

# NASA AMES ARC JETS AND RANGE, CAPABILITIES FOR PLANETARY ENTRY

**Ernest F. Fretter**

*Thermophysics Facilities Branch, NASA Ames Research Center, MS 229-4, Moffett Field, CA 94035, e-mail: Ernest.F.Fretter@nasa.gov*

## **ABSTRACT**

NASA is pursuing innovative technologies and concepts as part of America's Vision for Space Exploration. The rapidly emerging field of nanotechnology has led to new concepts for multipurpose shields to prevent catastrophic loss of vehicles and crew against the triple threats of aeroheating during atmospheric entry, radiation (Solar and galactic cosmic rays) and Micrometeoroid/Orbital Debris (MMOD) strikes. One proposed concept is the Thermal Radiation Impact Protection System (TRIPS) using carbon nanotubes, hydrogenated carbon nanotubes, and ceramic coatings as a multi-use TPS. The Thermophysics Facilities Branch of the Space Technology Division at NASA Ames Research Center provides testing services for the development and validation of the present and future concepts being developed by NASA and national and International research firms. The Branch operates two key facilities - the Range Complex and the Arc Jets. The Ranges include both the Ames Vertical Gun Range (AVGR) and the Hypervelocity Free Flight (HFF) gas guns best suited for MMOD investigations. Test coupons can be installed in the AVGR or HFF and subjected to particle impacts from glass or metal particles from micron to 1/8 inch (6.35-mm) diameters and at velocities from 5 to 8 km/s. The facility can record high-speed data on film and provide damage assessment for analysis by the Principle Investigator or Ames personnel. Damaged articles can be installed in the Arc Jet facility for further testing to quantify the effects of damage on the heat shield's performance upon entry into atmospheric environments.

## **1.0 ARC JET COMPLEX**

### **1.1 Mission**

We provide ground-based high-enthalpy flow environments in support of experimental research and development activities in thermal protection materials, aerothermodynamics, vehicle structures, and hypersonics.

### **1.2 Heritage**

The Ames Arc Jet Complex has a rich heritage of over 40 years in TPS development for every NASA Space Transportation and Planetary program, including Apollo, Space Shuttle, Viking, Pioneer-Venus, Galileo, Mars Pathfinder, Stardust, X-33, X-34, SHARP-B1 and B2, X-37 and MER-A and B. With this early TPS history came a long heritage in the development of arc jets. These facilities are used to simulate the exit and entry heating that occurs for locations on the body where the flow is brought to rest (stagnation point or nose cap, wing leading edges and on other TPS areas of the space craft). Exposures have been run from a few minutes to over an hour, from one exposure to multiple exposures of the same sample, in order to understand the TPS materials' response to a hot gas flow environment representative of real hyperthermal environments.

The Ames Arc Jet Complex is a key enabler of the three major areas of interest to TPS development: selection, validation, and qualification.

### **1.3 Facilities**

The Ames Arc Jet Complex has seven available test bays located in two separate laboratory buildings. At the present time, four bays contain Arc Jet units of differing configurations that are serviced by common facility support equipment. This support equipment includes two D.C. power supplies, a steam ejector driven vacuum system, a water-cooling system, high-pressure gas systems, data acquisition system, and other auxiliary systems. The magnitude and capacity of these systems is the primary reason why the Ames Arc Jet Complex is unique in the aerospace testing world. The largest power supply can deliver 75 MW for a 30 minute duration or 150 MW for a 15 second duration. This power capacity, in combination with a high-volume 5-stage steam ejector vacuum system, enable facility operations that can match high-altitude atmospheric flight on relatively large size test objects. The arc heaters themselves are of either the Ames designed segmented constricted type or the Hül's design. When combined with a variety of nozzles of both conical and semielliptical cross sections, the resulting

facility capabilities offer wide versatility for testing both large flat-surface test objects as well as stagnation flow models that are fully immersed in the test stream.

### 1.3.1 Aerodynamic Heating Facility (AHF)

The AHF can operate with either a 20-MW constricted arc heater or a Hüls arc heater. The constricted heater operates at pressures from 1 to 9 atm and enthalpy levels from 11 to 33 MJ/kg while the Hüls heater operates at pressure from 1 to 40 atm and enthalpies from 3.5 to 9.5 MJ/kg. Either heater can be coupled with a family of conical nozzles with exit diameters ranging from 76 to 914 mm. A large add-air mixing plenum allows for very low enthalpies for ascent heating simulations. A five-arm fully programmable model insertion system provides exposures of up to five test samples during a single run. Table 1 summarizes testing features for the constricted heater.

- Air or Nitrogen gases
- 20-MW Ames-designed constrictor arc heater or 12 MW Hüls arc heater.
- Nozzles from 3 to 36" exit diameter (76 to 914 mm)
- Samples sizes up to 8" diameter (203mm) or 26 x 26" (660 by 660 mm) wedge configuration
- Pressures from 0.005 to .125 atm (with Hüls heater in excess of 5 atm)
- Heat fluxes from less than 1 on a wedge to over 300 W/cm<sup>2</sup> on a 4" dia hemisphere
- 5-arm fully programmable model insertion system

### 1.3.2 Interaction Heating Facility (IHF)

The IHF is equipped with a 60-MW constricted heater that operates at pressures from 1 to 9 atm and enthalpy levels from 7 to 47 MJ/kg (3000 to 20000 Btu/lb). The facility is designed to operate with interchangeable conical nozzles with exit diameters ranging from 152 mm (6") to 1 m (41"). When the heater is coupled with the semielliptical nozzle, the test stream is suitable for testing flat panels of up to 610 x 610mm (24" by 24") in simulated hypersonic boundary layer flow environments.

Testing features include:

- 60-MW Ames-designed constrictor arc heater
- Nozzle exit sizes from 152mm to > 1m (6" to 41")
- Stagnation, free jet wedge, or flat panel with semielliptic nozzle

- Stagnation pressures from 0.01 to over 1 atm
- Heat fluxes from 5 to >6000 kW/m<sup>2</sup>
- Enthalpies from 7 to 47 MJ/kg (3000 to 20,000 Btu/lb)
- Power supply capable of delivering 75 MW for 30 minutes or 150 MW for a 15 second duration

### 1.3.3 Panel Test Facility (PTF)

The PTF facility operates with a 20-MW constricted heater that is coupled with a semielliptical nozzle. The heater operates at pressures from 1 to 9 atm and enthalpy levels from 7 to 35 MJ/kg (3000 to 15000 Btu/lb). The test stream generated is suitable for the simulation of boundary layer heating environments on flat panel samples of approximately 355 by 355mm (14" by 14"). However, it is possible to test sample sizes of 406 by 406mm (16" by 16").

The testing features include:

- 20-MW Ames-designed constrictor arc heater
- Semielliptic nozzle
- Test samples up to 355 by 355 mm (14" by 14")
- -4 deg to +8 deg inclinations of the surface of the test sample
- Run durations up to 30 minutes possible
- Cold wall (fully catalytic) heat flux from 6 to 340 kW/m<sup>2</sup> (0.5 to 30 Btu/ft<sup>2</sup>s)
- Surface pressures from 66 to 4700 Pa (.0006 to .05 atm)

### 1.3.4 Turbulent Flow Duct (2x9)

Turbulent Flow Duct (2x9) is a supersonic duct used to study highly active, turbulent, two-dimensional fluid flows over a flat surface. The duct is rectangular and can accommodate models 203mm wide by up to 508mm (8" to 20") of any desired depth. The duct operates at surface pressures from 0.02 to 0.15 atm and of shear stresses from 5 to 70 kg/m<sup>2</sup>. A Hüls arc heater operating at enthalpy levels from 3 to 9 MJ/kg produces the flow.

Testing features include:

- Air or nitrogen gases
- Linde (Hüls) free-length arc heater (12-MW)

- Test samples of 203mm high by 508mm long (8" by 20")
- Surface pressures from 0.02 to 0.15 atm
- Cold wall heat fluxes from 20 to 700 kW/m<sup>2</sup> (2 to 60 Btu/ft<sup>2</sup>-s)
- Enthalpy range from 3 to 9 MJ/kg (1300 to 4000 Btu/lb)

### 1.3.5 Developmental Arc Jet Facility (DAF)

The Development Arcjet Facility, (DAF), at the NASA Ames Arc Jet Complex is designed for the following potential uses (1) high life-cycle testing of TPS for 2<sup>nd</sup> and 3<sup>rd</sup> generation RLV, (reusable launch vehicles) (hours in duration); (2) TPS materials testing in simulated high enthalpy Earth atmospheric entry environments (40 to 100 MJ/kg); (3) quick-turnaround thermal protection materials tests in all planetary atmospheric gases, (e.g. carbon dioxide, hydrogen-helium, nitrogen/methane, and argon); (4) test bed for new arc jet diagnostic instrumentation; and (5) chemical vapor deposition (CVD) and nano-technology materials experiments (e.g. diamond film, carbon nanotube production).

An existing one-inch diameter segmented arc heater serves as the DAF plasma generator. The test cell is supported by existing systems including dc power supply, high pressure cooling water, gas delivery, and vacuum pumping. The unique features of this facility are its small scale, ease of use, low cost, and low power requirement compared with the rest of the Arc Jet Complex

#### Capabilities

- Multiple gases or gas mixtures (N<sub>2</sub>, O<sub>2</sub>, Air, CO<sub>2</sub>, Ar, H<sub>2</sub>, He, CH<sub>4</sub>) for simulations of a wide range of planetary entry profiles
- 3-MW Aerotherm™ segmented arc heater
- Stagnation or free wedge configurations
- Multiple model insertion system, up to 10 positions available

## 2.0 RANGE COMPLEX

### 2.1 Range Heritage

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. The Range Complex has provided critical testing in support of many of NASA's Space Transportation and Planetary Programs including Mercury, Gemini, Apollo, Shuttle, Viking, Pioneer

Venus, Galileo, Cassini, Stardust, Mars Odyssey, Mars Exploration Rovers, Mars Science Laboratory, International Space Station, National Aerospace Plane and X-37.

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. Today it continues to provide unique, critical and mission enabling 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 vehicle configurations for supersonic and hypersonic flight.

### 2.2 Overview

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).

#### 2.2.1 Vertical Gun Range

The Ames Vertical Gun Range (AVGR) was designed to conduct scientific studies of lunar impact processes in support of the Apollo missions. In 1979, it was established as a National Facility, funded through the Planetary Geology and Geophysics Program. In 1995, increased science needs across various discipline boundaries resulted in joint core funding by three different science programs at NASA Headquarters (Planetary Geology and Geophysics, Exobiology, and Solar System Origins). In addition, the AVGR provides programmatic support for various proposed and ongoing planetary missions (i.e. Stardust, Deep Impact).

Utilizing its 0.30 cal light-gas gun and powder gun, the AVGR can launch projectiles to velocities ranging from 0.5 to nearly 7 km/sec. By varying the gun's angle of elevation with respect to the target vacuum chamber, impact angles from 0° to 90° with respect to the gravitational vector are possible. This unique feature is extremely important when examining crater formation processes.

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.

The target chamber is roughly 2.5 meters in diameter and height and can accommodate a wide variety of targets and mounting fixtures. The chamber can maintain vacuum levels below 0.03 torr, or can be back filled with various gases to simulate different planetary atmospheres. Impact events are typically recorded using high-speed video or film.

### **2.2.2 Hypervelocity Free-Flight Facility**

The Hypervelocity Free-Flight (HFF) Range currently comprises two active facilities: The Aerodynamic Facility (HFFAF) and the Gun Development Facility (HFFGDF). The HFFAF is a combined Ballistic Range and Shock-tube Driven Wind Tunnel. The primary purpose of this facility is to examine the aerodynamic characteristics and flow-field structural details of free-flying aeroballistic models. The HFFAF has a test section that is equipped with 16 shadowgraph-imaging stations. Each station can be used to capture an orthogonal pair of images of a hypervelocity model in flight. These images combined with the recorded flight time history can be used to obtain critical aerodynamic parameters such as lift, drag, static and dynamic stability, flow characteristics, and pitching moment coefficients. For very high Mach number (i.e.  $M > 25$ ) simulations, models can be launched into a counter-flowing gas stream generated by the shock tube. The HFFAF is the Agency's only aeroballistic capability, and is the only ballistic range in the nation that is capable of testing in atmospheres other than air. The facility can also be configured for hypervelocity impact testing and shock tunnel testing.

The HFFGDF is used for gun performance enhancement studies, and occasional impact testing. The Facility utilizes the same arsenal of light-gas and powder guns as the HFFAF to accelerate particles ranging in size from 3.2mm to 25.4mm (1/8 to 1 inch) diameter to velocities ranging from 0.5 to 8.5 km/s (1,500 to 28,000 ft/s). Both facilities support three of NASA's strategic Enterprises: Aerospace Technology, Human Exploration and Development of Space, and Space Science. Most of the research effort to date has centered on Earth atmosphere entry configurations (Mercury, Gemini, Apollo, and Shuttle), planetary entry designs (Viking, Pioneer Venus, Galileo and MSL), and aerobraking (AFE) configurations. The facility has also been used for scramjet propulsion studies (NASP) and meteoroid/orbital debris impact studies (Space Station, and RLV).

### **2.2.3 Electric Arc Shock Tube**

The Electric Arc Shock Tube Facility is used to investigate the effects of radiation and ionization that

occur during very high velocity atmospheric entries. In addition, 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 102mm (4 inch) or a 610mm (24 inch) shock tube. The high-pressure 102mm shock tube can also drive a 762mm (30 inch) shock tunnel. Energy for the drivers is supplied by a 1.25-Mj-capacitor storage system. It can be charged to a preset energy level at either a 0- to 40-kV mode (1530  $\mu\text{F}$ ) or a 0- to 20-kV mode (6120  $\mu\text{F}$ ). Voltage, capacitance and arc-driver components are selected to meet, as effectively as possible, the test objectives of a given program.

## **3.0 SUMMARY**

The Arc Jets and Range Complex directly support NASA's three main goals: to understand and protect our home planet, to explore the universe and search for life, and to inspire the next generation of explorers. These Facilities also support the three enabling goals of ensuring provision of space access, extending the duration and boundaries of human space flights, and enabling revolutionary capabilities through new technology.

Ames Research Center's Arc Jets & Ballistic Range Complex forges fruitful partnerships with organizations (government, industry and academia) that need to completely, accurately and efficiently test concepts that use innovative techniques, materials and/or design ideas.

We provide a wide variety of hyperthermal and hypervelocity test conditions to examine the aerothermodynamics and flow field characteristics of entry (Earth or other planetary atmospheres) and hypersonic vehicles, simulate meteor or asteroid impacts on a planet or moon surface, and to simulate micrometeoroid impacts on a spacecraft.

Our goal: to provide the Nation with unique, critical and mission enabling testing capabilities by conducting low-cost "flight tests" in ground based facilities. The Arc Jets and Range Complex has a remarkable, comprehensive suite of highly adaptable world-class test hardware. When combined with our staff's extensive expertise and wide range of test experiences, we offer a unique set of testing possibilities.