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Ames Research Center

Entry Systems and Technology Division

Relevant Ground Test Facilities for Outer Planet Entry Missions at NASA Ames Research Center

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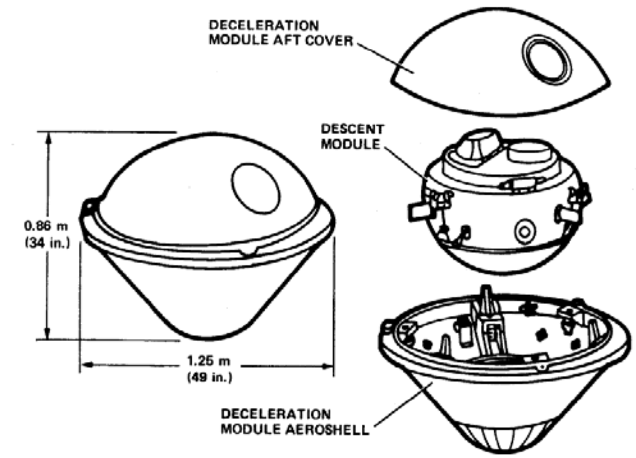
OPAG Meeting, January 2014

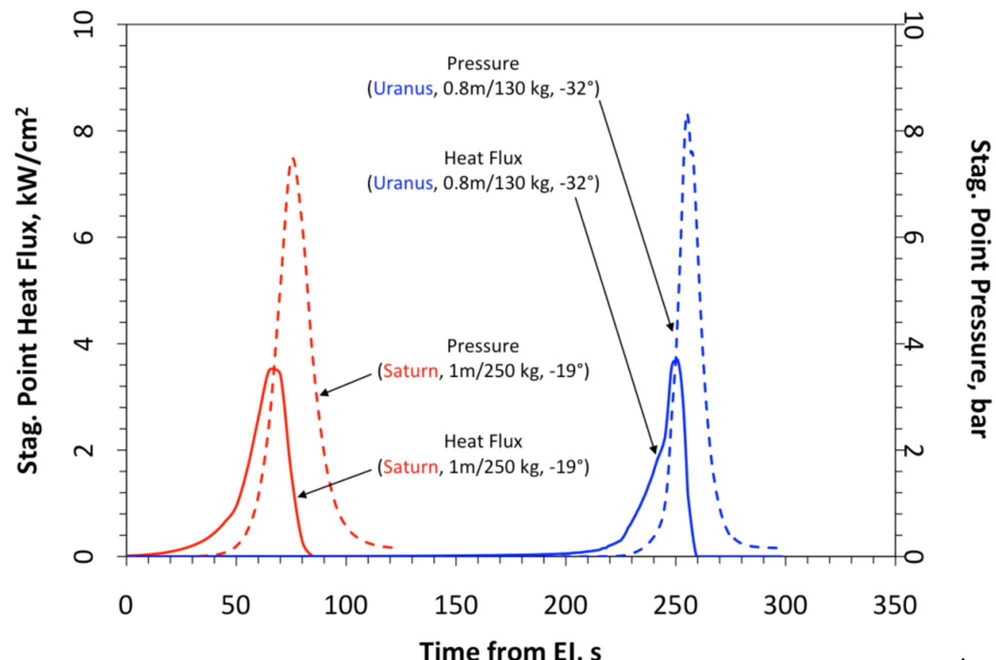
Outer Planet Entry Environments

Entry Systems and Technology Division

- **Entry missions, such as probes to Saturn or Uranus, require the Thermal Protection System (TPS) materials to protect against the extreme environments**
  - **TPS material response is highly nonlinear and depends on factors such as heat flux, pressure, shear, gas composition, etc.**
  - **Outer planet ballistic entry missions will experience very high heat fluxes and pressures (up to ~5000 W/cm^2 and ~10 atm)**
- **Achieving these conditions simultaneously in one ground test facility is challenging**



Galileo Deceleration Module

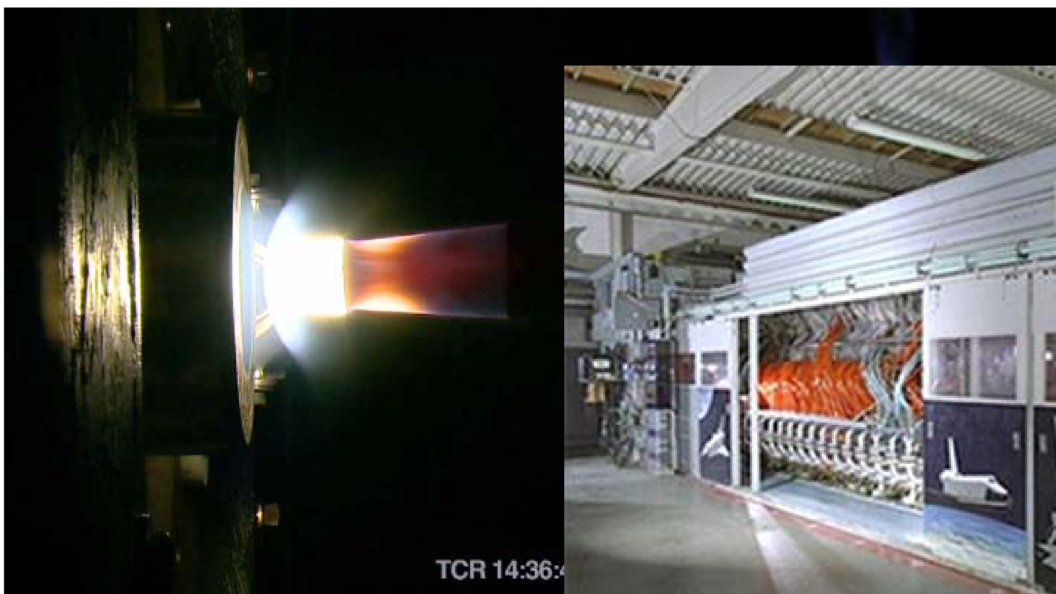


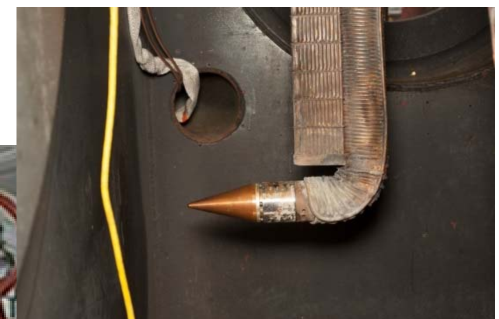
SMD Outer Planet Entry Tasks

- **Recognizing the importance of appropriate ground testing and analysis to support Outer Planet entry conditions, SMD funded 4 tasks relevant to Saturn and Uranus missions in FY12/13:**
  - **Woven TPS project initiation (Raj Venkatapathy's presentation, next talk)**
  - **Development and installation of 3" nozzle for the Interaction Heating Facility (IHF) arc jet**
  - **Chemical kinetic effects on aeroheating uncertainties, including shock tube testing**
  - **Roughness induced heating augmentation, including ballistic range testing**

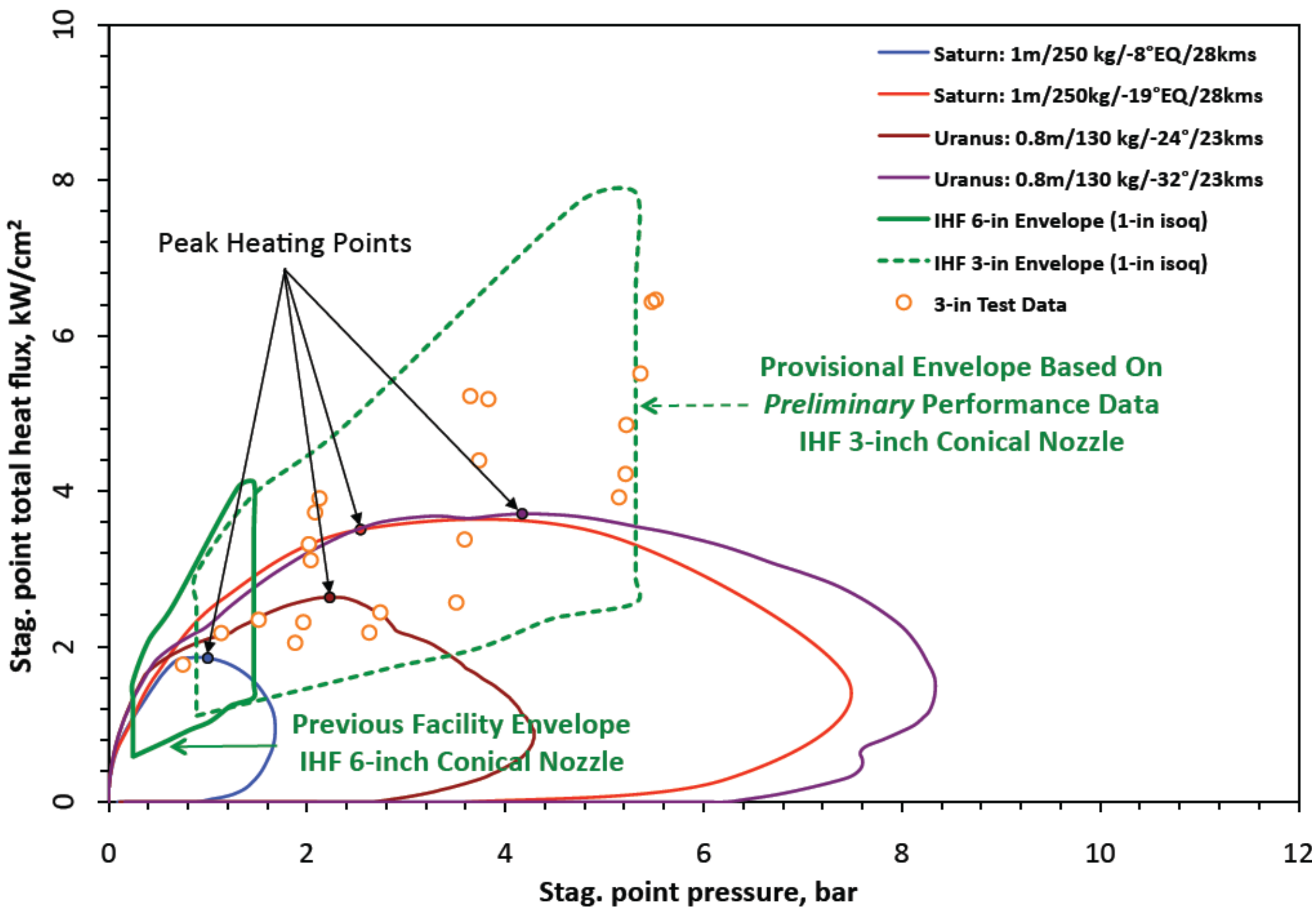
NASA Ames Arc Jet IHF: 3” Nozzle

- **SMD Outer Planets recently funded the implementation of a new nozzle for the Interaction Heating Facility (IHF) arc jet**
  - **3” nozzle completed and tested in September 2013**
  - **Achieves higher heating and pressure conditions than previously possible in IHF**
  - **Greatly enhances ability to develop and qualify TPS materials relevant to Outer Planet missions**





ARC IHF: 3” Nozzle Operating Envelope



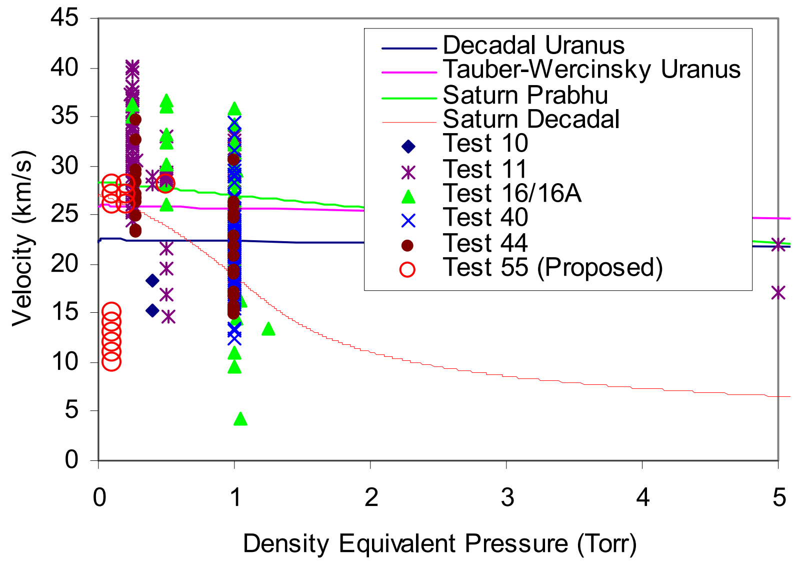
High heat fluxes and pressures are relevant to Outer Planet entry conditions, as well as high speed Earth return and Venus probe missions

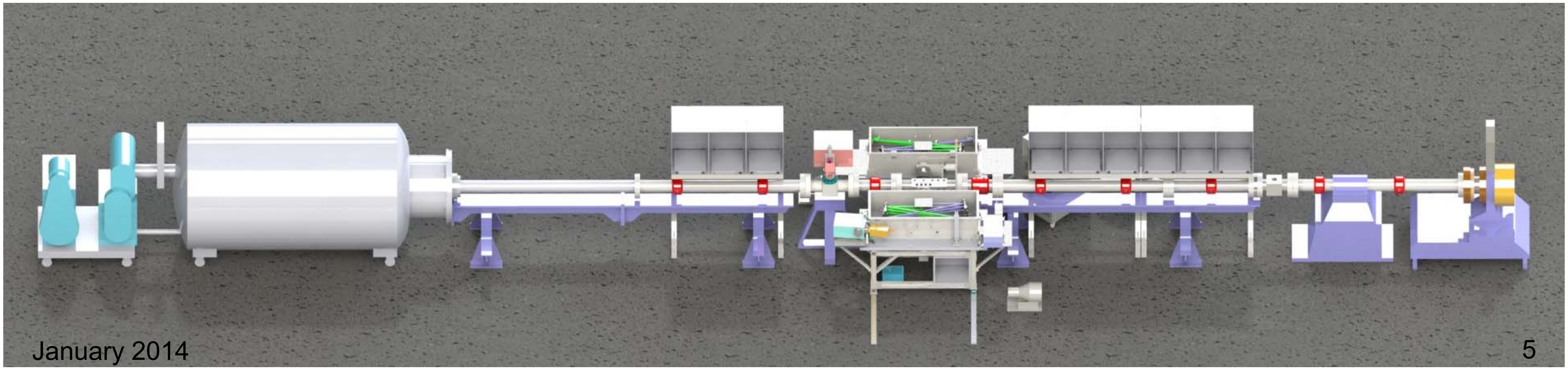
Shock Tube Studies for Saturn/Uranus Entry

Entry Systems and Technology Division

- **The Electric Arc Shock Tube (EAST) at NASA Ames is the agency's only facility capable of generating flight similar environments (simultaneous enthalpy, pressure, and gas composition)**
  - **Test times too short for material response studies**
  - **Tests in EAST have been used to validate and build aerothermal models for radiative heating and reaction kinetics**
- **A limited number of tests for Hydrogen mixtures have been performed in EAST in the 70s and more recently in '99, '05.**
- **New tests are being planned this FY to take advantage of significant upgrades to the facility**

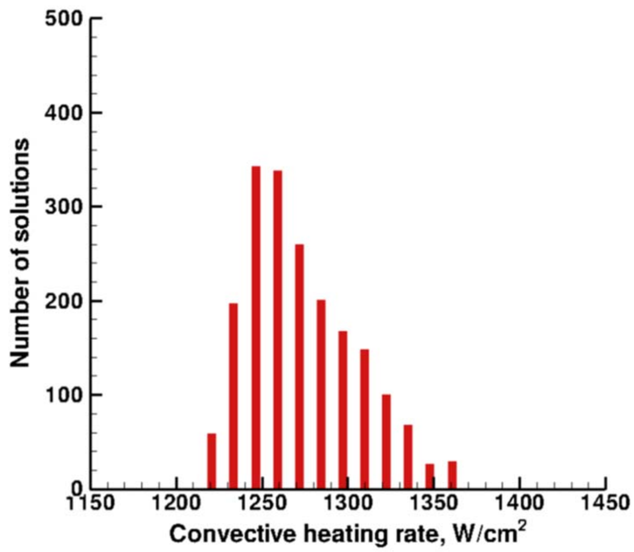
Pressure/Velocity Map of EAST Tests in H_2 mixtures



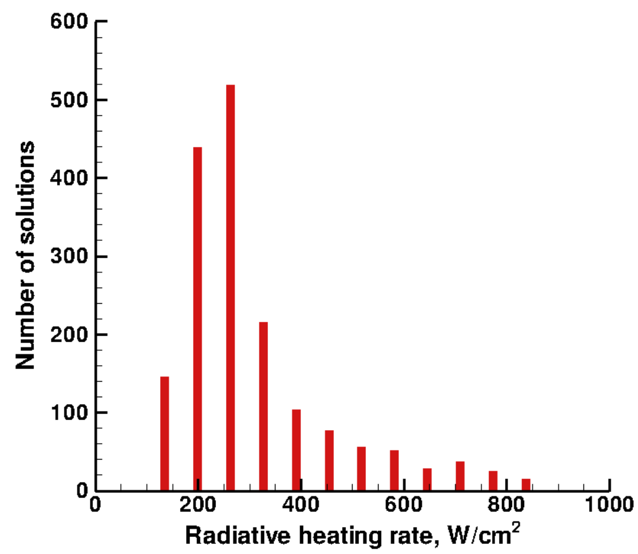


Aerothermal Uncertainty Study in EAST

- **SMD Outer Planets recently conducted a study of the impact of aerothermal uncertainties on entry heating predictions**
  - **Uranus uncertainties were small (2.5%) unless the walls were non-catalytic to H recombination, where the uncertainty could increase up to 25%**
  - **Saturn uncertainties in Convective Heating were ~6%, while Radiative Heating uncertainties were as much as 3x (8-40% of Total Heating)**
- **Tests planned in EAST:**
  - **Directly measure radiance for Saturn-similar entry environments**
  - **Measure H recombination rates at conditions representative of the boundary layer for Uranus entry**



Probability distribution for Convective Heating (Saturn)



Probability distribution for Radiative Heating (Saturn)

NASA Ames Free Flight Ballistic Range

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Facility designed to study entry probe aerodynamics and aerothermodynamics

Model vehicles, launched from a gun, fly ballistic trajectories through an enclosed 34 m long flight range. Test gas selected to simulate flight through planetary atmospheres.

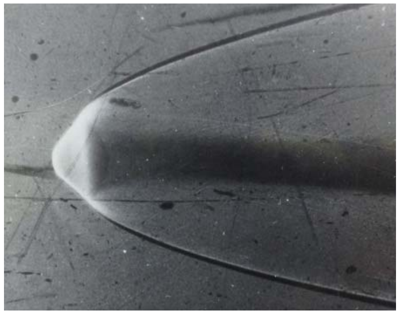
Performance Envelope:

Velocity:	0.2 km/s to 8.5 km/s
Static Pressure:	$4x10^{-5}$ to 1 bar
Test gas:	Air, N_2, CO_2, **He/H_2**, Ar, etc.
Reynolds number:	$0.03x10^6$/m to $500x10^6$/m
Max model diam:	0.038 m

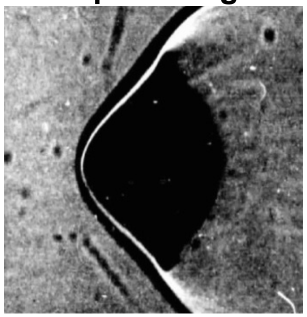
Galileo Probe Free Flight Testing

Shape change of carbon-phenolic models measured in high radiative heating environments (1 MW/cm^2 achieved by flight through Xenon)

Shock Radiation



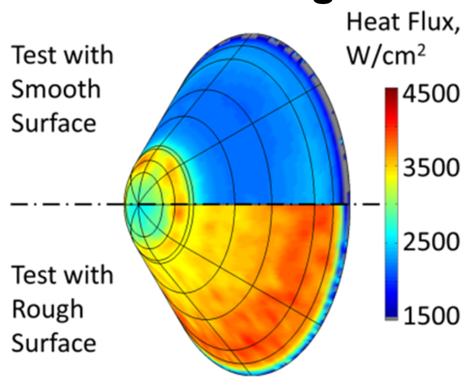
Shape Change



Park and De Rose, NASA TM 81209

Heat Flux Augmentation due to Roughness

Effects of surface roughness on convective heating to probe geometries measured at various conditions and test gases



Wilder, Reda, and Prabhu, to be presented at the AIAA Aerospace Sciences Meeting, January 2014 (AIAA-2014-0512)

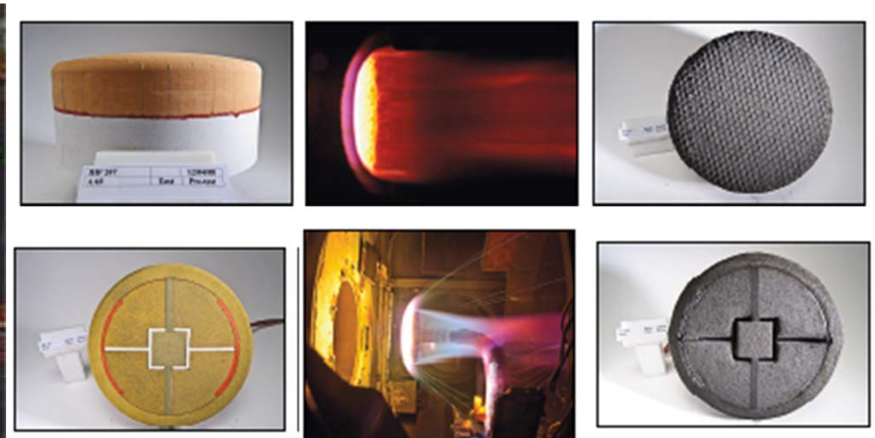
Summary

- **Understanding the aeroheating on entry probes to Outer Planet destinations involves complex phenomena (material/atmospheric flow interaction leading to surface roughness, chemical kinetic rates, etc)**
  - **Further testing is planned for this year for radiative heating effects at Saturn**
  - **Surface roughness effects are significant and will need to be incorporated during mission planning (not currently accounted for in aeroheating predictions)**
- **Once the entry environments have been defined for a mission concept, the TPS material response can be tested at high heat fluxes and pressures in the IHF arcjet at Ames**

BACKUP

Arc Jet Testing

- **Arc jets are capable of producing controllable and long duration high-temperature environments that simulate flight hypersonic entries**
  - **Only 2 arc jet facilities exist in the US that are capable of delivering sufficient power for high heat fluxes: ARC Interaction Heating Facility (IHF) and AEDC**
  - **AEDC produces environments too high in pressure (~100 atm)**
  - **Until recently, IHF was not capable of delivering both high heat flux and high pressure**



Woven TPS (HEEET) Testing in 3" Nozzle

Pre-test

Post-test

- **Tested at facility maximum conditions (5000 W/cm^2, 5 atm)**
- **1" diameter flat face coupons**
- **Evaluated different resin loads—all performed well (5 samples plus one with seam)**
- **Lessons learned—extreme environment testing requires redesign of current model holders**