VeXAG Technology Forum
Facilities Overview

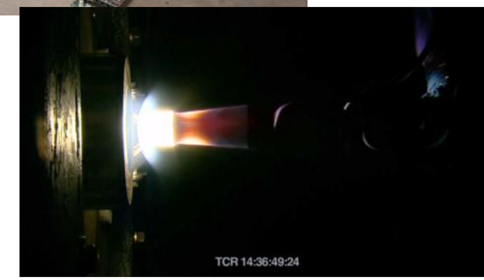
Tibor Kremic

Inputs provided by Helen Hwang, Sabrina Feldman,
Natasha Johnson, and others

Nov 19, 2013

Outline

- Introduction
- Simulation Facilities
- Entry/Descent/Landing Facilities



- <u>Introduction</u>

- Successful proposal and execution of future Venus missions will require the existence of, and access to, specialized facilities

- Simulation needs – For science, development/test, and qualification
  - Accurately simulate conditions the instruments or space craft systems will encounter during a Venus mission
    - Atmospheric missions: Chemistry (e.g. sulfuric acid clouds), temperature, pressure)
    - Surface missions: Temperature, Pressure, Chemistry, “Wind”?
  - For some applications, size of facility will be important

- Entry Condition Testing – for entry system development/test & qualification
  - Create the aerothermodynamic entry environment (heating and pressure conditions and aerodynamics)

Atmosphere and Surface Simulation | Two Unique Needs for Venus | Entry Condition Testing

Venus Simulation

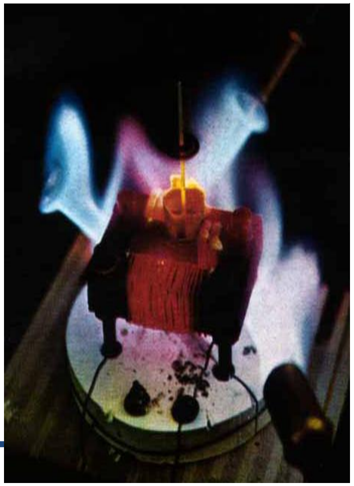
Venus Simulation

- Science
- Test / Qualification

Science

- Significant unanswered questions exist about the chemistry, reaction rates, surface/atmosphere interactions and the relevance to Venus atmosphere and climate, and many other questions
- Answering these questions requires:
  - Accurate simulation of the expected conditions and
  - Short and long term experiments with accurate measurements
- The right capabilities may enable direct science benefits

High Temperature GE Motor (Hunter 2013 VeXAG slides)



Test / Qualification

- Instruments and spacecraft systems intended for use in the Venus atmosphere and at the surface will need testing during development and for flight qualification
- Lack of accurate simulation capabilities and test data will increase risk of proposal success and the mission itself

Simulation Chamber Summary

Location	Volume (ft^3)	Dimensions (ft by ft)	Pressure (bar)	Temperature (°C)	Species	Notes	Public/ROSES Availability	
NASA JPL	0.0009	.049 by .49	1 to 1000	20 to 1000	CO_2, N_2, SO_2	Accelerated Weathering	Yes	
MIT	0.001	0.04 by 1	1 to 200	20 to 700	CO_2	Pressure or temperature	No	
LANL	0.005	0.04 by 1	1 to 10,000	20 to 150	CO_2	LIBS/RAMAN	No	
Univ. of Wisconsin	0.008	0.05 by 1	1 to 270	20 to 650	CO_2	DOE Reactor Corrosion	No	
MIT	0.02	0.08 by 4	1 to 200	20 to 700	CO_2	Pressure or temperature	No	
NASA GSFC	0.13	0.41 by 1	1 to 95.6	20 to 500	CO_2, N_2, SO_2	Materials	Yes	
NASA JPL	0.45	0.33 by 5.25	1 to103	20 to 500	CO_2, N_2,$H_2$0, SO_2, CO, He, Ne, Ar	RLVT, Optical Access	Yes	Would require some start-up investment
NASA JPL	0.5	.59 by 1.83	1 to 103	20 to 500	CO_2, N_2,$H_2$0, SO_2, CO, He, Ne, Ar	VMTF, Materials and Small Systems	Yes	
Georgia Inst of Technology	1.05	1.16 by 1	1 to 100	20 to 343	CO_2, N_2	Higher altitude only	No	
NASA Glenn	5.30	1.5 by 3	1 to 100	20 to 500	CO_2, N_2, SO_2	Any altitude, Under Construction	Yes	Would require some start-up investment
NASA Glenn	28.3	3 by 4	10^{-3} to 103	20 to 537	CO_2, N_2, SO_2, Ar, H_2O, CO, He, Ne, OCS, HCl, HF	Any altitude, Optical Access, Under Construction	Yes	

JPL Venus Materials Test Facility (VMTF)

- JPL's VMTF is used to identify materials and components that can be exposed to the Venus environment.

- Additionally, it can support pre-qualification testing of critical items in a simulated Venus atmosphere (equivalent temperature, pressure, and gas composition) to demonstrate environmental compatibility.

- It is plumbed for trace gases as well as the primary Venus atmosphere constituents (CO_2, N_2).

Venus Materials Test Facility

Facility Manager: Dr. Linda Del Castillo

Capability: 0.18 m dia × 0.56 m tall chamber, ≤500±15° C, ≤103 bars, CO_2 with trace gases

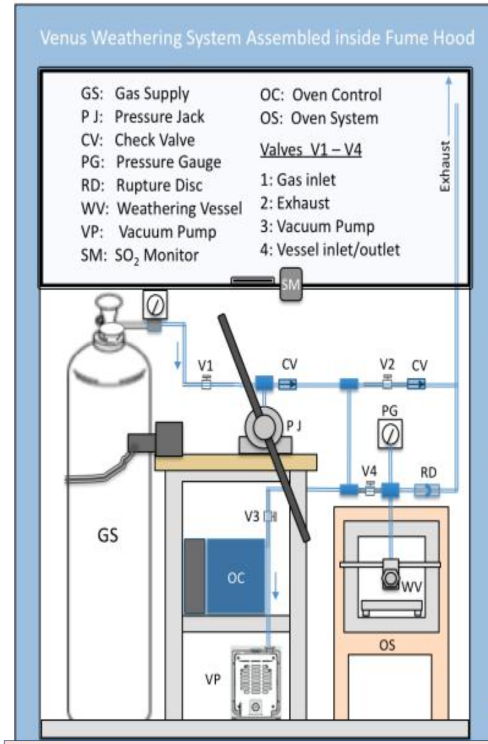
Use: Test materials compatibility and components in Venus surface conditions

Commissioned: Dec. 2008

JPL Venus Weathering Chamber (VWC)

- **The VWC is a unique facility for studying the weathering of basalt and other primary minerals on the surface of Venus to understand changes in mineralogy that have occurred due to interactions with the atmosphere.**

- **The chamber incorporates a novel pressure system for studying rock alteration under model Venus atmospheric conditions. By boosting specific gas densities (CO_2 and SO_2) above Venus' known partial pressures while maintaining the 462°C surface temperature, the chamber accelerates geochemical reaction rates to simulate years, decades, or even centuries of weathering.**



Venus Weathering Chamber

Facility Manager: Mr. David Aveline

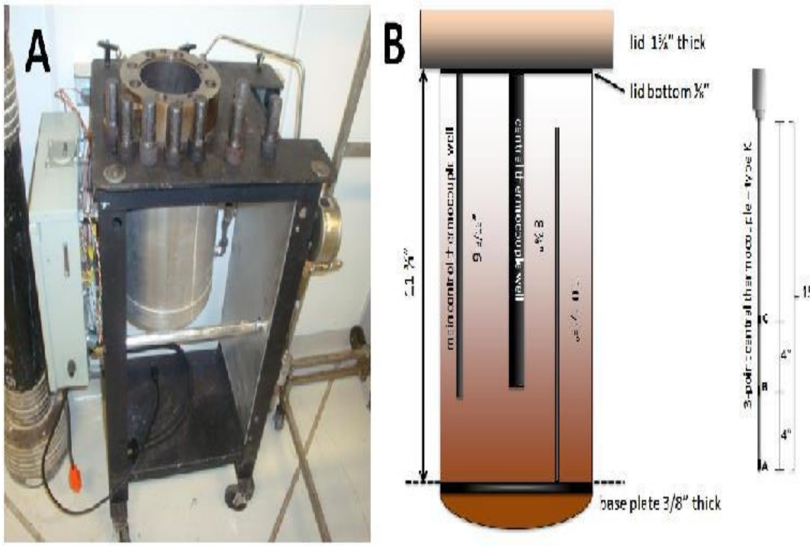
Capability: 0.015 m dia × 0.15 m long, ≤1000±1° C, ≤1000 bars, CO_2 with elevated partial pressure of N_2 and SO_2

Use: Accelerate rock weathering to emulate Venus geologic time

Commissioned: Sept. 2010

GSFC Venus In situ Chamber Investigations (VICI)

- .4’ x 1’ Chamber designed for short term component and materials testing
- Ideal for tests lasting a few hours to days
- Facility can provide real time monitoring of tested items via feedthroughs



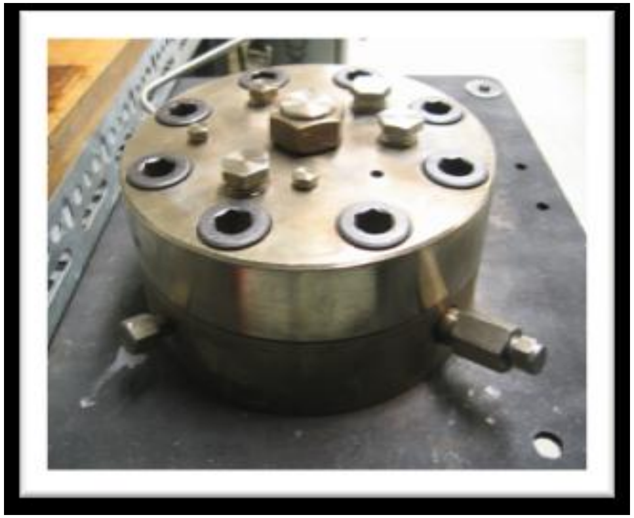
GSFC VICI

POC: Dr. Natasha Johnson

Capability: 0.41 ft dia × 1 ft tall chamber, Up to 500C and 95.6 bars,

Plumbed for CO_2 , N_2 and SO_2

Test materials compatibility and components in Venus surface conditions



Glenn Extreme Environment Rig (GEER)

GEER - Large volume chamber designed for short or long term science, materials, and full scale instrument and spacecraft system testing and qualification

National Aeronautics and Space Administration
Glenn Research Center at Lewis Field

Basic Capabilities

- 3 ft dia x 4 ft long internal volume
- 10^{-3} to 103 bar and 20 to 537C
- Ability to accurately control and measure known Venus atmospheric elements down to surface
  - 8 individual gas streams
  - PPB compositional accuracy
  - FTIR gas analyzer
- POC: Dr. Tibor Kremic or Mr. Dan Vento

Unique features

- Large volume
- Ability to handle known Venus atmospheric elements – unique liner approach
- Flexible infrastructure (will handle second or much larger chamber
- Designed for potential cold wall*
- Designed to allow simulation of changing atmosphere (e.g. drop of probe)*
- Scrubber system

* These features are not all immediately available

Currently In Commissioning Phase

Glenn Extreme Environment Rig (GEER)

GEER - Large volume chamber designed for short or long term science, materials, and full scale instrument and spacecraft system testing and qualification

C-2013-4436

Currently In Commissioning Phase

Venus EDL

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

POC: Helen H. Hwang

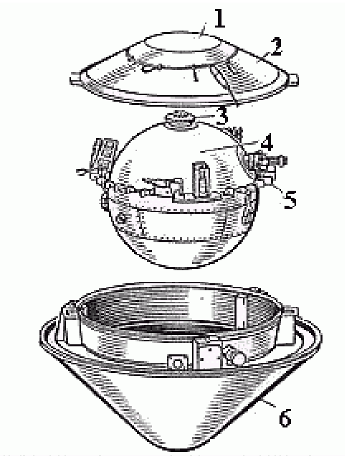
Helen.Hwang@nasa.gov

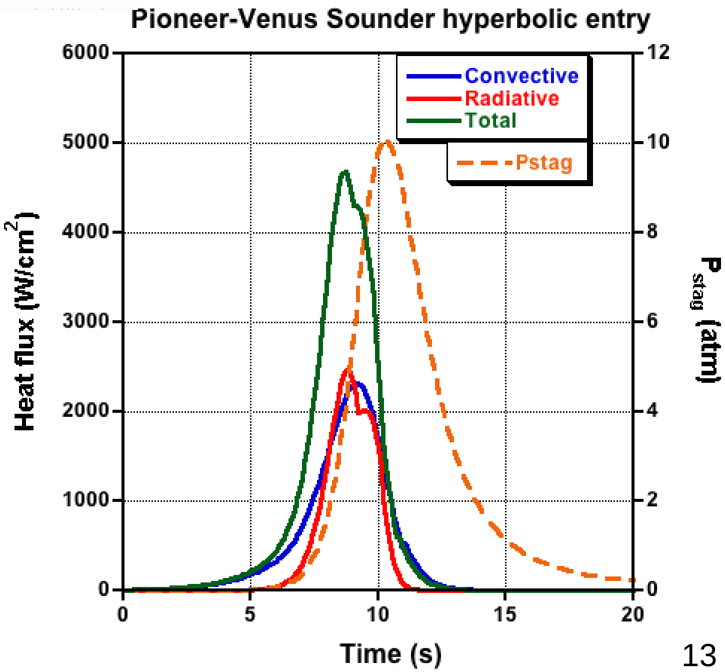
George Raiche, Dinesh Prabhu, Ethiraj Venkatapathy, Brett Cruden, Michael Wilder

VEXAG Meeting, November 2013

Venus Entry Environments

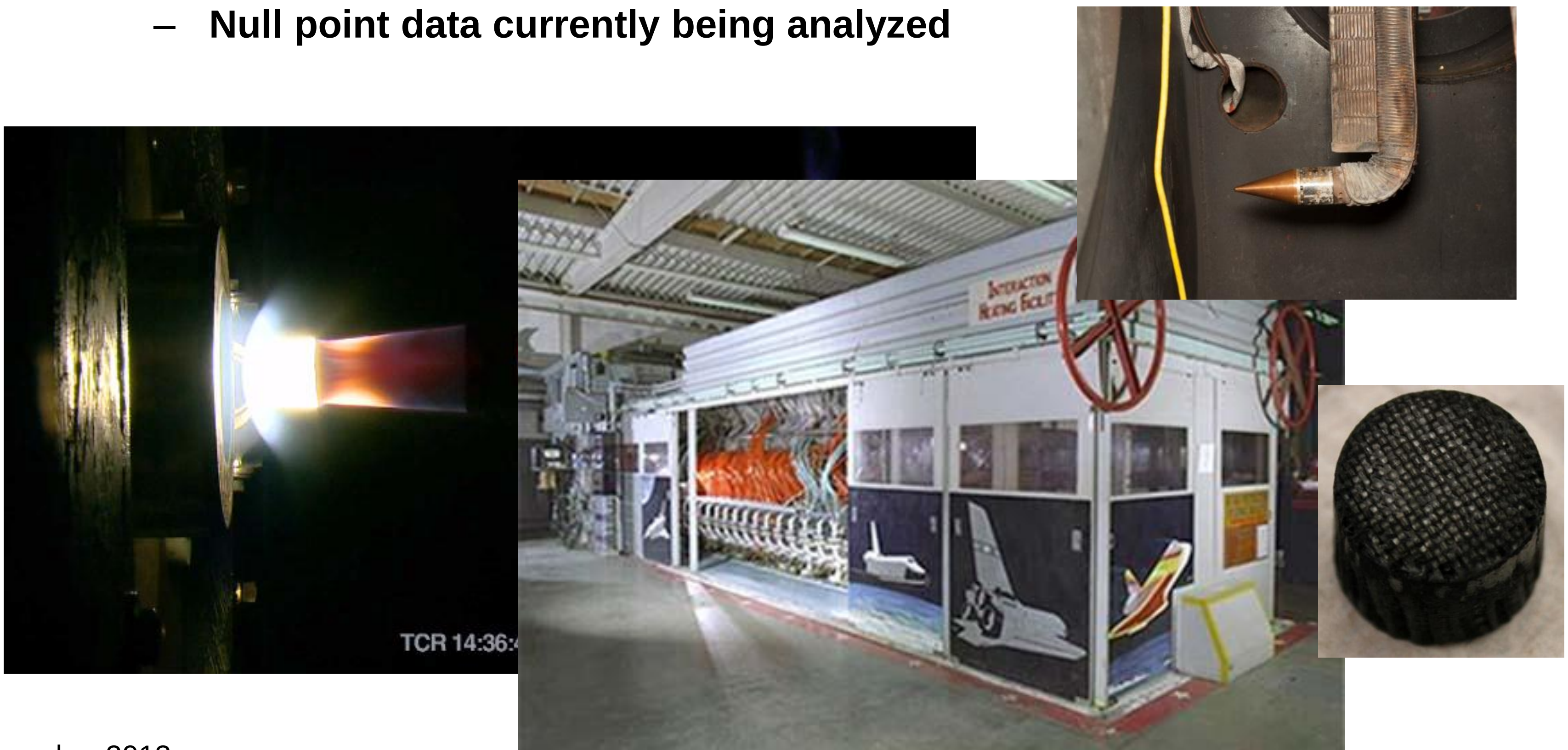
- **Entry missions, such as Venus probes or landers, require the Thermal Protection System (TPS) materials to protect against the extreme environments**
  - **TPS material response is highly nonlinear and depends on factors such as heat flux, pressure, shear, gas composition, etc.**
  - **Venus ballistic 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**





NASA Ames Arc Jet IHF: 3" Nozzle

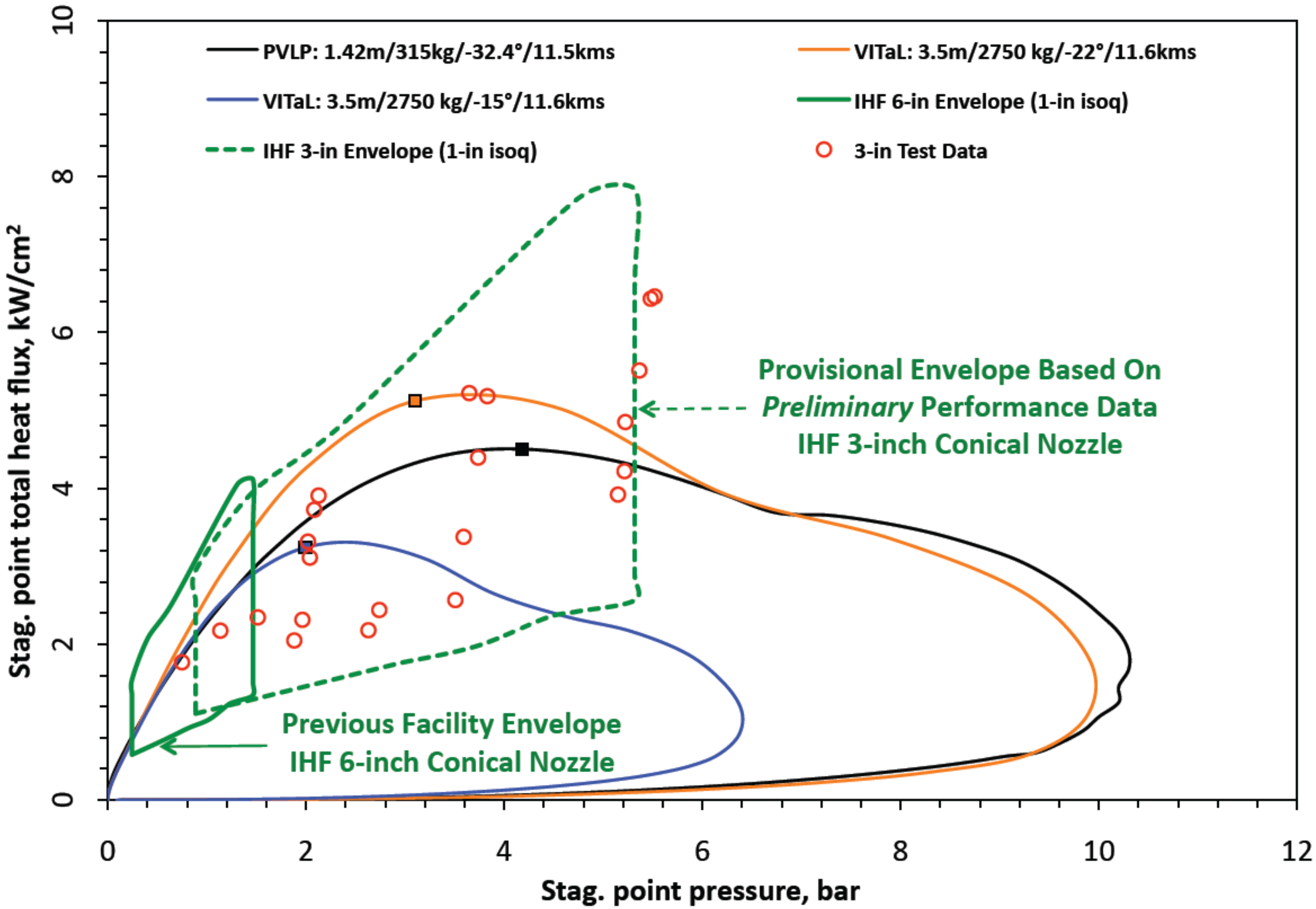
- **SMD Outer Planets recently funded the implementation of a new nozzle for the Interaction Heating Facility (IHF) arc jet**
  - **3" nozzle completed and tested in September**
  - **CFD calculations were used during both design and testing phase to guide the development of the test envelope**
  - **Null point data currently being analyzed**



ARC IHF: 3” Nozzle Operating Envelope

Ames Research Center

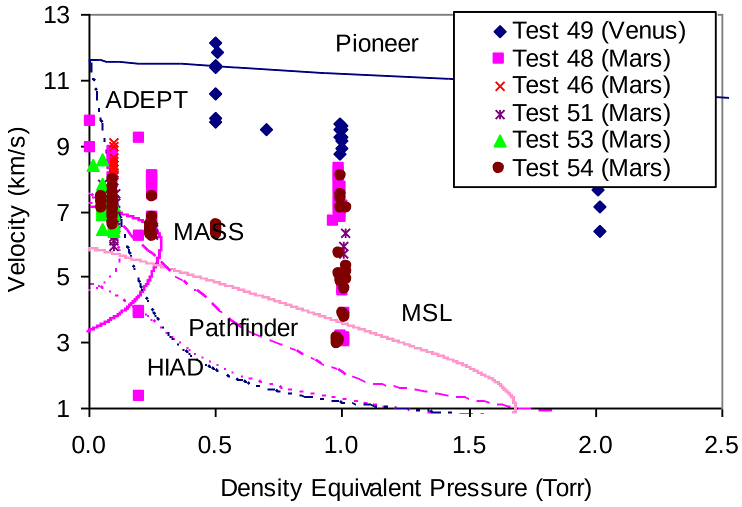
Entry Systems and Technology Division

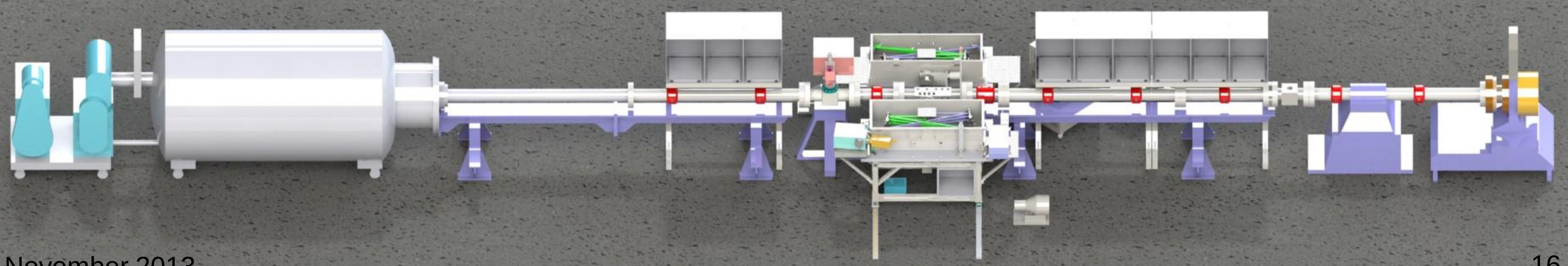


High heat fluxes and pressures are relevant to Venus entry conditions, as well as high speed Earth return and Outer Planet missions

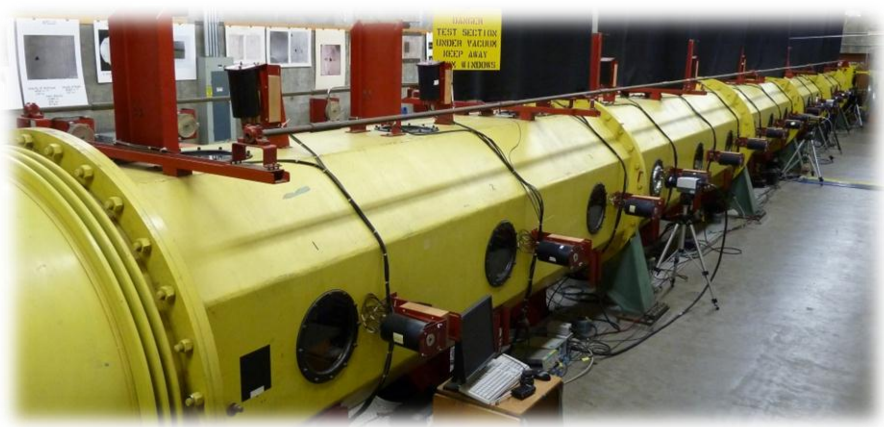
Radiative Heating for Venus Entry

- **Radiative heating scales as approximately V^8, therefore high velocity entries (e.g. Venus) have significant radiative heating**
- **The Electric Arc Shock Tube (EAST) at NASA Ames is the agency's only facility capable of generating radiative signatures representative of the flight environment**
  - **The shock tube is used for validating *aerothermal (radiation) models*, as opposed to Arc Jets which are used for validating material response models.**
- **Measurements can lead to significant reductions in uncertainties in radiative heat load (e.g., MPCV lunar return).**





NASA Ames Free Flight Ballistic Range



Models launched from a gun to fly ballistic trajectories through an enclosed 34 m long flight range to simulate flight through planetary atmospheres

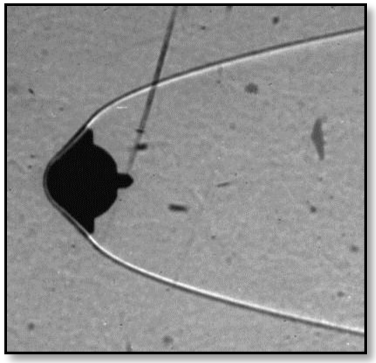
Performance Envelope:

Velocity*:	0.2 km/s to 8.5 km/s
Mach number:	0.5 to 25 (30 in CO_2)
Pressure:	$4x10^{-5}$ to 1 bar
Test gas:	CO_2, Air, N_2, He/H_2, Ar, etc.
Reynolds number:	$0.03x10^6$/m to $500x10^6$/m
Max model diam:	0.038 m (hypersonic)
	0.06 m (supersonic)

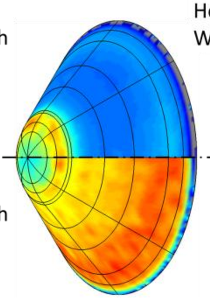
Test Capabilities:

- **Aerodynamics**
  - Measurements used to establish aerodynamic databases for probe geometries
  - Simultaneous measurements of static and dynamic aerodynamic characteristics
  - Can test lifting geometries
- **Aerothermodynamics**
  - Measure augmented heating due to surface roughness caused by ablation
  - Measure heating augmentations due to turbulence

Pioneer-Venus Probe Model



Heat Flux Augmentation due to Surface Roughness



70º Sphere-Cone in Flight through CO_2 at 5 km/s

Backup

Technology Questions

- What science is enabled and what is limited by existing technologies
- What science goals are driven by technology development? What synergies may change the way Venus science is done? How should we prioritize technologies?
- What are gaps due to lack of communication
- What are funding gaps

Non-NASA Simulation Test Facilities

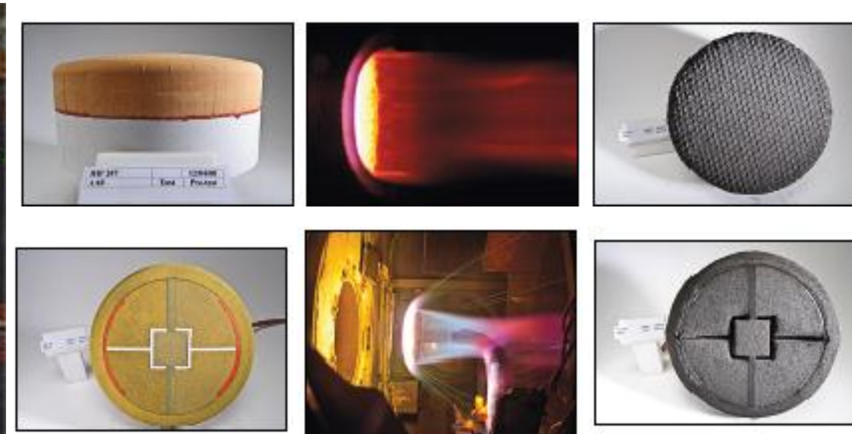
- As shown in the table on slide 5, a number of other simulation chambers exist across the US
  - These are not available for access outside the respective institution
- In addition to those listed, a number of other chambers also exist that can contain high temperature and pressure conditions, however, they are generally designed for a specific applications (E.g combustion chambers) and would not be practically useable for Venus simulation purposes

Non-NASA Entry System Test Facilities

- Other facilities exist within and outside the US that may cover some aspects of the entry Venus conditions   e.g. The Arnold Engineering Development Center (AEDC) houses some specialized test facilities including arc driven facilities (HEAT H1-H3)
- AEDC: can simulate stagnation pressures well over 100 bar but can not each the needed heat fluxes

Arc Jet Testing

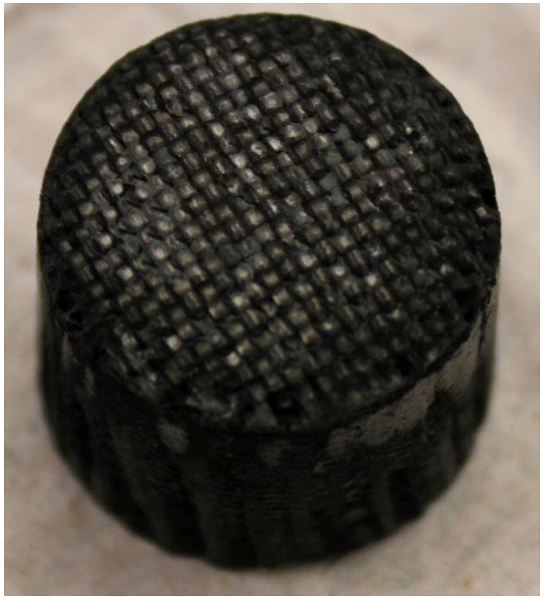
- **Arc jets are capable of producing controllable and long duration high-temperature environments that simulate flight hypersonic entries**
  - **Only 2 arc jet facilities exist in the US that are capable of delivering sufficient power for high heat fluxes: ARC Interaction Heating Facility (IHF) and 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

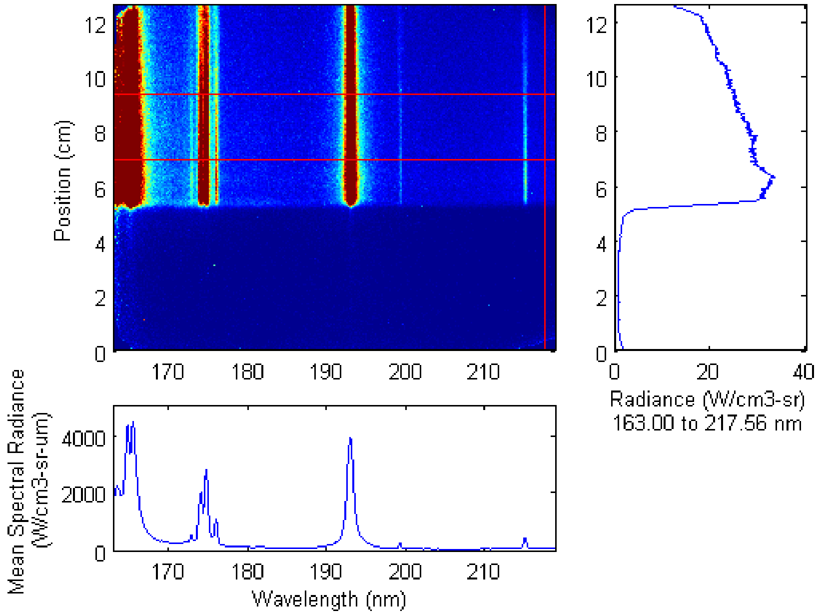


- Tested at facility maximum conditions (5000 W/cm^2, 5 atm)
- 1” diameter flat face coupons
- Evaluated different resin loads—all performed well (5 samples plus one with seam)
- Lessons learned—extreme environment testing requires redesign of current model holders

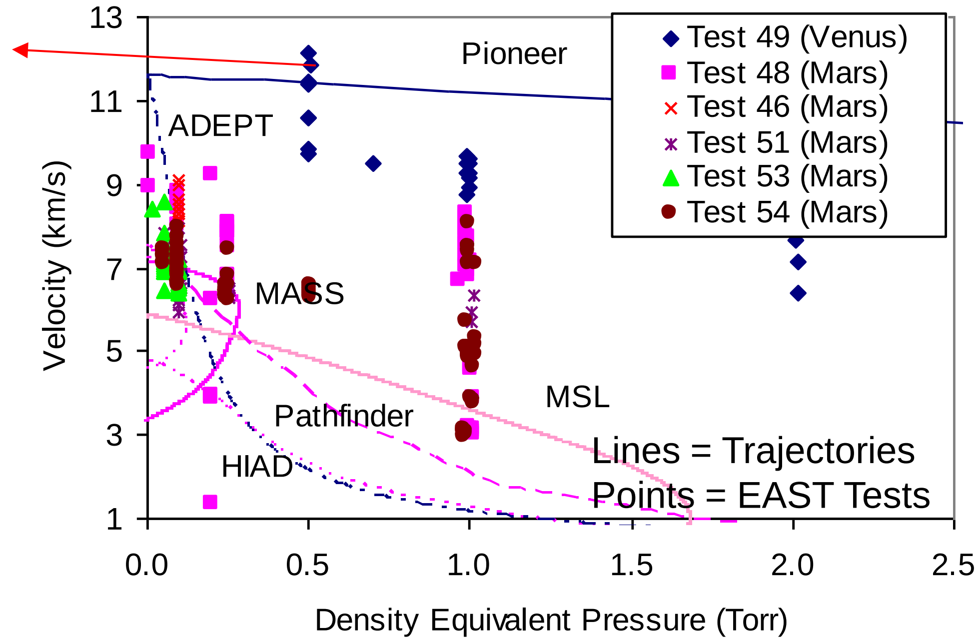
Venus-Like Entries in EAST

Entry Systems and Technology Division

Representative EAST Data, at 11.9 km/s



Pressure/Velocity Map of EAST Tests in CO_2/N_2



- **Each EAST test measures radiance as a function of wavelength and position behind the shock at a particular (p, v) trajectory point. The (multi-dimensional) integral of this data determines heat flux.**
- **A 29-shot test series for a representative ballistic Venus entry was performed in EAST in 2009. Comprehensive evaluation would warrant additional testing**
- **Newer technologies such as ADEPT would experience peak heating at much lower pressure/density than previously tested. Testing in this regime is being enabled via refurbishment of the Low Density Shock Tube (LDST)**