Jet Propulsion Laboratory
California Institute of Technology

Hot-Structure Earth Entry Vehicle Concept for Robotic Mars Sample Return

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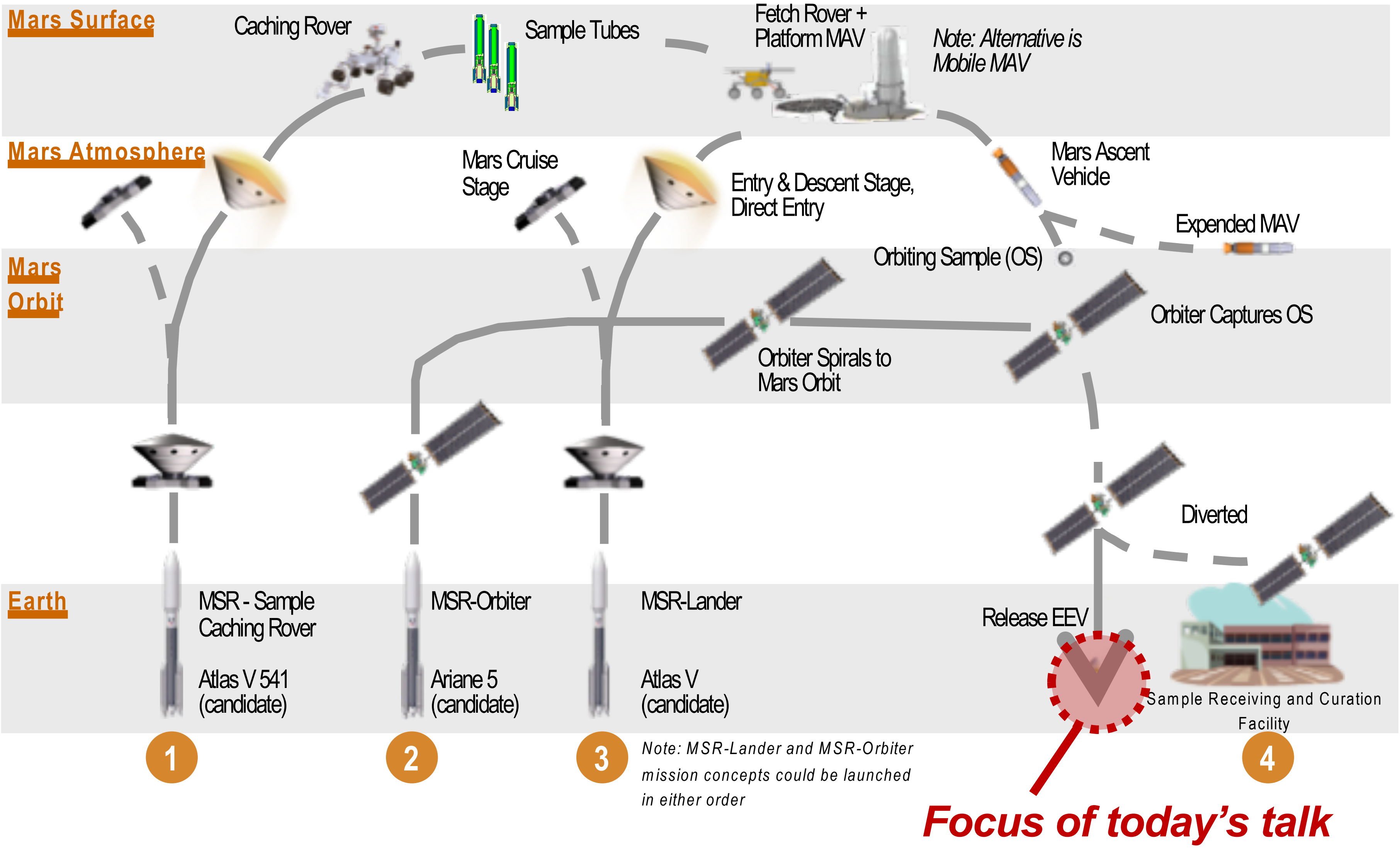
Potential Mars Sample Return – Notional Architecture



Note: MSR-Lander and MSR-Orbiter mission concepts could be launched in either order

Focus of today's talk

EEV Elements

1. **Contained-OS (C-OS)**

- Provides biological containment of Orbiting Sample (OS) and samples

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2. **Containment Assurance Module (CAM)**

- Provides thermal/structural protection/isolation to C-OS
- Provides impact attenuation for ground impact
- Integrates lid or cover for loading of C-OS

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3. **Aero-Thermal System (ATS)**

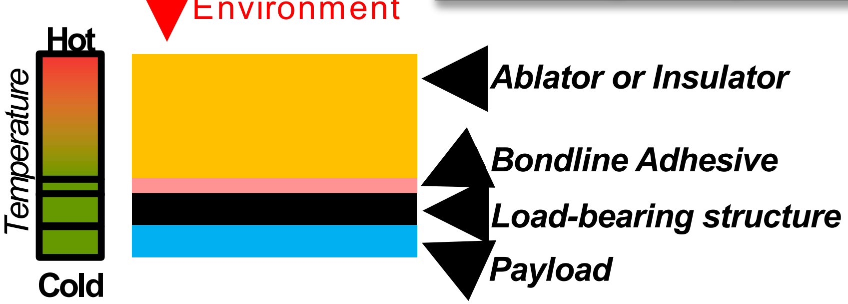
- Provides thermal/structural support for CAM
- Reduces terminal velocity to reasonable level for passive energy absorber systems
- Assures aerodynamically passive EDL in the preferred 'nose forward' orientation
- *Not required* to provide impact attenuation

Focus of today's talk

Hot vs. Cold Structure Entry Vehicles

- **<u>Cold Structure</u>**
  - Load-bearing structure is kept at low temperature using insulative or ablative TPS

<u>1D slice through TPS</u>:


Entry Environment

Hot

Temperature

Cold

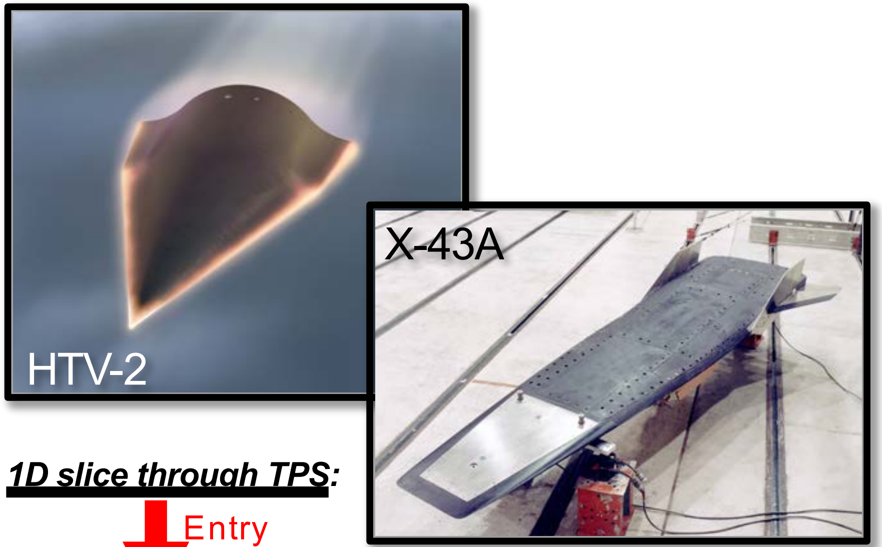
Ablator or Insulator

Bondline Adhesive

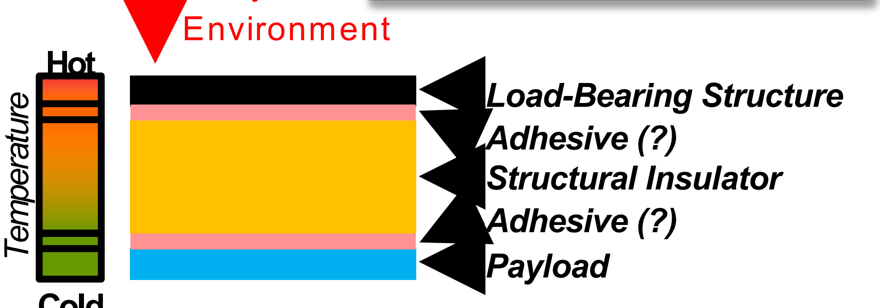
Load-bearing structure

Payload

- **<u>Hot Structure</u>**
  - Load-bearing structure is high-temperature capable



<u>1D slice through TPS</u>:


Entry Environment

Hot

Temperature

Cold

Load-Bearing Structure

Adhesive (?)

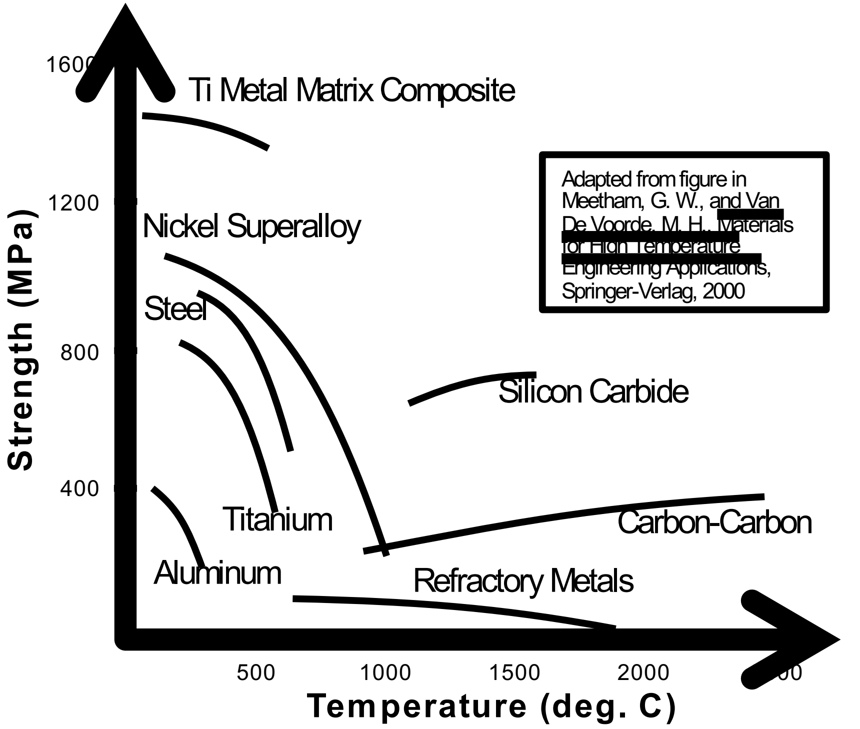
Structural Insulator

Adhesive (?)

Payload

High-Temperature Structural Materials

- High-Temp Metals/Alloys
  - Max temperatures range from ~700K (Titanium) to ~1500 K (Niobium)
  - Pros: cost; fabrication; integration; ductility
  - Cons: density; significant strength loss at higher temperatures
- Composites (C-C, CMCs, UHTCs)
  - Max temperatures >2500K (depends on coating if used)
  - Pros: low density; high specific strength
  - Cons: cost; fabrication; brittleness

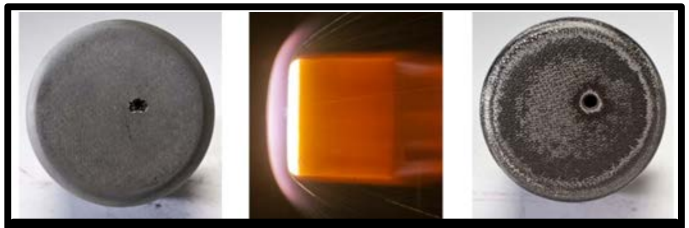


Adapted from figure in Meetham, G. W., and Van De Voorde, M. H., Materials for High Temperature Engineering Applications, Springer-Verlag, 2000

Carbon-Carbon is a mature/existing hot structure material

Rationale for Carbon-Carbon (C-C) EEV Concept

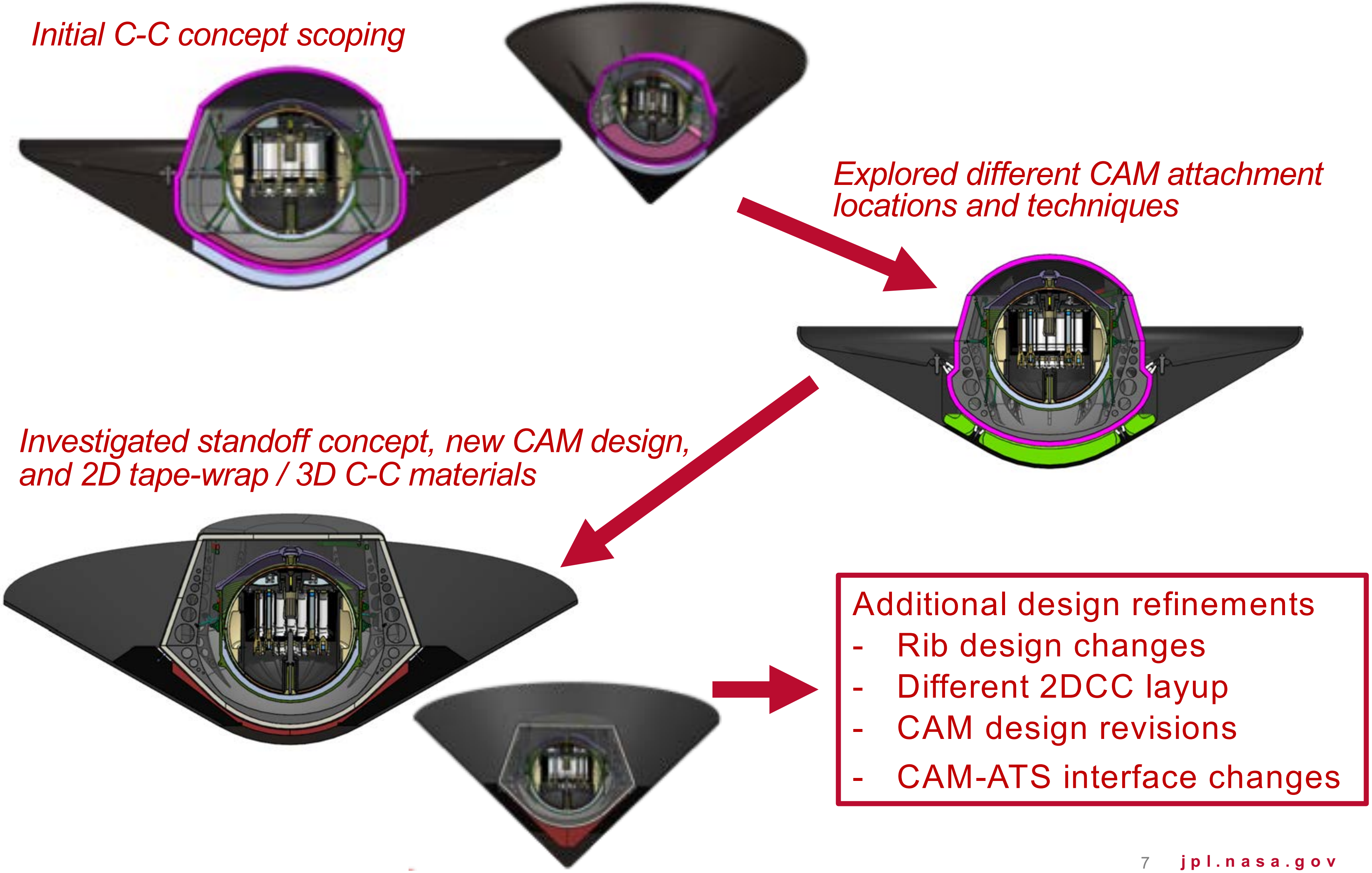
- Potential benefits
  - Material properties
    - C-C has strength and density similar to Aluminum that does not degrade with temperature
    - Recession rate is low vs. typical ablators
  - Reliability
    - Hot structure + CAM TPS concept provides a redundant TPS capability
    - Aeroshell puncture may not lead to catastrophic failure
  - Design
    - Potential mass savings – structure is TPS
  - Maturity
    - Ground and flight testing examples
    - Multiple manufacturers available today
- Potential challenges
  - Material properties
    - Mechanical properties at high temperatures / high strain rates required
  - Design
    - Hot- to cold-structure interface a primary design driver
    - Thermal-induced stresses and re-radiation need to be considered



Example of arcjet testing of Carbon-Carbon samples with hypervelocity impact damage. Ref: Agrawal, P., Munk, M. M., Glaab, L. A., "Arcjet Testing of Micro-Meteroid Impacted Thermal Protection Materials," AIAA Paper 2013-2903, 2013.

CAM = Containment Assurance Module

Carbon-Carbon EEV Concept Development



Initial C-C concept scoping

Explored different CAM attachment locations and techniques

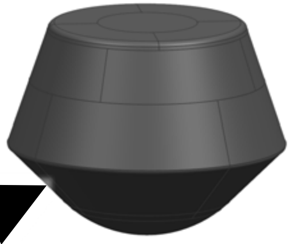
Investigated standoff concept, new CAM design, and 2D tape-wrap / 3D C-C materials

Additional design refinements
- Rib design changes
- Different 2DCC layup
- CAM design revisions
- CAM-ATS interface changes

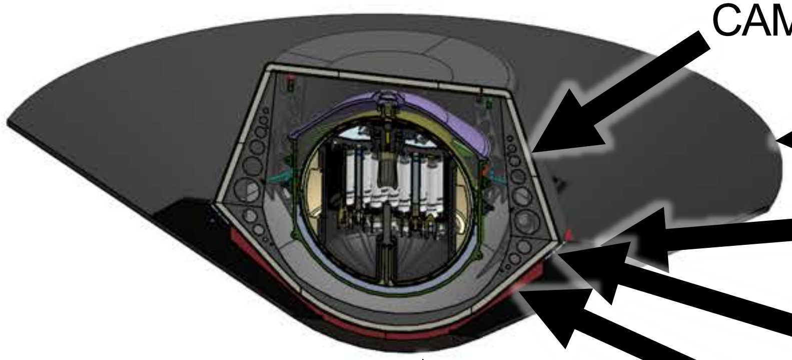
Predecisional information for planning and discussion only

V2.2 Concept (60-deg Blunt Case)

60-deg Sphere-Cone
1.2 m Base Diameter
30 cm Nose Radius



CAM TPS = TUFI-coated FRCI-12



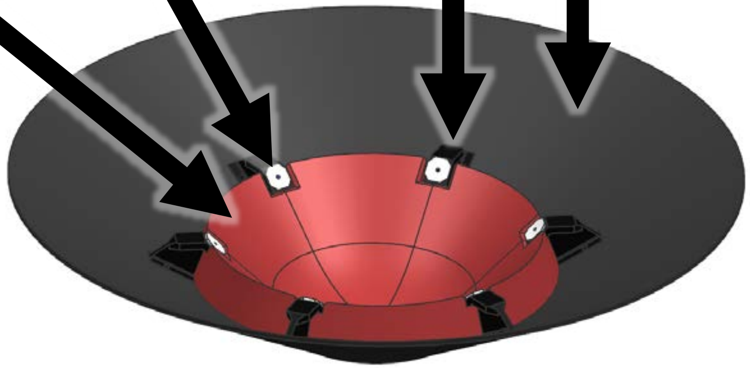
2DCC Aeroshell

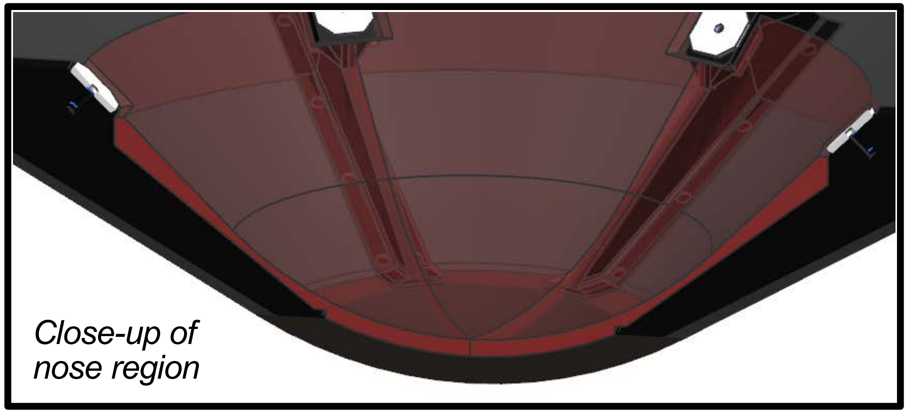
3DCC Ribs

Zirconia insulator spacers

Carbon foam insulation

3DCC Nose Cap

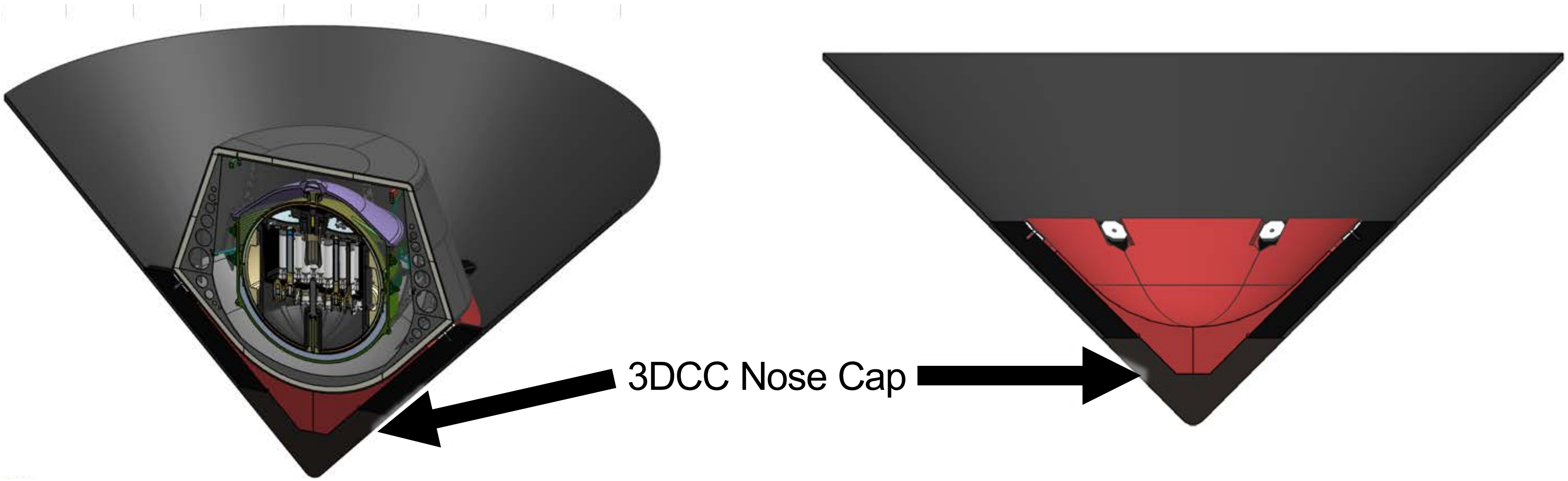




Close-up of nose region

V2.2 Concept
(45-deg Sharp Case)

45-deg Sphere-Cone
1.2 m Base Diameter
2 cm Nose Radius



3DCC Nose Cap

Mass Comparison

CAM = Containment Assurance Module
C-OS = Contained-OS (Orbiting Sample)
ATS = Aero-Thermal Structure

	60-deg Blunt*	45-deg Sharp*
EEV Entry Mass	90.4 kg	99.4 kg
ATS	30.1 kg	39.1 kg
CAM	26.9 kg	26.9 kg
C-OS	33.4 kg	33.4 kg

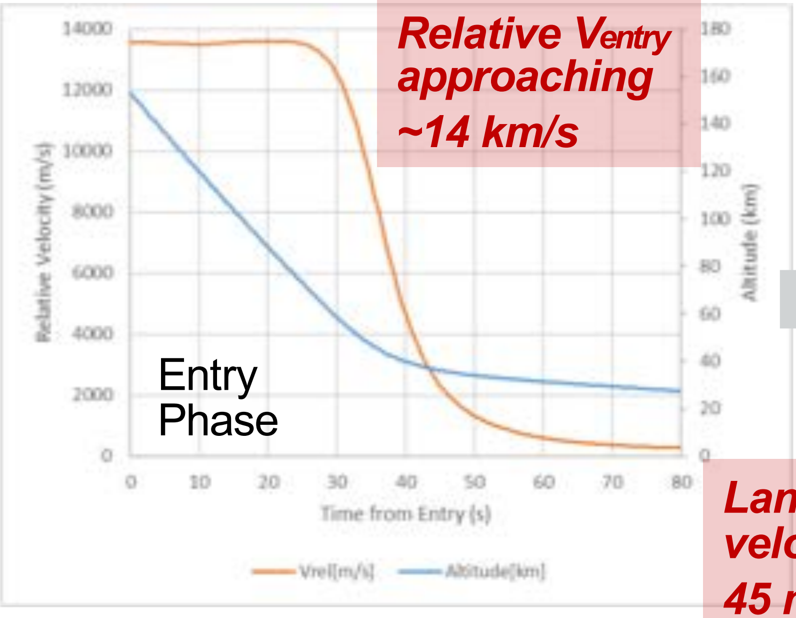
Masses include 25% or more contingency

Non-optimized designs within 100 kg mass allocation

Analysis Methodology

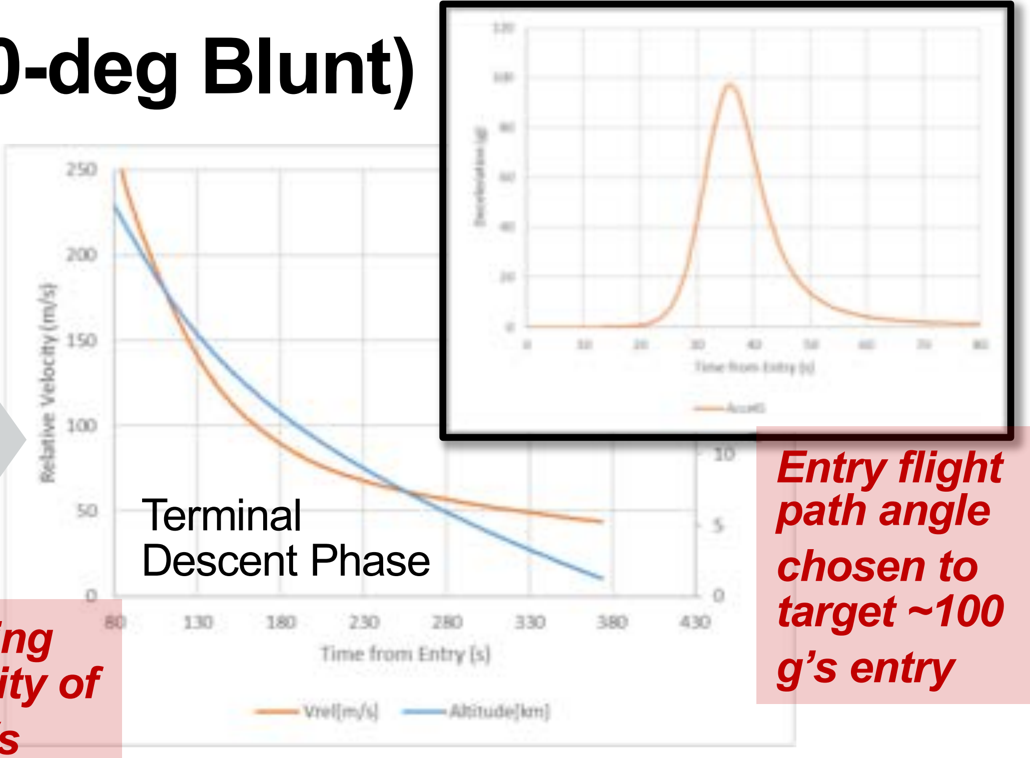
- Trajectory Analysis (3DOF – JPL DSENDS code)
  - Entry velocity = 13.55 km/s, EFPA = -15 deg (inertial)
  - Entry mass = 100 kg (mass allocation)
  - Diameter = 1.2 m
  - Nose radius = 30 cm (60-deg Blunt) or 2 cm (45-deg Sharp)
  - Landing at Utah Test and Training Range (UTTR)
- Aeroheating Environments Analysis
  - CBAERO code assuming: fully turbulent, fully catalytic surface
  - Margins: 1.35x (Convective), 1.55 (Radiative), 1.1x (Pressure)
- Thermal/Ablation Analysis
  - 1D analysis – run at points along heatshield (FIAT code)
  - Material properties as function of temperature

Trajectory Results (60-deg Blunt)



Entry
Phase

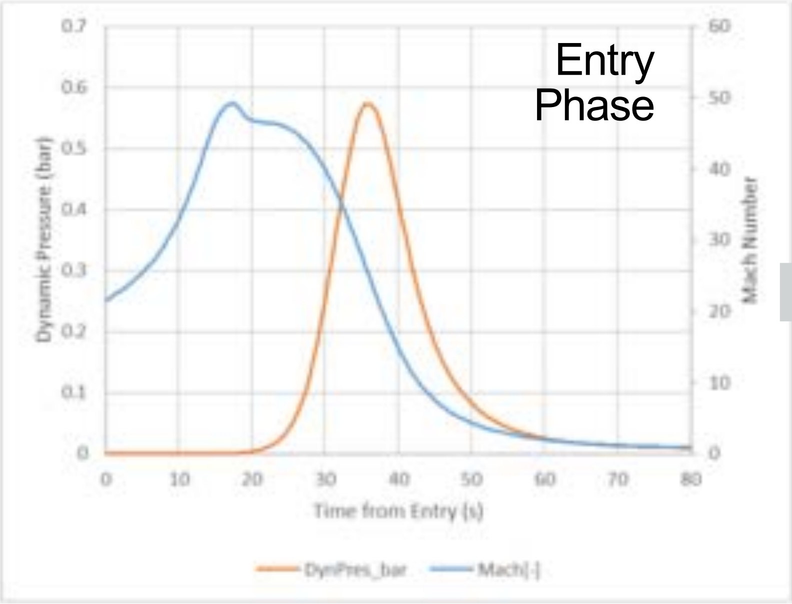
Relative V*entry *approaching ~14 km/s



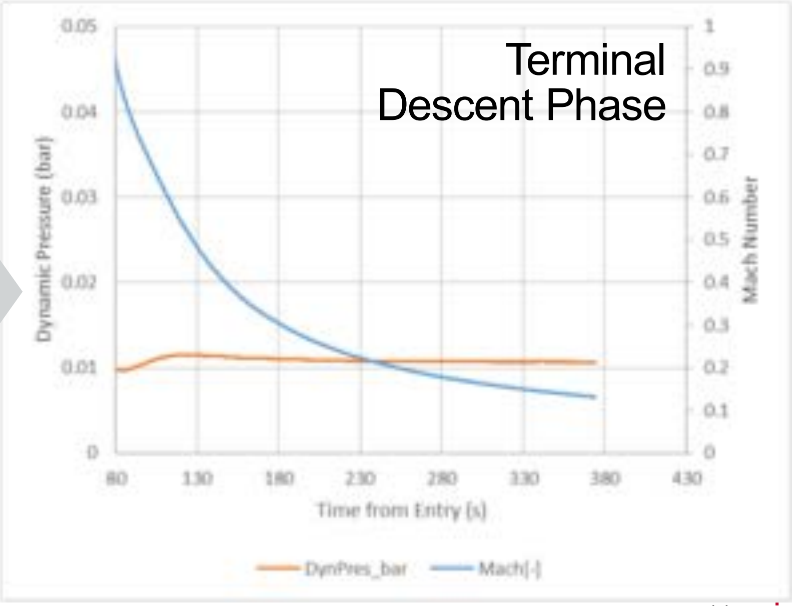
Terminal
Descent Phase

Entry flight path angle chosen to target ~100 g's entry

Landing velocity of 45 m/s



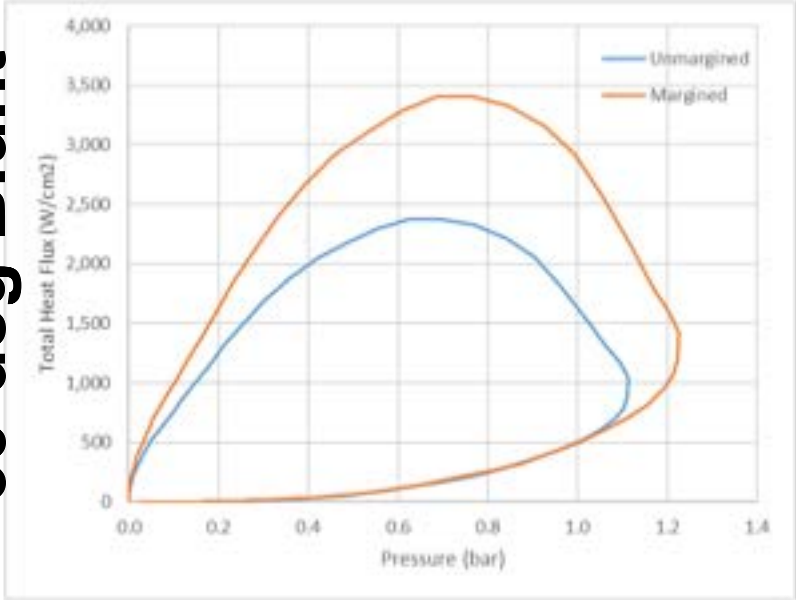
Entry
Phase

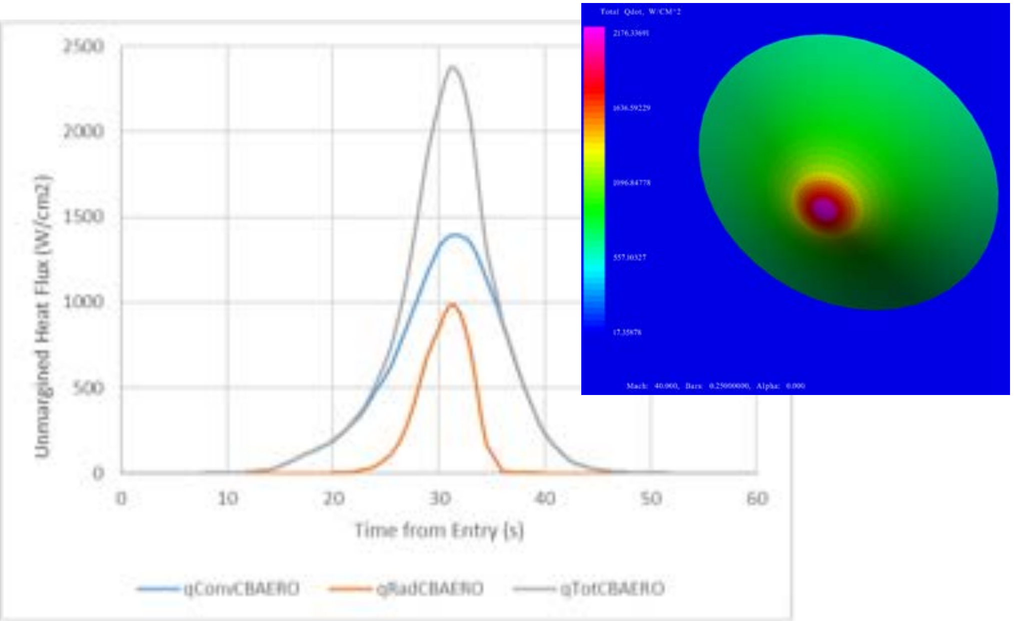


Terminal
Descent Phase

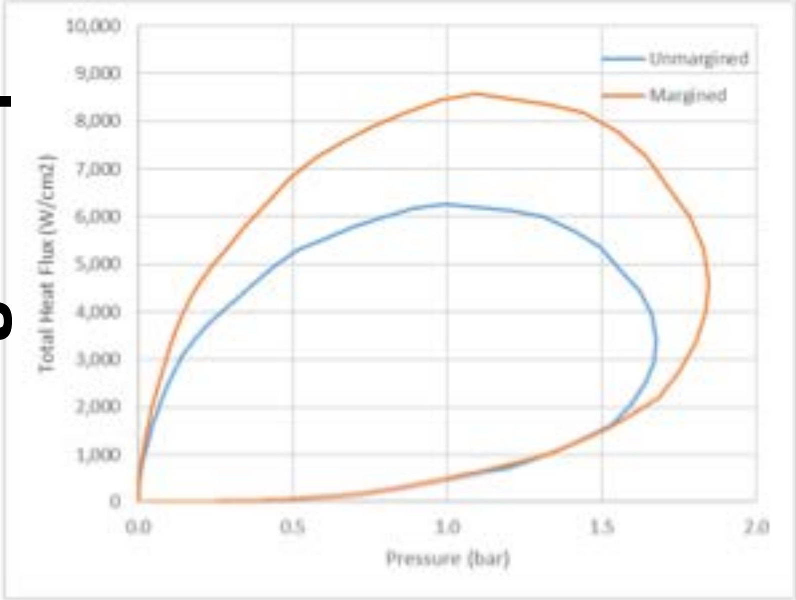
Aerothermal Results (Stagnation Point)

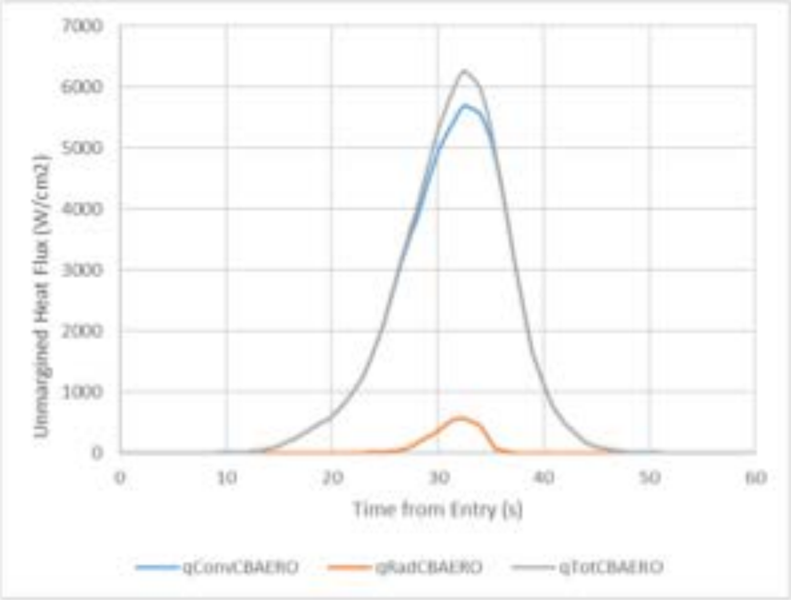
60-deg Blunt



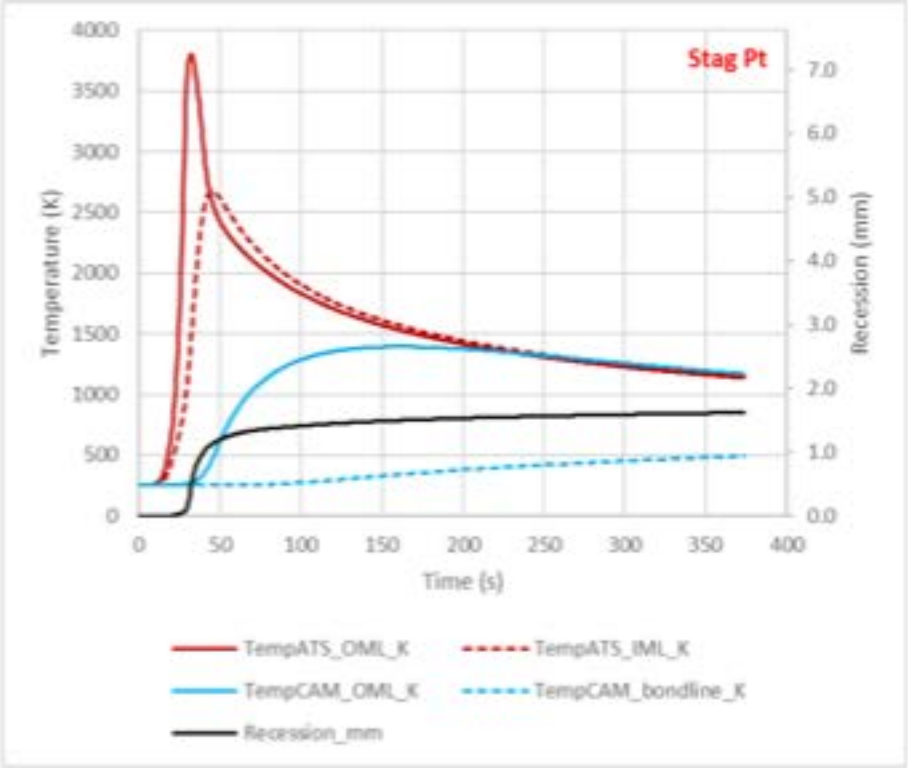


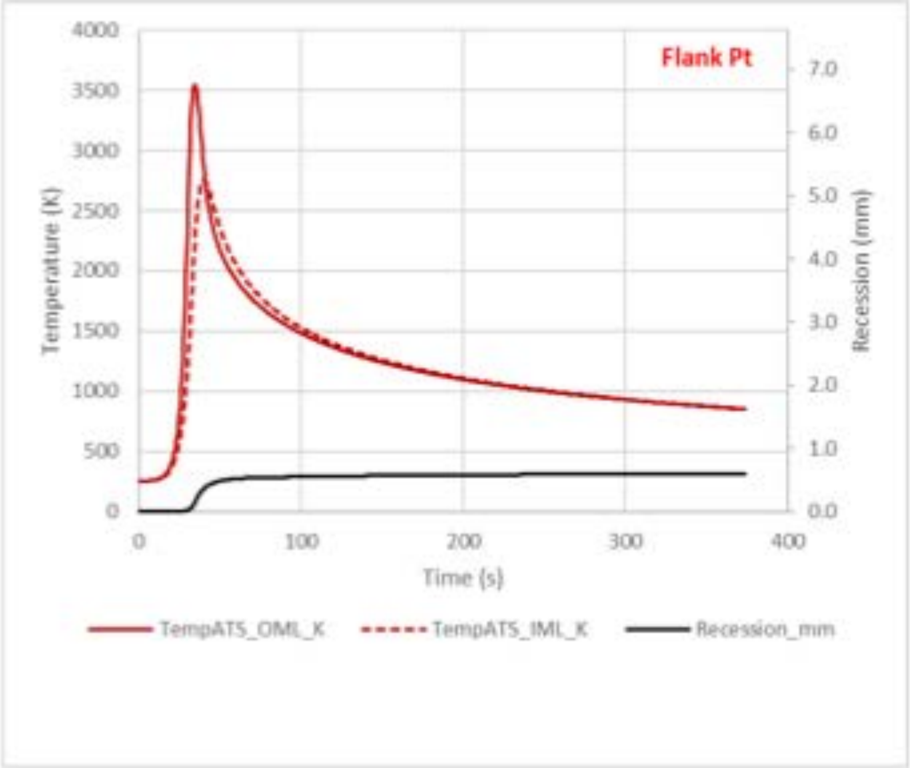
45-deg Sharp





Thermal Analysis Results (60-deg Blunt)

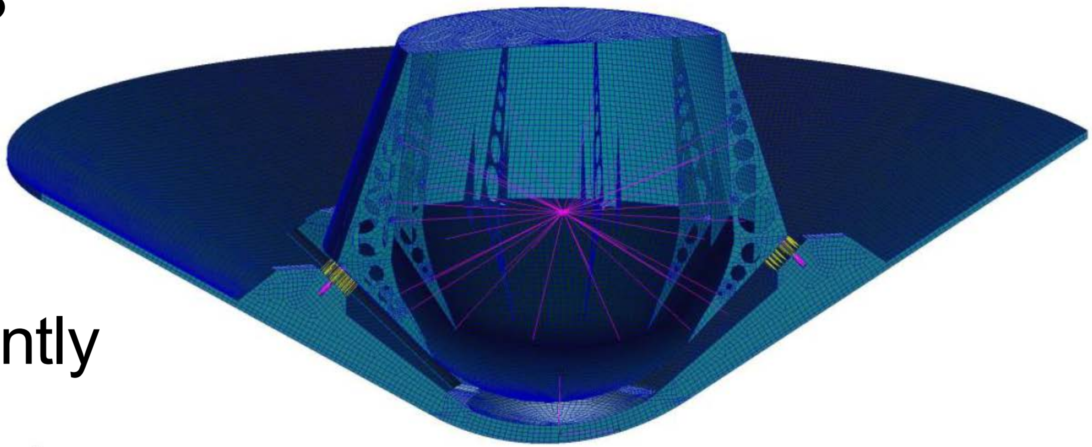




Observations

- *Use of carbon foam insulation between ATS and CAM keeps Shuttle tile materials within max use temp limit (~1800 K)*
- *Likely CAM bondline temperature limit (~525 K) met*
- *C-C recession is low (<2 mm on nose, <1 mm on flank)*

Structural Analysis



FEM analysis by
Keith Peterson (NASA Ames)

- Preliminary Finite Element Modeling (FEM) recently performed to assess structural capability of concept
  - Analysis identified areas to improve the design
  - This has led to recent design iterations to better distribute CAM and C-OS load onto ATS

Predecisional information for planning and discussion only

Summary and Next Steps

- Carbon-Carbon hot-structure EEV concept shows promise for EEV application
  - Potential reliability benefits for MMOD damage
  - Compatible with existing manufacturing infrastructure
  - Low mass relative to heritage TPS options such as Carbon-Phenolic

- Next Steps
  - Continue iteration on V3 C-C EEV concept
    - Incorporate lessons learned from V2.2 and earlier concepts to better distribute loads to ATS
  - Additional discussion with C-C vendors on manufacturing approaches

MMOD = Micro-Meteoroid / Orbital Debris

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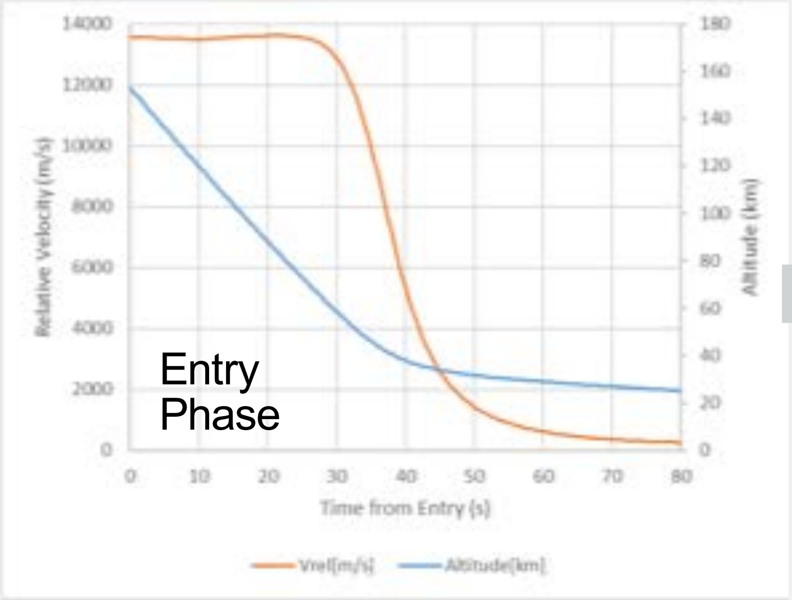
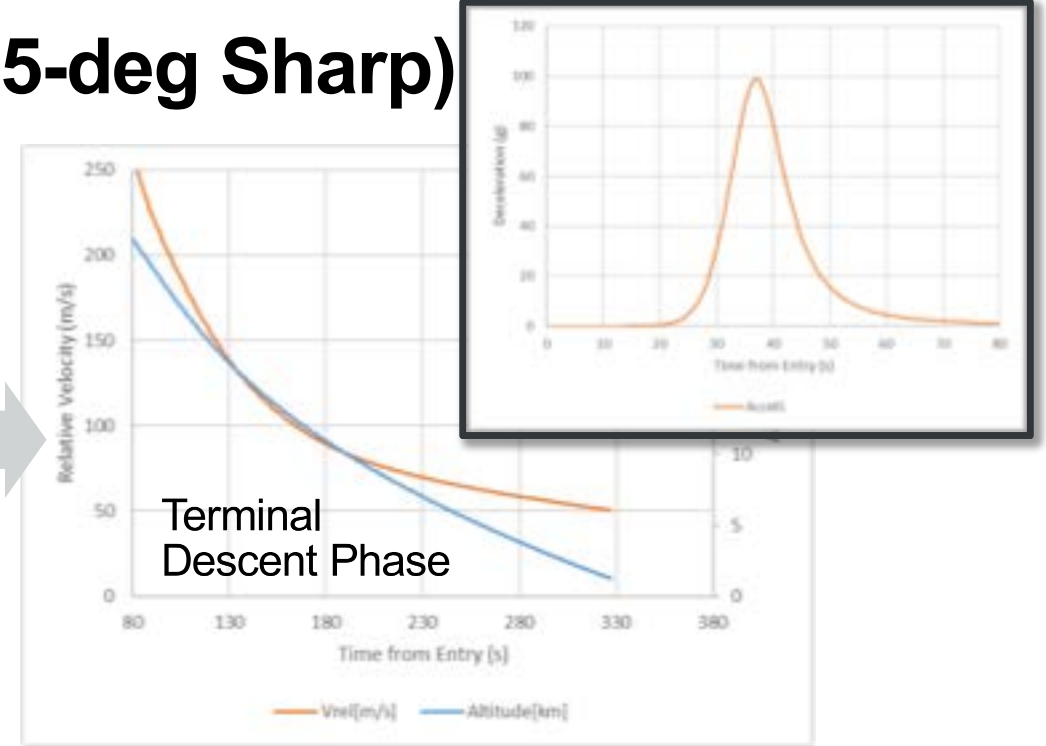
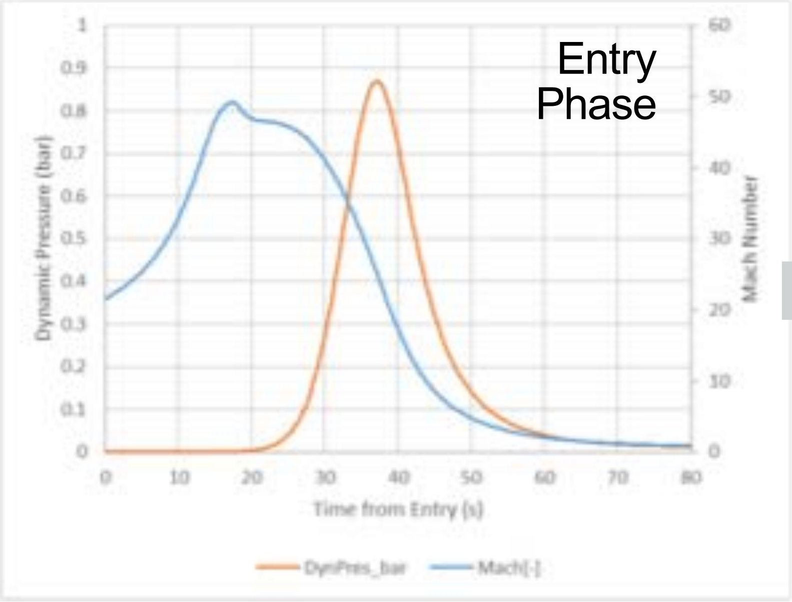
jpl.nasa.gov

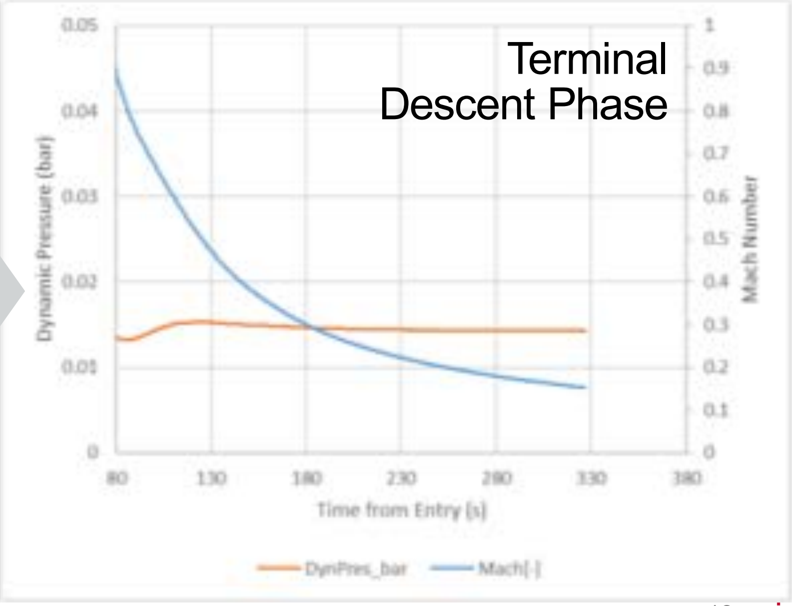
BACKUP

Trajectory Results (45-deg Sharp)

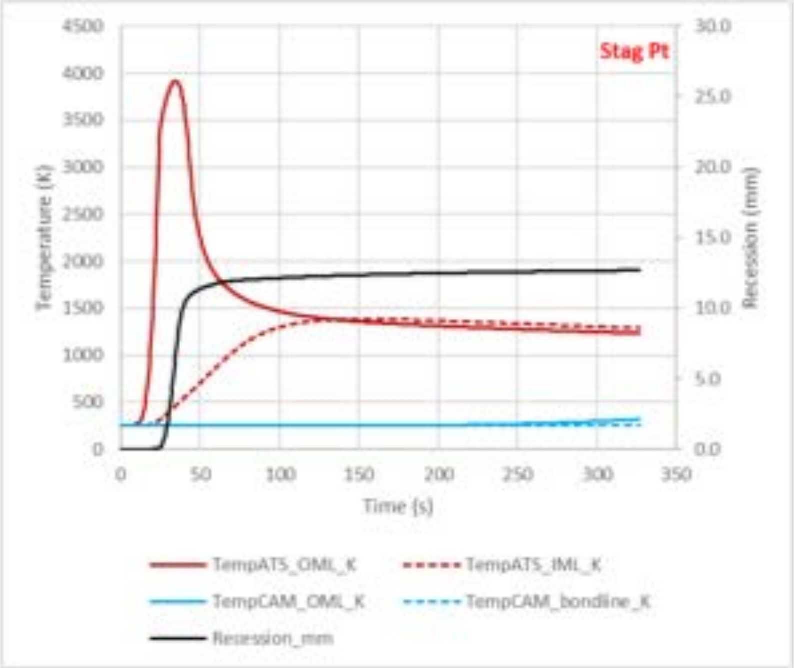


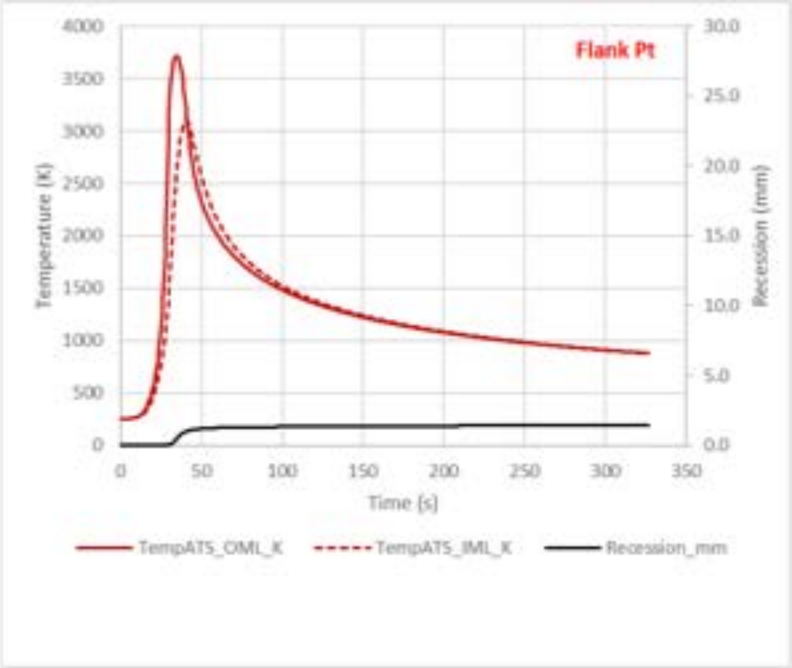






Thermal Analysis Results – 45-deg Sharp Case





Observations (as compared with 60-deg Blunt case):

- *Stag Pt:*
  - *Higher recession at nose tip due to significant heat flux increase*
  - *However, thicker 3DCC reduces backwall temperatures; thicker carbon foam layer also significantly reduces CAM temperatures*
- *Flank Pt*
  - *Higher peak temperatures and recession on ATS frustum*