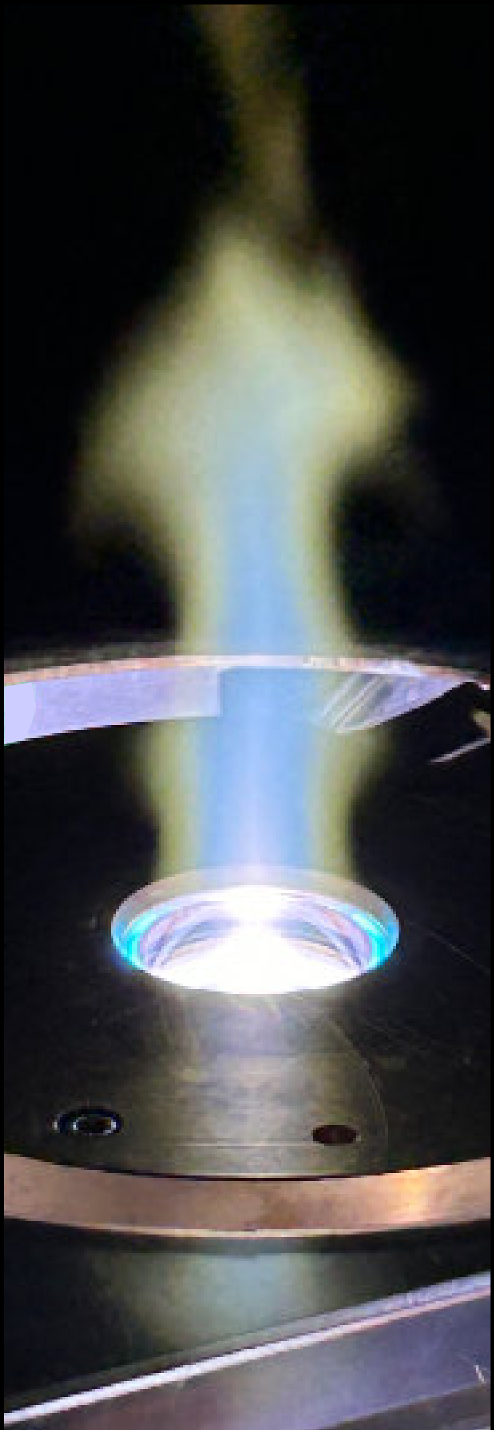
EXPERIMENTAL AEROSCIENCES


SANDIA NATIONAL LABORATORIES

ENGINEERING SCIENCE
EXPERIMENTAL FACILITY
ALBUQUERQUE, NEW MEXICO
EXCEPTIONAL SERVICE IN THE NATIONAL INTEREST

HYPERSONIC WIND TUNNEL

The Sandia National Laboratories Hypersonic Wind Tunnel provides simulation of aerodynamic environments encountered during reentry and high-speed atmospheric flight. Development of Sandia's Hypersonic Wind Tunnel began in 1958, with Mach 5 operation beginning in 1962 and Mach 8 and 14 added shortly thereafter. It is the only hypersonic wind tunnel capable of testing vehicle concepts and generating aerodynamic data in the Department of Energy complex. It is available as a test resource for investigations by Sandia, Lawrence Livermore, and Los Alamos laboratories, as well as external customers. The facility is unique in scale compared to larger national hypersonic test assets, enabling rapid research and development at low cost within a secure environment. To date, over 20,000 runs of the Hypersonic Wind Tunnel have been conducted in support of national security missions.

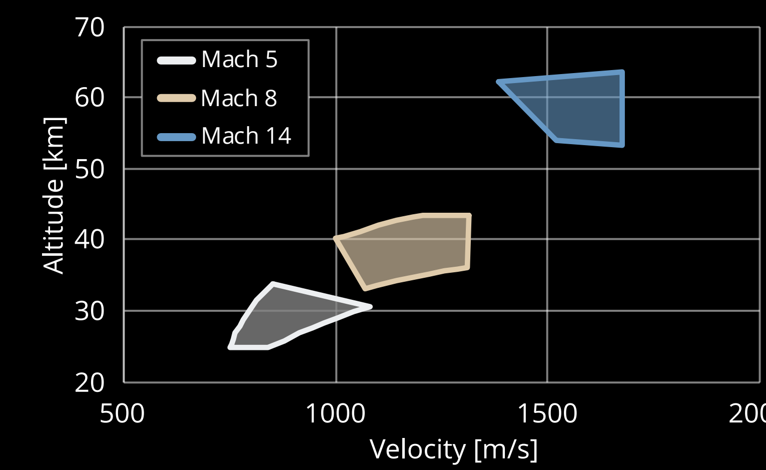
SPECIFICATIONS:

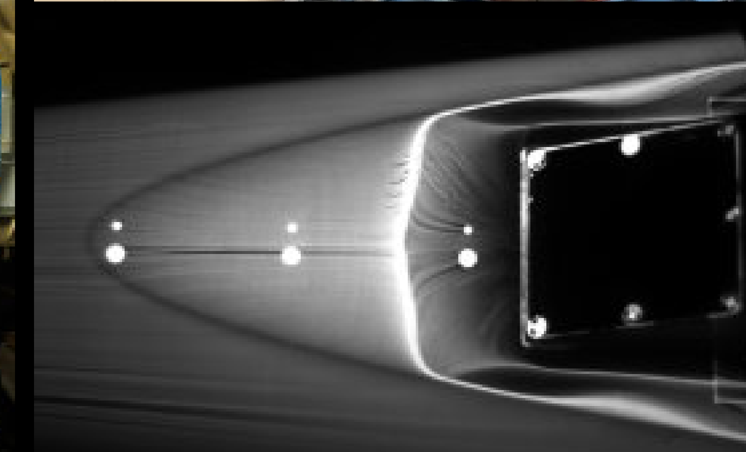
- Mach Numbers 5, 8, and 14
- Reynolds Numbers 0.05 to 25 million per meter
- Run Duration of 45 seconds per 45 minutes
- Test Section Diameter 0.45 meters
- Stagnation temperatures up to 1400 Kelvin
- Model Pitch Range -9 to +17 degrees. Larger ranges on request

EXAMPLE APPLICATIONS:

- Static Force and Moment Measurement
- Aerodynamic Coefficients Database Generation
- Aero-Induced Pressure and Vibration
- Hypersonic Fluid-Structure Interaction
- Hypersonic Boundary Layer Transition
- Dynamic Controls Testing
- Directed-Energy Aerodynamic Effects Testing
- Hypersonic Aero-Optics Effects
- Computational Model Validation Experiments

OPERATING ENVELOPE





Sandia National Laboratories
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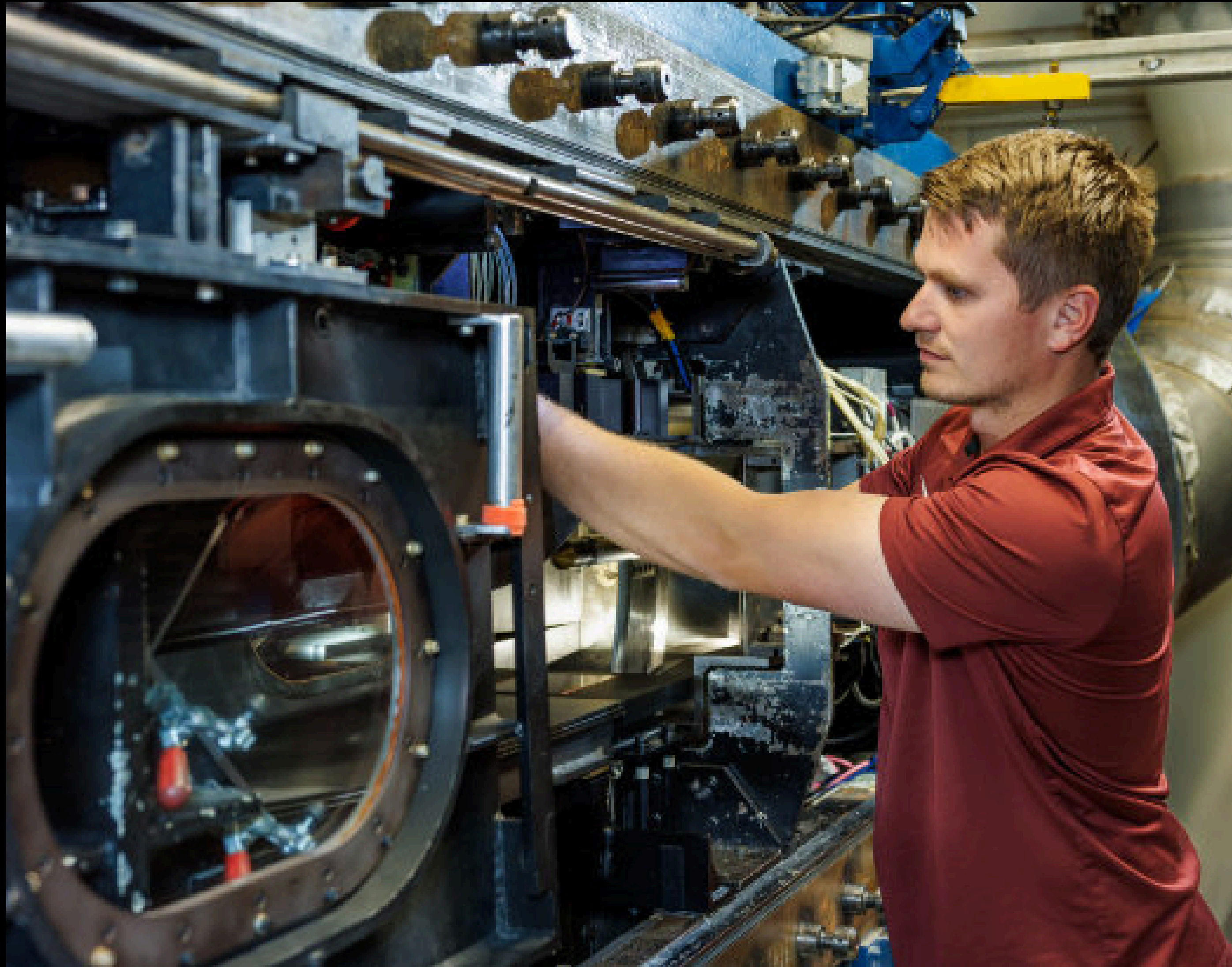
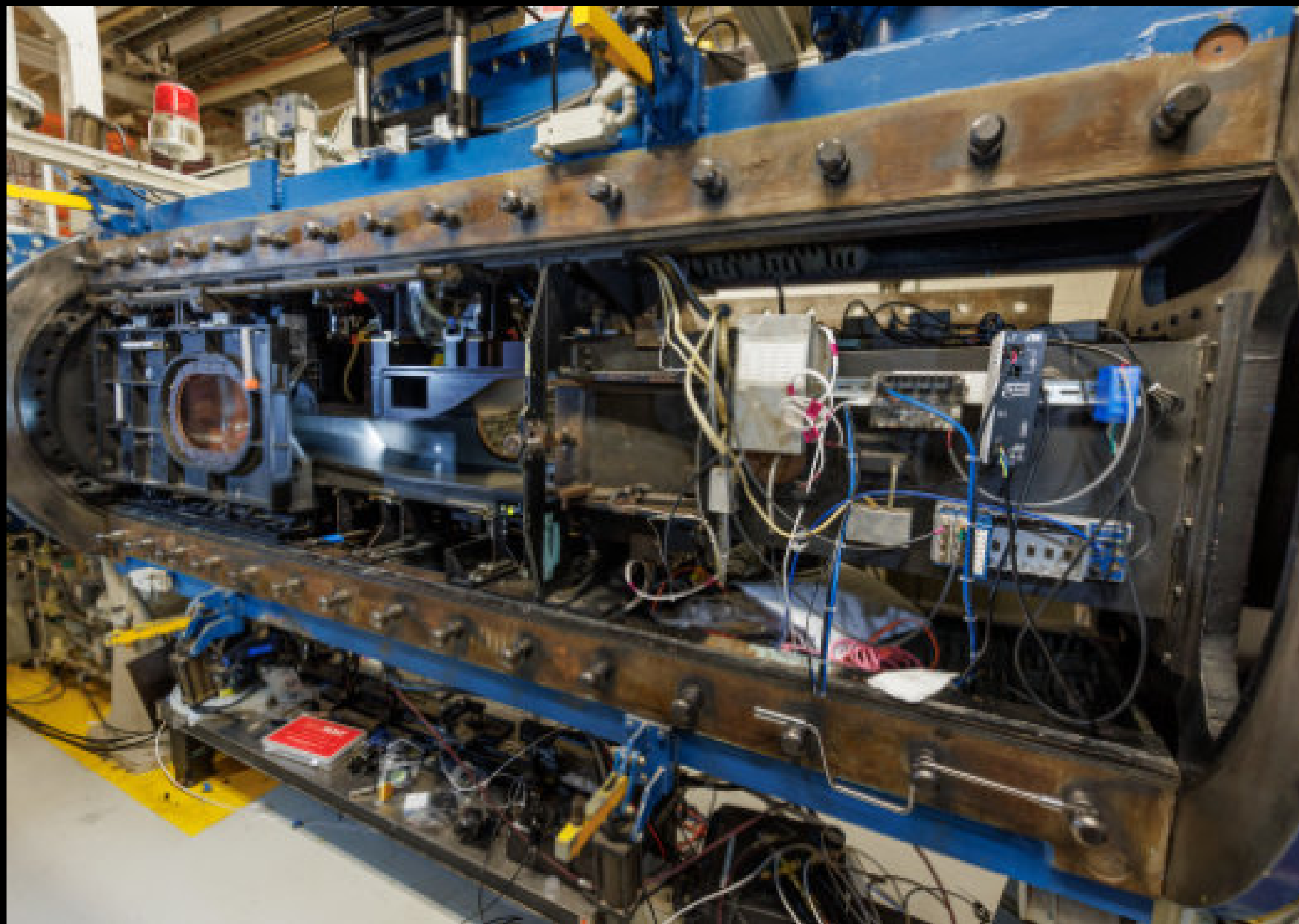
HYPERSONIC WIND TUNNEL

TRISONIC WIND TUNNEL



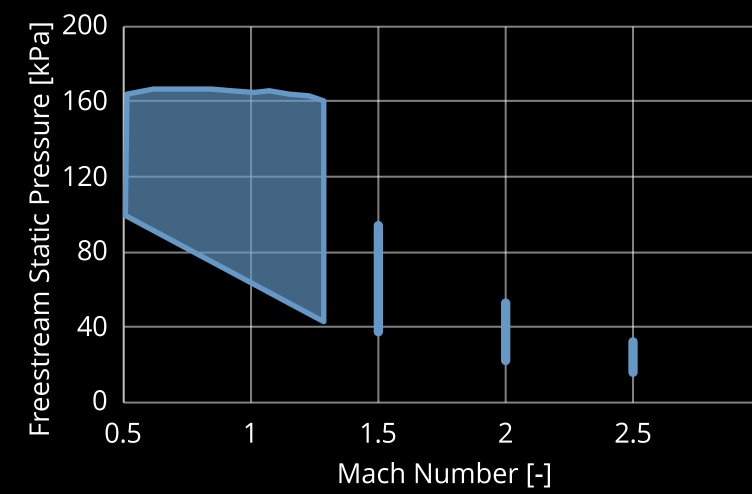


TRISONIC WIND TUNNEL

The Sandia National Laboratories Trisonic Wind Tunnel provides realistic simulation of aerodynamic environments at lower speeds than the Hypersonic Wind Tunnel, as needed for investigations of gravity bombs, missiles, and commercial aerospace applications. Development of Sandia's Trisonic Wind Tunnel began in 1952, with transonic operation from Mach 0.5 to 1.3 beginning in 1955 and supersonic capability at Mach 1.5, 2.0, 2.5, and 3.0 added in 1959. It is the largest and most versatile subsonic and supersonic wind tunnel in the Department of Energy complex and is available as a test resource for investigations by Sandia, Lawrence Livermore, and Los Alamos laboratories, as well as external customers. Upgrades made in the 1980s and the 2000s expanded the operating envelope of the facility and reduced the freestream noise level to improve testing fidelity in laminar, transitional, and turbulent flow regimes. To date, over 35,000 runs of the Trisonic Wind Tunnel have been conducted in support of national security missions.

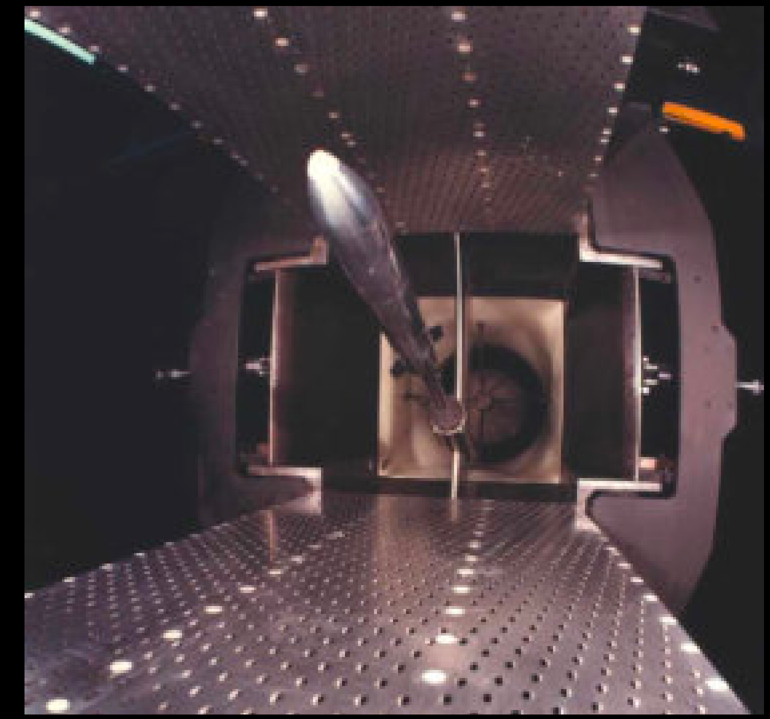
SPECIFICATIONS:

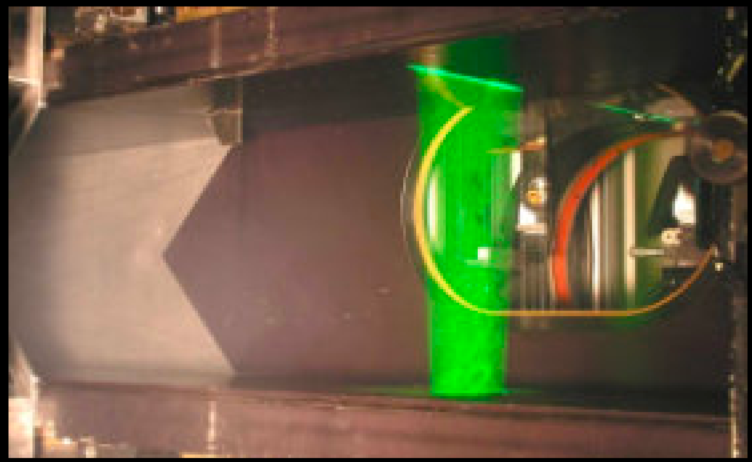
- ▶ Transonic Mach Number Range 0.5-1.3
- ▶ Supersonic Mach Numbers 1.5, 2.0, 2.5, and 3.0
- ▶ Reynolds Numbers 0.9 to 6 million per meter
- ▶ Run Duration 60 seconds every 20 minutes
- ▶ Test Section Size 0.3 × 0.3 meters
- ▶ Model Pitch Range -6 to +15 degrees

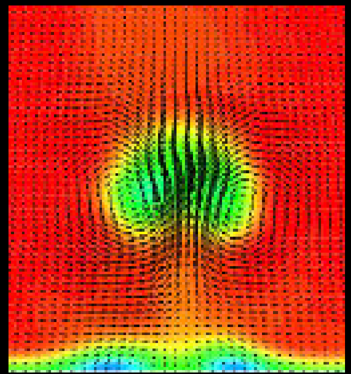


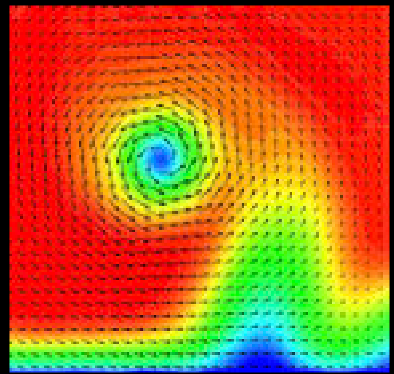
EXAMPLE APPLICATIONS:

- ▶ Static Force and Moment Measurement
- ▶ Aerodynamic Coefficients Database Generation
- ▶ Aero-Induced Pressure, Vibration, Resonance
- ▶ Turbulence Model Dataset Generation
- ▶ Jet/Plume Interaction Studies
- ▶ Aero-Optic Distortion and Beam Steering
- ▶ Computational Model Validation Experiments









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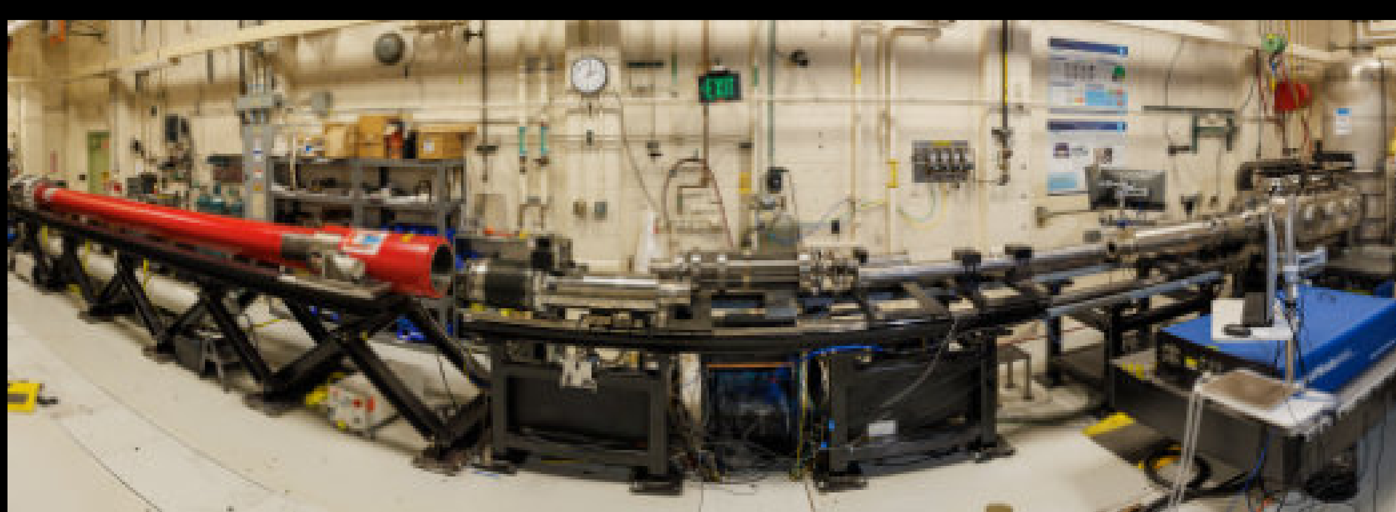
HYPERSONIC SHOCK TUNNEL



HYPERSONIC SHOCK TUNNEL

The Sandia National Laboratories Hypersonic Shock Tunnel replicates the true temperature and velocity of hypersonic flight by using shock heating. This enables generation of the realistic, extreme stagnation temperatures in excess of 8000 K. The facility uses a free-piston to compress and heat a driver gas, which bursts a diaphragm and generates a shock wave propagating through the test gas. The shock compresses and heats the test gas, which is then accelerated using a hypersonic nozzle into the test section. Due to the transient shock heating process, test durations are much shorter than traditional wind tunnels. However, due to the extreme flow velocity, the short duration still permits steady aerodynamic effects to be studied.

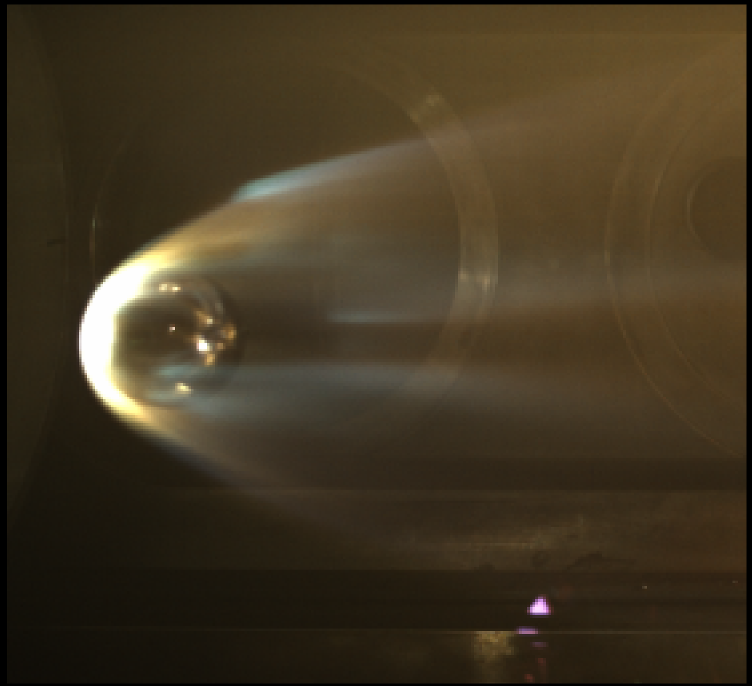
The facility is only the second free-piston shock tunnel in the nation, and the only residing in a secure facility. Additionally, HST can be run as a shock tube to produce high pressures simultaneous with high temperatures. It is available as a test resource for investigations by Sandia, Lawrence Livermore, and Los Alamos laboratories, as well as external customers.

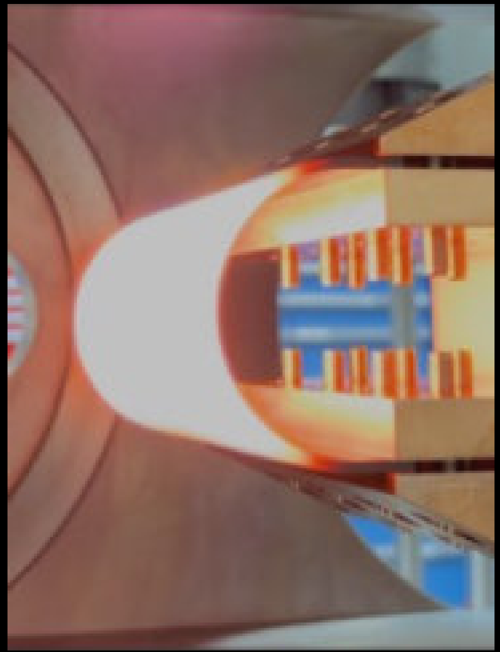
SPECIFICATIONS:

- ▶ Flight-Replicated Mach Numbers 7 through 14
- ▶ Reynolds Numbers up to 300,000 per meter
- ▶ Run Duration 1 millisecond, up to 5 runs per day
- ▶ Test Section Diameter 0.45 meters
- ▶ Stagnation temperatures up to 9000 Kelvin
- ▶ Model Pitch Range -17 to +17 degrees

EXAMPLE APPLICATIONS:

- ▶ Thermal Protection System Material Response
- ▶ High-Enthalpy Effects on Aerodynamics
- ▶ High-Enthalpy Aero-Induced Vibration
- ▶ Thermochemical Non-equilibrium Calibration
- ▶ Hypersonic Optical Signatures
- ▶ Free-Flight Dynamic Aerodynamic Coefficients
- ▶ Gas Optical Properties at Extreme Pressure and Temperature





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PLASMA TORCH

PLASMA TORCH

The Sandia National Laboratories Inductively Coupled Plasma Torch provides a long-duration, high-temperature environment for evaluation of material response and for research of air chemistry. The torch uses inductive coupling as the heating mechanism, as opposed to direct electrode heating. This eliminates contaminants which may interfere with chemical processes at material surfaces. The facility contains a rotating sample arm to switch between stream heat-flux calibration to material testing.

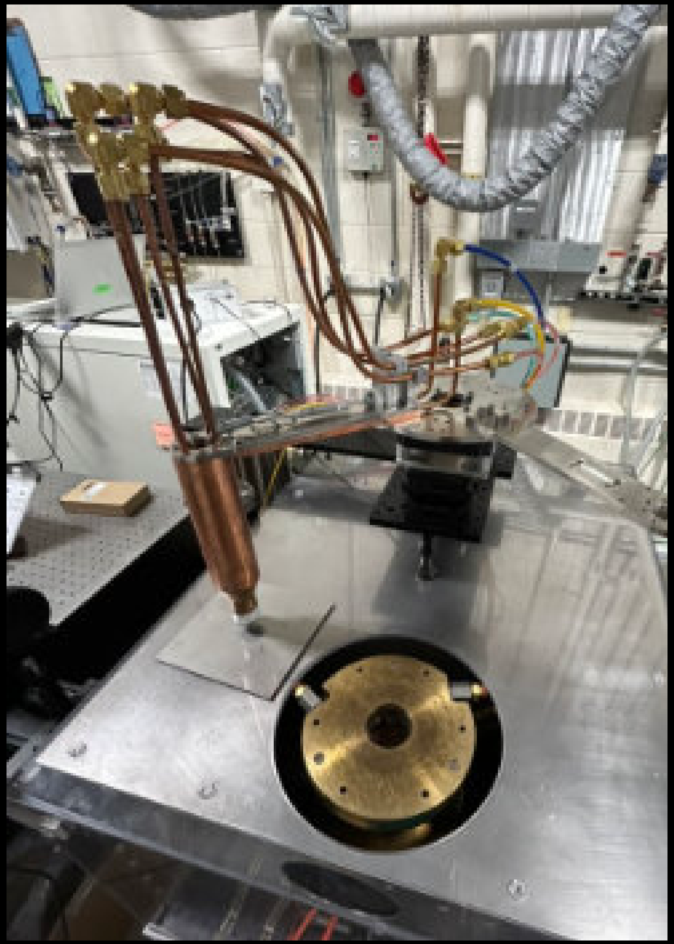
The facility is one of several inductive torches that exist in the nation, but resides in a secure facility and together with a variety of laser and optical diagnostic capabilities. This allows unique surface and gas-phase databases to be generated on flight materials. The plasma torch is available as a test resource for investigations by Sandia, Lawrence Livermore, and Los Alamos laboratories, as well as external customers.

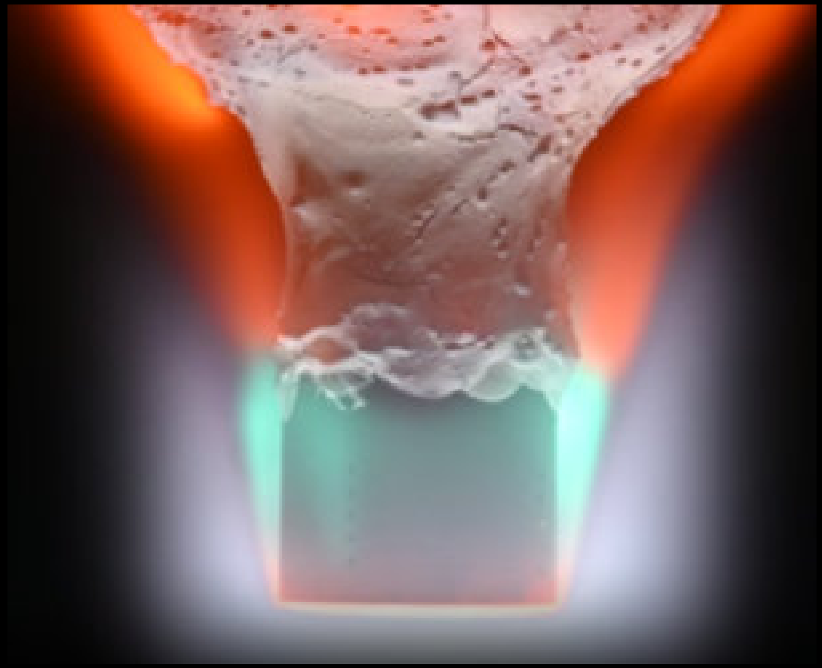
SPECIFICATIONS:

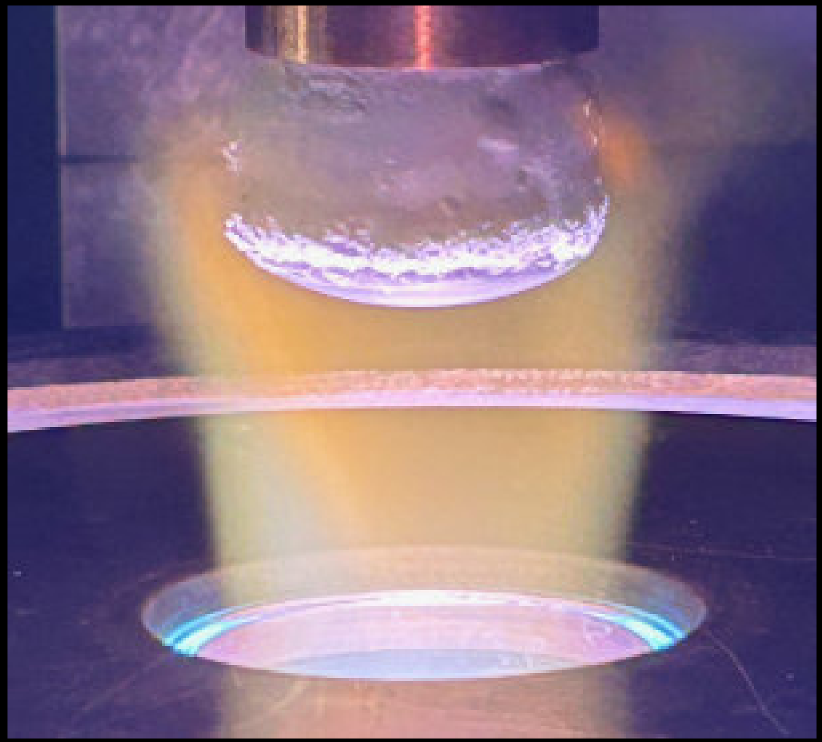
- ▶ Exit temperature up to 6000 Kelvin
- ▶ Stagnation heat flux up to 200 W/cm^2
- ▶ Exit diameter 4 cm
- ▶ Ambient pressure environment
- ▶ Run duration over one hour

EXAMPLE APPLICATIONS:

- ▶ Thermal Protection System Material Response
- ▶ Thermochemical Non-equilibrium Calibration
- ▶ Hypersonic Optical Signatures







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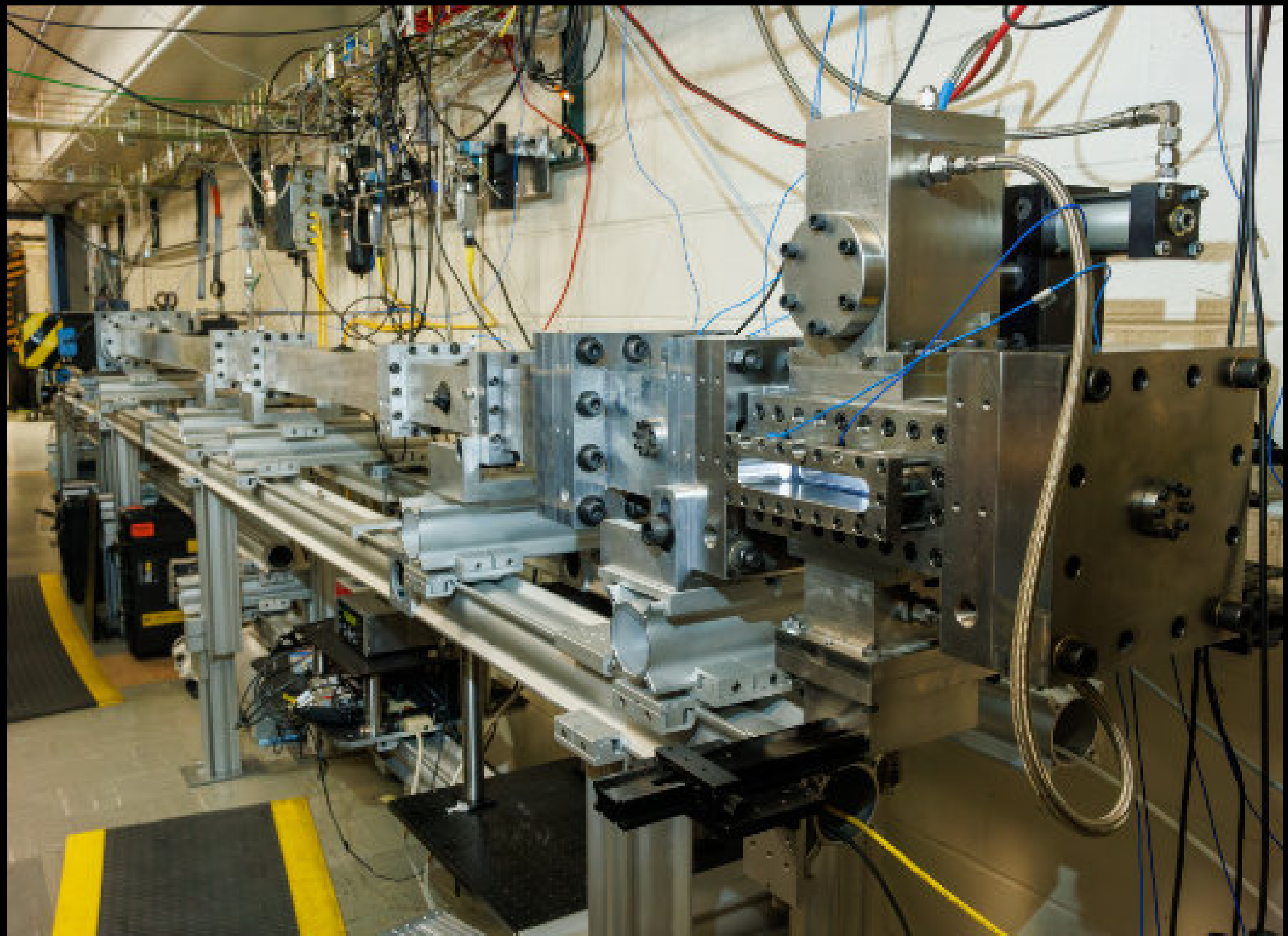
MULTIPHASE SHOCK TUBE



MULTIPHASE SHOCK TUBE

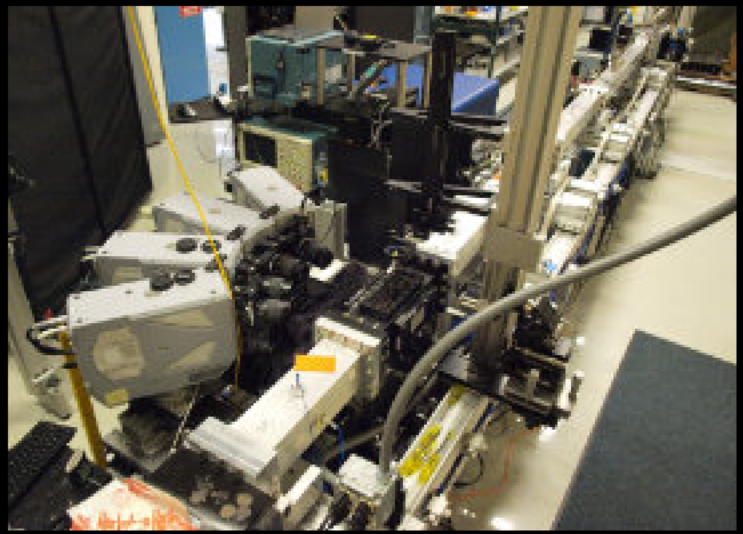
The Sandia National Laboratories Multiphase Shock Tube is a unique experimental facility able to subject dense particle 'curtains' or liquids to impulsive shock loading. The shock tube is divided into a high-pressure driver section and a low-pressure driven section, with a diaphragm between the two. The driver section is pressurized, rupturing a diaphragm, and producing a shock wave that propagates into the driven section where experiments occur. Spherical particles loaded into a hopper above the low-pressure section flow into the shock tube before the diaphragm breaks, creating a dense particle curtain that is hit by the shock wave.

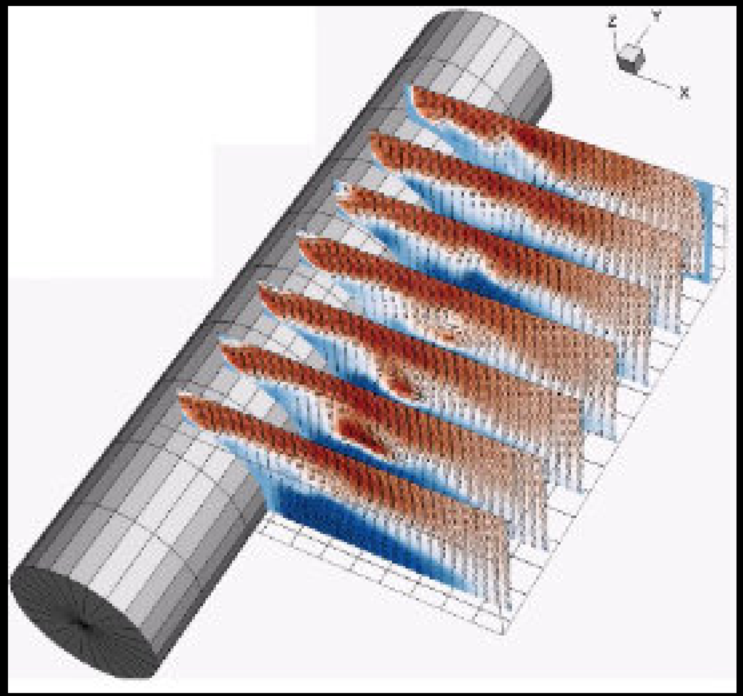
SPECIFICATIONS:

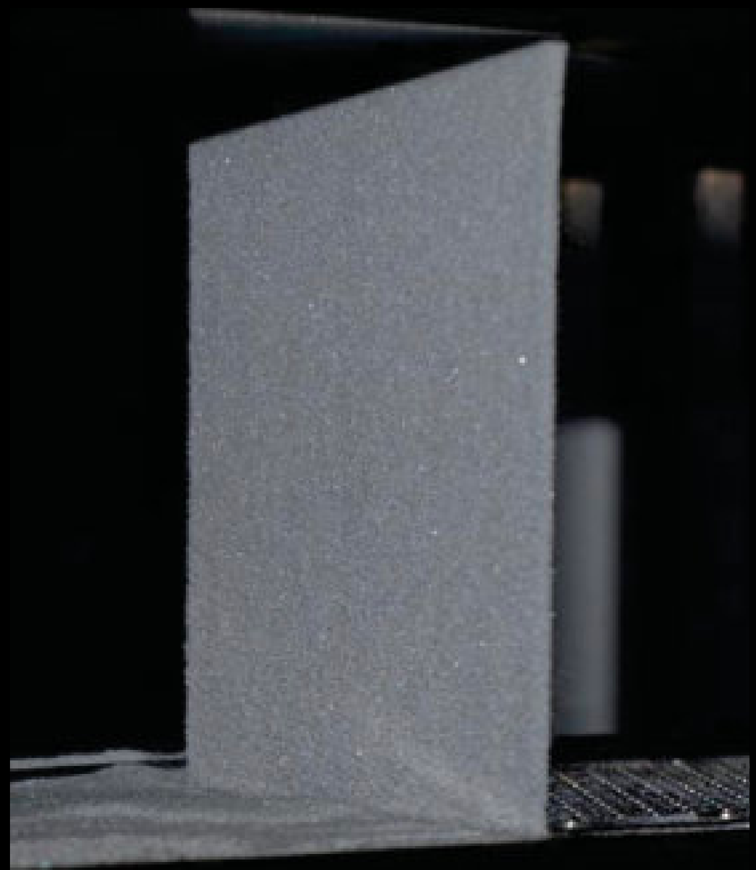
- ▶ Driver length 2 meters
- ▶ Shock Tube length 4 meters
- ▶ Shock Tube cross-section 10 × 10 cm
- ▶ Shock Mach numbers up to 2 in atmosphere and up to 5 in vacuum.

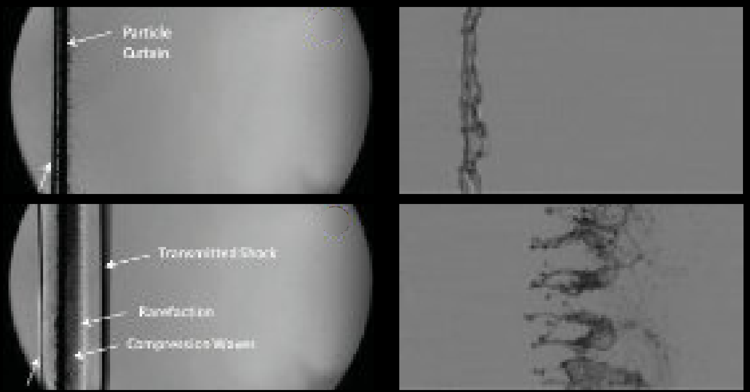
EXAMPLE APPLICATIONS:

- ▶ Particle and Liquid Shock Dispersion
- ▶ Impulsive Aerodynamics
- ▶ Blast-Structure Interaction
- ▶ Diagnostics Development









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HIGH ALTITUDE CHAMBER

HIGH ALTITUDE CHAMBER

The blowdown-to-vacuum operation of the Hypersonic Wind Tunnel requires a large volume and pumping capacity to sustain low vacuum levels during the test duration. Three spheres connected in series and a high-capacity vacuum pump facility provide this capability. In 1962, a need emerged for testing of flight components at vacuum and a hatch, floor, and centrifuge were installed into one of the vacuum spheres, creating a large high-altitude chamber facility. It is one of the largest vacuum chambers in the Department of Energy complex and is available as a test resource for investigations by Sandia, Lawrence Livermore, and Los Alamos laboratories, as well as external customers. It is certified for classified testing, light explosive operations, and has numerous feed-throughs to deploy diagnostics in the chamber.

SPECIFICATIONS:

- ▶ Sphere Diameter of 8.2 meters
- ▶ Chamber Hatch Diameter of 1.5 meters
- ▶ Maximum Altitude Replication 70 kilometers
- ▶ Maximum Vacuum Level 30 milliTorr
- ▶ Pump Down Time 30 minutes
- ▶ Secure Customer Acquisition Room

EXAMPLE APPLICATIONS:

- ▶ Radiative Heat Transfer Measurements
- ▶ Energetic Device Testing
- ▶ Small Rocket Motor Testing

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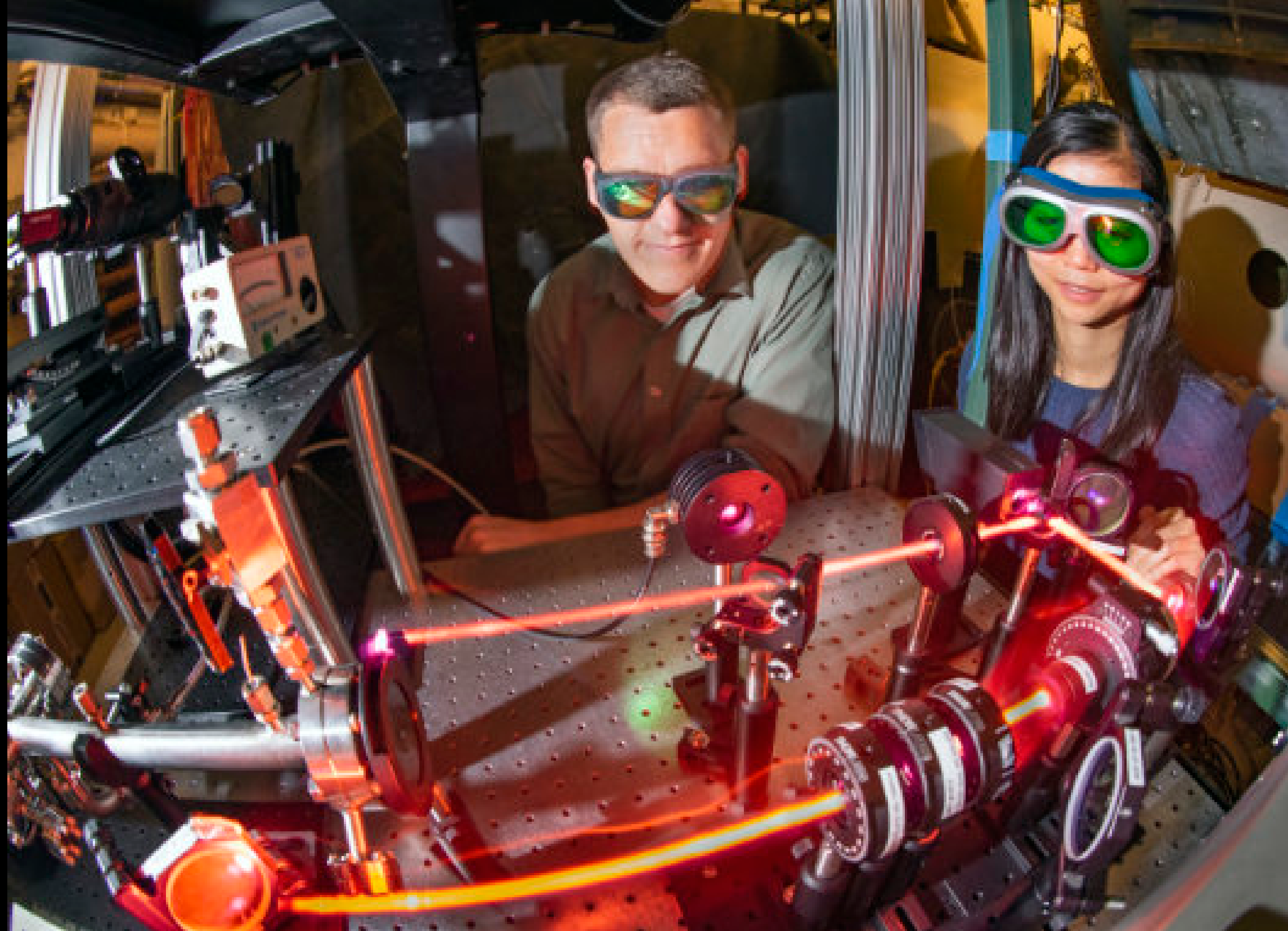
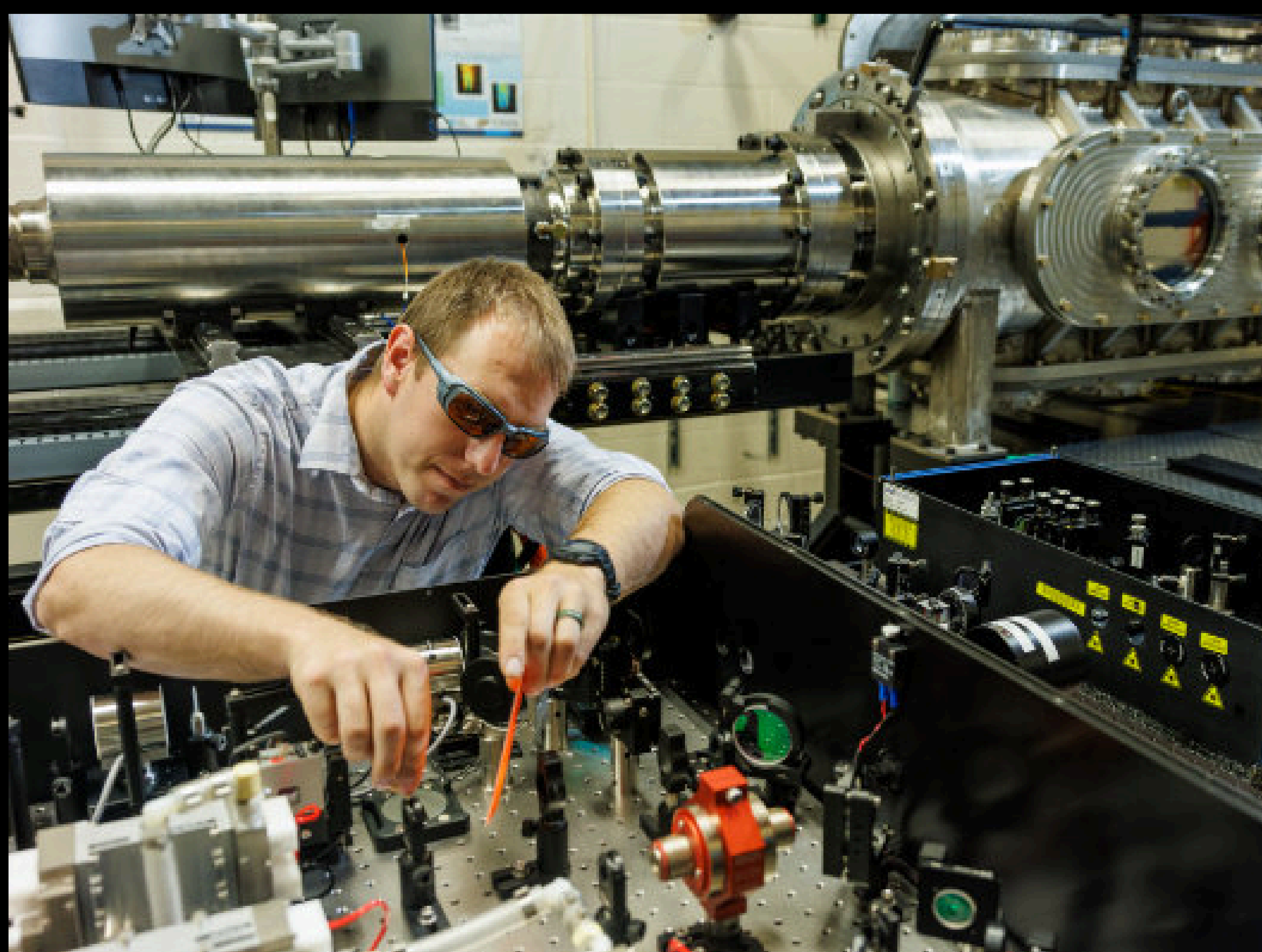
NONINTRUSIVE DIAGNOSTICS





NONINTRUSIVE DIAGNOSTICS

The extreme temperatures, pressures, and velocities experienced in many aerodynamic applications pose a unique challenge for measurement, requiring novel diagnostic technologies to achieve the required sensitivity and range. Additionally, nonintrusive techniques are required to ensure that the measurement itself does not modify flow behaviors. Sandia develops and applies several optical techniques for aerodynamic measurement and closely collaborates with multiple university and commercial partners to develop, mature, and transition novel measurement techniques to the broader community.

Surface measurement techniques are used to capture critical aerodynamic parameters such as surface heat-flux and shear, and to identify topological features such as flow separation and reattachment. A palette of gas measurement techniques capture the thermochemical state and velocity of gases using continuous, pulsed, and ultrafast lasers coupled to high-speed and intensified cameras and spectrometers.

SURFACE MEASUREMENT CAPABILITIES:

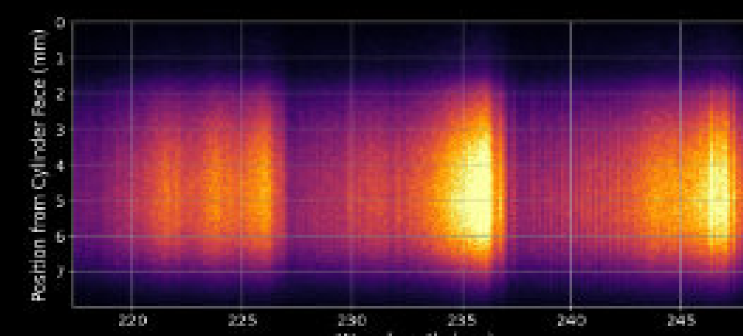
- Oil-Flow Visualization and Oil-Film Interferometry
- Pressure and Temperature Sensitive Paints
- High-speed Pressure, Shear, and Heat Flux Gages

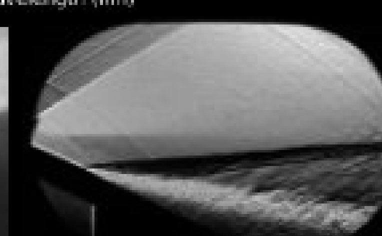
GAS MEASUREMENT CAPABILITIES:

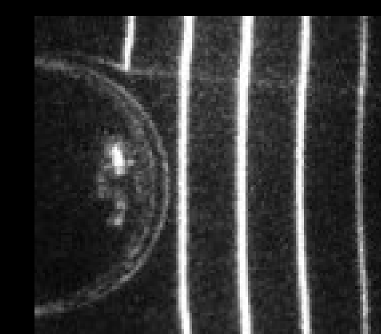
- Schlieren and Shadowgraph Imaging
- Particle Image Velocimetry
- Molecular Tagging Velocimetry (FLEET, NO MTV)
- Laser-Induced Fluorescence (tracer chemicals OH, NO, CO, Acetone, among others)
- Coherent Anti-Stokes Raman Scattering (N2, O2, H2, among others)
- Focused Laser Differential Interferometry
- Tunable Diode Laser Absorption Spectroscopy
- Optical Emission Spectroscopy
- Laser-Induced Breakdown Spectroscopy
- Digital In-Line Holography
- Filtered Rayleigh Scattering

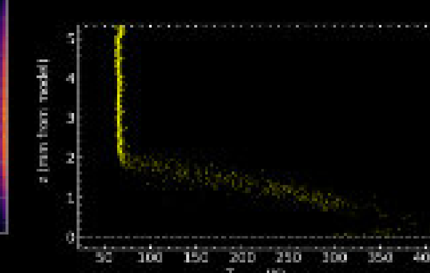
HARDWARE AVAILABILITY:

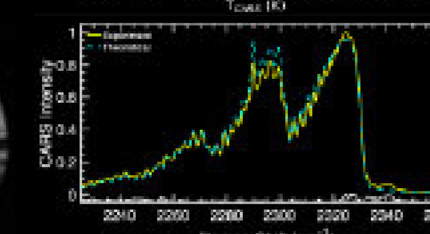
- Two high-power pulse-burst Nd:YAG laser sources for time-resolved applications
- Five pulsed Nd:YAG laser sources
- Two dye lasers for broad frequency tuning
- Custom-built optical parametric oscillators for frequency conversion
- Numerous quantum cascade and inter-band cascade laser diode sources
- Three femtosecond laser sources and associated wavelength conversion modules
- Two picosecond laser sources

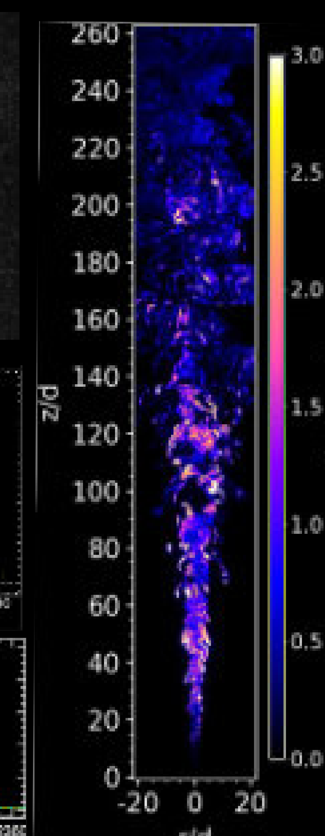












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FLIGHT INSTRUMENTATION

FLIGHT INSTRUMENTATION

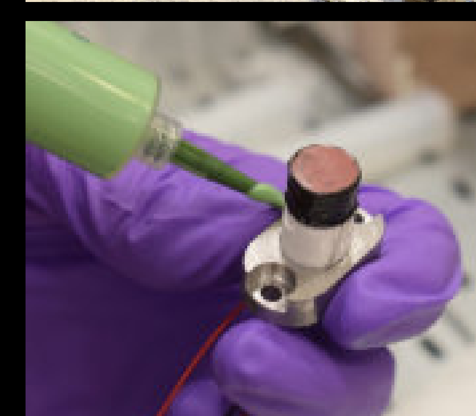
Sandia has conducted hundreds of flight tests in its history and continues to contribute to flight test programs for national security needs. Flight testing provides the ultimate validation of vehicle performance. Additionally, flight tests provide aerodynamic environments such as turbulence levels and thermochemistry that cannot be fully replicated in ground test facilities.

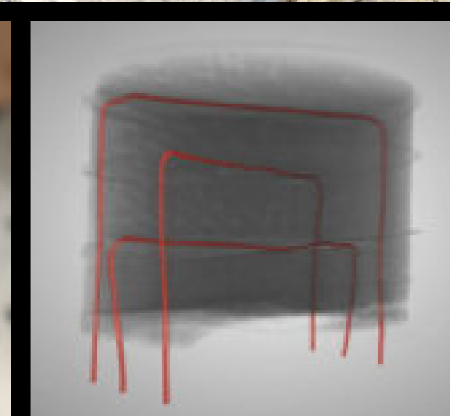
Compared to ground testing, instrumentation is more limited and challenging to implement. Sensors must be designed to handle vibrational loads of launch and reentry, while remaining sensitive enough to measure relevant aerodynamic parameters. Additionally, telemetry and physical installation requirements must be considered. Due to these unique requirements, Sandia serves as an integrator and development partner for commercial sensor vendors and develops custom measurement solutions when commercial options are unavailable.

Following flight tests, Sandia provides expertise in data analysis and interpretation. This includes data fusion between multiple measurements and comparison to pre- and post-test simulation predictions. The integrated experiment-simulation approach provides holistic insights into vehicle performance.

FIELDED MEASUREMENT CAPABILITIES

- High-Speed Pressure
- Surface Shear Stress
- Surface Heat Flux
- Surface and Material In-Depth Temperature
- Multi-Axis Acceleration
- Optical Radiometers
- Emission Spectroscopy
- Laser Absorption Spectroscopy
- Aeroshell Recession
- Custom Optical Instrumentation





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ENGINEERING SCIENCE EXPERIMENTAL FACILITY

ALBUQUERQUE, NEW MEXICO

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