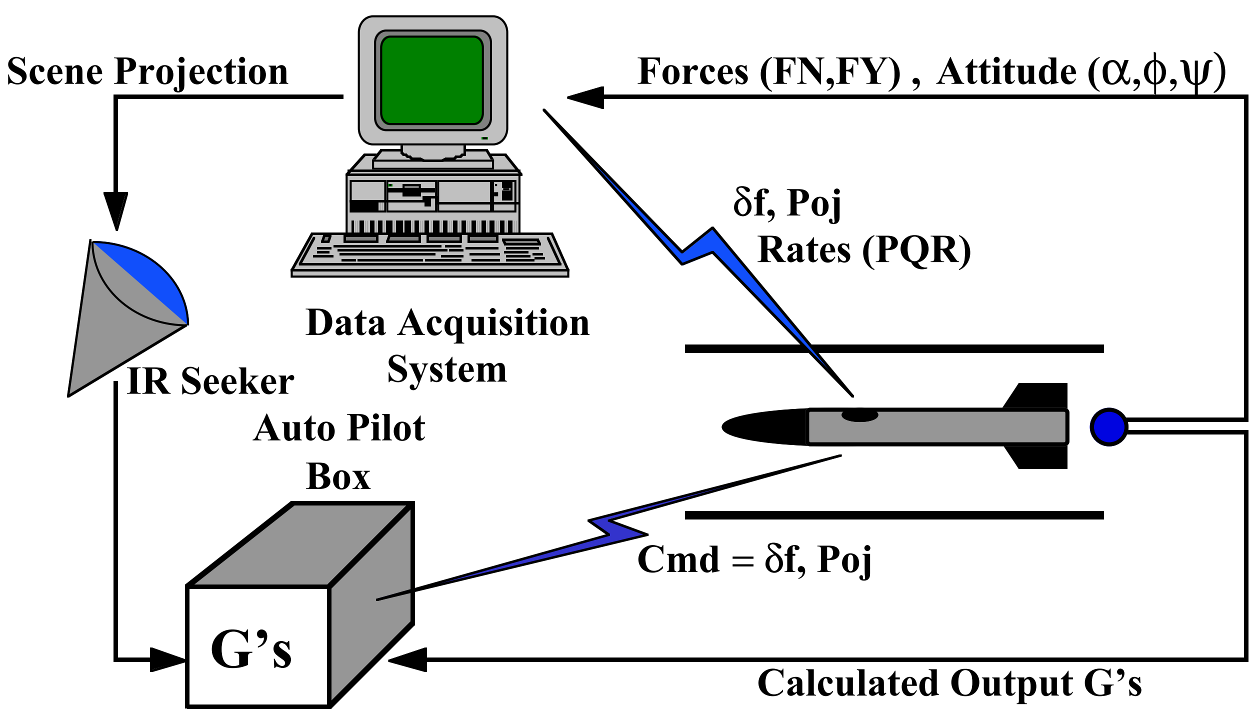
Missile free-flight testing utilizing pre-programmed guidance commands has historically been the first opportunity in which an airframe/control system could be tested in a closed-loop sense in real flight conditions.

Free-flight testing is a destructive test in which the hardware is often not recovered or is recovered but unuseable. The amount of free-flight data collected per test event is on the order of 30 to 120 sec of useable data.

The Virtual Flight Test (VFT) technique will provide a ground test capability that may be used to demonstrate and validate the robustness of autopilot software and control systems in a wind tunnel test environment.

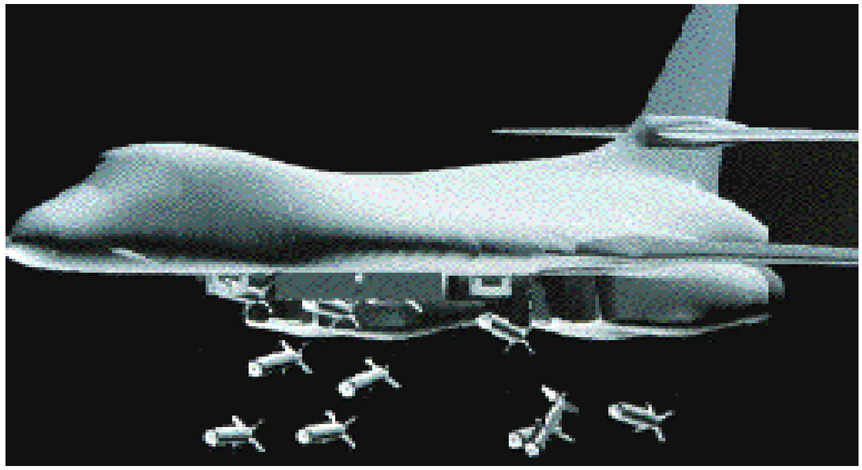
Recent advances in communications and transducers will allow the test article to be tested in a wind tunnel environment on a spherical gas bearing that allows pitching, yawing, and rolling motion. Control commands from an autopilot will be transmitted to the model using telemetry. The control commands will be executed and the model will respond accordingly. The responses will be recorded by a data acquisition computer where trajectory calculations are made and transmitted back to the autopilot for new commands to be issued.

CLOSED-LOOP GUIDANCE / CLOSED-LOOP CONTROL



Analysis

Air Frame and Stores Integration



A Computational Fluid Dynamics model of the B1-B bomber simulates dropping conventional weapons.

Safe separation and accurate delivery of ordnance from aircraft determine acceptable aircraft-store integration.

Safe separation ensures that the store release will not compromise the safety or integrity of the aircraft and its crew. Accurate aircraft delivery of unguided munitions ensures that released munitions will impact their target area predictably and effectively.

AEDC has developed an integrated approach to testing and analysis, referred to as integrated testing and evaluation (IT&E), that promises to greatly reduce the costs and time incurred in certification of stores for delivery from tactical aircraft (see page 4).

The current state of weapon delivery technology requires that many hours of wind tunnel testing and flight testing be conducted to certify safe release of weapons and to calibrate the aircraft's flow-field compensation algorithm used in the onboard operational flight program (OFP).

A methodology that applies ground simulation techniques in place of flight test techniques to algorithm calibration has been developed at AEDC, thereby reducing calibration flight test hours and associated cost and time.

Application of the methodology will include the prediction of safe release from existing and new aircraft; the calibration of flow-field compensation algorithms for existing and new aircraft; the prediction of weapon delivery accuracy for existing aircraft; the prediction of weapon delivery accuracy for new aircraft during the design phase; and the prediction of effects of aircraft or weapon design changes on aircraft weapon delivery accuracy.

This project is the first AEDC program to use IT&E toward a single objective. That objective is the acceleration of the process and the decrease in the cost of certifying aircraft-store configurations. Safe separation and accurate delivery require:

- prediction of physical clearances during the weapons-separation process
- prediction of store trajectories in the near-field of the aircraft
- prediction of flow-field effects on the near-field trajectory of the weapon's ballistic flight to the ground.

Ground simulation methods determine near-field trajectories in two complementary ways: on-line in the wind tunnel by using a combination of direct measurements and computations; and off-line using only analytical and computational methods. Both ways require knowledge of the aerodynamic and ejector loads acting on the store at release and during its trajectory.

On-line

In the wind tunnel, the captive trajectory support (CTS) system supports and moves scaled stores to simulate a store release. An internal strain gage balance inside the store model measures the loads experienced by the store in the aircraft flow field. Numerical integration of the equations of motion then determines the path and attitude of the store.

The store is positioned at the next trajectory location by the CTS system. Since the flow on the store is allowed to become steady at each new position, this method is often referred to as a quasi-steady method.

Off-line

Aerodynamic loads on a store are determined in one off-line method by mathematically superimposing the store on a known flow field and applying analytical methods based on linear flow theory. Aircraft flow fields are determined by probe measurements in the wind tunnel or from computation of the flow fields directly from the descriptive set of non-linear partial differential equations. The direct computational method is referred to as computational fluid dynamics (CFD).

Probe measurements in the wind tunnel are made by translating a five-hole conical probe through the region beneath an aircraft sub-scale model. Neither the measured flow field nor the computed flow field will reflect the mutual interference that occurs when a store is present close to the aircraft.

Additional CFD calculations are then made to improve the method by providing increments to the baseline aerodynamic loads caused by mutual interference of a particular store with the aircraft. This is done by using CFD to computationally place a store at the desired carriage location and determining its loads, and then calculating the loads on the same store in the free stream.

The absolute loads provided by CFD can be in error, but the increment in loads between store-in-free-stream and store-at-carriage are accurate.

The preferred off-line method, however, requires no CFD, but is somewhat more expensive. In this method, a wind tunnel test is conducted wherein a sub-scale model of the store of interest is placed at various points in the flow field at various attitudes and free-stream Mach numbers.

The loads on the store are measured and tabulated. Off-line, then, the loads on the store at any position or attitude can be determined by interpolation within the tabulated data.

With any of the off-line methods, a store trajectory is determined in exactly the same manner as in the on-line mode, except that the loads are determined analytically or by interpolation of the tabulated data.

The main benefit of the off-line methods is their flexibility. Many "what-if" trajectories can be made at in-between Mach numbers, attitudes at release, ejector forces, or store center-of-gravity (cg) locations.

Thus, a combination of testing, analysis, and computations produces an efficient and accurate determination of the near-field trajectory of a given store, thereby providing the necessary safe-separation information. Each discipline enhances the overall store separation certification process by complementing the others.

Computational Fluid Dynamics

Computational fluid dynamics (CFD) store separation problems often focus on time-accurate movement of air-launched weapons such as guided bombs and rocket-assisted, fly-away weapons. The time-accurate moving body problem presents a particularly difficult undertaking for CFD analysts, primarily because such solutions typically take months of computer time to complete.

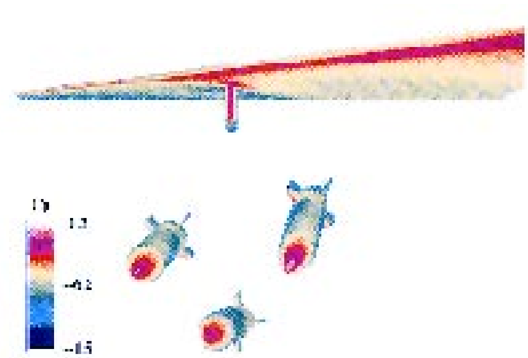
Recently, CFD engineers at AEDC developed a new high-speed computational algorithm based on revolutionary concepts. They realized the primary stumbling block was the size of the time-step taken in the computation of a weapon's trajectory after it is released from an aircraft. Because in modern codes time-step size is limited by numerics, not physics, they focused their efforts on enlarging the time-step capability of AEDC's workhorse CFD flow solver software, known as XAIR.

In order to accomplish this, AEDC CFD engineers included the relevant terms on the implicit side of the matrix equation with a minimum of approximation. Then, they solved the set of equations completely rather than approximately at each time step.

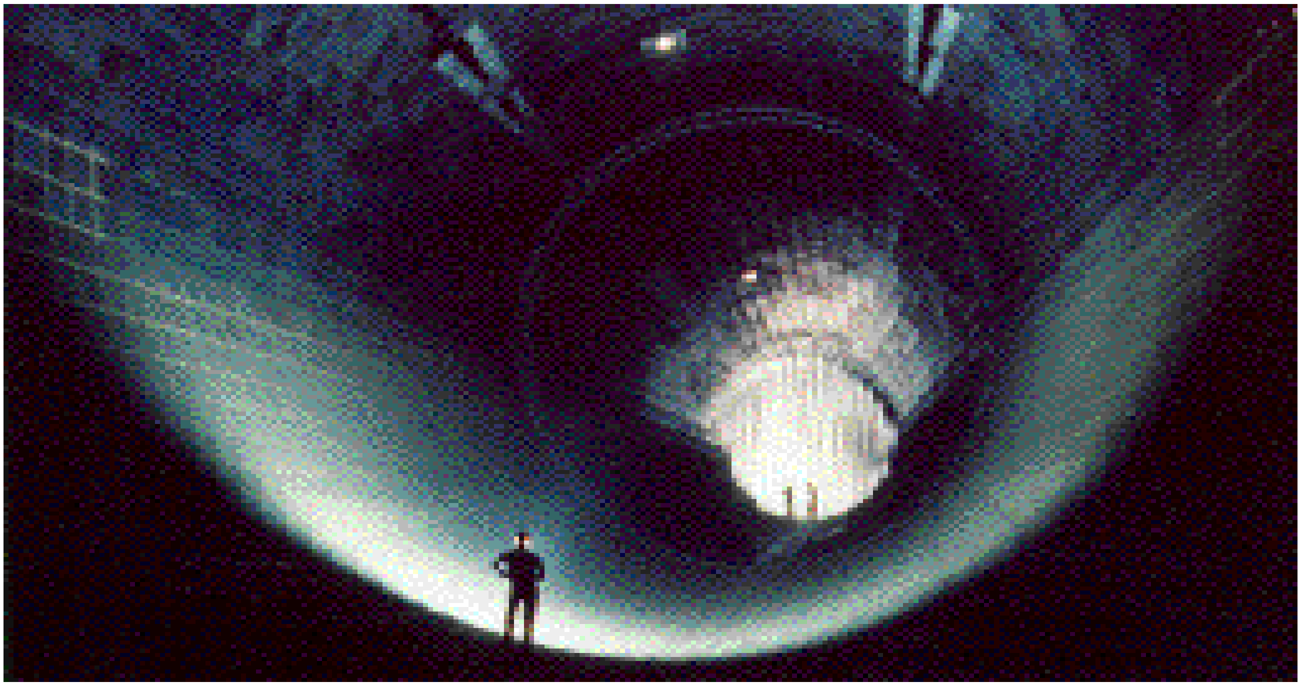
Next, they turned to the task of building a faster solver for each time step. Starting from first principles, the CFD team carefully analyzed and made timing studies of all the solver techniques available in the literature. They settled on a simple method that they were able to refine even further.

The new code proved to be so stable and accurate that the CFD team was able to tackle problems with extremely large time steps, over 100 times larger than could be handled by previous solvers. The new flow solver's capabilities were so advanced that a new name was given to it: NXAIR.
Using the old solver, an inviscid, time-accurate problem required 250 C-90 CPU hours. With the new solver, a viscous (not inviscid), time-accurate problem required only 70 C-90 CPU hours.

TER Navier-Stokes M=0.95
T–0.4 sec



Facilities



Vertical turning vanes guide the air flow around corners in PWT's closed-circuit 16-ft Wind Tunnels.

Wind Tunnels

The subsonic, transonic, and supersonic wind tunnels that comprise the Propulsion Wind Tunnel (PWT) facility are the 16-ft Transonic (16T), 16-ft Supersonic (16S), and the Aerodynamic 4-ft Transonic (4T) Wind Tunnels.

Tunnel 16T

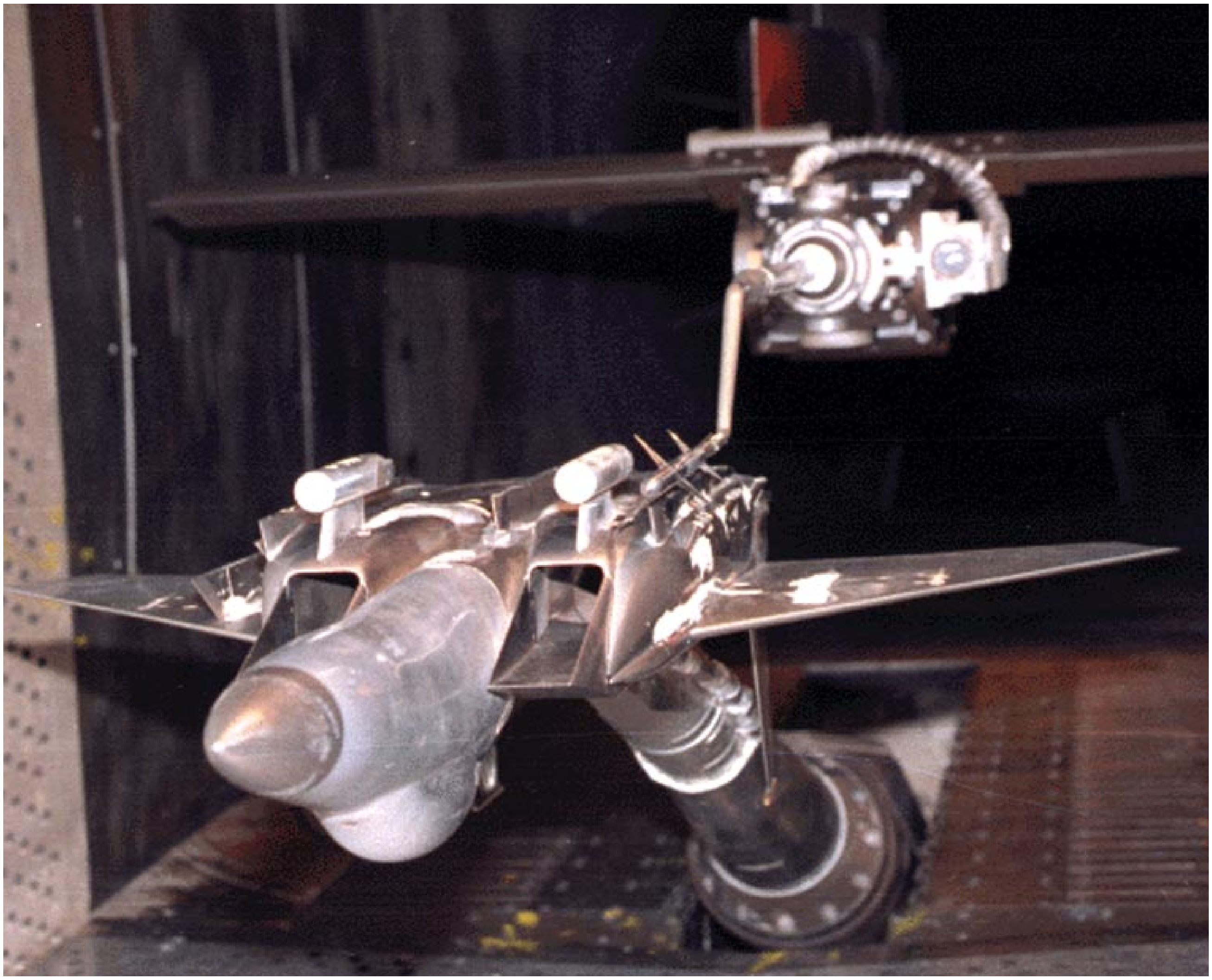
The PWT 16-ft Transonic Wind Tunnel is a closed-loop variable-density, continuous-flow tunnel capable of operating at Mach numbers from 0.06 to 1.6 and stagnation pressures from 160 to 4,000 lb psfa. The maximum attainable Mach number can vary slightly depending on the tunnel pressure ratio requirements of a particular test installation. The maximum stagnation pressure attainable is a function of Mach number and available electric power. The tunnel stagnation temperature can be varied from approximately 80° to 140°F depending on cooling water temperature. The tunnel is equipped with a scavenging system that removes combustion products when testing rocket motors or gas turbine engines.

Two test carts are available for testing in Tunnel 16T. The High Angle Automated Sting (HAAS) cart provides the capability for sting-mounting a model and testing at pitch angles from -20 to nearly 90 deg. The second cart can be configured as an open test section with various model support struts, with the captive trajectory support (CTS) system for store separation testing, or with the Pitch Boom system for testing at model angles smaller than those attainable with the HAAS cart.

Tunnel 16S

The PWT 16-ft Supersonic Wind Tunnel is a closed-loop variable-density, continuous-flow tunnel capable of operating at Mach numbers from 1.50 to 4.75, but is currently available for operation at Mach numbers from 1.6 to 3.4 and stagnation pressures from 200 to 1,600 psfa. The minimum stagnation temperature obtainable varies from about 120° to 140°F. Due to operating constraints, the maximum stagnation temperature currently attainable is approximately 160°F. The tunnel is equipped with a scavenging system that removes combustion products when testing rocket motors or gas turbine engines.

Models are normally supported by the Standard Sting Support System in Tunnel 16S. This system has a 11-deg pitch capability. It is possible to mount various adapters (some with remote actuation capability) to the support system to increase its attitude capability.



F-15E model in 4-ft Transonic Wind Tunnel in a store separation test.

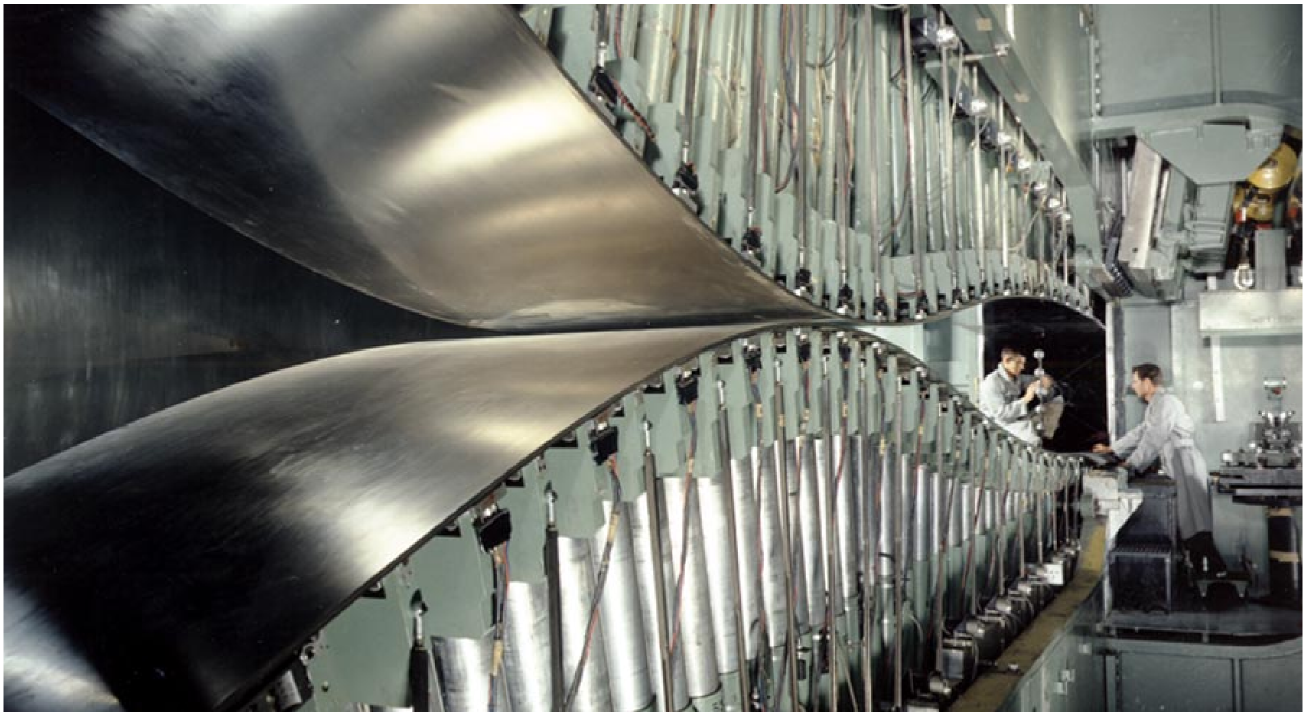
Tunnel 4T

The PWT 4-ft Transonic Wind Tunnel is a closed-loop, continuous-flow, variable-density tunnel.

Two operating modes are available: an Independent Drive System (IDS) mode; and a Plenum Evacuation System (PES) mode. The IDS operating mode offers significant energy savings but is limited to a maximum Mach number of 1.3. Stagnation pressures from 200 to 3,400 psfa are available for Mach numbers from 0.2 to 0.9 for IDS operations. The PES operating mode provides a Mach number capability of 0.1 to approximately 2.0. Stagnation pressures from 200 to 3,400 psfa are available at all Mach numbers for PES operations.

A sting model support system with -7 to 28-deg pitch capability is available in Tunnel 4T. Also, a Tunnel 4T CTS is available for store separation testing.

An AEDC project engineer looks over a Marine Corp. AV-8B Harrier II aircraft before a wind tunnel test.



Tunnel A flexible nozzle.

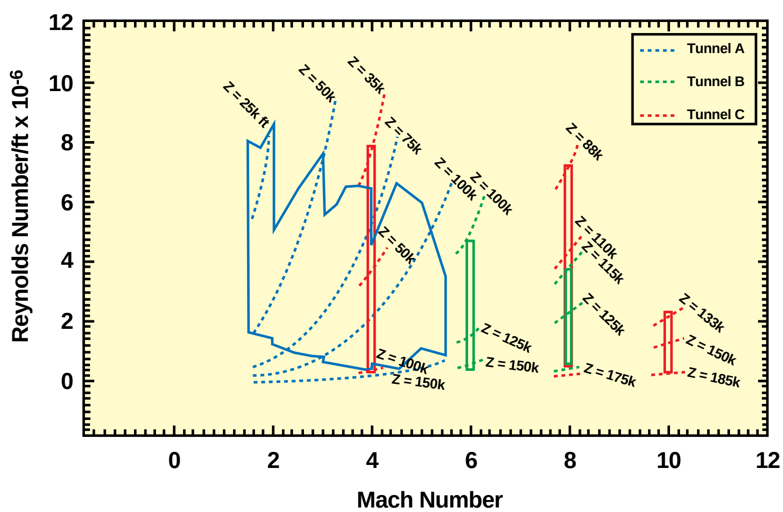
Tunnels A,B,C

The von Karman Gas Dynamics Facility (VKF) wind tunnels A,B, and C are large (40-in. and 50-in. test sections) supersonic/hypersonic aerodynamic continuous-flow test facilities. They are used to obtain aerodynamic and aerothermodynamic data for flight vehicles, and provide high quality, uniform airflow in the Mach 1.5 to 10 regime. Most high-speed flight vehicles (space planes, reentry vehicles, and missiles) have been tested in these facilities. Recent examples include defensive missiles (THAAD, ARROW, and LEAP), Space Planes (U.S. National Aerospace Plane, HOPE Japanese space vehicle, Japanese Aerospace Plane), and tactical missiles (AMRAAM, AIM-9X, and the Navy Standard Missile).

The tunnels are used to investigate vehicle static/dynamic stability and control parameters, jet interaction effects, pressure and aeroheating distributions, and inlet performance.

Tunnels B (Mach 6 & 8) and C (Mach 4, 8, and 10) are the country's only operational hypersonic test and evaluation facilities with continuous-flow capabilities.

The Mach 4 Tunnel C is used primarily for materials and aeroheating studies. Each tunnel is equipped with a model injection system to permit removal of the test articles during air-on operation, thereby enhancing test productivity. Special photographic equipment and techniques are used in the tunnels for flow visualization studies and to aid in flow-field analysis.



A wide range of test equipment and analysis tools exists for each facility. Included are new pitch-roll systems, an x-y-z probing mechanism, auxiliary mass flow system, six-component gas balances, model attitude control system, and the captive trajectory support (CTS) system. The CTS is a six-degree-of-freedom system permitting staging or store separation studies to be conducted in either the grid or trajectory modes of operation in each tunnel.

Dynamic Stability

A thorough understanding of dynamic stability and other transient flow phenomena is important when optimizing flight vehicle control systems or predicting flight vehicle trajectories.

A complete set of conventional dynamic test mechanisms is available at AEDC for both the large and small wind tunnels to obtain information on pitch, yaw, and roll damping, cross and cross-coupling derivatives, spin damping, and Magnus effects.

Damping information is determined by measuring the motion of a test article in the wind tunnel. Flexure balances are used to permit test article pitching, yawing, and rolling motion. Static force-and-moment balances are incorporated with the flexure balances to make cross and cross-coupling measurements. Gas or ball bearings are used with the static force-and-moment balances to make spin-damping and Magnus measurements. Mechanical damping test techniques using cylindrical or spherical gas bearings are also available to measure the energy dissipation of mechanical systems.

A newly developed test technique for determining dynamic information is the use of kinematic telemetry with a free-drop test article. With this technique, the motion of the test article is determined by onboard accelerometers, telemetered to a nearby receiver, and displayed in near real time.

Another newly developed dynamic test technique is the measurement of short duration loads or impulse loads from, for example, a pulsating jet. The test technique combines the capabilities of accelerometers and standard static force-and-moment balances to achieve a test mechanism that has the operational efficiency of a traditional static force-and-moment balance and the frequency response of an accelerometer.

Static Stability

Over many years, AEDC has refined static stability testing techniques for full- and sub-scale aerodynamic models.

To accomplish this goal, an inventory of high-precision, six-component, internal strain gage balances is maintained for use in Aerodynamic Wind Tunnels 4T, A, B, and C. Balances ranging from 10 lbf to 1,500 lbf normal force capacity are available, some of which are designed for models requiring flow-through mass ejection. Typical balance uncertainty is within 0.5% of the rated load.

Special-purpose balances and gaging are also available for measuring model component loads. A fully-instrumented balance gaging and calibration laboratory is staffed by trained professionals who can respond to customer needs and requirements. The staff can aid in the selection of an optimal balance during test planning. The selected balance is then check-calibrated by applying combined loads of the magnitudes anticipated for the test. Each balance is temperature-compensated over the range of 80° to 180°F. Balance temperature is stabilized during testing via a water jacket arrangement.

A direct-current excitation system is used for balance force-and-moment measurements. Each measurement channel is equipped with a signal conditioner and high-precision amplifier. The amplifier provides selectable voltage gains to a maximum of 2,500, and selectable filters to a minimum bandwidth of 0.5 Hz. The output of the amplifier is then multiplexed to a high-speed analog-to-digital converter for recording and on-line calculations of force-and-moment coeffficients.

The wind tunnels consist of four continuous-flow, variable-density, closed-circuit facilities that are capable of providing Mach number simulation in the subsonic, transonic, supersonic and hypersonic speed regimes.

Tunnel A features a 40-in. by 40-in. test section, while the Tunnel B & C test sections are 50-in. in diameter. Tunnels A, B, and C have a model injection system which allows access to the test article while the tunnel remains in operation.

Tunnel 4T contains a 48-in. test section that has a removable sidewall for model access.

Test article stability and control data can be obtained at virtually any attitude via a combination of pitch and roll mechanisms with offset stings and attachments.