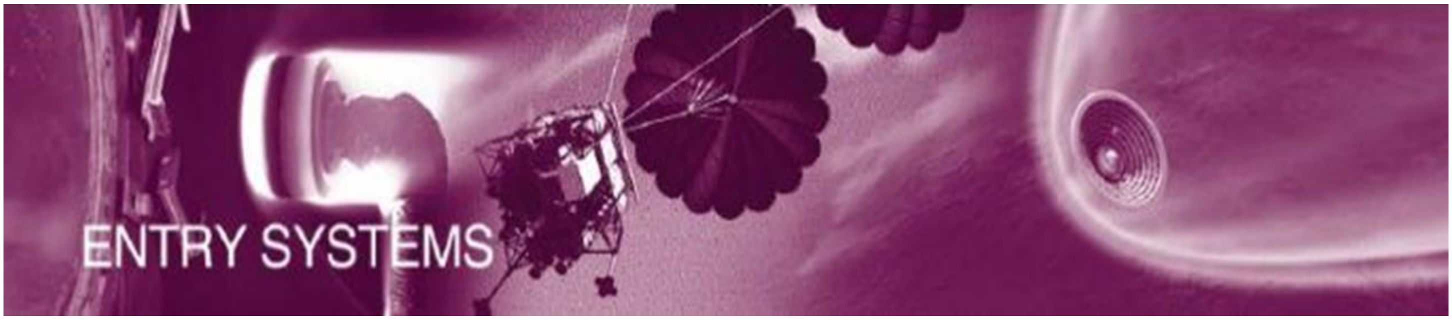


RANGE COMPLEX

NASA Ames has a long tradition in leadership with the use of ballistic ranges and shock tubes for the purpose of studying the physics and phenomena associated with hypervelocity flight. Cutting-edge areas of research run the gamut from aerodynamics, to impact physics, to flow-field structure and chemistry. This legacy of testing began in the NACA era of the 1940's with the Supersonic Free Flight Tunnel, and evolved dramatically up through the late 1950s with the pioneering work in the Ames Hypersonic Ballistic Range. The tradition continued in the mid-60s with the commissioning of the three newest facilities: the Ames Vertical Gun Range (AVGR) in 1964, the Hypervelocity Free Flight Facility (HFFF) in 1965 and the Electric Arc Shock Tube (EAST) in 1966. Today the Range Complex continues to provide unique and critical testing in support of the Nation's programs for planetary geology and geophysics; exobiology; solar system origins; earth atmospheric entry, planetary entry, and aerobraking vehicles; and various configurations for supersonic and hypersonic aircraft.

SUMMARY DESCRIPTION OF THE TEST COMPLEX

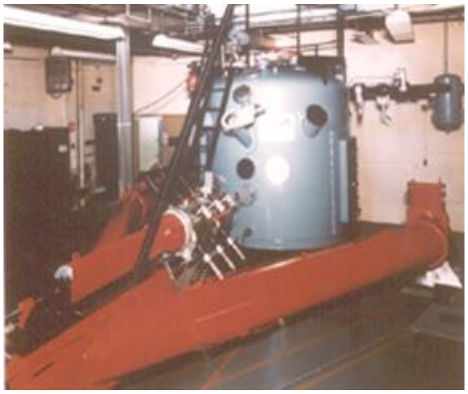
The Test Complex currently consists of three ranges: the Ames Vertical Gun Range (AVGR), the Hypervelocity Free Flight (HFF) Facilities and the Electric Arc Shock Tube (EAST).

The Ames Vertical Gun Range is used to simulate the physics and mechanics of planetary impact cratering and micrometeoroid impacts. The facility utilizes various model-launching guns that can achieve impact velocities approaching 7 km/sec. The angle of elevation of the gun with respect to the horizontal plane can be varied in 15-degree increments from 0 to 90 degrees, thus permitting oblique angles of impact with respect to the gravitational vector. Impact events can be recorded with a variety of high-speed imaging options.

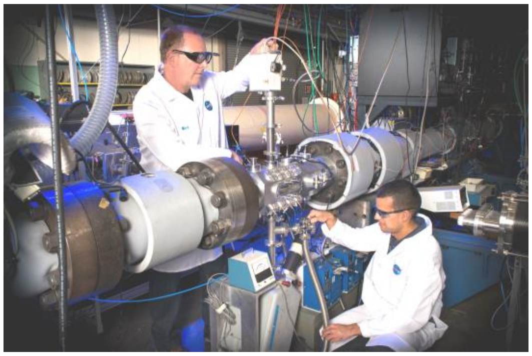
The Hypervelocity Free-Flight Aerodynamic Facility (HFFAF) is used to examine the aerodynamic characteristics of atmospheric entry and hypervelocity vehicle configurations, and to study flow field structure and gas dynamic phenomena. The Hypervelocity Free-Flight Gun Development Facility (HFFGDF) is used to expand light-gas gun operational capabilities, and to perform hypervelocity impact testing experiments. Both facilities support three of NASA's Mission Directorates: Aeronautics, Exploration and Science. The HFFAF is the Agency's only aeroballistic capability, and can provide critical aerodynamic parameters such as lift, drag, static and dynamic stability, flow characteristics, and pitching moment coefficients for velocities ranging from 0.5 to 8.0 km/s. The HFFAF is the only ballistic range in the nation that is capable of testing in atmospheres other than air. In addition the HFFAF has high-speed thermal imaging capabilities, which can be used to measure global surface temperature distributions and hence determine aerothermodynamic characteristics. Much of the research effort to date has centered on Earth atmosphere entry configurations (Mercury, Gemini, Apollo, and Shuttle), planetary entry (Viking, Pioneer-Venus, Galileo, and Mars Science Lab), supersonic and hypersonic flight (X-15), aerobraking (AFE) configurations, and scramjet propulsion studies (NASP). Both facilities have been used for meteoroid/orbital debris studies (ISS, and RLV).

The Electric Arc Shock Tube (EAST) Facility is used to investigate the effects of radiation and ionization that occur during very high velocity atmospheric entries. The EAST can also provide air-blast simulations requiring the strongest possible shock generation in air at initial pressure loadings of 1 atm or greater. The facility has three separate driver configurations. Depending on test requirements, the driver can be connected to a diaphragm station of either a 4-in or a 24-in shock tube. The high-pressure 4-in shock tube can also drive a 30-in shock tunnel. Energy for the drivers is supplied by a 1.25-MJ-capacitor storage system.

The Ames Range Complex provides the Nation with the capability to conduct low-cost "flight tests" in ground-based facilities.



Ames Vertical Gun Range
Impact & Cratering



Electric Arc Shock Tube
Outer Planetary Entry
&
Radiation / Ionization Study

Hypervelocity Free-Flight Facility

AMES VERTICAL GUN RANGE (AVGR)

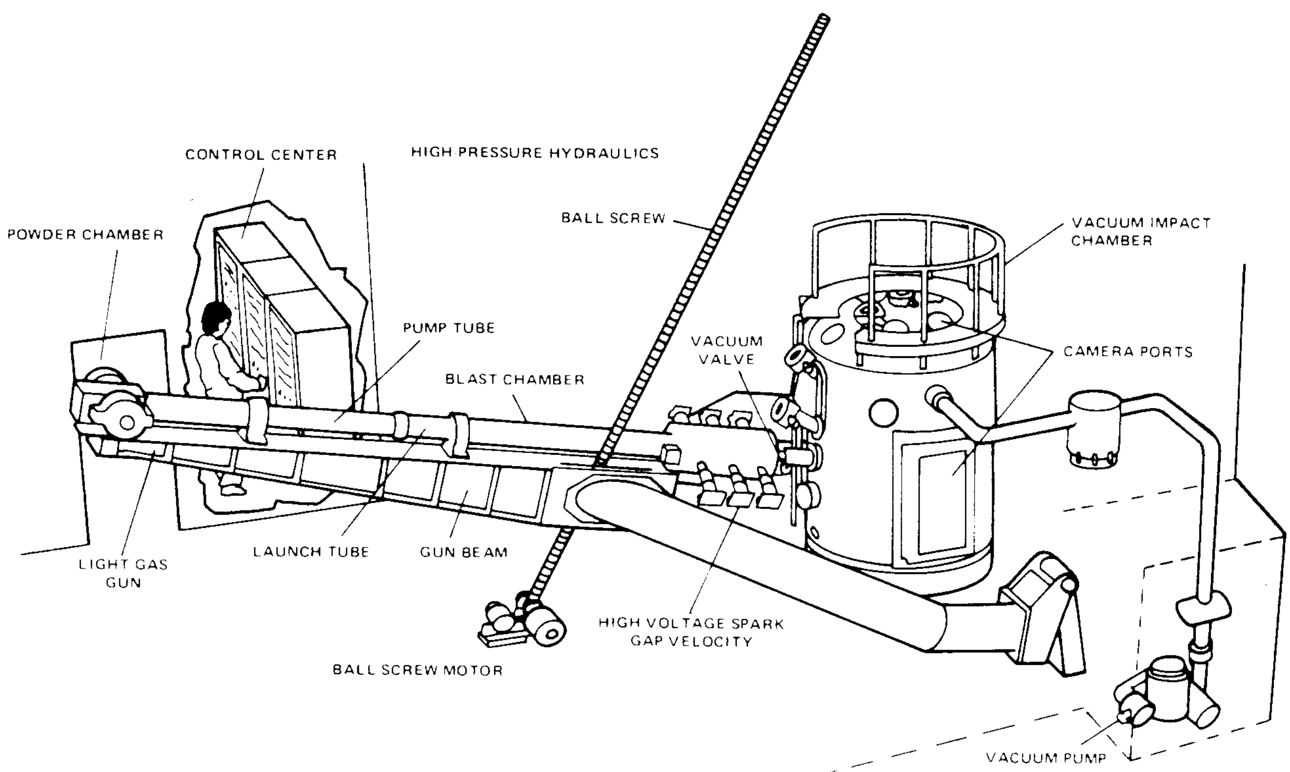
The Ames Vertical Gun Range (AVGR) is a unique NASA facility that is typically used to simulate high-speed, celestial body impacts on a small scale. Data obtained from such studies can be used to establish a clearer understanding of the physics and phenomena associated with crater formation processes; projectile (impactor) failure modes and mechanisms; and, debris dispersion and characterization. The AVGR utilizes a family of model-launching guns to accelerate particles of various sizes, shapes (sphere, cylinder, irregular shapes), and material composition (metallic, plastic, glass, mineral) to velocities approaching 7 km/sec. The angle of elevation of the gun with respect to the horizontal plane can be varied in 15° increments from 0° to 90°, thus permitting oblique angles of impact with respect to the gravitational vector. A large impact chamber of 2.5 m diameter by 2.5 m high can accommodate sizable targets of varying composition (solid, liquid, aggregate, etc.) and allow for testing at sub-atmospheric pressures and in gases other than air. Primary instrumentation consists of a diverse suite of state-of-the-art, high-speed imaging systems that can record the impact event and cratering processes with tremendous detail. In addition, spectroscopy, Particle Induced Velocimetry (PIV), and other forms of instrumentation can be accommodated through special arrangement. The AVGR first began operations in 1966 in support of the Apollo program as a means to better understand lunar surface geomorphology. More than four decades later, this modest (6000 ft^2) facility continues to provide invaluable data for NASA's Planetary Geology and Geophysics program. During its illustrious history, the AVGR has supported NASA's Exobiology and Solar System Origins programs, and provided critical enabling data for such missions as Cassini, Stardust, Mars Odyssey, Mars Exploration Rovers (MER), Deep Impact and Lunar Crater Observation and Sensing Satellite (LCROSS).

The types of projectiles that can be launched include spheres, cylinders, irregular shapes, and clusters of many small particles. The projectiles can be metallic (i.e. aluminum, copper, iron), mineral (i.e. quartz, basalt), or glass (i.e. pyrex, soda-lime). For example, soda-lime spheres can be launched individually for sizes ranging from 1.5 to 6.4mm (1/16 to 1/4 inch) in diameter; in groups of three for sizes ranging from 0.2 to 1.2mm; or as a cluster of many particles for sizes ranging from 2 to 200-µm.

For both guns, projectiles are typically encased in a sabot (a plastic carrier) to align, support and protect them during their passage through the gun barrel (launch tube). Since the launch tube is rifled, the launch package [sabot and projectile(s)] exits the barrel with both an axial and angular velocity. The resulting centrifugal force separates the sabot from the projectile(s) leaving the projectile(s) in free flight. The projectile(s) pass through a velocity chamber and then into the target vacuum chamber. The velocity chamber uses a set of photomultiplier tubes, light sheets, cameras and counters to detect and record projectile passage (and ultimately determine velocity). At the entrance to the target chamber there is a valve-like device, which deflects the trailing gun gases after projectile passage. The result is a very clean target impact with minimal propellant debris. The target chamber is roughly 2.5 meters in diameter and height and can accommodate a wide variety of targets/mounting fixtures. The chamber can maintain vacuum levels below 0.03 torr, or can be back filled various gases to simulate different planetary atmospheres. Impact events are typically recorded using high-speed video or film.

AVGR PERFORMANCE SUMMARY

PARAMETER	TYPE	MIN	MAX	UNIT OF MEASURE
LIGHT-GAS GUN BORE	Discrete	0.22	0.62	inches
POWDER GUNS BORE	Discrete	0.30	0.30	inches
PROJECTILE VELOCITY	Range	0.5	7.0	km/s
PROJECTILE SIZE	Range	0.005	7.6	millimeters
PRESSURES	Range	0.04	760	torr

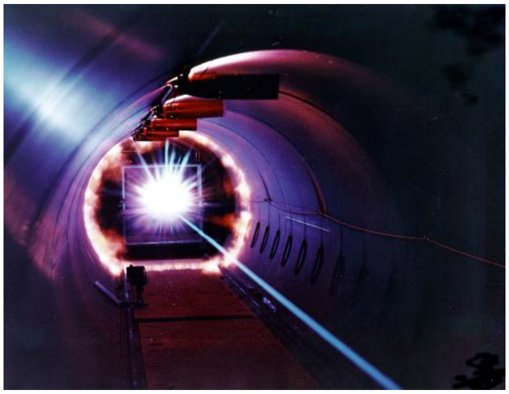


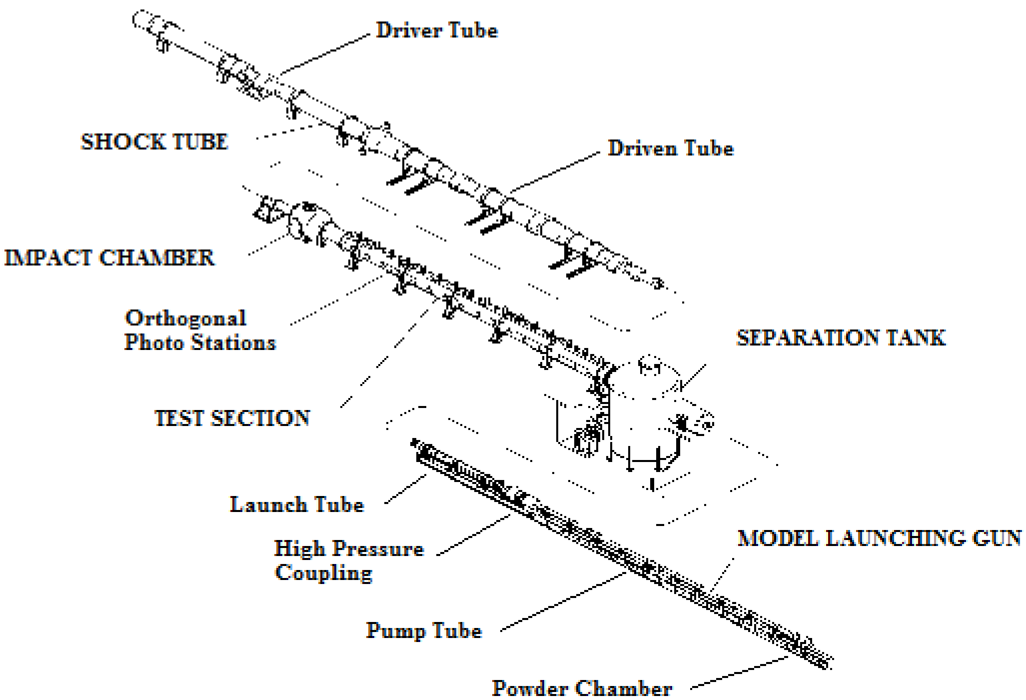
HYPERVELOCITY FREE-FLIGHT FACILITIES

The Hypervelocity Free-Flight (HFF) Range at Ames Research Center (ARC) currently comprises two active facilities: The Aerodynamic Facility (HFFAF) and the Gun Development Facility (HFFGDF). Both facilities were constructed in 1964 and are located in Building N-237.

HYPERVELOCITY FREE-FLIGHT AERODYNAMIC FACILITY

The Hypervelocity Free-Flight Aerodynamic Facility (HFFAF) is one of two functioning facilities located within the HFFF complex at Ames Research Center, and was NASA's only Aeroballistic Range and large scale Combustion Driven Shock Tunnel. The HFFAF is unique in its ability to test in gases other than air and sub-atmospheric pressures. Originally constructed in 1964, the HFFAF consists of: a model launching gun; a sabot separation tank/vacuum chamber; a 75-foot long by 3.5 foot diameter test section with sixteen, orthogonal, shadowgraph imaging stations; a 4'x4'x6' test cabin/impact chamber; and the largest combustion driven shock tube in the United States (no longer in operation). This multifaceted facility can be configured to perform Aeroballistic/Aerothermodynamic testing; Shock Tunnel testing; Aeroballistic testing; and Hypervelocity Impact testing. For standard Aeroballistic testing 2-stage light-gas guns, power guns or air guns can be used to launch free-flight models of various shapes and sizes into the test section. During the model's flight, the spatial and time history is recorded via shadowgraph imagery and interval timers. This information is then used to reconstruct the model's trajectory and ascertain the various aerodynamic parameters (such as lift, drag, pitching moment coefficients, dynamic stability criterion, etc.). For Aerothermodynamic testing thermal imaging cameras (both Visible ICCD and IR) are used to observe model surface temperature distributions at different points along the flight path in order to infer heat transfer rates and transition to turbulence locations. In addition, spectrographs can be used to study model ablation behavior, and to examine flow-field characteristics (such as spectral emission details of shock layers and wakes). When operated as a shock tunnel, large-scale models (such as a scramjet engine) are mounted in the test cabin, and the shock tube is used to generate a hypervelocity flow over and/or through the model. Pressure, temperature, heat flux, and skin friction sensor data can be recorded using a multi-channel high-speed digital data acquisition system. Laser holographic interferometry and other optical diagnostic tools are also available for this operational mode. Lastly, when operated as a hypervelocity impact facility, a light-gas gun can be used to launch impact particles (typically spheres) into targets of various configurations and angles of incidence. The results of the impact events can be recorded using a suite of high-speed video camera systems. Interestingly, nearly every US spacecraft that has entered an atmosphere, both manned (i.e. Mercury, Gemini, Apollo, Shuttle) and unmanned (i.e. Pioneer Venus, Viking, Galileo, MER, MSL), plus the International Space Station has had some form of supportive testing performed in the ballistic range complex. More recent programs/customers include: Crew Exploration Vehicle (CEV/Orion), Supersonic Inflatable Aerodynamic Decelerator (SIAD/LDSD), Fundamental Aerodynamics Program (FAP), SpaceX (Dragon), and Blue Origin (New Shepard).





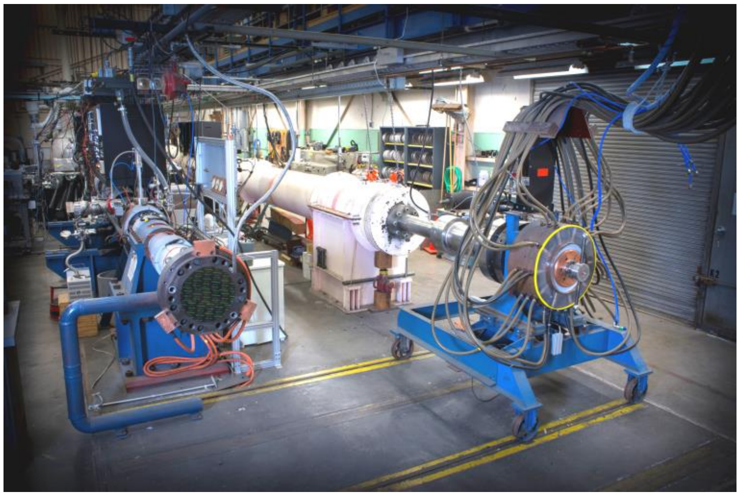
HYPERVELOCITY FREE-FLIGHT GUN DEVELOPMENT FACILITY

The HFF Gun Development Facility consists of: a light-gas gun; a sabot separation tank; a flight tube; and an impact chamber. This facility is used primarily for gun performance enhancement studies. In particular, operational parameters and hardware configurations are adjusted and/or modified in an effort to increase maximum velocity (and/or launch mass capabilities), while maintaining acceptable levels of gun barrel erosion. The facility operates in a manner similar to the HFFAF with the primary difference being a shorter flight path, 38ft (11.6m) as compared to 114ft (34.7m). The HFFGDF utilizes the same arsenal of light-gas guns to accelerate particles ranging in size from 1/8 inch (3.2mm) diameter to 1 inch (25.4mm) diameter to hypervelocity speeds. Particle velocity is measured using several, photomultiplier-tube-based time of arrival stations. Several of the outputs can be used to trigger flash x-ray channels.

HFF PERFORMANCE SUMMARY

Parameter		Min	Max	Unit of Measure
Light-gas gun bore	Discrete	0.28	1.5	inches
Powder guns bore	Discrete	20	61	millimeters
Velocity	Range	700	26000	feet/sec
Model mass	Range	5	200	grams
Pressures	Range	0.03	760	torr
Reynolds Number	Range	100	5 million	per foot

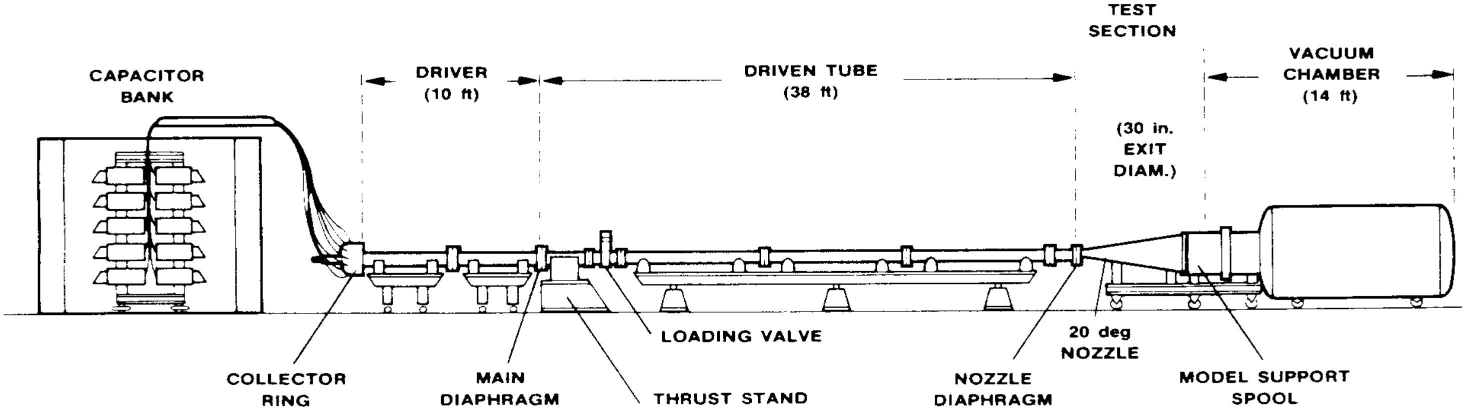
ELECTIC ARC SHOCK TUNNEL (EAST)



The Electric Arc Shock Tube Facility is used to investigate the effects of radiation and ionization that occur during very high velocity atmospheric entries. The EAST can also provide air-blast simulations requiring the strongest possible shock generation in air at an initial pressure loading of 1 atmosphere or greater. The facility has three separate driver configurations. Depending on test requirements, the driver can be connected to a diaphragm station of either a 4-in or a 24-in. shock tube. The high-pressure 4-in shock tube can also drive a 30-in shock tunnel. Energy for the drivers is supplied by a 1.25-Mj-capacitor storage system. It can be charged to a preset energy at either a 0- to 40-kV mode (1530 µF) or a 0- to 20-kV mode (6120 µF). Voltage, capacitance and arc-driver components are selected to meet, as effectively as possible, the test objectives of a given program.

EAST PERFORMANCE SUMMARY

Shock Speed: 4-in Shock Tube	1 Torr hydrogen: 46 km/s
	1 Torr air: 20 km/s
Shock Speed: 24-in Shock Tube	1 Torr air: 5 km/s



THERMOPHYSICS FACILITIES BRANCH: SAFETY, ACCURACY, PROFESSIONALISM

The Ames Research Center Thermophysics Facilities Branch forges fruitful partnerships with organizations that need to completely, accurately and efficiently test concepts that use innovative materials and/or new design ideas.

We provide a variety of hyperthermal and hypervelocity environments from simulations of the heating of ascent and entry (Earth or other planetary atmospheres) to hypersonic flight regimes. Our goal: seamless integration of your material or flow characterization, model design, pretest planning, testing, and final report.

The Ames Thermophysics Facilities have a remarkable, comprehensive suite of highly adaptable world-class test hardware. When combined with our senior staff's extensive expertise and the wide range of test experiences, we offer a unique set of testing possibilities.

Full details can be found in the Test Planning Guide, available upon request by contacting:

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