Ames Research Center

Space Technology Research and Development (STRAD) Pre-Solicitation Conference

Charles Smith

Chief, Space Technology Division

Apr. 1, 2008

Outline

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  - Electric Arc-Driven Shock Tube - EAST
  - Ballistic Range
  - Material Labs
- Expectations for Future Work

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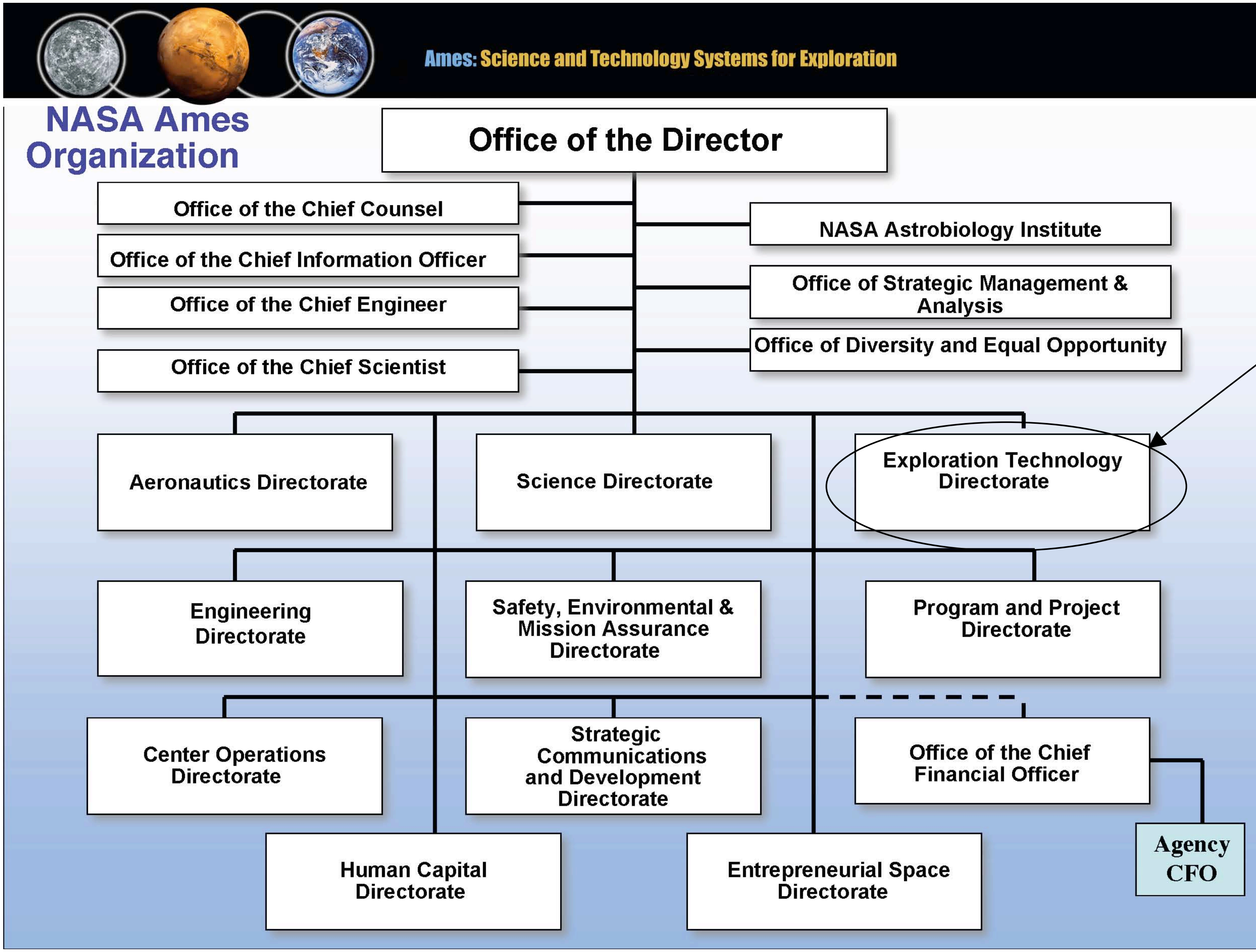

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Exploration Technology Directorate

Space Technology Division

- Director: Eugene Tu
  Deputy: Carol Russo
  Associate Director: James Clement
  Operations Manager: Patti Powell
  - Intellegent Systems (TI)
    Chief: Dave Korsmeyer
    Deputy: Dennis Koga
    - Autonomous Systems & Robotics
    - Collaborative & Assistant Systems
    - Robust Software Engineering
    - Discovery & Systems Health
  - Human Systems Integration (TH)
    Chief (a): Patty Jones
    Deputy (a): Michael Shafto
    - Human Information Processing Research
    - Human-Automation Integration Research
    - System Safety Research
  - Space Technology (TS)
    Chief: Charles Smith
    Deputy: Harry Partridge
    - Reacting Flow Environments
    - Thermo-Physics Facilities
    - Thermal Protection Materials & Systems
    - Nanotechnology Research
  - NASA Advanced Supercomputing (TN)
    Chief (a): Rupak Biswas
    Deputy (a): Bryan Biegel
    - Applications
    - Research
    - Engineering

(a) = acting

Space Technology Division

Space Technology Division
Charles Smith, Chief
Harry Partridge III, Deputy Chief
Sonia I. Maiello, Asst. Chief

Thermo-Physics Facilities Branch
George A. Raiche II, Chief
Scott Eddlemon, Deputy

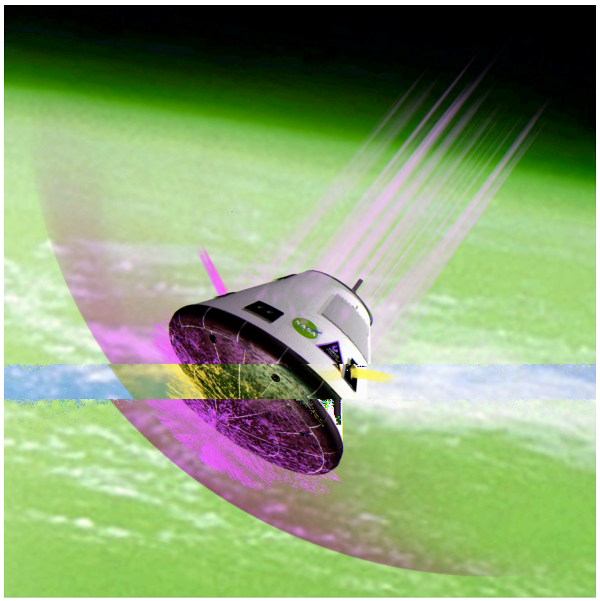
Nanotechnology Branch
Harry Partridge, Chief (Acting)

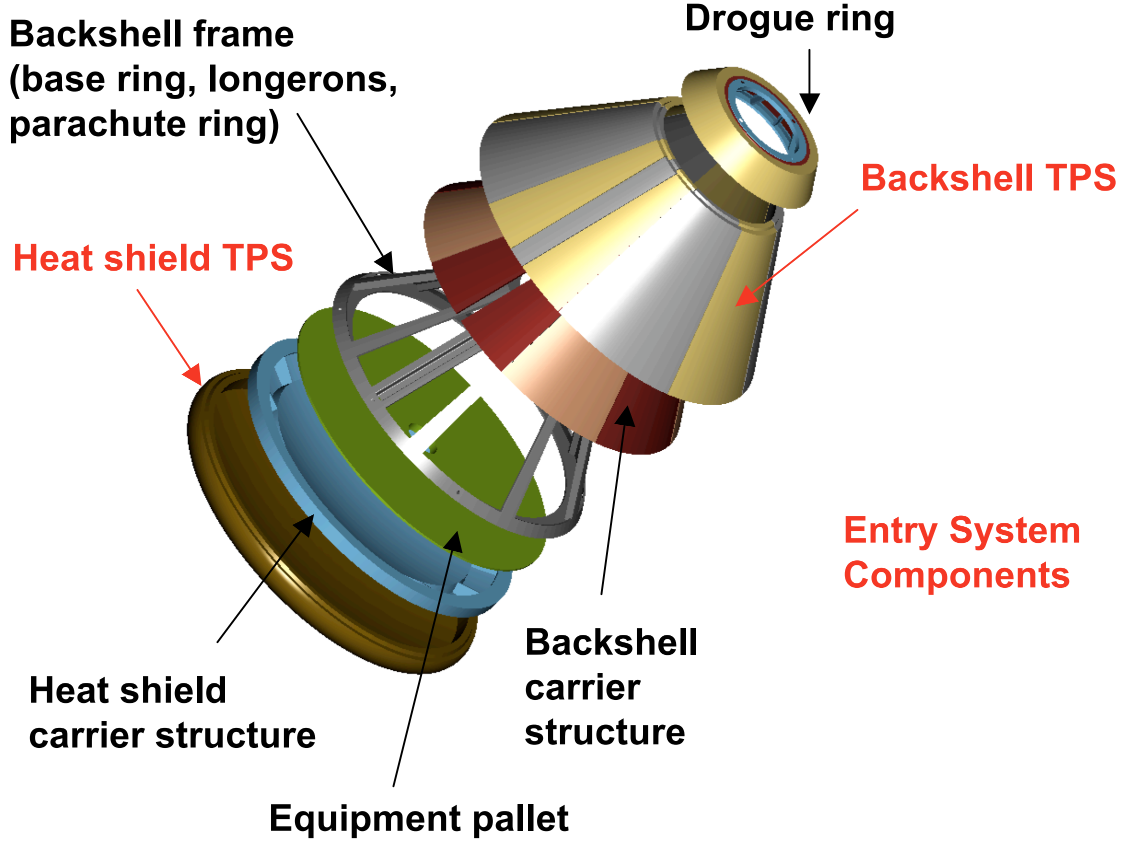
Reacting Flow Environments Branch
Michael Wright, Chief (detailed)
Aga M. Goodsell, Deputy

Thermal Protection Materials and Systems Branch
Sylvia M. Johnson, Chief

Entry Systems Overview

The Space Technology Division provides the customer unmatched convenience and responsiveness through a single interface which manages all aspects of entry system development, design, test, and evaluation. The breadth of our reentry expertise and the unique capability of our high enthalpy test facilities allows for the delivery of an integrated product through which we advance entry system solutions from concept to flight article.





Entry System Components

NASA Entry Vehicles / Missions Supported by Ames

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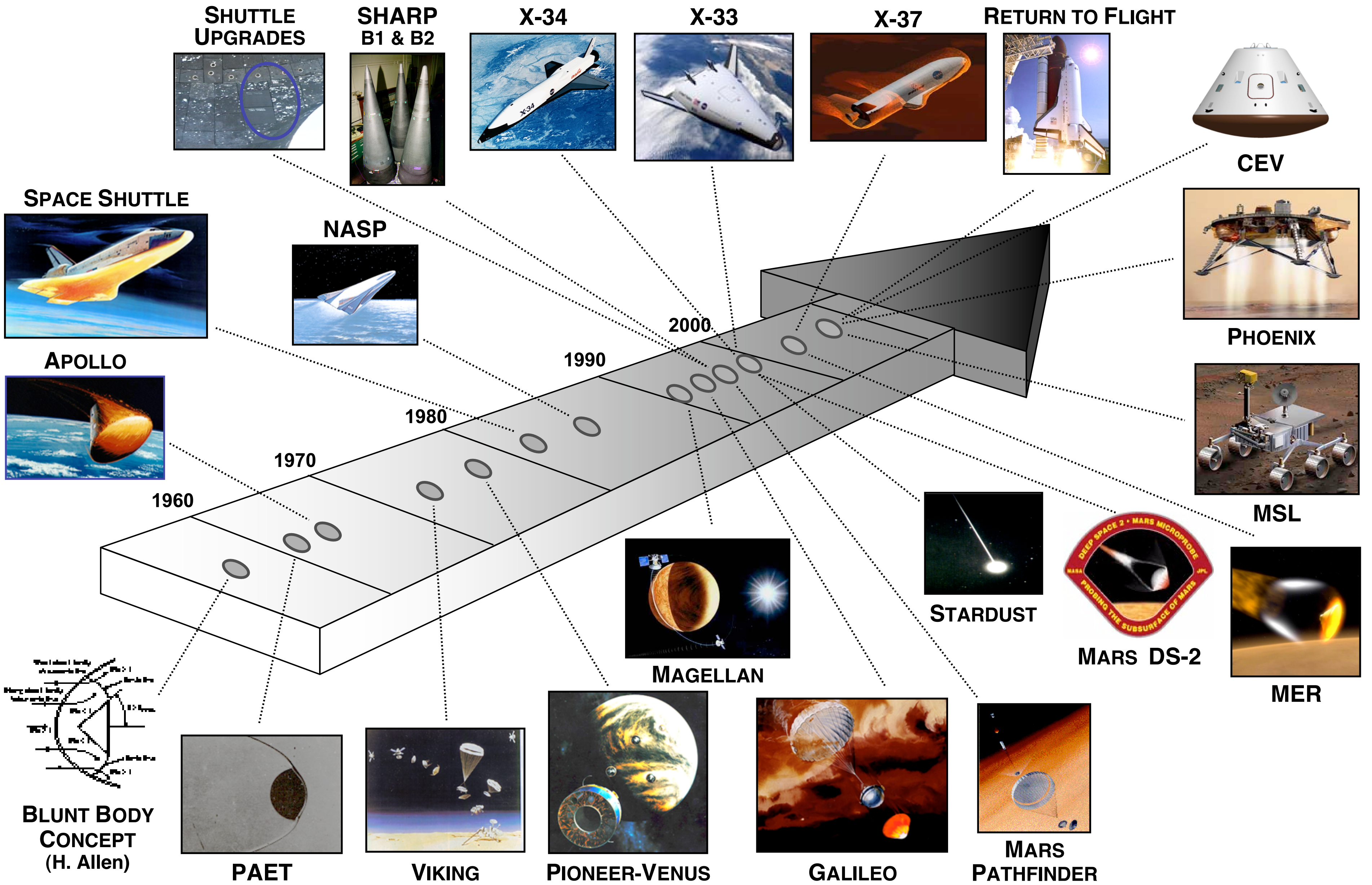

Integrated Capability Provides Mission Critical Support

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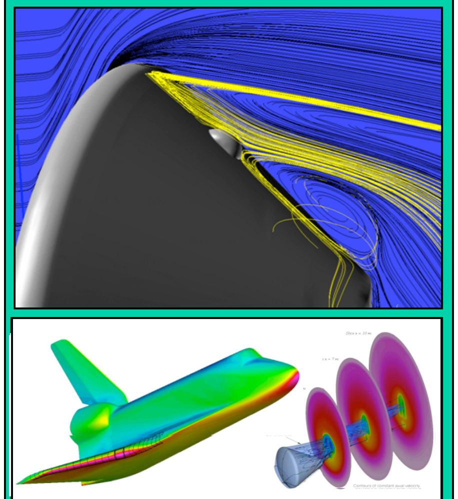
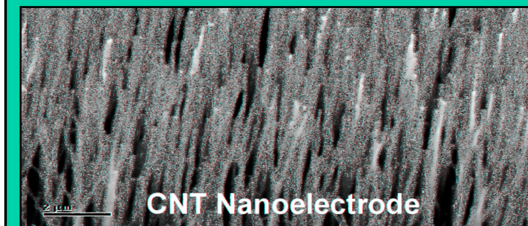
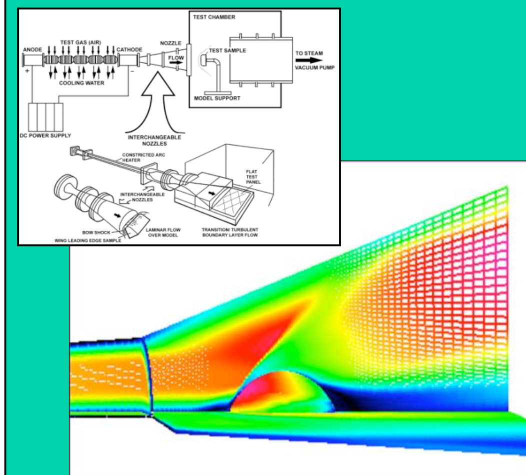
Flight Prediction & Modeling



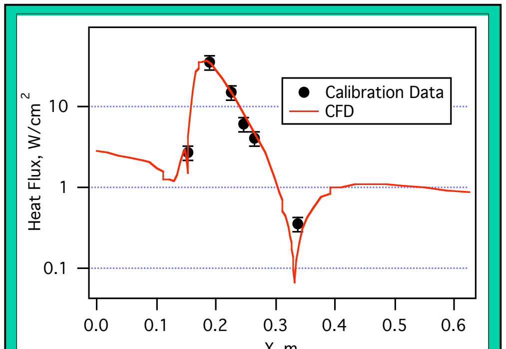
Sensor Development



Facility Modeling

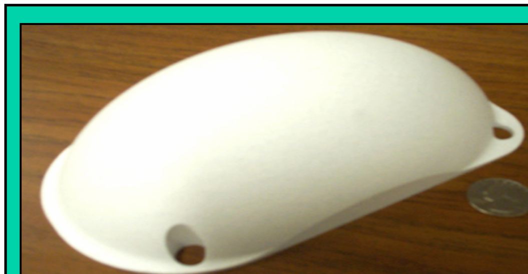


Ground Testing



Validated Simulation Models

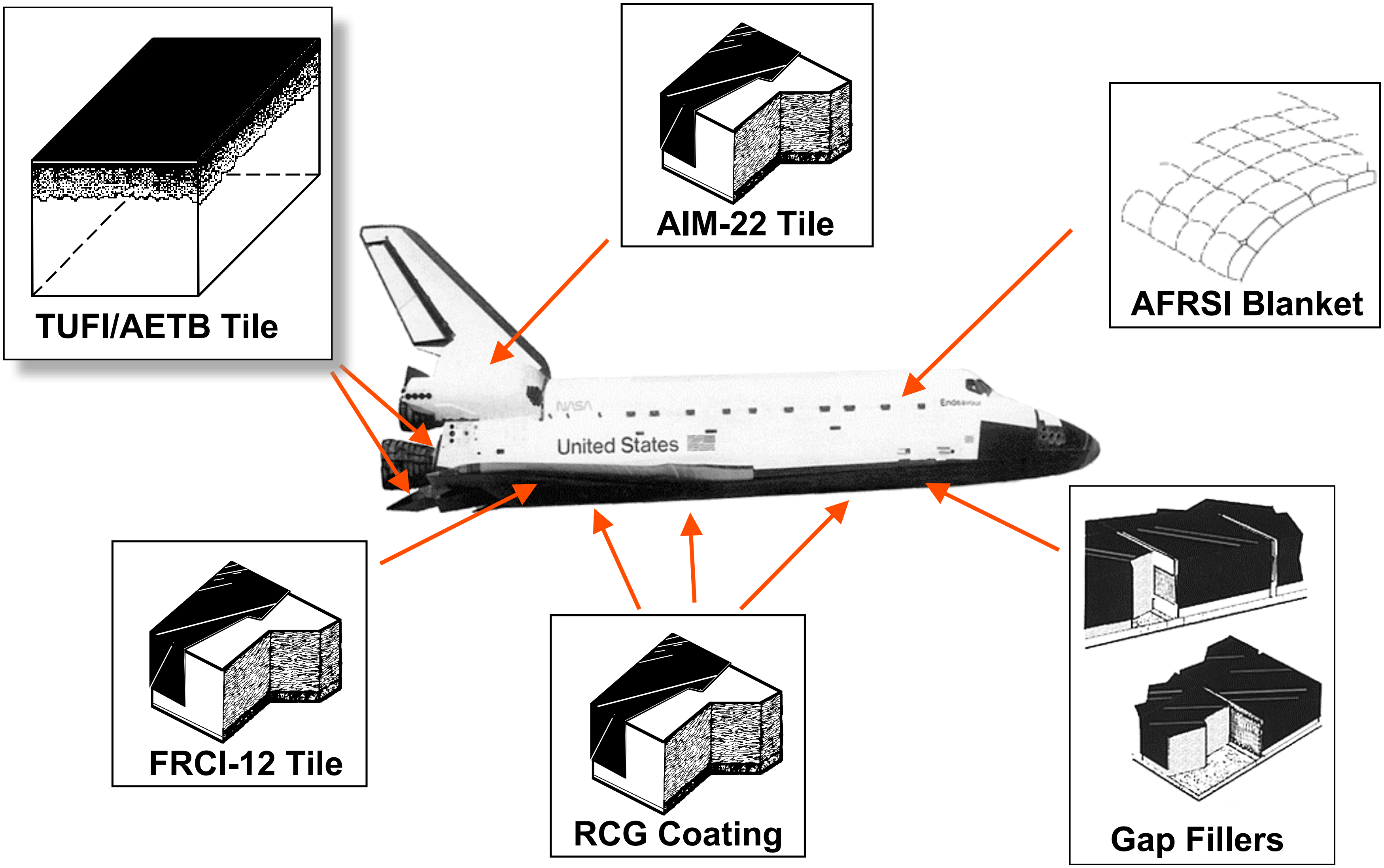
Materials Labs



Fabrication

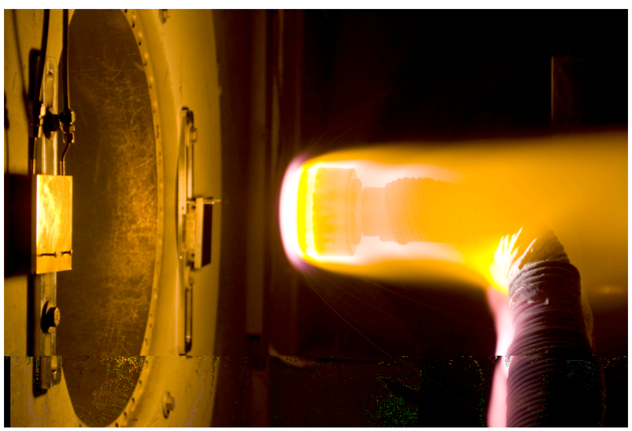
Ames-Developed Thermal Protection Materials Adopted to Date on Shuttle

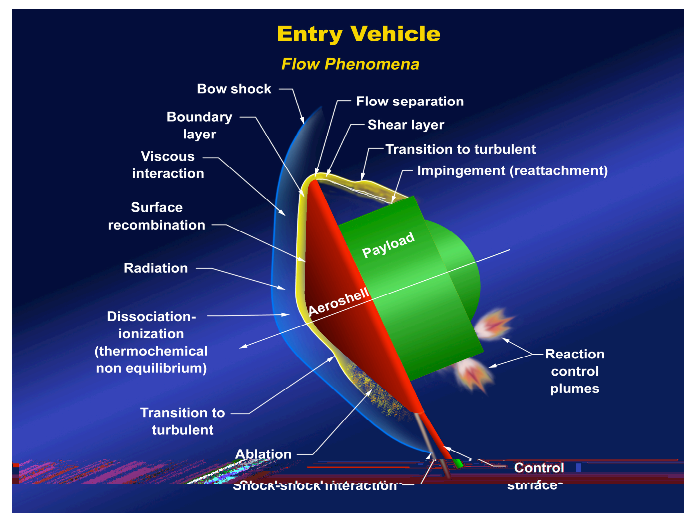
Space Technology Division



Ames Research Center Contributions to NASA in Thermal Protection Systems

- **NASA Ames has been involved in developing, testing, or qualifying the heat shield for every U.S. spacecraft that has entered Earth's atmosphere or the atmosphere of another planet.**
- **We can handle every stage of heat shield development, from conception, material properties investigations, modeling and simulation, to fabrication, testing and delivery**
- **Ames is continually developing or improving new materials, new simulation tools and/or test techniques. This will enable safer, more reliable systems for future exploration and science missions.**





Disciplines Required for Agency Leadership in Entry System Heat Shields

- TPS materials research & development
  - New materials development
  - Material characterization
  - Material testing
  - Material databases
- Sizing / design of TPS for specific missions
- Heat shield focused systems analysis and systems development
- Aerothermal predictions: computational and experimental
  - Convective and radiative heating
- Test and test techniques
  - Arc jet complex
  - Ballistic range
  - Shock tube
- Instrumentation: development and installation
- Flight experiment support and leadership
- Ground-to-flight traceability

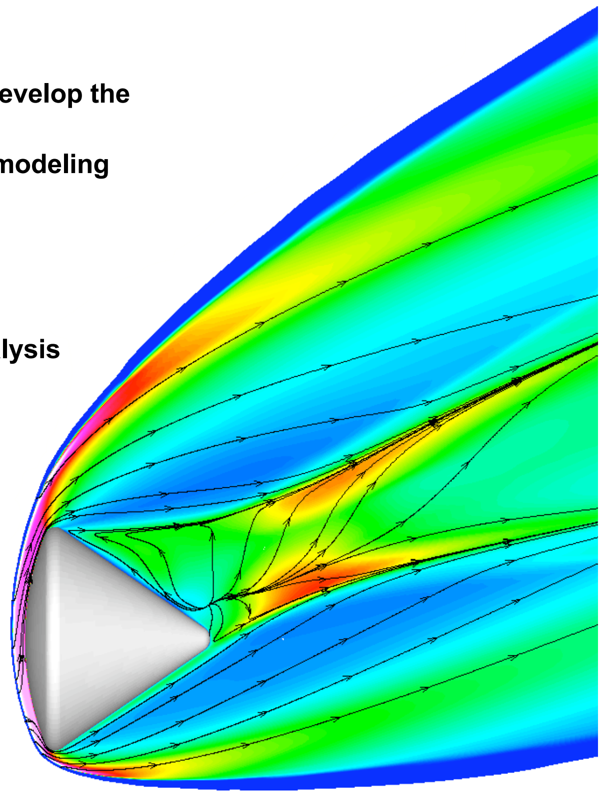
Current Projects Support by STRAD

- Aeronautics Research Mission Directorate (ARMD)
  - Fundamental Aeronautics Program - Hypersonics Task
    - Aerothermodynamics, advanced materials, program assessment
- Exploration Systems Mission Directorate (ESMD)
  - Constellation - Crew Exploration Vehicle (CEV)
    - Constellation Aerosciences Project (CAP)
    - CEV TPS Advanced Development Project (ADP)
    - Commercial Orbital Transportation Services (COTS)
    - Mars Entry Descent and Landing Instrumentation (MEDLI)
    - Lunar Environment Arcjet Facility (LEAF)
- Science Mission Directorate (SMD)
  - Mars Science Laboratory (MSL)
- Space Operations Mission Directorate (SOMD)
  - Shuttle operations support in support of TPS

Reacting Flow Environments Branch (TSA)

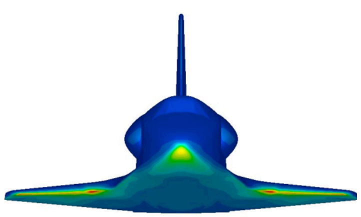
Vision: Provide aerothermal analyses and entry system design to support NASA strategic objectives in solar system exploration

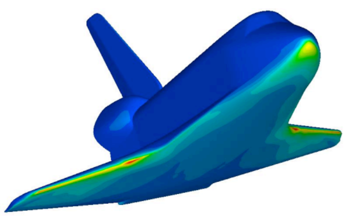
- **Requirements development, design, and qualification for entry systems**
  - Requirements Development
    - Aerothermal analysis tools are employed to define the environments that the entry system must be designed to endure.
  - Flight Hardware Development and Design
    - Aerothermal analysis tools and high enthalpy test facilities are used to develop the aero/aerothermodynamic databases employed in design.
    - Aerothermal environment, shock layer radiation, and material response modeling tools are used in conjunction to size the thermal protection system.
    - Trajectory Shape Optimization
  - Qualification
    - Uncertainty and Sensitivity Analysis
    - Aerodynamics/aerothermodynamics test design, oversight, and data analysis
    - High-enthalpy facility modeling, diagnostics, and development
    - Flight testing design and analysis
    - Ground-to-flight traceability
- **Hypersonics Modeling Support**
  - Grid generation (Gridgen, Gridpro)
  - Aerothermal modeling (DPLR)
  - Shock layer radiation modeling (NEQAIR)
  - Material response modeling (TPSSizer/FIAT)
- **Experimental facilities (Arc Jet , Shock Tube, Ballistics Range) Support**
  - Principal Investigators
  - Data Analysts
  - Facility Development
  - Test Design



Space Shuttle Orbiter Support

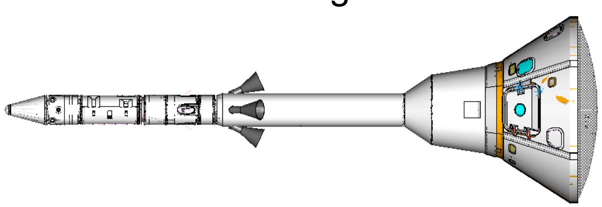
- Description
  - NASA's goal is to finish the International Space Station (ISS) and retired the Shuttle fleet by 2010. To meet that aggressive schedule, the optimal schedule includes 6 launches per year.
- Goals of the Reacting Flow Environments Branch in support of the Orbiter
  - To keep the crew and the vehicle safe upon launch and reentry using the expertise of its staff in CFD for real-time, on-orbit TPS damage assessment
  - Provide 24-hour support when in Orbit: at Ames, JSC and KSC, either as the Lead or as the Support organization.

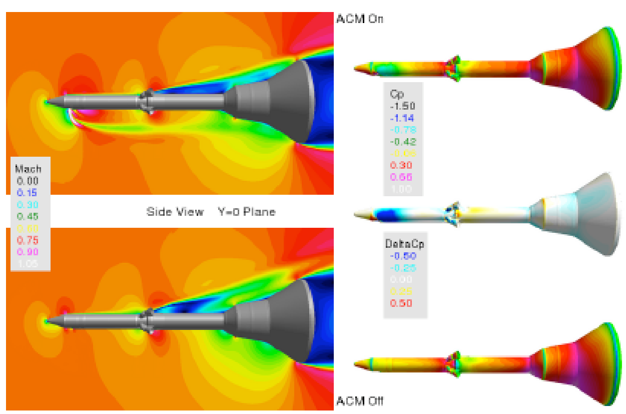




Crew Exploration Vehicle (CEV) Support

- Description
  - The CEV Aerosciences Project (CAP) is a multi-center project responsible for producing aerodynamic and aerothermodynamic GFE data for the Orion flight databases.
  - At Ames, CAP is responsible for creating the databases and contributing data from ground-based aerodynamic tests in the Ames Unitary Plan Wind Tunnel (AUPWT) and ballistics ranges (HFAFF, GDF), shock layer radiation tests in the EAST facility, and aerothermal heating tests in the T5 shock tunnel at the California Institute of Technology.
  - CAP is also responsible for providing computational aerodynamic (OVERFLOW, CART3D) and aerothermodynamic (DPLR, NEQAIR) data for a range of Mach numbers from subsonic to hypersonic.
- Goals
  - To provide the aerodynamic and aerothermal database required for design and operation of Orion, including the Crew Module (CM), Launch Abort Vehicle (LAV), and Service Module (SM).
- TSA Support
  - Provide input to the aerothermal database required for design and operation of Orion, including the Crew Module (CM), Launch Abort Vehicle (LAV), and Service Module (SM).
  - Manage CAP activities at Ames.





CEV TPS Advanced Development Project

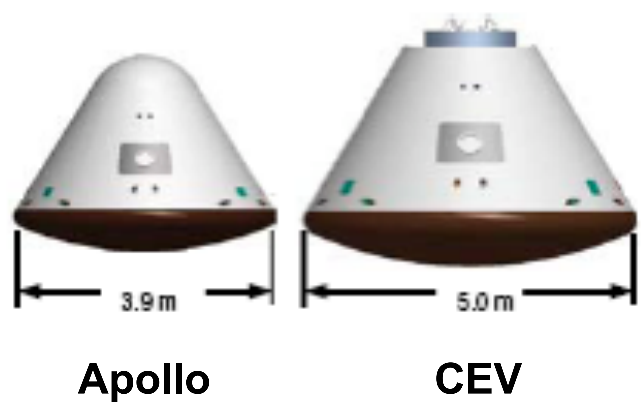
- Description
  - The Crew Exploration Vehicle, Orion, is in development under Project Constellation, and is scheduled for launch in late 2014, after the Orbiter retires. NASA Ames is leading a key component of the vehicle design, which is the Orion heat shield. This includes oversight on thermal protection design, thermal testing, structural testing and results documentation. These data will be used for a preliminary design for the Orion head shield.
- Goals
  - To develop a design data book, to be used as a source document for down select to a single heat shield design that will withstand the atmosphere of entry to the moon, and subsequent return to Earth.

CEV TPS Advanced Development Project

- TPS ADP Main Goal: Develop a single heat shield, capable of both lunar & LEO missions

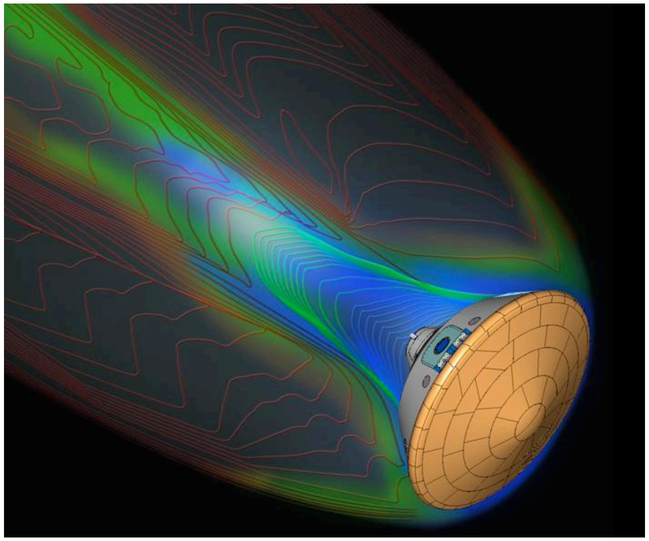
	Velocity, km/s	Heat Flux, W/cm^2	Heat Load, kJ/cm^2
Lunar	**11.0**	**~1000**	**~ 100**
LEO	**8.0**	**~ 175**	**~50**

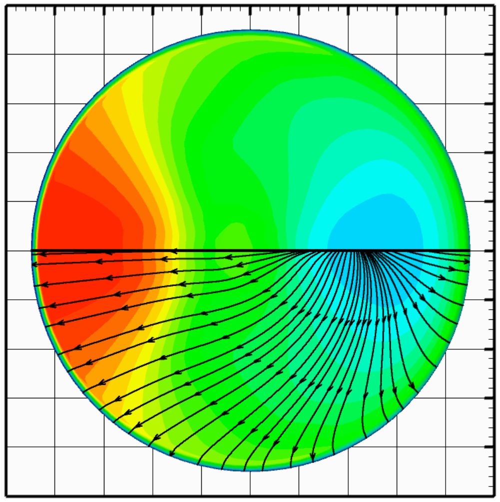
- Challenge: Largest Diameter Lunar Capable Heat Shield Ever (CEV is not Apollo)
  - Apollo heritage TPS Avcoat is not TRL 9 because material went out of production
  - Increased scale of CEV presents unique heat shield performance risks
- TSA Support
  - Provide management of the heat shield development
  - Material response analysis for design



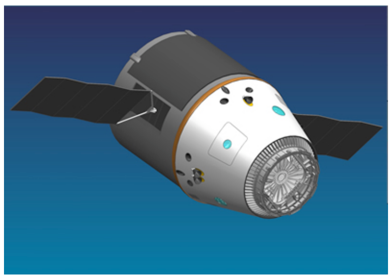
Mars Science Laboratory

- Description
  - The Mars Science Laboratory (MSL) mission is will be the largest robotic mission on the Martian surface ever attempted. It is the latest in a series of missions to Mars under the strategy of “follow the water” with the primary purpose of investigating the past or present ability of Mars to support life.
- TSA Support
  - The Ames role is to provide V&V for the predicted aerothermal environments of Martian entry for which the MSL heat shield must be qualified.
  - Thermal response analysis and heat shield sizing for design.
  - Manage the TPS activities in support of MSL at Ames.





Commercial Orbital Transportation Systems



- Description
  - Managed through the NASA Commercial Crew & Cargo Program Office (C3PO) at JSC, the COTS (Commercial Orbital Transportation Systems) Project provides funding and technical support to help US Industry develop and demonstrate commercial space transportation capabilities.
  - At Ames, the Space Portal Group supports COTS by helping industry partners 1) develop the emerging market for commercial space services, 2) educate the investment community, 3) work with regulatory agencies to increase attractiveness of the enterprise, and 4) build community awareness.

- Goal
  - To assist US Industry develop commercial space transportation systems and services that NASA can purchase after the Shuttle Program ends to support the operation of the International Space Station and future Low Earth Orbit (LEO) missions at a reduced cost to the Government given the economies of scale that a market-based space services industry could provide.
- TSA Support
  - Provide aerothermal analysis support and consulting services.

Mars Science Laboratory Entry, Descent and Landing Instrumentation (MEDLI)

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The Mars Science Laboratory Entry, Descent, and Landing Instrumentation (MEDLI) package is a suite of EDL instrumentation that will be flown in the forebody heatshield on MSL:

Mars Entry Atmospheric Data System (MEADS):

Pressure ports to obtain atmospheric and aerodynamic data

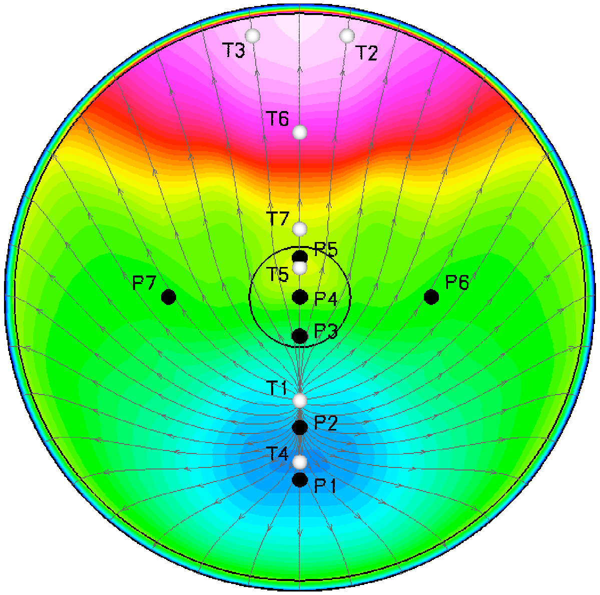
MEDLI Instrumented Sensor Plug (MISP):

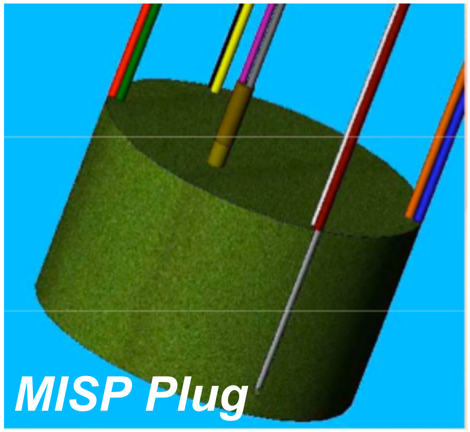
TC plugs and recession sensors to obtain aerothermal/TPS performance

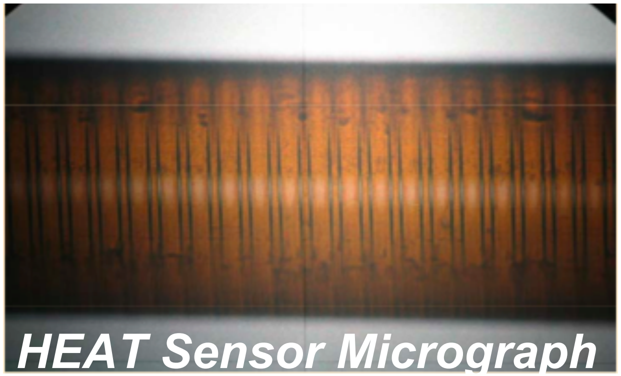
Ames contributions:

MISP overall lead, deputy PI, qualification testing, electronics and MEADS support

Instrumentation Placement







Future Growth Areas - Reacting Flow Environments Branch

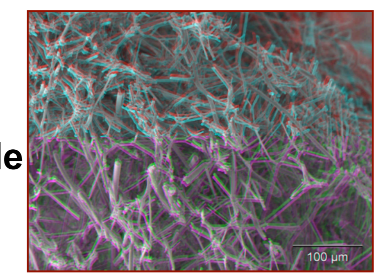
- **Priority Development List**
  - Gas Surface Interaction Development in DPLR and coupling to Material Response
  - Radiation Coupling in DPLR
  - N-equation turbulence models for DPLR

- **Other needs**
  - DPLR Installation Support
  - Data Analyst
  - Engineering Tool Development
  - NEQAIR Development
  - Detached Eddy Simulation (DES) Capability in DPLR
  - Time Accurate version of DPLR
  - DPLR Multigrid Convergence Improvements

Thermal Protection Materials & Systems Branch (TSM)

Vision: Apply materials science and engineering in a complete process including basic research, material development, fabrication, analytical predictions and application, to support NASA mission goals.

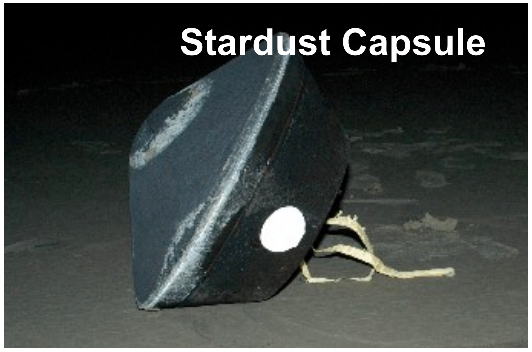
- **Materials Development**
  - **Ablative TPS**
    - **PICA (Phenolic Impregnated Carbon Ablator)**
    - **SIRCA (Silicone Impregnated Refractory Ceramic Ablator)**
  - **Reusable acreage insulation**
    - **Advanced ceramic tile – AETB (Alumina Enhanced Thermal Barrier)**
    - **Advanced coatings – TUFI (Toughened Uni-Piece Fiborous Insulation)**
    - **Flexible blankets – FRSI, AFRSI**
  - **High-temperature reusable materials**
    - **TUFROC (Toughened Uni-piece Fibrous Reinforced Oxidation- resistant Composite)**
    - **UHTC (Ultra-high Temperature Ceramic)**
- **Materials Characterization and Testing**
  - **Material property testing**
  - **Composition testing**
  - **Microscopic structure – SEM**
  - **Arc-jet testing**
- **Flight Hardware**
  - **SIRCA for MER (Mars Exploration Rover)**
  - **SIRCA wing leading edge tiles for X-34**
- **TPS modeling, databases**
  - **Thermal/mechanical finite element modeling**
  - **TPSX material properties database**

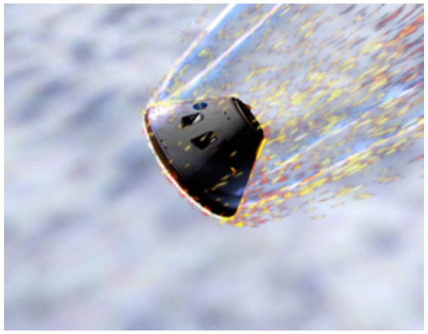


Ceramic Tile

PICA
(Phenolic Impregnated Carbon Ablator)

- Developed at NASA Ames
- Mission applications
  - Used successfully on the Stardust Earth entry probe
  - Primary heatshield material option for the new Orion vehicle
- Low-density ablator
  - Density ~ 0.270 gm/cm^3
  - High heat flux capability
  - Carbon substrate
  - Phenolic impregnation





Orion Heatshield
Manufacturing Demonstration Unit

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SIRCA
(Silicone Impregnated Refractory Ceramic Ablator)

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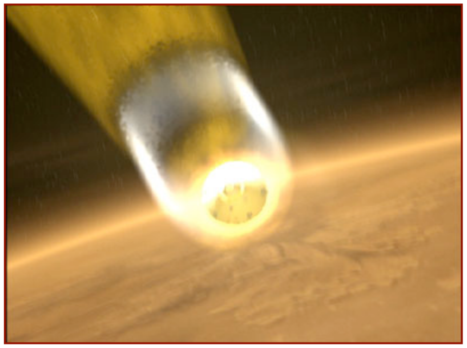
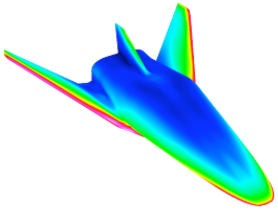
- Developed at NASA Ames
- Low-density ablator
  - Density ~ 0.24-0.26 gm/cm^3
  - For heat fluxes < 200 W/cm^2
  - Made by infiltrating silicone resin into a silica-based tile
- Mission Applications
  - Mars Pathfinder
  - X-34 – wing leading edge tiles
  - MER - back interface plate, Transverse Impulse Rocket System (TIRS) Cover TPS



Sharp Leading Edge Technology
UHTC (Ultra-high Temperature Ceramics)

- Benefits of sharp leading edge technology
  - Enhanced vehicle performance
  - Leads to improvements in safety
    - Increased vehicle cross range
    - Greater launch window with safe abort to ground
- Sharp leading edges place significantly higher temperature requirements on the materials:
  - Current shuttle RCC leading edge materials: T~1650°C
  - Sharp leading edged vehicles will require: T>2000°C
- Ultra-High Temperature Ceramic (UHTC) compositions are one candidate for use in sharp leading edge applications.
  - based on refractory diborides/SiC
- Based on work performed by ManLabs Inc. in the 1960's and 1970's for the Air Force
- In the early 1990's Ames began investigating these materials for sharp leading edge applications.
- SHARP-B1(1997) and SHARP-B2 (2000) ballistic flight experiments



Current TSM Projects/Activities

- Orion (CEV) Advanced Development Program for heatshield TPS
- Shuttle Return to Flight (RTF): repair material for RCC; characterizing ET foam
- Mars Science Lander: PICA heatshield support
- Hypersonics materials development
- COTS (Commercial Orbital Transportation Systems)
- TPSX: maintain database
- Ceramics Lab: support arc-jet testing by preparing models etc
- Labs: Materials Characterization, SEM, and TPS Development

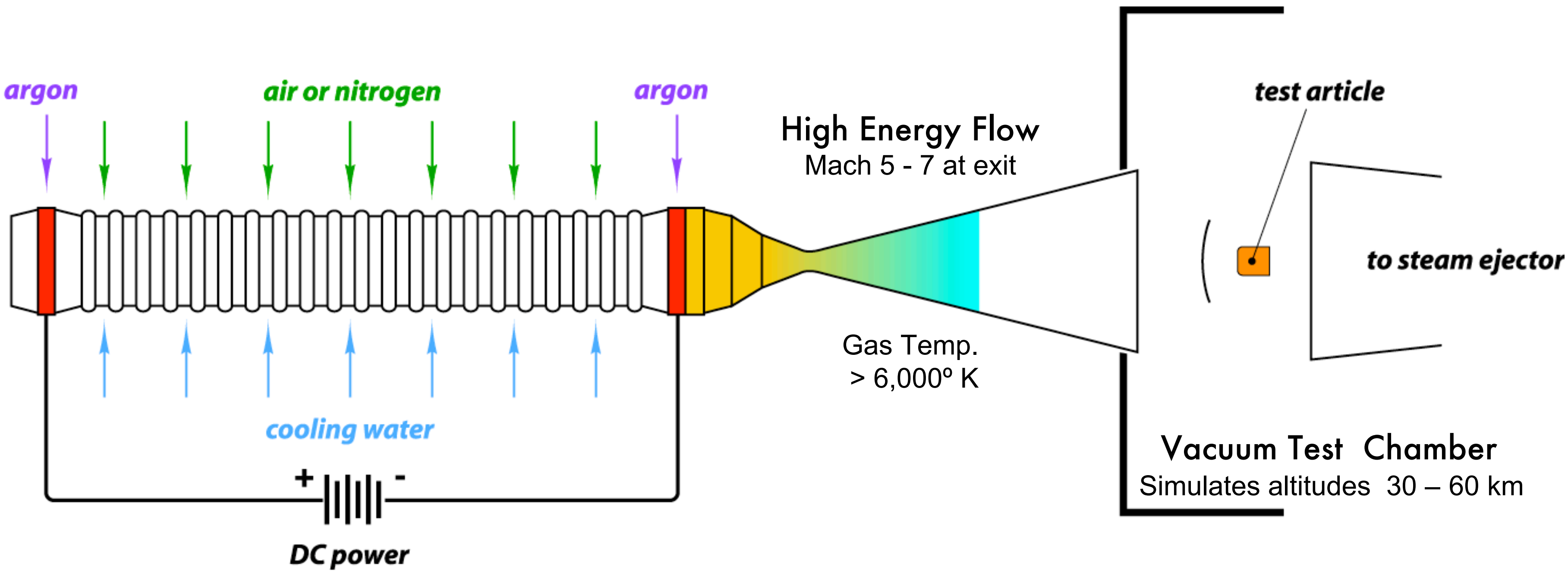
Major Test Facilities of the Space Technology Division

- Arc Jet Complex
  - 20MW Aerodynamic Heating Facility (AHF)
  - 20MW Panel Test Facility (PTF)
  - 20MW Turbulent Flow Duct
  - 60MW Interaction Heating Facility (IHF)
  - Ancillary Facilities
- Hypervelocity Free-Flight Facility (HFFF)
- Electric Arc Shock Tube (EAST) Facility

ARCJET Basics

Objective: Simulate entry heating in a ground-test facility

Goal: Verify a thermal-protection material/system design before flight



Method: Heat a test gas (air) to plasma temperatures by an electric arc, then accelerate into a vacuum chamber where the specimen is placed

Ames Arc Jet Complex

- Over 45 years heritage in arc jet testing
- High power (75 MW and 20 MW continuous DC power supplies)*
- Large test articles (up to 60 x 60 cm)*
- Continuous high enthalpy flows (2-40 MJ/kg in air)
- Spectroscopic and LIF flow diagnostics available
- Several tests per day/hundreds per year
- Four operational arc jets: (3) 20 MW and 60 MW input power *
- Large vacuum pumping capacity (100 g/sec @ 0.5 torr) *
- Continuous operation (to 60 minutes)

*** Largest within NASA and U.S.**

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NASA Ames Arc Jet Complex

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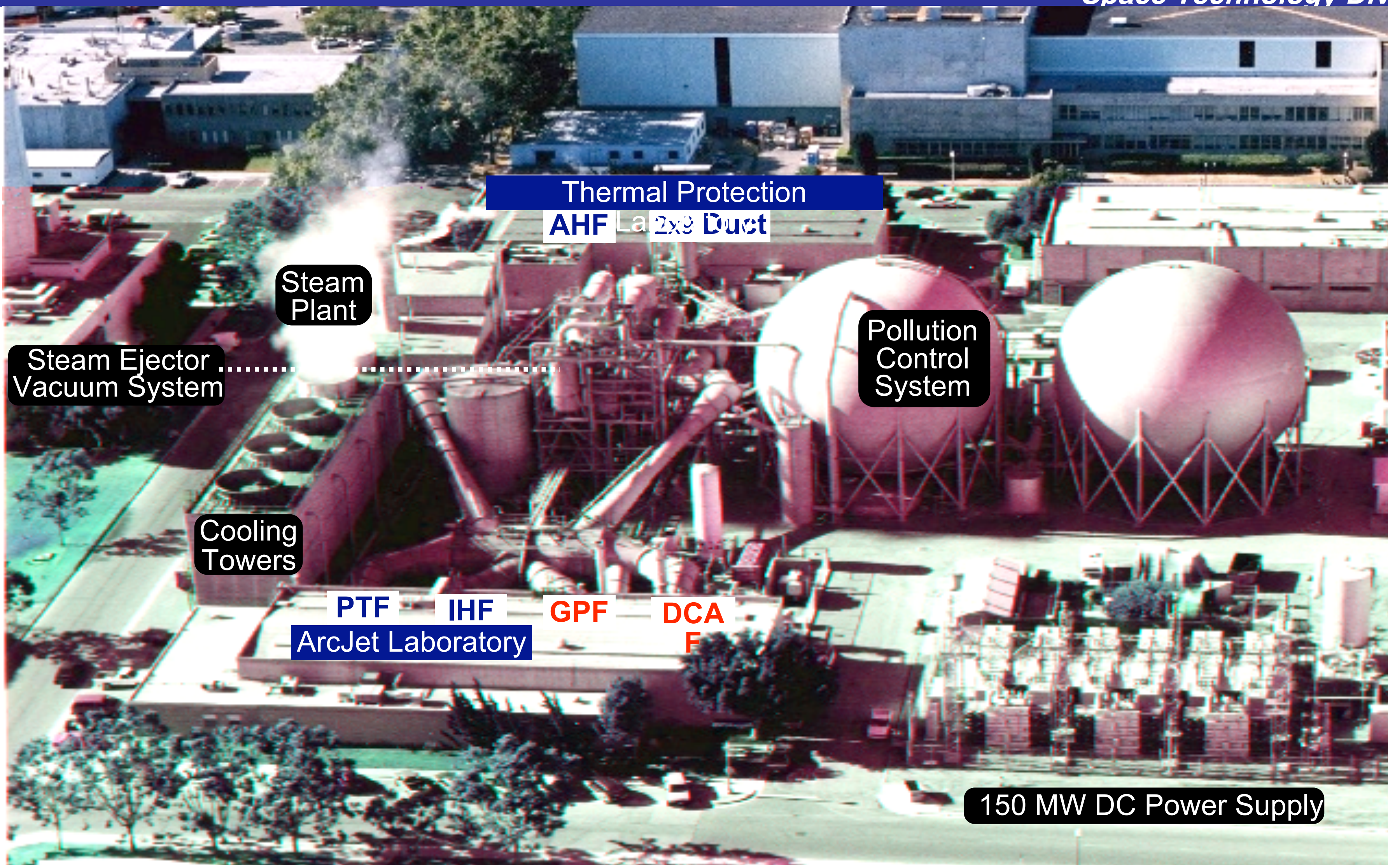

KEY

- 2 x 9 Duct - Turbulent Flow Facility
- AHF - Aerodynamic Heating Facility
- IHF - Interactive Heating Facility
- PTF - Panel Test Facility
- GPF - Giant Planet Facility
- DCAF - Direct Connect Aerodynamic Facility

Ames Arc Jet Facilities

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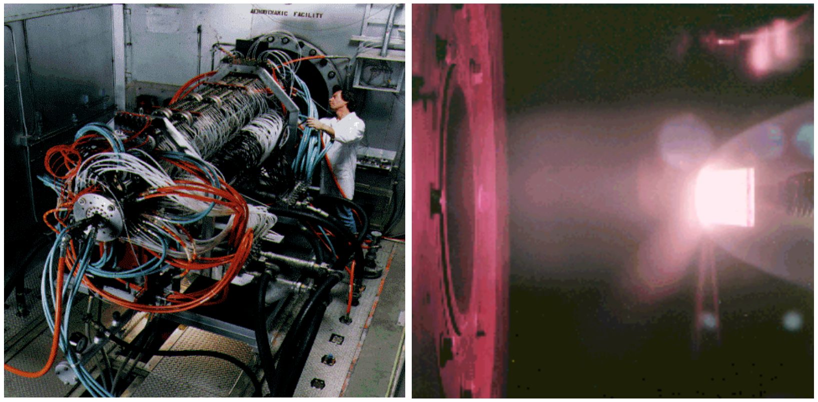
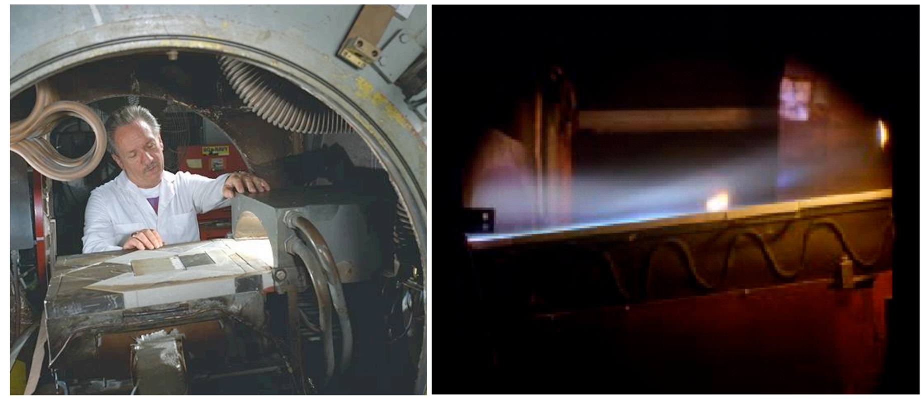
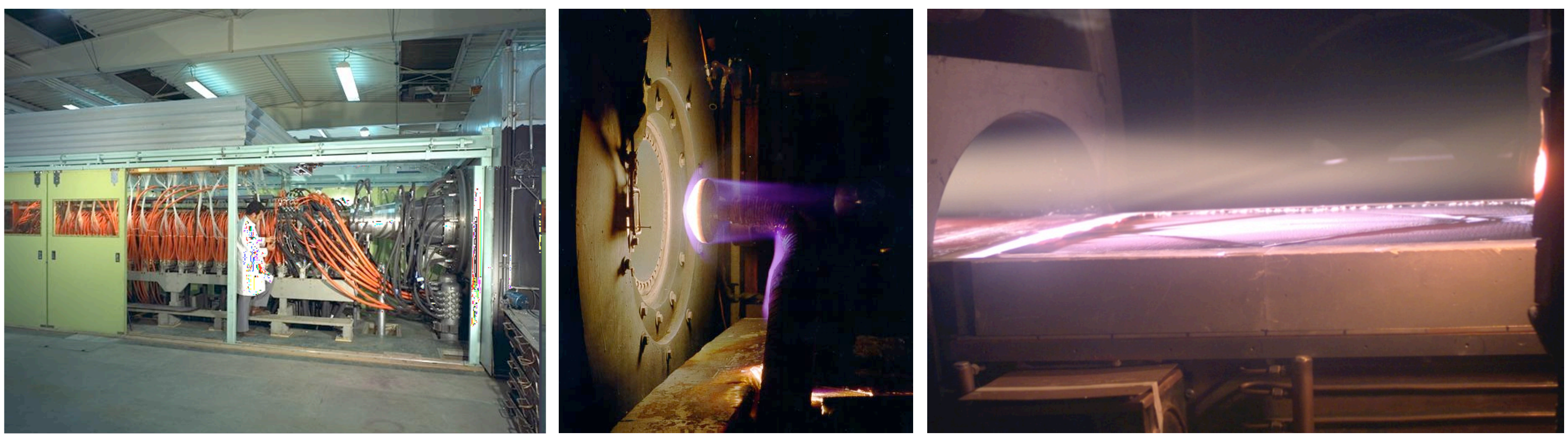


Aerodynamic Heating Facility
20 MW – TPS Free Jet Testing



Panel Test Facility
20 MW – TPS Panel Testing Configuration (30x30 cm panel)



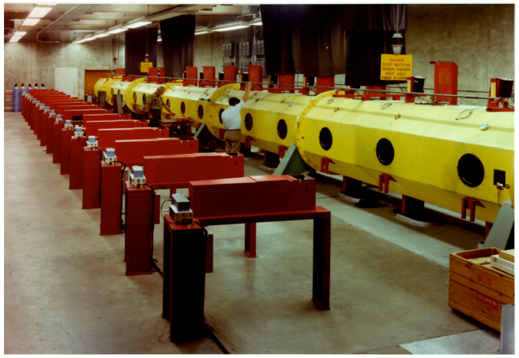
Interaction Heating Facility
60 MW – TPS Free Jet and Panel Testing (60x60 cm panel) Configurations
Largest and Highest Power Arc Jet within NASA

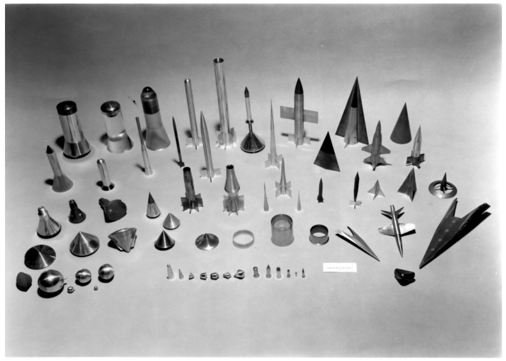
Hypervelocity Free-Flight Facility

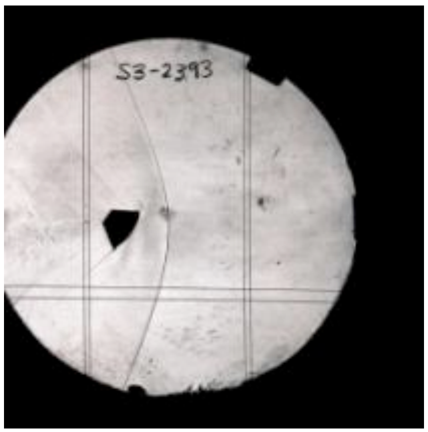
- The Hypervelocity Free-Flight Facility (HFFF) supports three of NASA's Strategic Enterprises:
  - Aerospace Technology
  - Human Exploration and Development of Space
  - Space Science

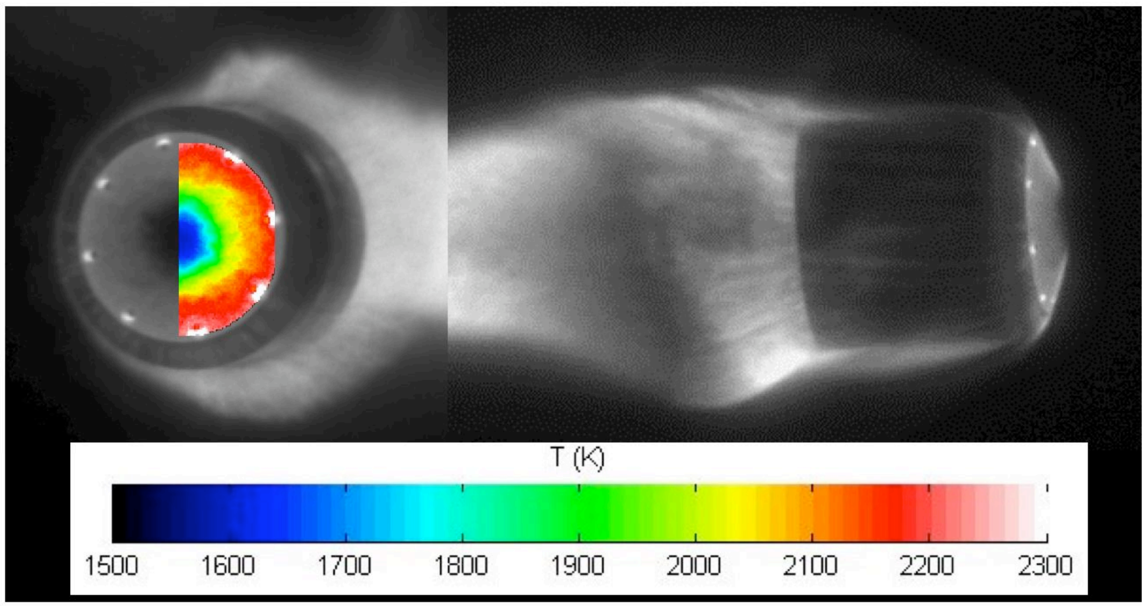
- HFFF is the Agency's only Aeroballistic capability, providing critical aerodynamic parameters (such as lift, drag, pitching moment coefficients, dynamic stability, etc.) at very high velocities (5-8km/sec)
  - Only ballistic range in the nation that is capable of testing in atmospheres other than air

Hypervelocity Free-Flight Facility









Electric Arc Shock Tube Facility

Space Technology Division

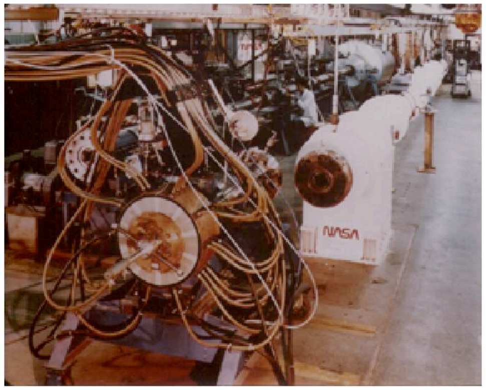
OPERATOR: Space Technology Division, Thermo-Physics Facilities Branch

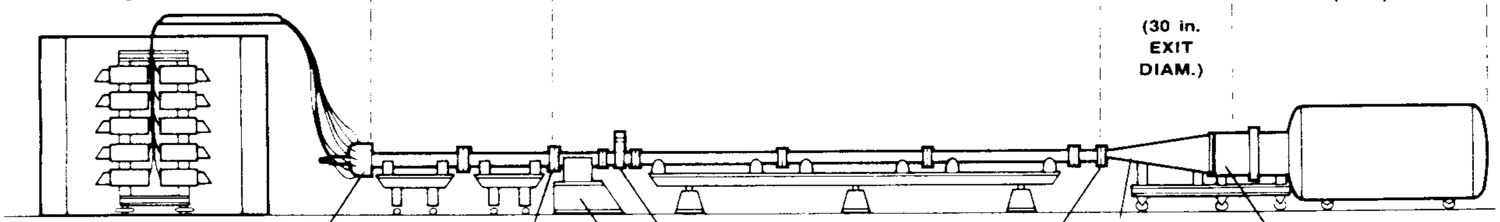
STATUS: Operational (Commissioned 1966)

LOCATION: N-229

PERFORMANCE:

- **Shock Speed**
  - **<u>4 in. Shock Tube</u>** **<u>24-in Shock Tube</u>**
  - **1 Torr hydrogen: 46km/s** **1 Torr air: M_s - 21**
  - **1 Torr air: M_s - 21**





The Electric Arc Shock Tube Facility is used to investigate the effects of radiation and ionization during outer planetary entries as well as for air-blast simulation which requires the strongest possible shock generation in air at initial pressure loadings of 1 atm or greater. The facility has five separate driver tubes. The different sized drivers can be converted at the 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.

Future Directions for the Space Technology Division

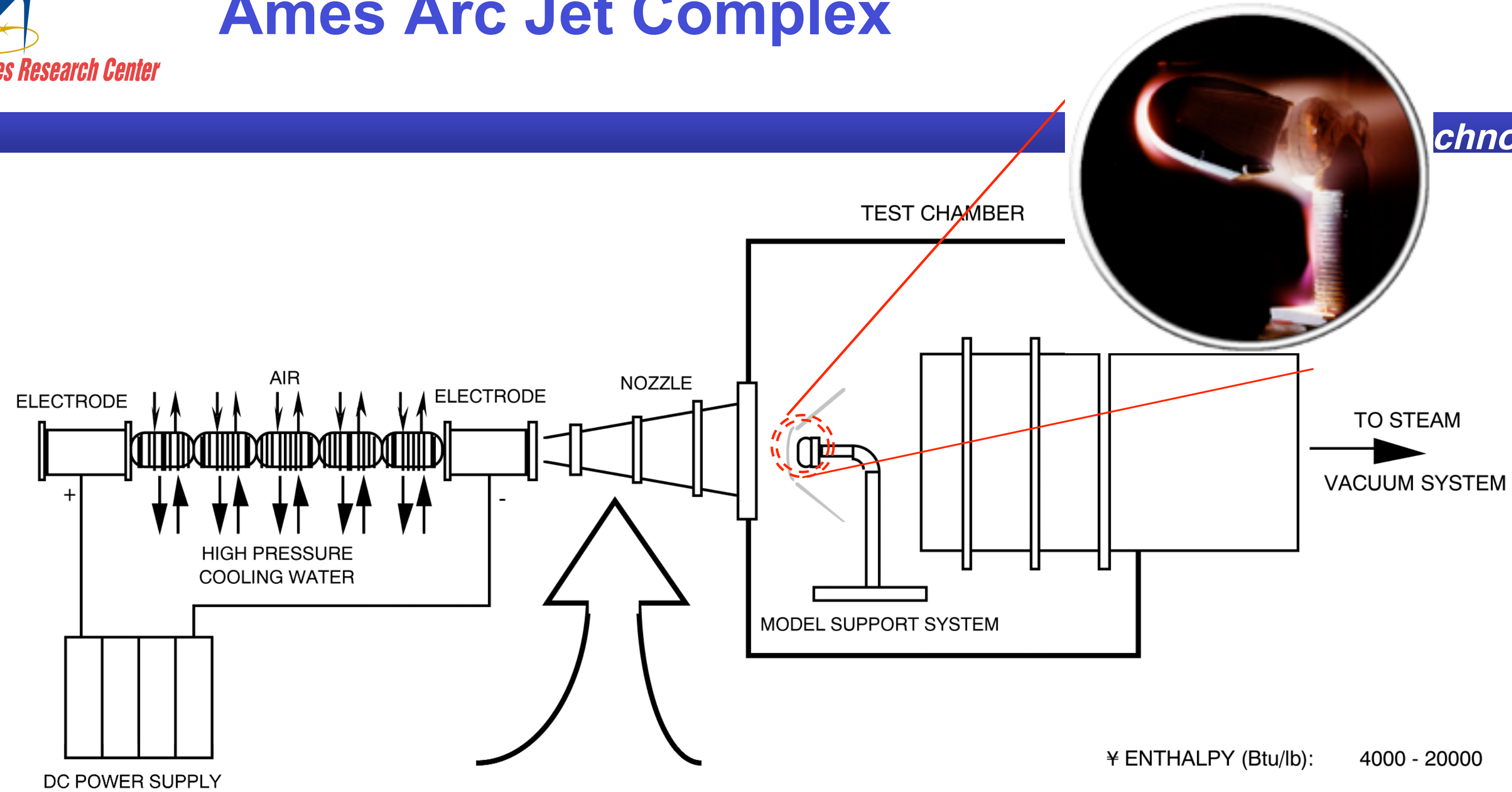
- Continued growth toward entry system fundamental physics, heat shield development and aeroshell design
  - Advanced system development
- Support for all four mission enterprises
  - Several science missions being pursued
- New material development
  - Ultra-high temperature ceramics for reusable TPS
  - Ablative materials for extremely high heating environments
  - Nano-based materials
- Advanced modeling and simulation tools
  - Computational material science
  - Coupled flow and material thermal response modeling
- System technologies
  - Material characterization
  - NDE
  - Damage assessment

BackUp Slides

Ames Arc Jet Complex

Ames Research Center

chnology Division



¥ ENTHALPY (Btu/lb): 4000 - 20000

¥ STAGNATION PRESSURE (atm):

FLAT-FACE MODEL 0.005 - 1.2

WEDGE MODEL 0.0001 - 0.15

¥ HEATING RATES (Btu/ft ^{2}-sec):

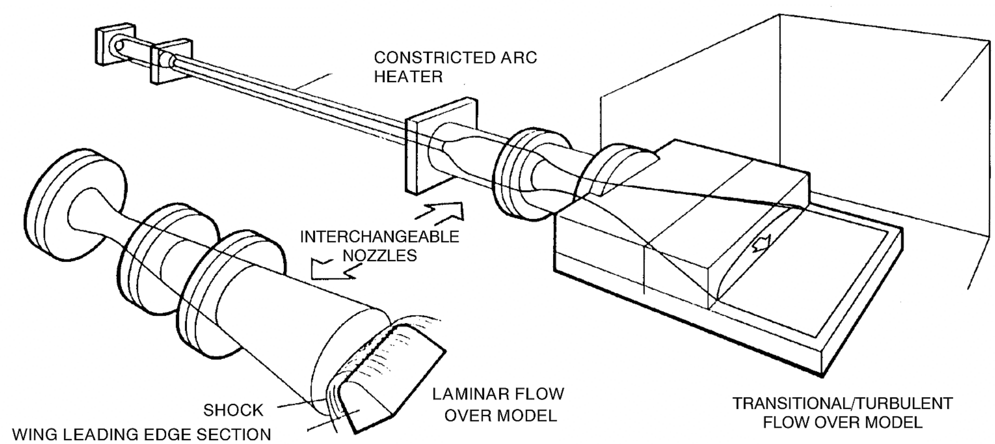
FLAT-FACE MODEL 20 - 660

WEDGE MODEL 0.5 - 45

¥ SAMPLE SIZE (ft):

FLAT-FACE MODEL Up to 1.5

WEDGE MODEL Up to 2.5 × 2.5



ArcJet Facility Capabilities

Interaction Heating Facility

- 60-MW power (highest in NASA)
- Enthalpy from 3000 to 20000 Btu/lb
- Stagnation pressure from 0.01 – 1.2 atm
- Nozzles size from 6 to 41-inch
- Sample size up to 12” diameter
- Semi-elliptic nozzle for flat samples up to 2 ft by 2 ft

Panel Test Facility

- 20-MW power
- Enthalpy from 3000 to 15000 Btu/lb
- Surface pressure 0.0006 – 0.05 atm
- Semi-elliptic nozzle 4” x 17” exit
- Flat samples up to 16” by 16”

Aerodynamic Heating Facility

- 20-MW power
- Enthalpy from 500 to 15000 Btu/lb
- Stagnation pressure 0.005 -0.15 atm
- Nozzles size from 7 to 36-inch
- Sample size up to 8” diameter
- 5-arm insertion system for maximum testing efficiency
- Gases: air and Nitrogen

Turbulent Flow Duct

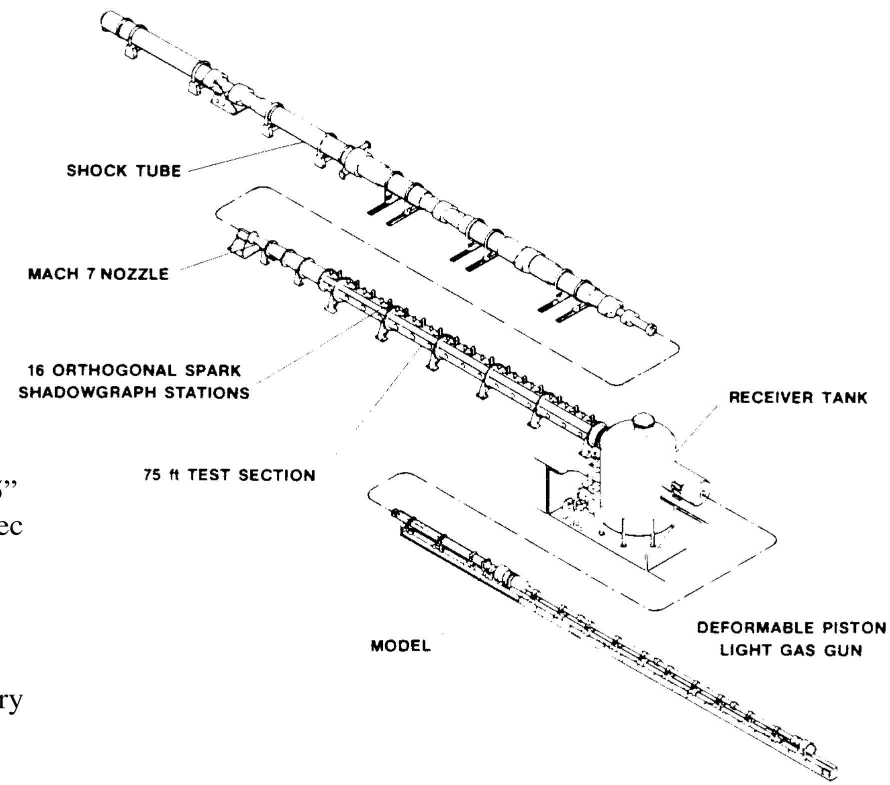
- 12-MW power (Huels heater)
- Enthalpy from 1300 to 4000 Btu/lb
- Surface pressures 0.02 to 0.15 atm
- Fully turbulent supersonic flow
- Nozzle exit 2” x 9”
- Sample size 8” x 10” or 8” x 20”
- Shear levels 1-15 psf
- Gases: air and Nitrogen

Hypervelocity Free-Flight Facility

- **HFFF is the Agency's <u>only</u> Aeroballistic capability, providing critical aerodynamic parameters (such as lift, drag, pitching moment coefficients, dynamic stability, etc.) at very high velocities (5-8km/sec)**
- **Only ballistic range in the nation that is capable of testing in atmospheres other than air**

DIMENSIONS OF TEST SECTION

- **Length, ft 75**
- **Diameter, ft 3.5**



PERFORMANCE SUMMARY

• Guns:	.28", .5", 1" and 1.5"
• Velocity:	5,000 to 30,000 ft/sec
• Maximum Reynolds Number:	2 x 10^6 1/ft
• Model acceleration:	1.5 x 10^6 g
• Model Mass:	5 to 100 gm
• Range Pressure:	0.03 - 760 torr
• Test Gas:	air, N_2, CO_2, arbitrary
• Range Temperature:	270° K
• Range Humidity:	0 to atmospheric