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Thermal Protection System (Heat shield) Development –
Advanced Development Project

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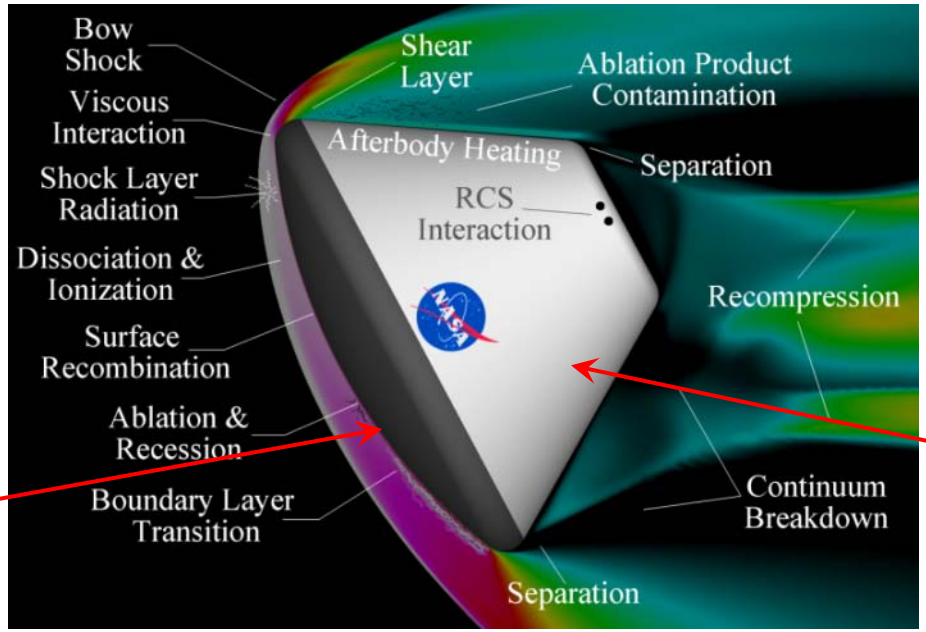
The Orion TPS Objective

Enable the CEV Project Office and the Prime to develop a CEV heat shield…

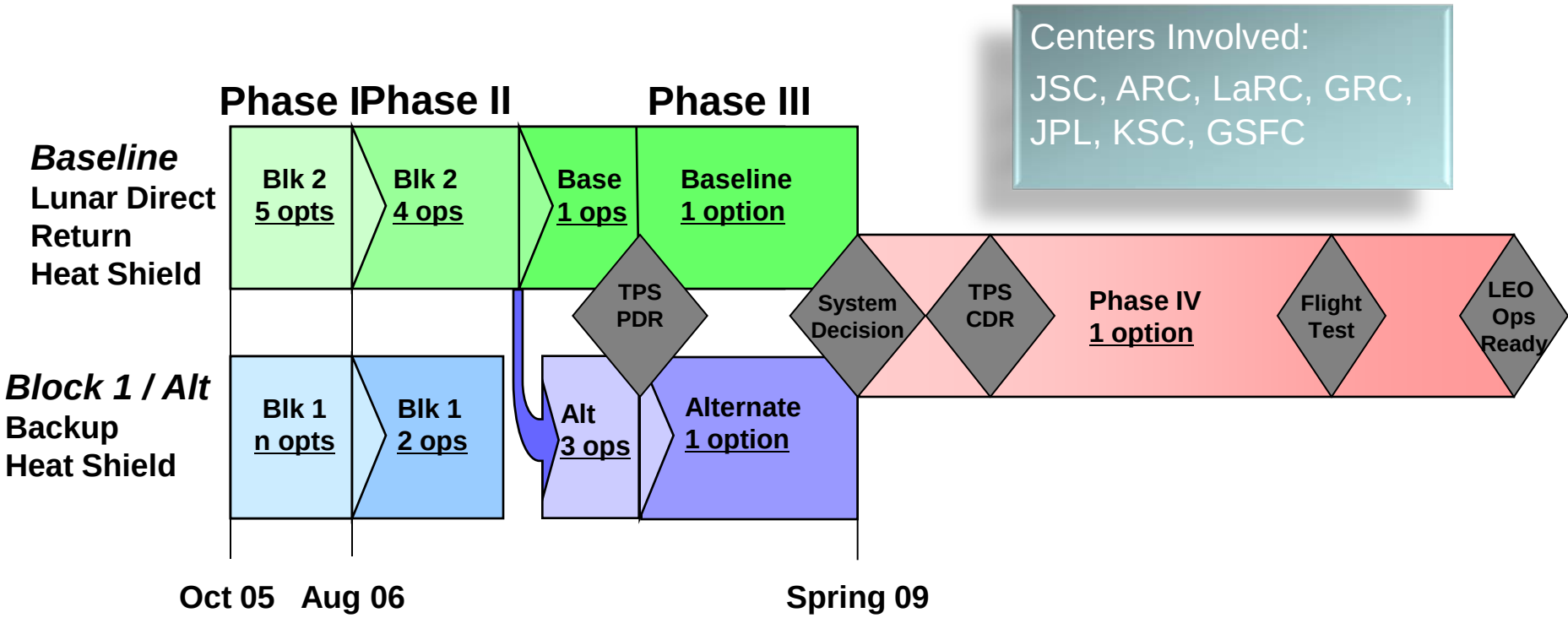


- **A top risk identified at project initiation was the development of a heat shield capable of both LEO and Lunar return**
  - Ablative TPS materials are required for LEO and Lunar missions
  - The US had focused little attention on ablative materials since Apollo era
  - Applicable ablative TPS materials were at low technology readiness levels (TRL ~ 3-4)
- **In Oct 2005, the CEV Project commissioned the CEV TPS Advanced Development Project to address the heat shield development risk**

… by initiating a Multi-Center Advanced Development Project to raise the TRL and reduce the risk of Lunar return capable ablative TPS materials and heat shield systems

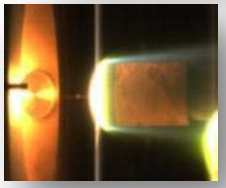
CEV TPS Development Strategy (Critical Path Item)

- Baseline Heat shield (Lunar and LEO return capable) by Orion IOC
- Alternate Heat shield (Lunar and LEO return capable) parallel development, maintained up through system decision
- NASA develops Baseline & Alternate heat shield designs up to Orion PDR
- Prime takes over responsibility of heat shields after CEV PDR – w/ NASA oversight
- Back shell TPS development controlled by Orion Prime – w/ NASA oversight

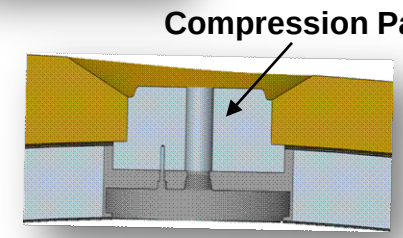


Scope of TPS ADP Primary Objectives

- **TPS materials fabrication and characterization**
  - Development of material constituent, processing and properties specifications
  - Detailed mechanical and thermal material properties testing



- **TPS materials thermal performance capabilities for LEO & Lunar returns**
  - Screening and comprehensive TPS materials thermal performance testing
  - TPS materials thermal response models
  - TPS thermal performance margins policy

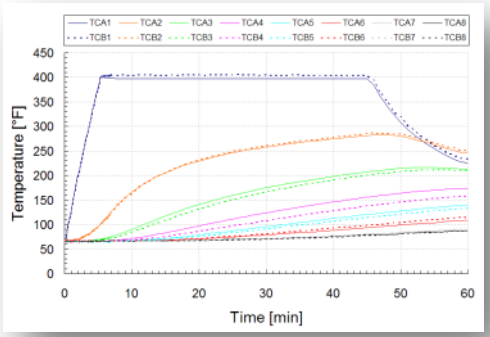


- **TPS materials thermal-mechanical performance capabilities**
  - Ground, launch, on-orbit, nominal and emergency entry, descent & landing loads
  - Thermal-structural integrated (carrier structure + TPS) testing
- **Design for all heat shield components**
  - TPS acreage, carrier-structure, TPS bonding, compression pads, main seals, gap/seams, close-outs, repairs

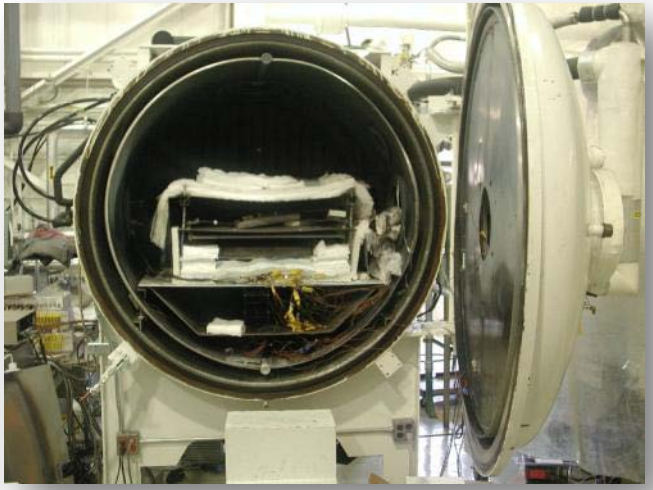
- **Integrated heat shield design and performance capabilities**
  - Integrated FEM analysis and design of all components
  - TPS material thermal, MMOD and integrated sizing
  - Integrated thermal-structural analysis and design of complete heat shield
- **Manufacturing for an integrated 5 meter heat shield**
  - Infrastructure, staffing , resources and equipment for full-scale heat shield production
  - Demonstration of full-scale heat shield manufacturing procedures

Heat shield Thermal-Structural Test and Analysis

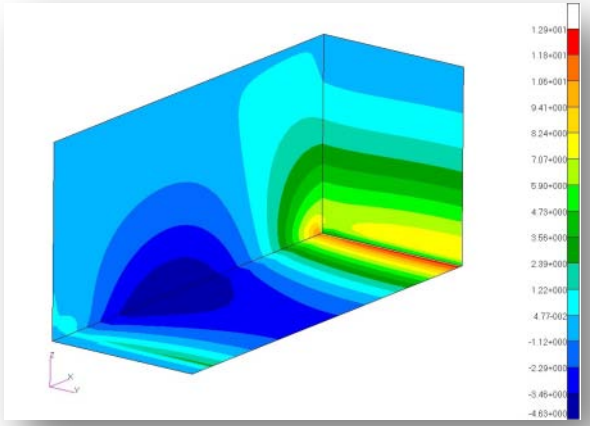
4-point Bend Flexure Test



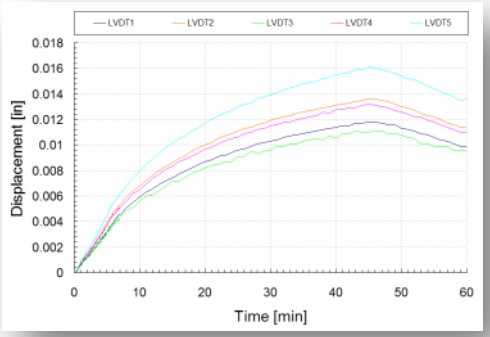
Temperature Transients



Thermal Vacuum Cycling-
Simultaneous thermal & vacuum exposure



Pre-test Analysis Predictions



Displacement Measurements

Testing performed primarily at LaRC

Environmental Chamber Test
(-150 F to +250 F)

Heat shield Arcjet Testing

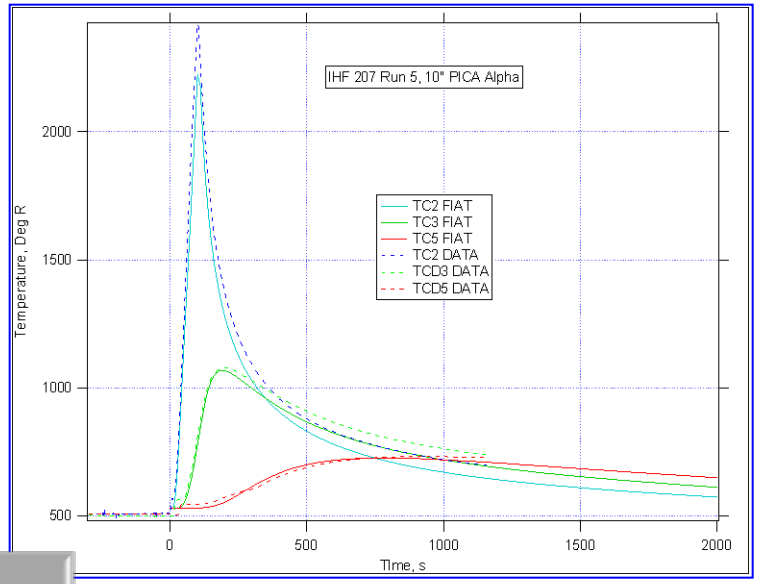
Heritage Avcoat

ADP Textron Avcoat

Gap & Seam Testing

Pre-test 100% N2 10% O2 23% O2 30% O2

Oxygen Sensitivity Testing



Model Correlation

Testing performed at both ARC & JSC

Direct Results of the Orion TPS ADP





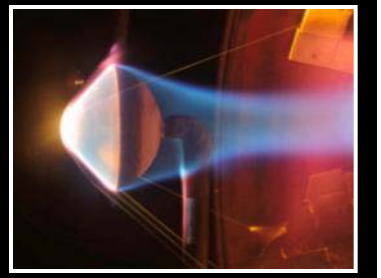
Competitive materials R&D resulted in multiple viable materials & systems


Avcoat: Selected for the Orion


PICA: Selected for MSL & Dragon


TPS ADP Arcjet tests revealed catastrophic failure mode of initial MSL TPS

MSL shifts to a new TPS ADP developed TPS material

Large article arcjet testing demonstrated during TPS ADP is now a necessary TPS tool

- New NASA TPS experts
- Multiple TPS firms
- Large scale manufacturing
- TRL = 5-6 ablative TPS
- Promising new TPS concepts
- Technology transfer to commercial space industry

TPS ADP Completion and Transition to Prime

- The ADP matured two heat shield designs, Avcoat and PICA, to PDR status
- The final down-select between PICA & Avcoat proceeded as planned (3/31/2009)
- The TPS ADP terminated as planned on 3/31/09, and responsibility for the heat shield was transitioned to LM
- NASA continues to play a vital role in the Orion TPS design activities
  - NASA has substantial in-house capability in TPS, including expertise developed during Shuttle Return-to-Flight activities and the CEV TPS ADP, which is being leveraged for the CEV TPS development, design and certification
  - The Prime Contractor retains primary responsibility for the development, design, test, certification and delivery of the TPS
  - The are several critical areas where NASA has in-line responsibilities, including:

<u>Analytical</u>

- Ablation thermal response model development
- MMOD-impacted TPS response models
- Margin Policy development and buy-down
- Compression pad analysis & design

<u>Testing</u>

- Arcjet and radiant heat
- Thermal barrier
- Material property
- Tuneable beam shock

Conclusions from the Orion TPS ADP

- **The Orion Thermal Protection System (TPS) ADP was a 3 1/2 year effort to develop ablative TPS materials for the Orion crew capsule**
  - The ADP was motivated by the lack of available ablative TPS's
  - The TPS ADP pursued a competitive phased development strategy with succeeding rounds of development, testing and down selections
  - The Project raised the technology readiness level (TRL) of 8 different TPS materials from 5 different commercial vendors, eventual down selecting to a single material system for the Orion heat shield

- **In addition to providing a heat shield material and design for Orion on time and on budget, the Project accomplished the following:**
  - Re-invigorated TPS industry & re-established a NASA competency to respond to future TPS needs
  - Identified a potentially catastrophic problem with the planned MSL heat shield, and provided a viable, high TRL alternate heat shield design option
  - Transferred mature heat shield material and design options to the commercial space industry, including TPS technology information for the SpaceX Dragon capsule

Capability: The development of Thermal Protection Systems (TPS), including thermal & structural analysis, design, materials & processes, and thermal (arcjet and radiant heat) testing

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