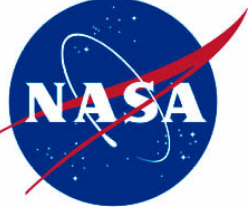


Thermal & Fluids Analysis Workshop TFAWS 2004

Jet Propulsion Laboratory
Pasadena, CA. August 31, 2004

NASA Reentry Material Technology Test and Evaluation

Langley 8-ft High Temperature Tunnel Aerothermal Ground Testing

Gerald Russell / AMRDEC
Joe Raymond & Forrest Strobel/ ITT
Jimmy Lee, Susan Spencer, Tony Oneil/NASA MSFC

September 2, 2004

Aerothermal Ground Test Objective

- **Conduct a screening test and evaluation program to identify best candidates for hypersonic/space exploration flight test demonstration**
- **Maximize leveraging/collaboration with NASA/DoD programs requiring material aerothermal test data**
  - NASA Aerocapture/Hypersonics
  - DARPA/Air Force (FALCON/CAV/RESE, SBIRs)
  - NAVY (HyFLY, SBIRs)
  - Army (Hypersonic Scramjets, Missiles, SBIRs)

Ground Testing Will Evaluate:

- **Seal & Attachment Technology**
- **TPS Thermal Performance**
- **Instrumentation**
- **Bondline Performance**
- **TPS Candidate Technologies:**
  - Metallics
  - Blankets
  - Tiles
  - Ablative/decomposing
- **Instrumentation Technologies:**
  - Ablation Rate Sensors
  - Heat Flux Gages
  - Embedded Thermocouples

Ground Test Candidate Materials

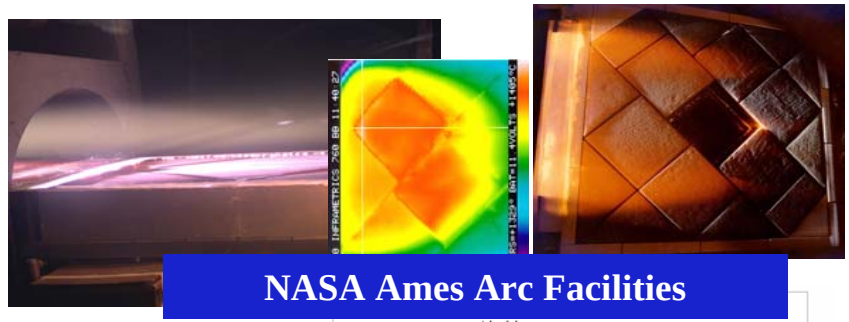
TPS Candidate	Classification	Vendor
CRI	Blanket/NASA	Boeing
AETB/TUFI	Tile/NASA	Ames Research Center
20° ply angle 2D C-C with RTV-12 (new MX-4830)	Carbon-Carbon/CAV	ATK Thiokol
Ceramic Foam	CMC Foam/NASA	Ames Research Center
SC-20	Ablative/NASA	Applied Research Associates
Hyperlite C	Ablative/NASA	Applied Research Associates
C-SiC	CMC/DoD/NASA	Physical Sciences Incorporated
MSTPS C-C RTV	Ablative/DoD/NASA	Aerothermo Technologies
RX2390	Ablative/DoD	Mineral Technologies
TMC	Metallic/NASA	FMW Composites
CeramARC	Ceramic/NASA/DoD	FMW Composites
Intergral TPS	Ablative/DoD	Vanguard Composites
20° ply angle 2D C-C with RTV-12 (FiberCote)	Carbon-Carbon/CAV	ATK Thiokol
20° ply angle 2D C-C with RTV-12 (Lewcott)	Carbon-Carbon/CAV	ATK Thiokol
Carbon-Carbon	Ablative/DoD/NASA	Fiber Materials Inc
Carbon Carbon-Silicon Carbide	Ablative/DoD/NASA	Fiber Materials Inc
HotBlox	Ceramic/NASA/DoD	Raytheon/American Technical Coatings
Acusil-2 Panel		AMRDEC/ITT
Molybdenum Plate	Calorimeter Plate	AMRDEC/ITT
TC Plugs/ARADS/Heat Flux Gages	Instrumentation Data	Possible Aerocapture Interest

Ground Aerothermal Testing

Ground Aerothermal Testing

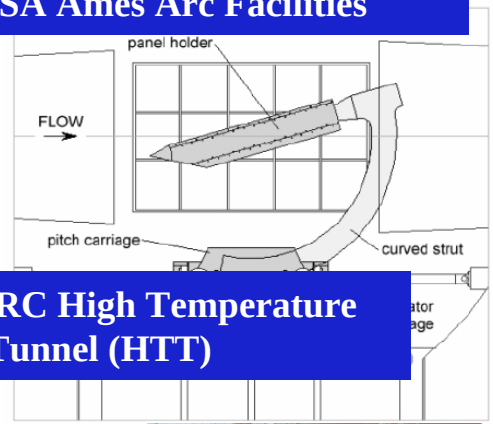
- Simulate aerothermal environments of interest
  - Shear
  - Recovery conditions
  - Pressure
  - Test duration (limited compared to flight test time)
- Conduct facility assessment for appropriate test validation
- Assess external TPS attachment and seal concept
- Collect thermal response data for model validation
- Assess flight instrumentation technology

Ground Aerothermal Testing

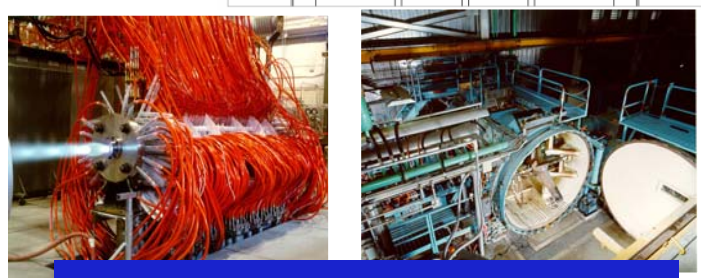


NASA Ames Arc Facilities

Facility Selection

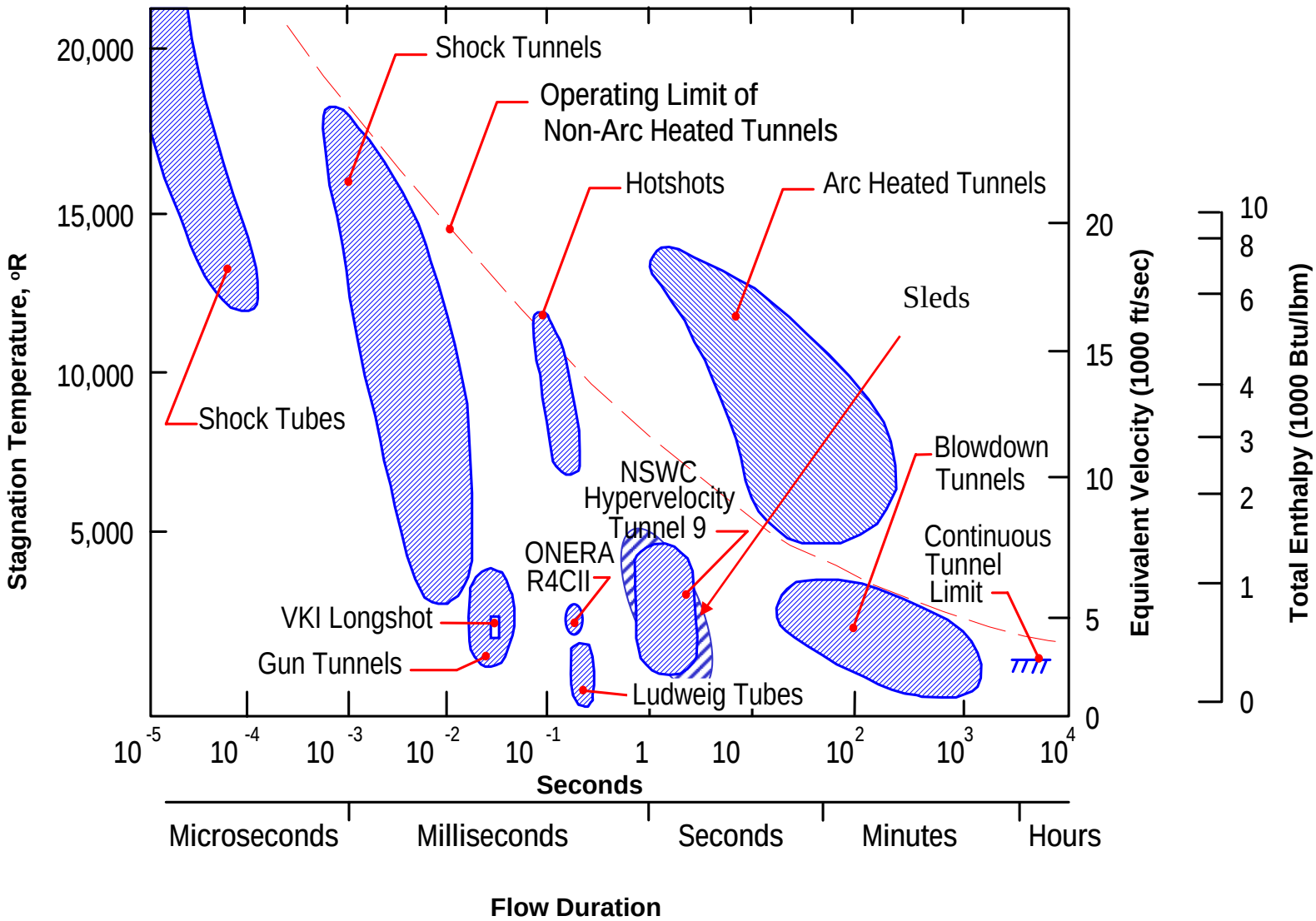


NASA LaRC High Temperature Tunnel (HTT)

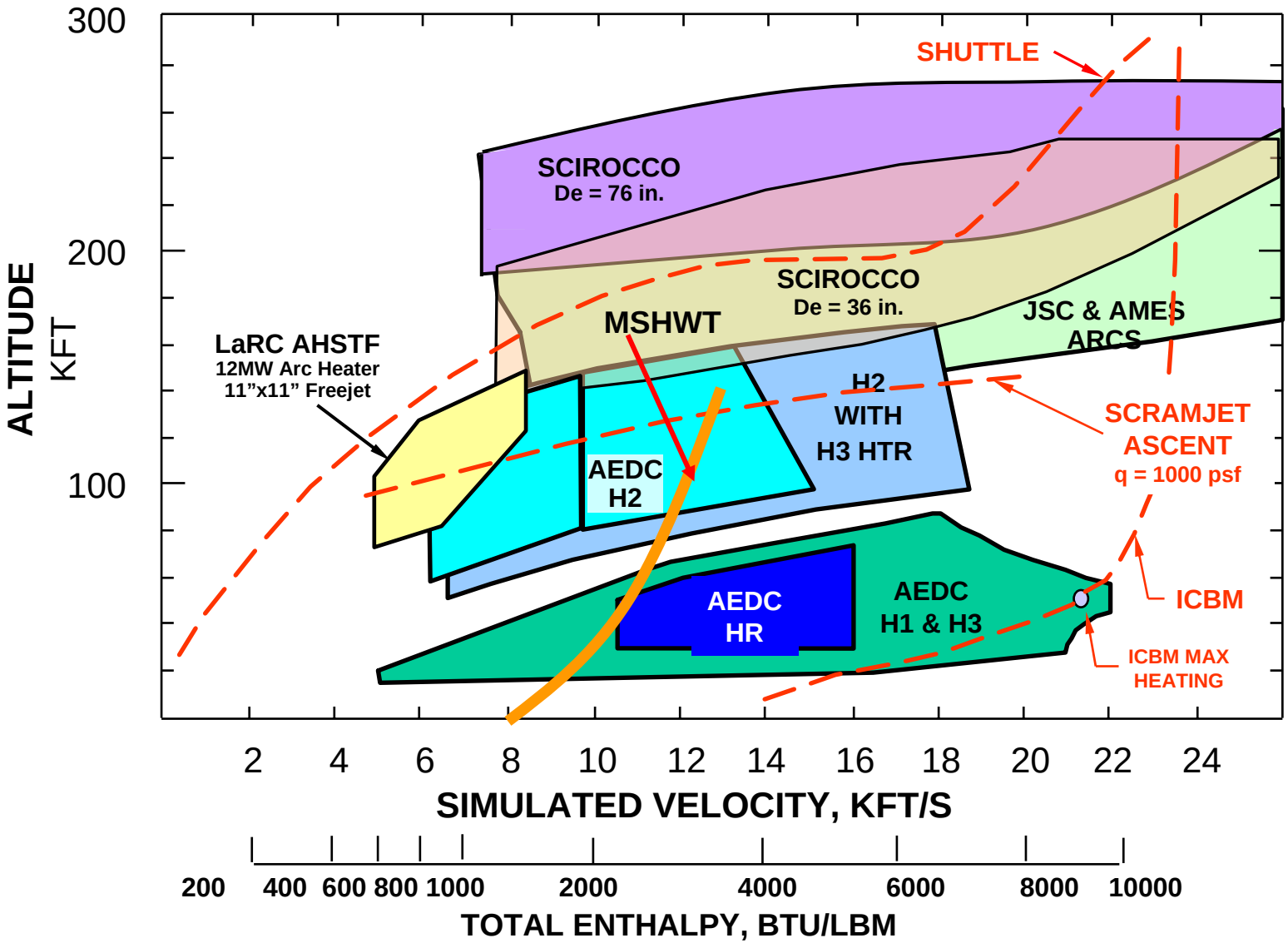


AEDC H2, or H3 Arc Heater Large Core (50,70 MW)

Ground Aerothermal Test Facility Conditions



ARC Test Facility Condition Envelopes

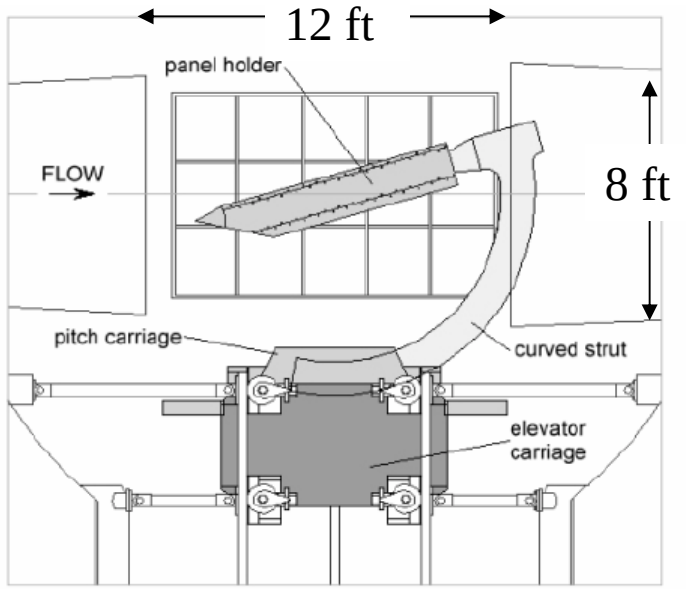


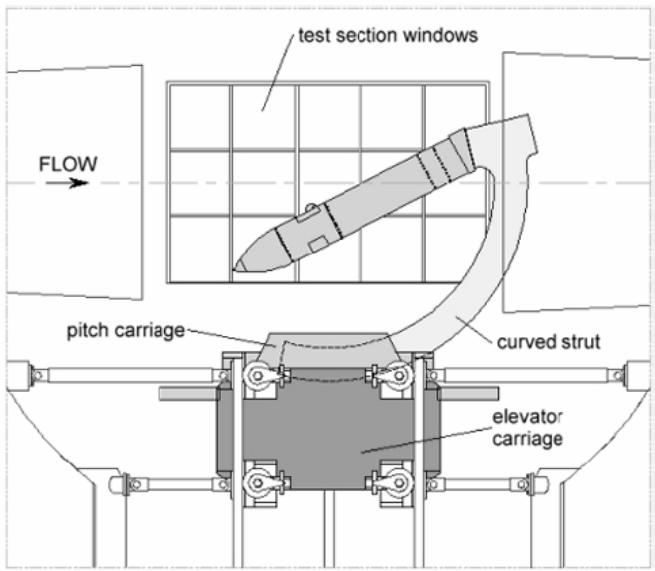
Facility Comparison

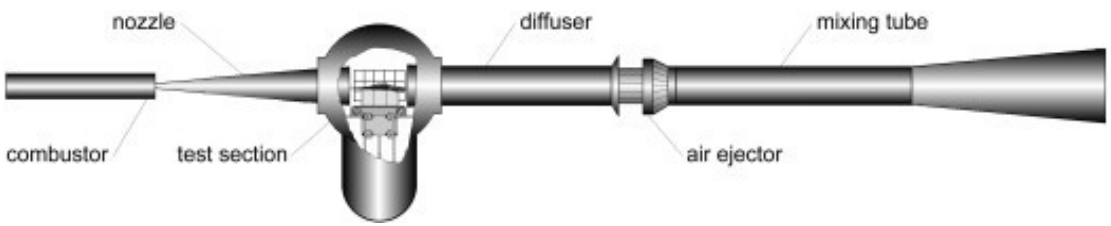
Parameter	Flight	AEDC H2	LaRC 8-ft HTT	AMES PTF
Mach	**5 - 10**	**5.9 - 7.8**	**7**	**5.5**
Enthalpy (BTU/lbm)	**492-1268**	**1800 – 2500**	**785 BTU/lbm max (Temp = 3650 R)**	**2000 - 14000**
Heat Flux (BTU/ft^2-sec)	**15 - 110**	**50**	**5.9 – 39.8**	**0.5 - 75**
Edge Pressure (atm)	**0.04 - 0.28**	**0.12**	**0.025 - 0.129**	**0.0005 – 0.05**
Test Duration	**600 seconds**	**Up to 20 minutes**	**120 seconds**	**30 minutes**
Test Article Size	**Reentry Vehicle**	**Up to 24 inch nozzle exit available**	**8 ft diameter by 12 ft long test section. Full size vehicle can be tested or full scale panel utilizing the HTT panel holder.**	**Test fixture for 14” x 14” flat panels**
Comments	**Pull out condition is severe**	**High enthalpy facility. Expanding flow in test section produces non-uniform conditions on test panel**	**Matches most parameters of interest but is limited in test duration**	**High enthalpy low pressure. Would not provide a good evaluation of the sealing concepts.**

Langley 8-ft HTT Test Section

- Mach 7 flow provided at 8-ft diameter nozzle exit
- Test Section is 12-ft long
- A 16-ft. I.D. pod intersects the test section from the bottom, containing a model injection system that can insert the model into the flowfield once steady flow has been achieved
- Diffuser system for attaining supersonic flow
- A 3.5 ft. x 5 ft. panel test fixture is available







Selected Test Conditions: LARC 8-ft HTT Panel

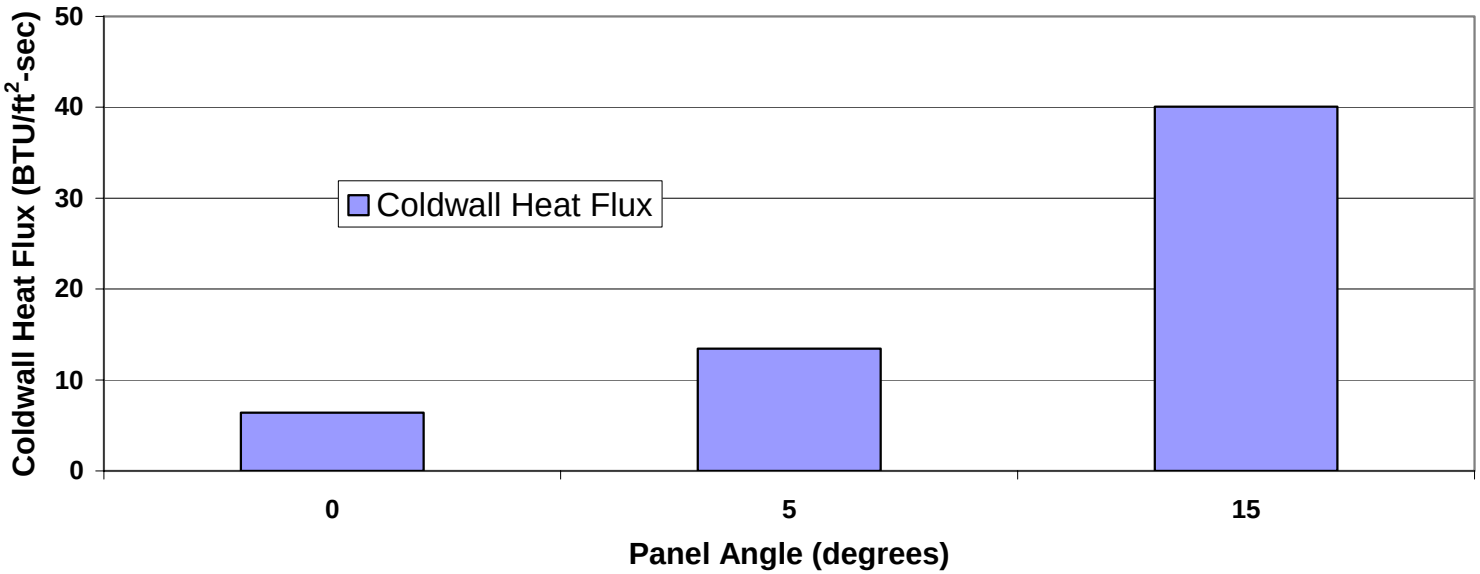
Selected Test Conditions: Peak Facility Operating Conditions at Mach 7, 80-100 kft:

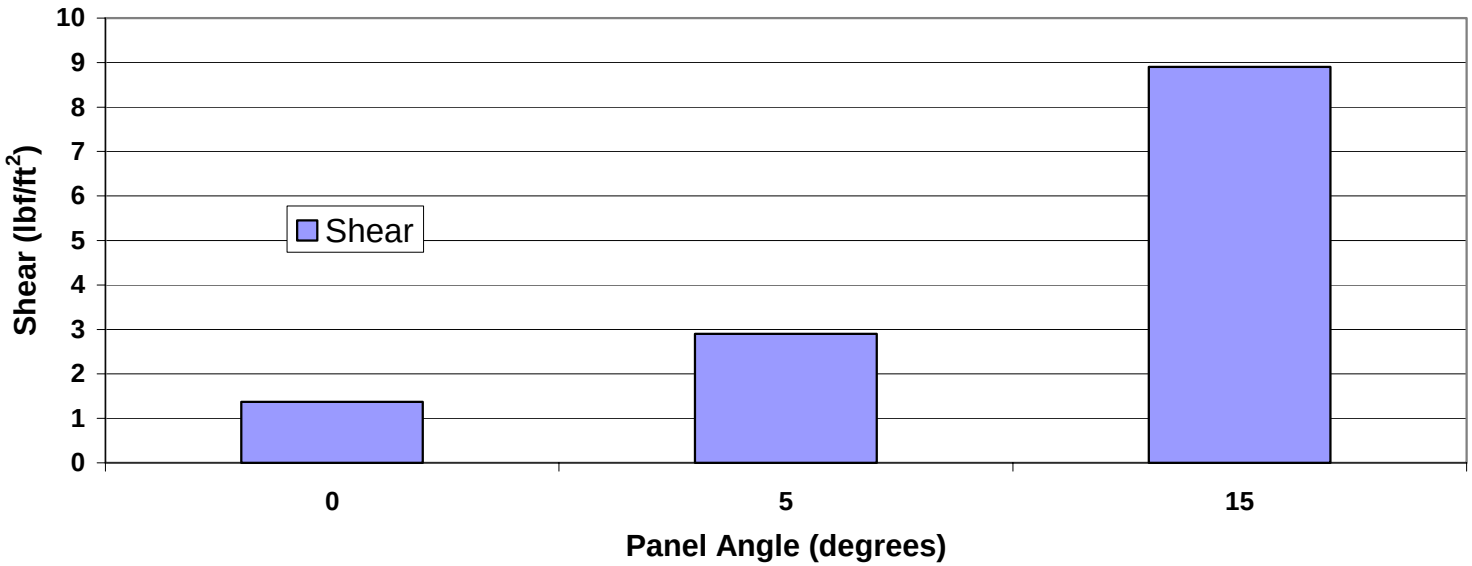
- 2000 psia freestream pressure
- 3190°F total temperature
- 120 second total test time at peak
- Vary Panel Angle from 0-degrees at startup to a 5 or 15 degree angle of incidence (Low and High Test Conditions)

Panel Angle Prescriptions of High and Low Test Conditions

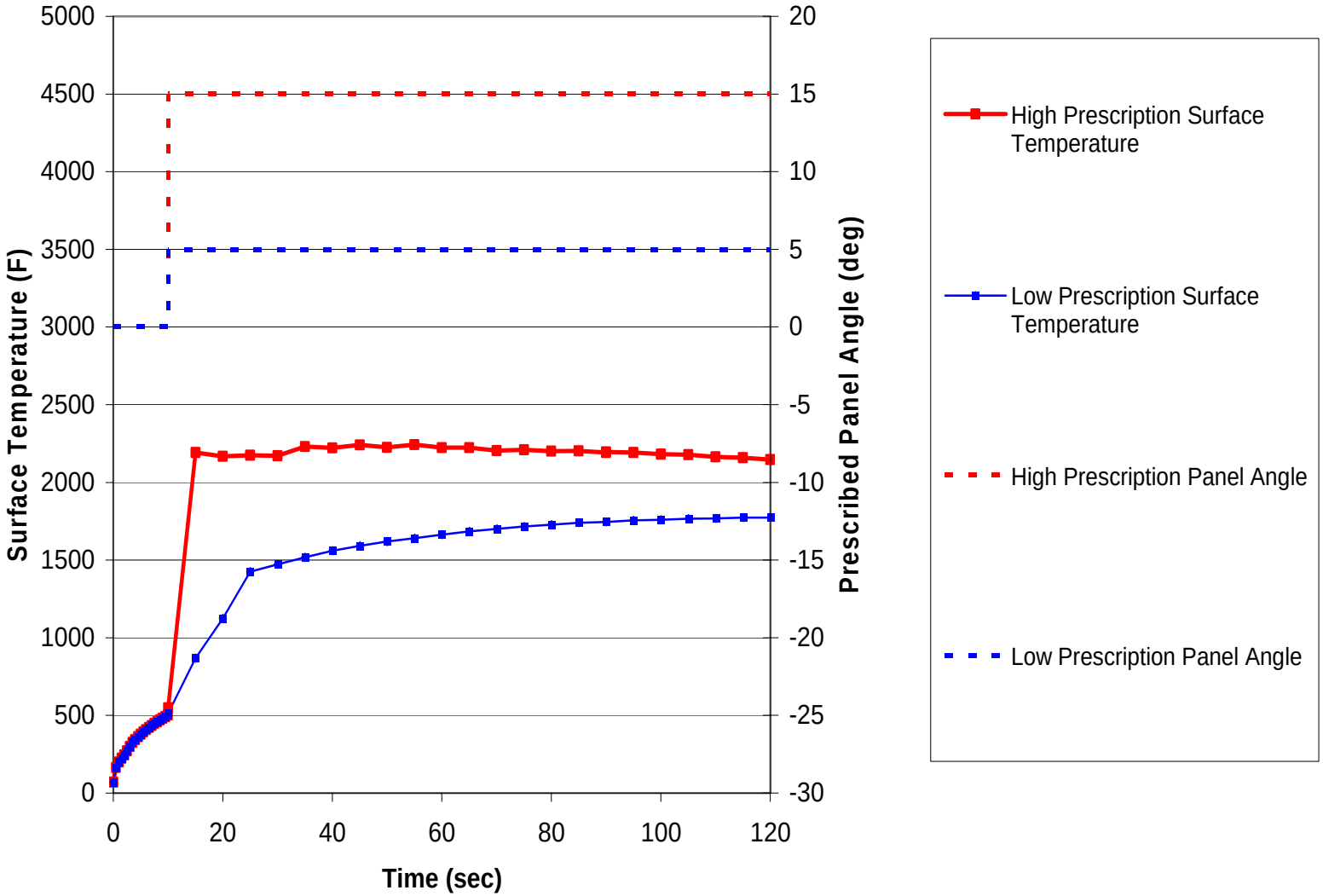
High Prescription				Low Prescription			
Time (sec)	Panel Angle (deg)	P_e (atm)	H_R (BTU/lbm)	Time	Panel Angle (deg)	P_e (atm)	H_R (BTU/lbm)
0	0	0.025	786	0	0	0.025	786
5	0	0.025	786	5	0	0.025	786
5	15	0.129	773	5	5	0.037	777
120	15	0.129	773	120	5	0.037	777

Coldwall Heat Flux and Shear versus Panel Angle for Selected LARC Test Conditions





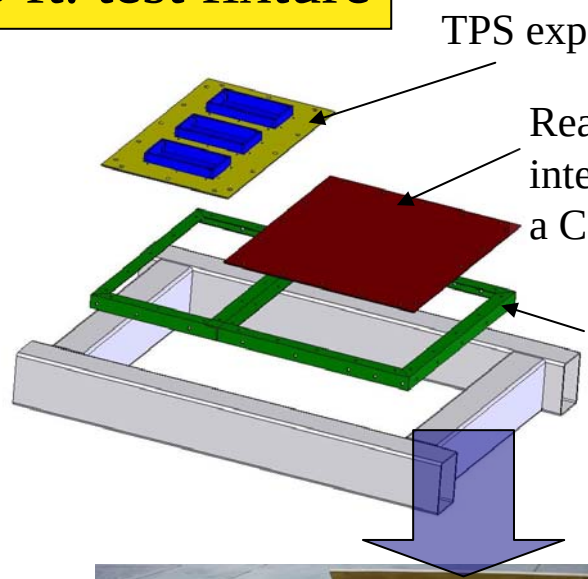
Predicted Surface Temperatures for 2-inch thick Silica Phenolic for Selected LaRC Test Conditions



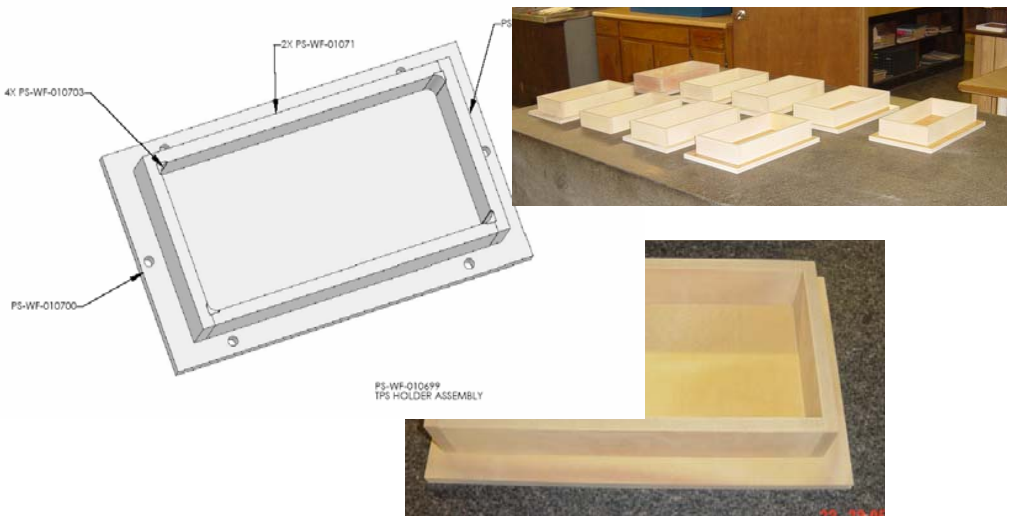
Test Panel Configuration

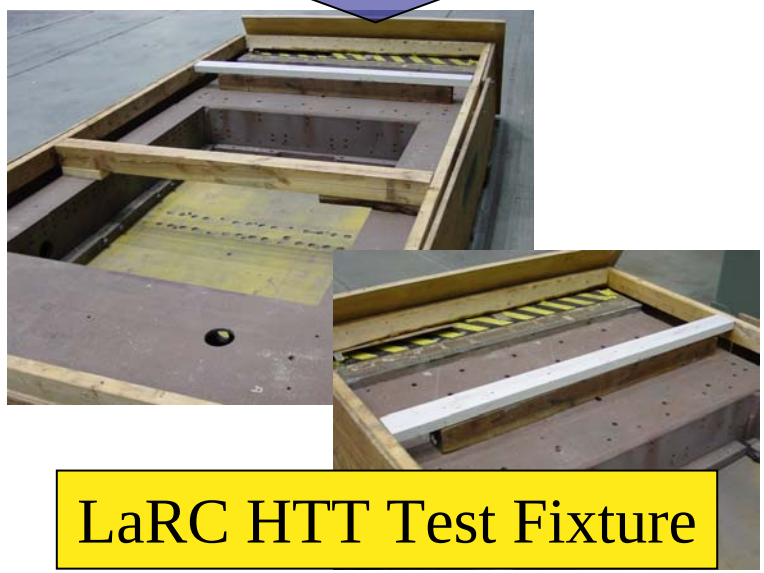
- **Three Panels will be tested simultaneously**
- **Silica phenolic holders:**
  - Constructed of separate panels of silica phenolic that are attached with mortis and tenon joints and bonded
  - 90 degree lay-up relative to heated surface

3.5 x 5 ft. test fixture



Silica phenolic holder



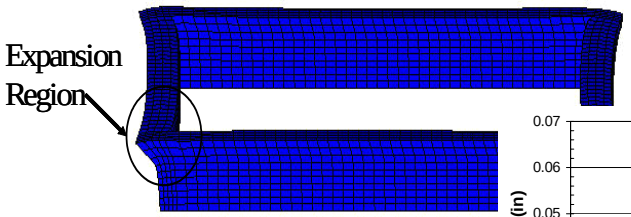


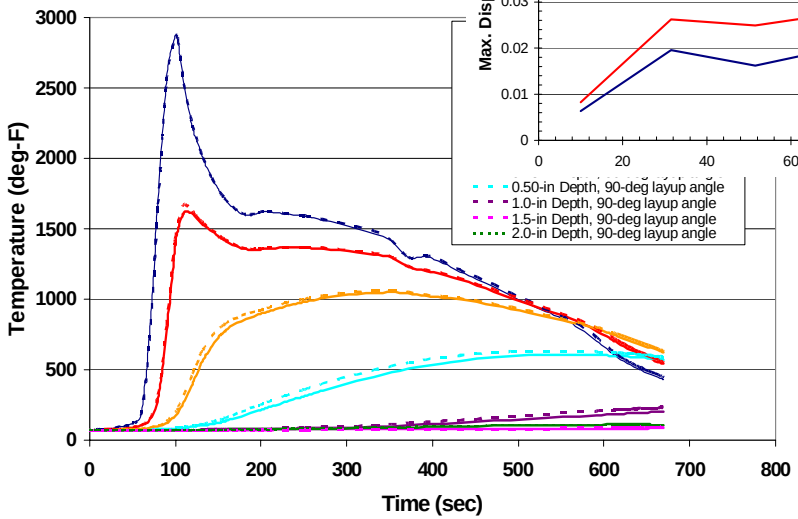
LaRC HTT Test Fixture

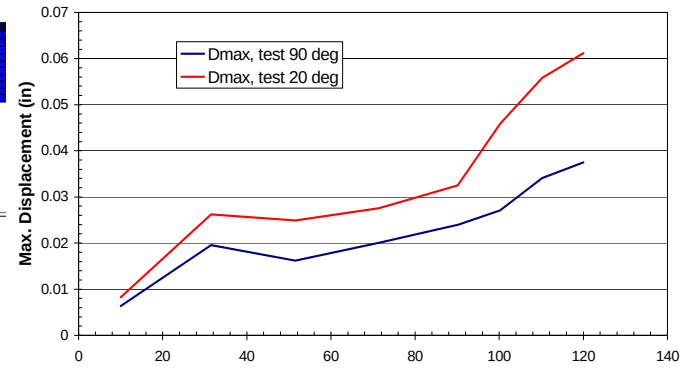
Test Fixture Design Verification

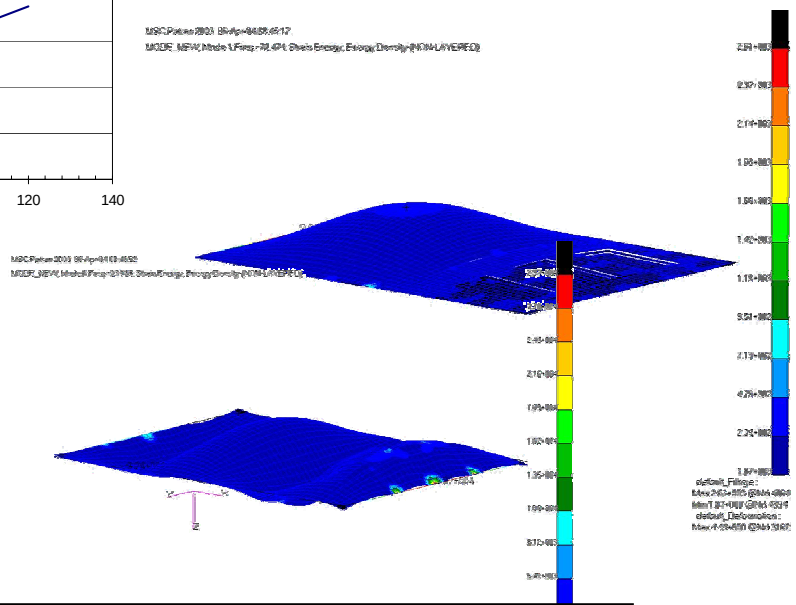
Thermostructural Analysis
- **Decomposition**
- **Thermal Expansion**

Test Fixture Modal Analysis
- **Modes 1-6**
- **Initial Natural Frequency = 70 Hz**
- **Redesigned to 130 Hz**



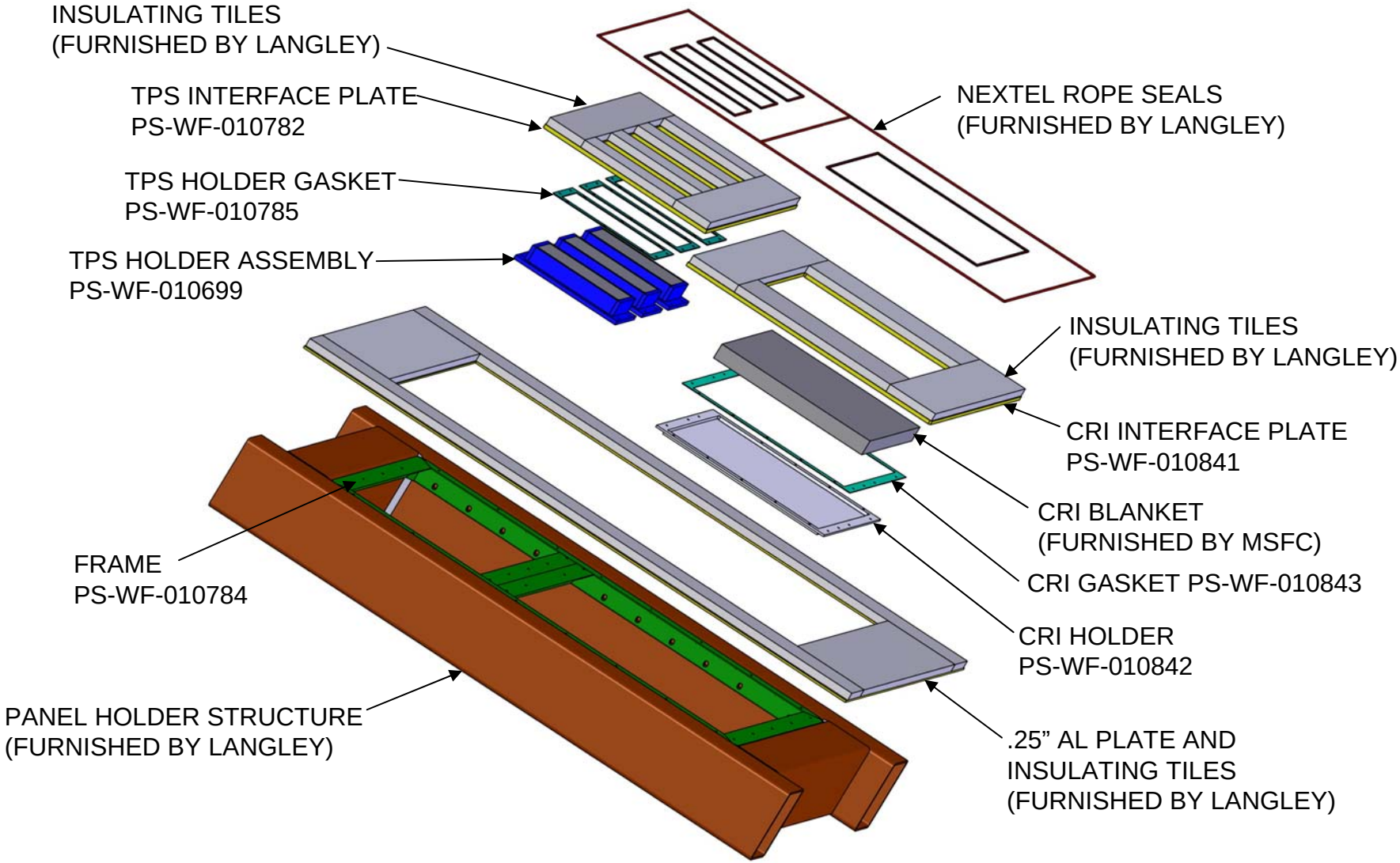






Robust Thermostructural Design

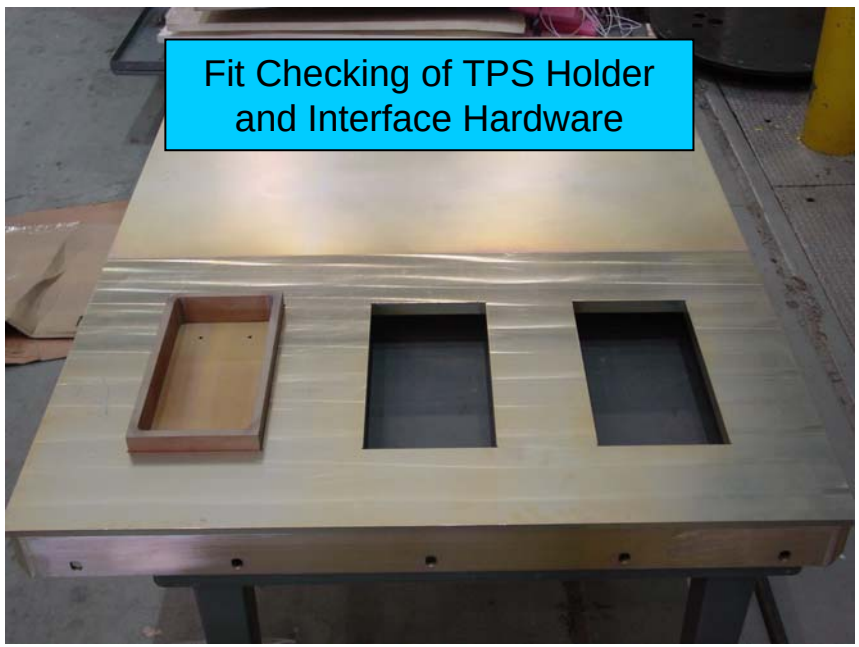
HTT Test Hardware Configuration with CRI Interface Installed

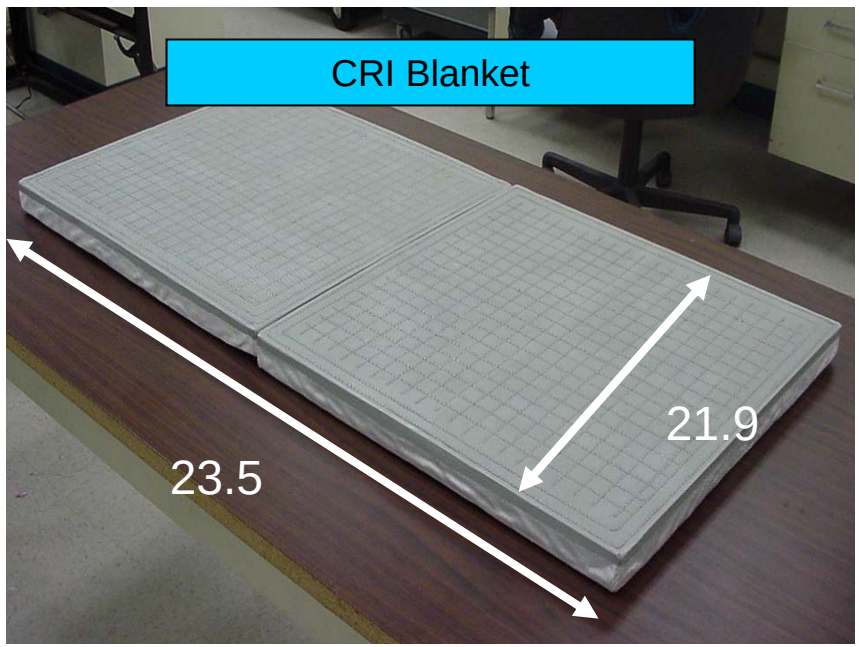


Interface Hardware / TPS Experiments

- All vendors have received Silica Phenolic panel holders
- TPS Samples should begin arriving at ITT in August.
- 1 NASA Ames Sample has been received

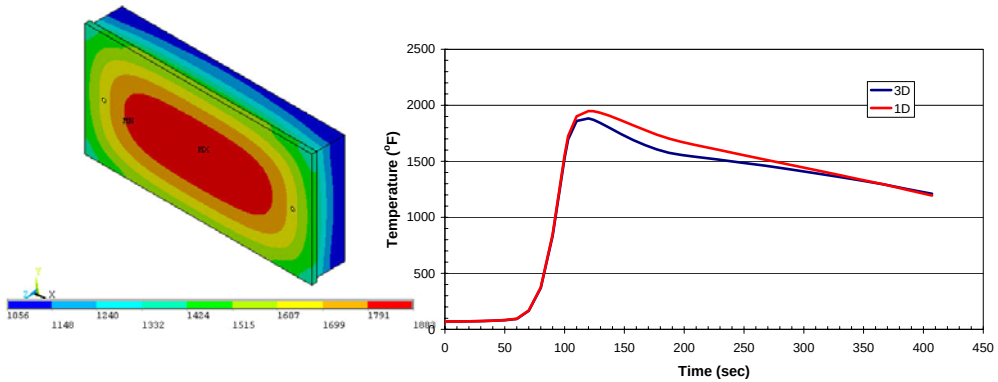
- Fabrication of all interface hardware is complete except for CRI blanket interface
- Design of CRI interface is complete, fabrication by Millennium Machine is in-process

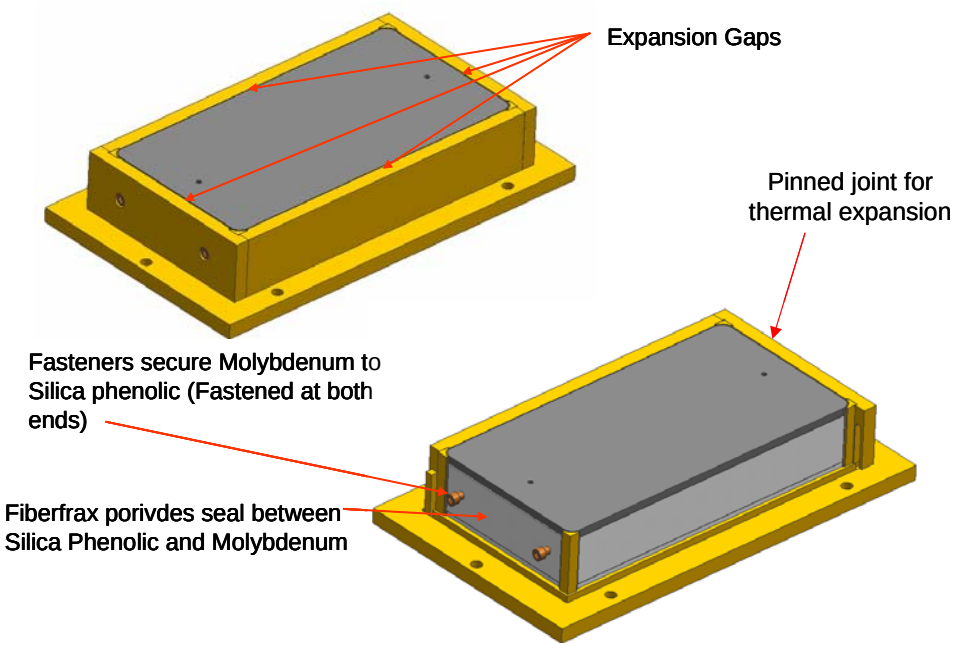




Calorimeter Design

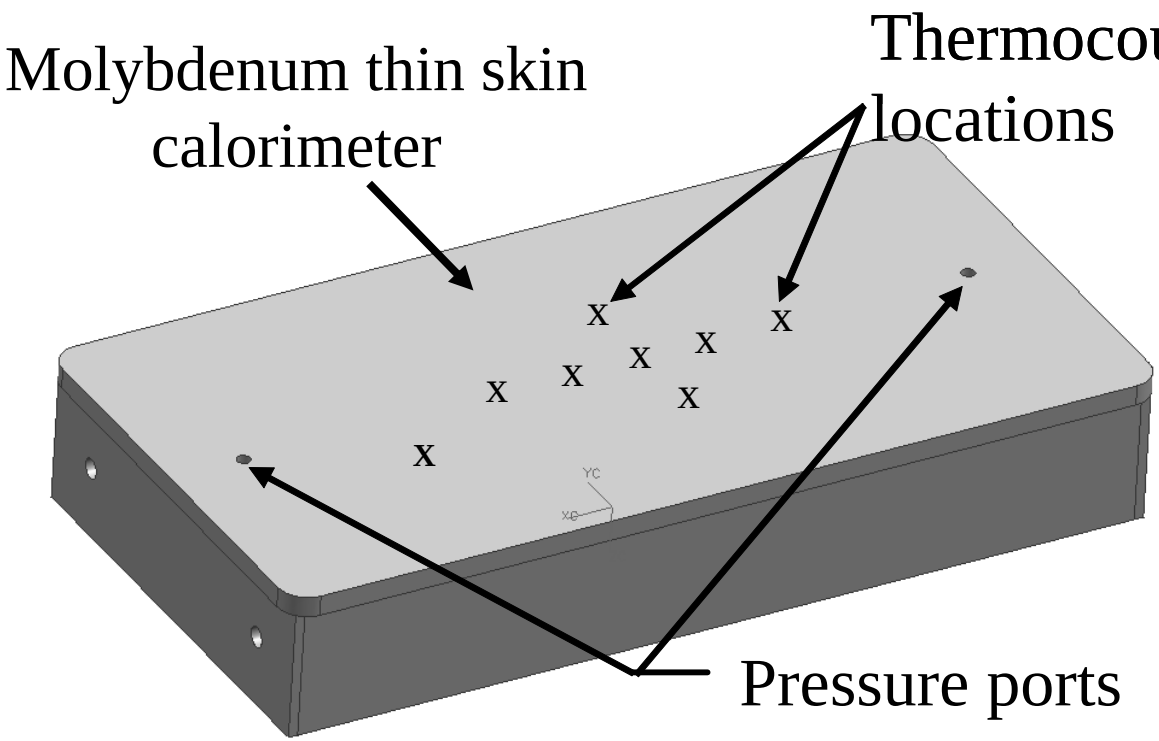
- **A thin skin calorimeter design has been developed for flight**
- **Candidate materials included 17-4PH steel, molybdenum, and oxygen free high conductivity (OFHC) copper**
- **Trade-off studies conducted to select material and thickness**
- **Thin skin criteria (ht/k < 0.1) applied in evaluating the materials**
- **17-4PH experienced excessive temperatures**
- **OHFC copper needed to be excessive thick (2 inch) to remain at acceptable temperatures**
- **Molybdenum, with a 0.25 inch thickness was selected for the design**
  - Temperature < 1800 ºF
  - Low thermal expansion



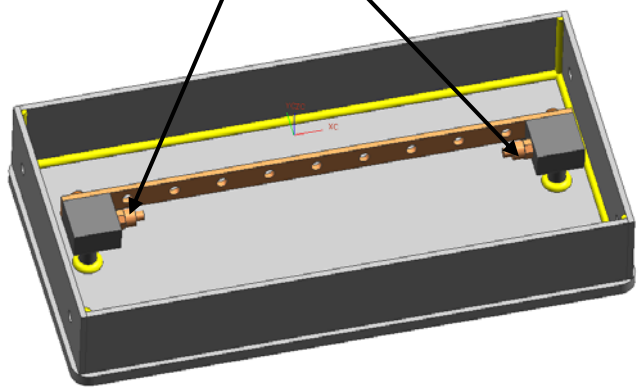


Calorimeter Plate Instrumentation

- **Calorimeter will be evaluated in HTT test and used to measure the facility heat flux**
- **Instrumentation includes 8 thermocouples and 2 pressure transducers**
- **Thermocouples used for redundancy and to quantify three dimensional conduction effects**

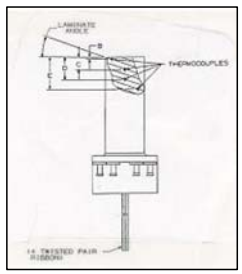


Pressure Transducers



Instrumentation Technology Panel

Astrometrics'
Delta-T Sensor

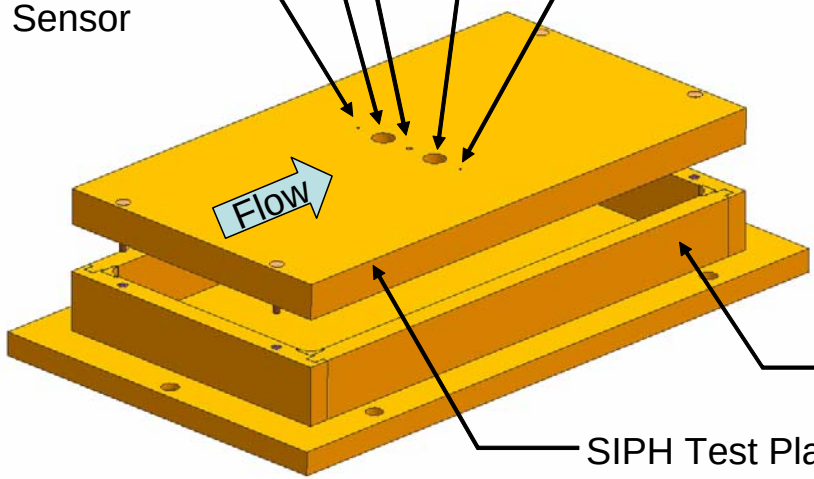


Astrometrics'
Thermocouple Plug
4 Element

Delta-M's
Thermocouple Plug
3 Element

Astrometrics'
Carbon Phenolic
ARAD Sensor

Astrometrics' Quartz
ARAD Sensor



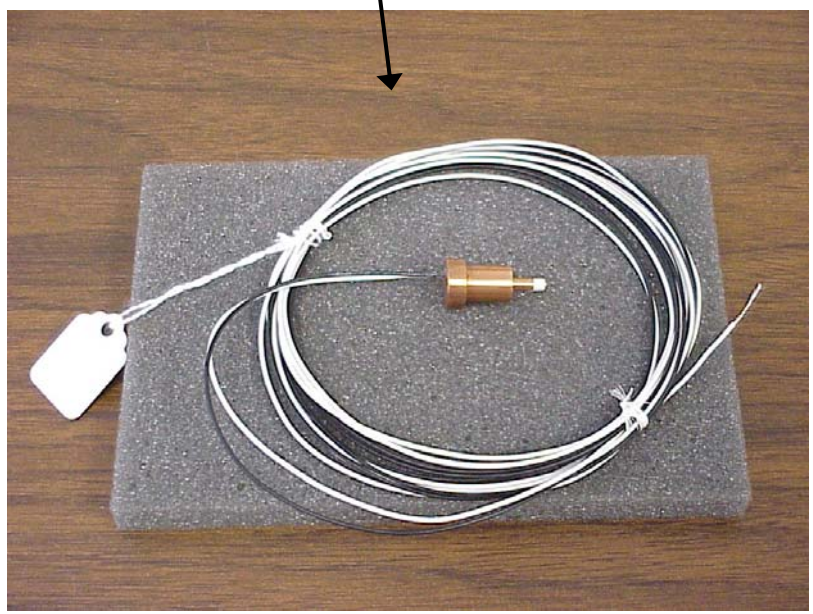
SIPH Holder
Assembly

SIPH Test Plate
20 Degree Ply

Instrumentation Test Hardware

Astrometrics
Silica Phenolic Thermocouple Plug

Astrometrics
Carbon Phenolic ARAD Sensor



MULTI-ELEMENT SIP QUAD EMBEDDED PLUG THERMOCOUPLE HAS TPS PLIES IN THE REQUIRED ORIENTATION FOR TESTING

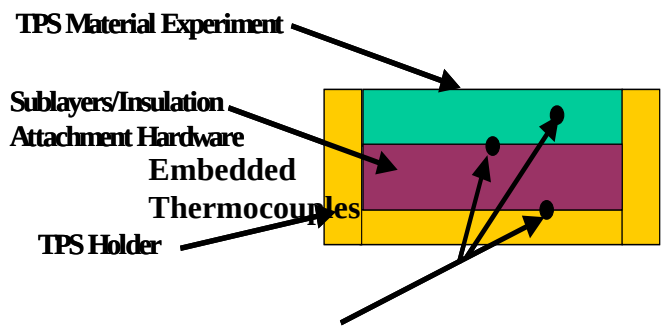
Ground Test Candidate Instrumentation/Database

•Vendors will instrument samples to obtain in depth thermal response

•Vendors will provide thermophysical properties

•Measured data and thermophysical properties will assembled in report and database for future material design model development if desired

- **Decomposition Kinetics**
- **Density**
- **Thermal Conductivity**
- **Specific Heat**
- **Dimensions (TC locations, Layers)**
- **Emissivity**



Preliminary Test Matrix

Test/Conditions		Position 1		Position 2		Position 3	
Test Day	**Test Condition**	**TPS Candidate**	**Vendor**	**TPS Candidate**	**Vendor**	**TPS Candidate**	**Vendor**
1	**Calorimeter Plate Prescription, 10 seconds at 0, 5, 10, and 15-deg**	Calorimeter Plate	AMRDEC/ITT	Calorimeter Plate	AMRDEC/ITT	Calorimeter Plate	AMRDEC/ITT
2	**High**	AETB/TUFI	Ames Research Center	Ceramic Foam	Ames Research Center	Calorimeter Plate	AMRDEC/ITT
3	**High**	PhenCarb-20	Applied Research Associates	SRAM-20	Applied Research Associates	SRAM-17	Applied Research Associates
4	**High**	C-SiC	Physical Sciences Incorporated	3D C/C-SiC with a SiC-Rich Seal Coat	Fiber Materials Inc	2D C/C-SiC with a SiC-Rich Seal Coat	Fiber Materials Inc
5	**High**	MSTPS C-C RTV	Aerothermo Technologies	Regular HotBlox	Raytheon/American Technical Coatings	HotBlox Light	Raytheon/American Technical Coatings
6	**High**	20-deg play angle staple PAN-based 2D C-C with RTV-12 (new MX-4830)	ATK Thiokol	20-deg play angle staple PAN-based 2D C-C with RTV-12 (FiberCote)	ATK Thiokol	20-deg play angle Needled PBCF-based 2D C-C with RTV-12 (Lewcott)	ATK Thiokol
7	**High**	Calorimeter Plate	AMRDEC/ITT	Silica Phenolic Instrumentation Technology Panel	AMRDEC/ITT	CeramARC	FMW Composites
8	**Low**	RX2390 (1)	Mineral Technologies / NAWC	RX2390 (2)	Mineral Technologies / NAWC	Acusil 2	AMRDEC/ITT
9	**Low**	TMC	FMW Composites	Intergral TPS	Vanguard Composites	Calorimeter Plate	AMRDEC/ITT
10	**Low - CRI Panel aft of TPS Experiment positions**	Calorimeter Plate	AMRDEC/ITT	Calorimeter Plate	AMRDEC/ITT	Calorimeter Plate	AMRDEC/ITT

Summary

- **Ground aerothermal test and evaluation planned for October 2004**
  - Langley Research Center High Temperature Tunnel (HTT)
  - Variety of candidate material technologies considered to include projected reusable technology such as blankets, tiles, and metallics as well as a significant number of ablative material technologies supporting NASA and DoD
  - Instrumentation candidate technology test and evaluation