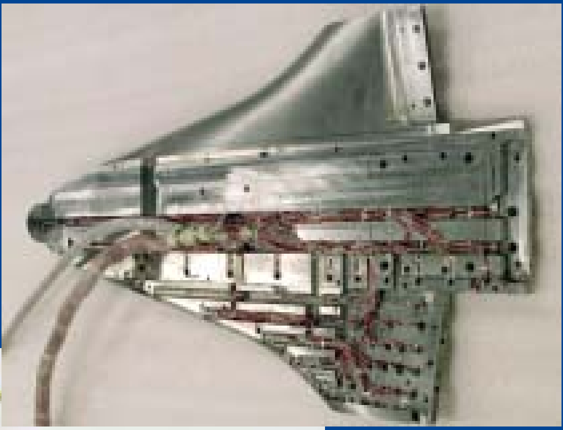
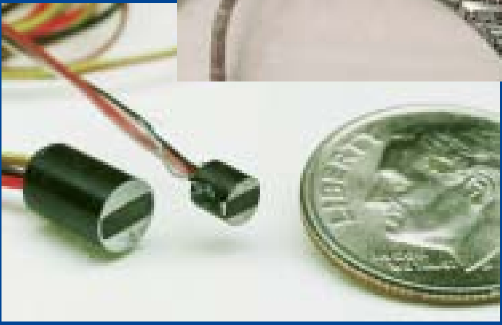




Aerothermodynamic Measurement Laboratory

Arnold Engineering Development Center

An Air Force Materiel Command Test Center

AEDC

The U.S. Air Force's Arnold Engineering Development Center (AEDC), located in Middle Tennessee, is a national aerospace ground test facility complex that conducts tests, engineering analyses, and technical evaluations for research, systems development, and operational programs for the DoD, governmental agencies, industry and allied international programs. The AEDC also conducts research and technology programs to develop advanced test techniques and instrumentation in support of existing and new test facilities.

AEDC Mission

Our mission is to provide customers with complete test and analysis capabilities. World-class test facilities have been integrated with state-of-the-art analysis techniques at AEDC to accomplish this mission.

Services

In addition to the test and evaluation capabilities, AEDC can provide a full range of other services for our customers. Available services include: model design and fabrication, calibration and installation of instrumentation, data reduction, computational simulation and reporting.

Aerothermodynamic Measurement Laboratory (ATMLab)

The Aerothermodynamic Measurement Laboratory provides technical expertise, skilled craftsmen, analytical tools, and calibration/characterization facilities in support of applied research in aerothermal test measurement techniques. The fundamental services of the ATMLab include specialization in heat transfer and transient temperature measurement for application to space and atmospheric high-speed flight models. Unique and specialized instrumentation is designed, fabricated, calibrated, and installed in supersonic and hypersonic test articles and facilities. A wide range of heat-flux transducer and temperature measurement methodologies have been modeled with state-of-the-art finite element analysis (FEA) tools, and instrumentation subsequently developed to aid in the definition of aerothermal flow characteristics. Examples include heat transfer measurements on wind tunnel models such as the Space Shuttle, HOPE and X-30 and on full-scale afterburning fighter jet engines. Most high-speed flight vehicle programs have required aerothermal capabilities provided by the AEDC test facilities and the technical services of the ATMLab.

Applications

The ATMLab has provided a variety of heat transfer instrumentation and data acquisition methods for use in various test facilities. Examples of applications include:

- Evaluation of aerothermal flow environment by direct heat transfer measurement
- Boundary layer transition detection and verification
- Definition and substantiation of CFD codes
- Heat-flux and temperature measurements on internally heated aerodynamic flight vehicles
- Test cell induced thermal loads on full-scale hardware such as the F/A-18E/F afterburning turbofan engine.

Technology/Knowledge

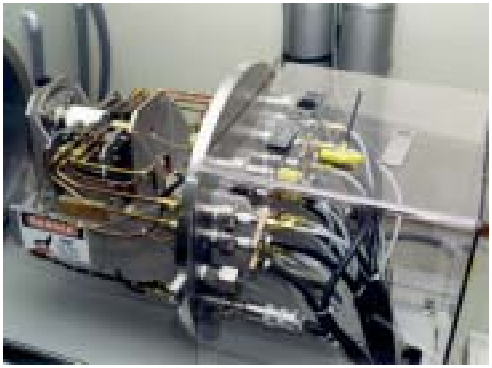
AEDC engineers have extensive experience with several types of discrete heat-flux sensors and test techniques for heat transfer data acquisition. Measurement sensors and methods include:

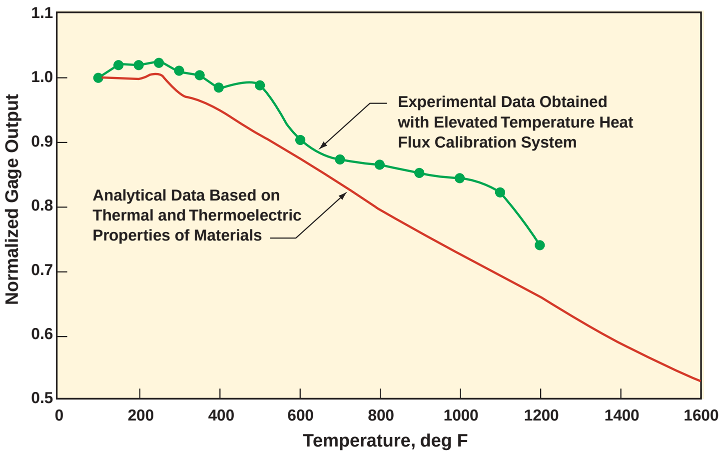
- Schmidt-Boelter Sensor
- Gardon Sensor
- Coaxial Surface Thermocouple
- Thin Skin Thermocouple
- Slug Calorimeter
- Null Point Calorimeter
- Thin Film Resistance Thermometer
- Thermal Mapping
  - Infrared Scanning
  - Hot Film Sensor

Expertise in the fields of applied and analytical temperature and heat transfer measurement techniques is maintained in the ATMLab for application to aerothermal requirements in aerospace, aerodynamic and propulsion test facilities.

Elevated Temperature Heat-Flux Calibration System

Heat-flux sensors have historically been restricted in calibration and application because of unknown sensor temperature effects. AEDC has recently significantly expanded its capabilities with the acquisition of an elevated temperature heat-flux calibration system. This is a world-unique system designed to characterize the effects of heat-flux sensor sensitivity with increasing sensor temperature. This capability effectively removes many previous application limitations and offers elevated temperature calibrations up to 1500 deg F (816 deg C) and 300 Btu/ft^2-sec (341 w/cm^2). Heat-flux sensor calibration results are traceable to the National Institute of Standards and Technology (NIST). Advantages of this system include significantly improved accuracy and productivity in elevated temperature applications. The sensitivity of a Gardon sensor decreases with increasing ambient temperature. Experimental results agree closely to predictions.

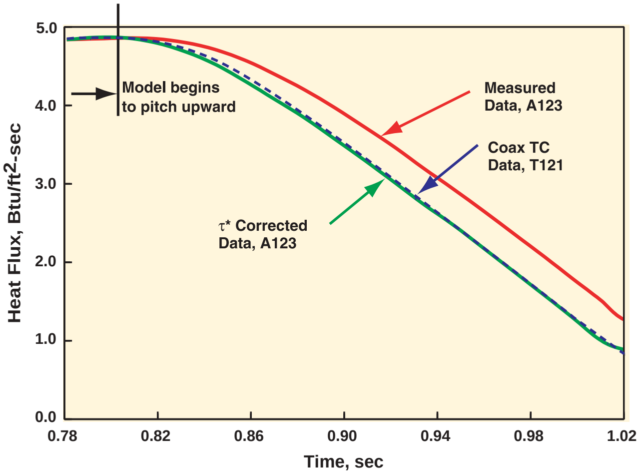




Gardon Gage Heat-Flux Sensitivity vs. Temperature

Transient Heat Transfer Measurement

Transient heat transfer measurements at AEDC have historically been conducted using coaxial surface thermocouples, thin-film resistance thermometers and null point calorimeters. The fundamental limitation of these devices is the assumption of one-dimensional, semi-infinite solid heat conduction. Because of practical model design constraints, the 1D semi-infinite conditions are not always met, introducing errors in the measurement. Although direct-reading heat-flux transducers are generally recognized as accurate quasi-steady-state devices, they have not been extensively used in transient applications because of their slow response time. To overcome this limitation, AEDC has developed a miniature Schmidt-Boelter sensor (0.125-inch diameter) with a time constant of 10 msec. The

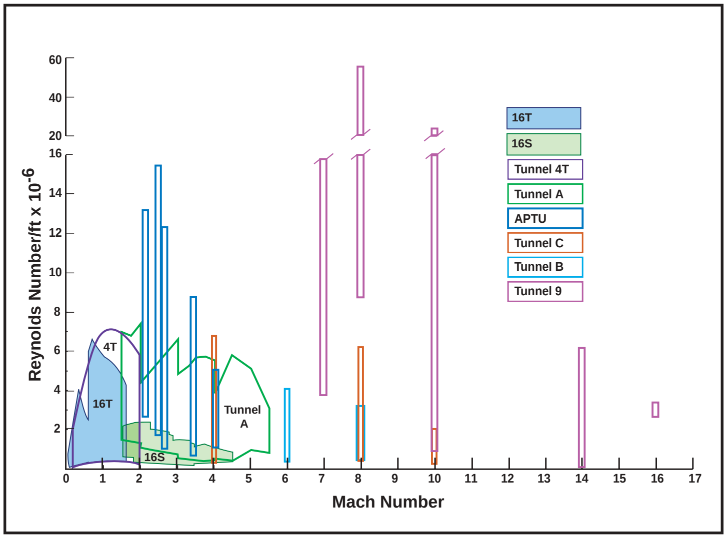


AEDC Tunnel 9 Transient Heat-Flux Data

transient time response of this sensor has been analytically predicted by finite element analysis (FEA) software and experimentally verified in the lab. The fast response of this sensor provides the capability to obtain data in transient applications with the improved accuracy of direct-reading sensors.

Aerothermal Wind Tunnel Facilities

AEDC facilities provide high quality flow in the Mach number 0.2 - 2.0 (Tunnel 4T), Mach number 1.5 - 10 (Tunnels A/B/C) and Mach number 7 to 16.5 (Tunnel 9 at White Oak, MD) flight regimes. These tunnels offer large test sections with variable-density flow capabilities. The tunnels are continuous flow tunnels except for Tunnel 9, which is a blow-down facility. The high enthalpy capabilities of Tunnel B, C, and 9 are well suited for the study of aerodynamic and aero-thermodynamic effects up to 2800 deg F. The tunnels are supported by the ATMLab and are routinely used to obtain aerodynamic and aerothermodynamic data for high-speed flight vehicles.



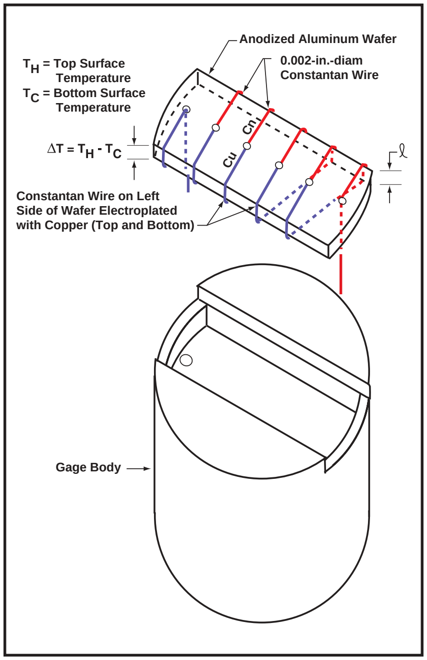
Performance Map of Aerothermal Wind Tunnels

Model Instrumentation

The ATMLab routinely instruments models for the AEDC wind tunnels, arc facilities and ballistic ranges. Expertise includes knowledge of the demanding and challenging flow environments of the various test cells and wind tunnels at AEDC. Additionally, the ATMLab also installs and supports installation of dynamic pressure (acoustic) and other miniature transducers.

Sensor Fabrication Capabilities

AEDC designs, fabricates, calibrates, and installs most types of temperature and heat transfer rate sensors. The ATMLab is equipped with the necessary equipment and skilled technicians to fabricate, install, and calibrate miniature component assemblies. The extremely small size of sensor components requires specialized training and skilled expertise during sensor assembly. Wire diameters on the order of 0.001 inch are used in the construction of the 0.125-inch diameter Schmidt-Boelter sensor. Innovative methods of assembling these sensors have been developed in the ATMLab. The lab also contains capabilities for the fabrication and experimental characterization of null-point calorimeters and several other types of heat transfer sensors. The fabrication and associated experimental characterization of null-point calorimeters for heat transfer measurements in very high heating conditions is an area of expertise that is unique to the AEDC.



Schmidt-Boelter Sensor

Calibration Uncertainties

The AEDC ATMLab maintains calibration standard heat-flux transducers calibrated at NIST with a certified accuracy of approximately 2 percent up to heat-flux levels of 5.5 w/cm^2. These standards are used to calibrate newly fabricated sensors, as well as other sensors from customers. The data acquisition system employed in the ATMLab adds an additional uncertainty of 0.25 percent to the heat-flux calibrations. Of course, these uncertainties apply only to laboratory heat-flux calibrations. The uncertainty of actual heat transfer measurements is dependent upon a number of other parameters. Commercial standards calibrated at heat-flux levels up to 500 Btu/ft^2-sec are used to calibrate sensors used for high heat-flux measurements. These standards are traceable to NIST and are reported to have an uncertainty of 5 percent.

Computation

Through an Integrated Test and Evaluation (IT&E) approach, flight tests, wind tunnel tests and engineering analysis are used to provide the aerospace community with information that can be used to accomplish program objectives quickly and with minimal risk. Technical specialists who work in the ATMLab are experienced in the application of state-of-the-art computational methodologies. Finite element analysis (FEA) software programs have been used to assist in the design of heat transfer measurement sensors and techniques. These programs provide the capability to solve transient 3-dimensional heat transfer problems at a variety of boundary conditions. These FEA methods have been effective in the design of transient heat transfer sensors, and in the identification of wind tunnel model areas where excessive heat conduction might degrade the accuracy of the thermal measurement.

For more information, contact:

Gary Mattasits
740 Fourth Street
Arnold AFB, TN
37389-6000
(931) 454-3767
FAX 454-3339
www.arnold.af.mil

Cleared for Public Release 2003-171