Flexible Ablators: Applications and Arcjet Testing

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Outline: Flexible Ablators & Testing

- **Background**

  What are flexible ablators?

  - Details in presentations by Beck, et. al., Session 7 A and Stackpoole, et. al., Poster Session 7 A

- **Applications**

  Where can/should flexible ablators be utilized?

  - Draws from presentations by Raj Venkatapathy, et. al., Session 4 and Alicia D. Cianciolo, et. al. - Session 6 B and the 2010 ELD SA NASA TM

- **Testing: Going beyond standard puck and wedge testing**

  New approaches for arcjet testing of flexible ablators: Building on presentation by Dan Empey, et. al. Session 4

- **Summary & Recommendations**

What are Flexible Ablators?

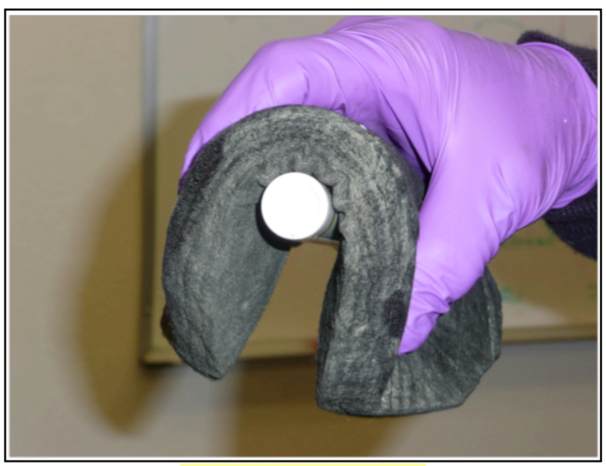
Standard low density ablators: rigid substrate impregnated with resin and heated

+ *impregnation*

heat ⇨ *treatment*

Example process for making Phenolic Impregnated Ceramic Ablator (PICA)

Flexible ablators replace rigid substrate with a flexible variant, e.g. carbon felt



PICA-flex

Initial arc-jet tests at JSC show PICA-flex performs well at 520 W/cm^2 (CW) and 35 kPA

Performance limits for flexible ablators are yet to be determined

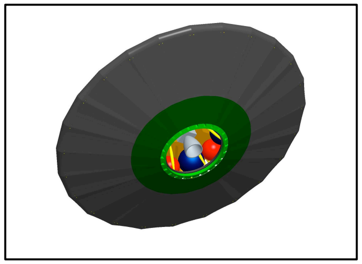
SIRCA-flex

Potential Applications for Flexible TPS: Deployables

Entry Systems & Technology Division

Entry Vehicle Concept	Location	q (W/cm²) A / E	Margin q?	Pressure (kPa) A / E	Shear (Pa) A / E
EDL SA, ADEPT	Peak Forebody	106 / 32	YES	11 / 8	42 / 25
EDL SA, ADEPT	Peak Forebody	67 / 21	no	9 / 6	27 / 16

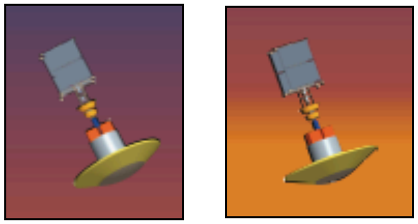
HIAD[1] Concept
(23 m diameter)



ADEPT[2] Concept
(23 m diameter)

1 Hypersonic Inflatable Aerodynamic Decelerator – EDL SA Phase I study
2 Adaptive, Deployable Entry and Placement Technology

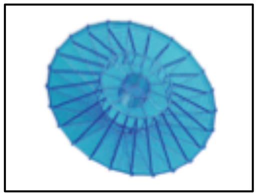
Entry Vehicle Concept	Diameter (m)	Location	q (W/cm²)	Margin q?	Pressure (kPa)	Shear (Pa)
EFF, Direct entry	6	Peak Forebody	223	YES	14	287
EFF, Direct entry	8	Peak Forebody	171	YES	10	207
EFF, Direct entry	10	Peak Forebody	134	YES	7	162



Exploration Feed Forward (EFF) **Concepts**
(6, 8, 10 m diameters)[3]

7.2 km/s entry, capable of delivering 3.4 mT to Mars surface[3] (7.2 mT arrival mass)
Compared to ~ 1 mT MSL EDL-SA EFF study[3]

Entry Vehicle Concept	Location	q (W/cm²)	Margin q?	Pressure (kPa)	Shear (Pa)
ADEPT, Venus	Peak Forebody	230	no	7	210
ADEPT, Saturn	Peak Forebody	295	no	11	245



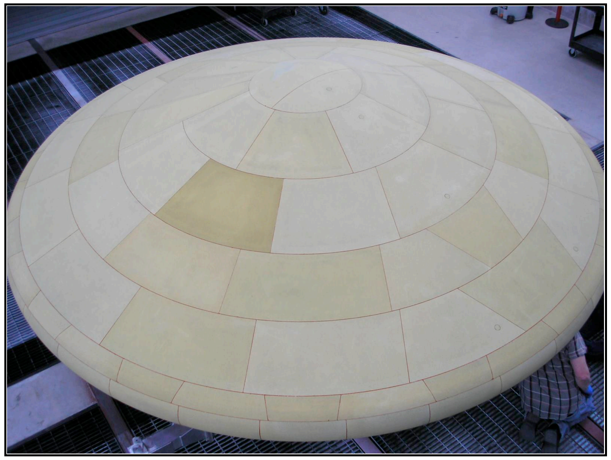
ADEPT Concept
(2.14 m diameter)

Flexible Ablators enable HIADs of ~ half the diameters of those using Flexible, Insulating TPS (Del Corso, et. al.)

Flexible Ablators for Use on Rigid Aeroshells

- **Flexible ablators are compliant and offer significant design/system integration advantages and possibly comparable performance to rigid counterparts**
  - Manufacturability (Broad goods ~ 1.8 m wide)
  - Large reduction in piece-parts and numbers of gaps/seams
  - Ease of assembly - Probably can be direct bonded
  - Enables larger diameter aeroshells
- **A game changing way to go beyond Orion/PICA and MSL/PICA aeroshells**

Orion Heat Shield
(5 m diameter)
Un-margined: 433 W/cm^2, 101 kPa & 146 Pa



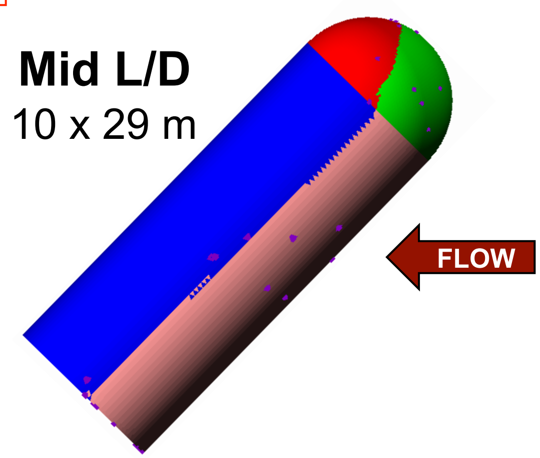
MSL Heat Shield
(4.5 m diameter)
Margined: 203 W/cm^2, 19.7 kPa, 490 Pa

More: Flexible TPS for Use on Rigid Aeroshells

Potential applications for Heavy Mars Down-mass Concepts

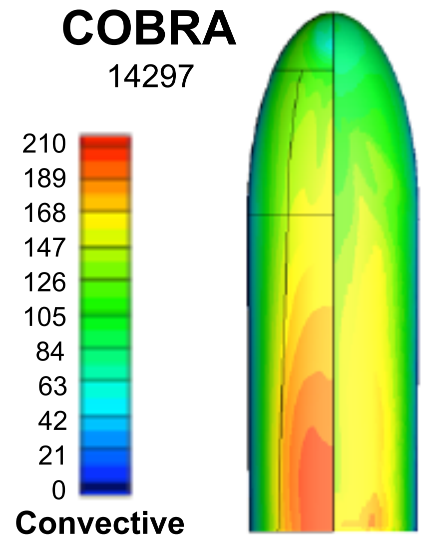
Location on Max L/D Vehicle	Rigid TPS	q (W/cm^2) A / E	Margin q?	Pressure (kPa) A / E	Shear (Pa) A / E
Windward cylinder	PICA/LI-900	437 / 130	YES	24 / 17	512 / 266
Windward cylinder	PICA/LI-900	301 / 87	no	21 / 15	373 / 194
Nose, max	LI-900	26 / 11	no	1 / 1	30 / 21
Cylinder side, max	LI-900	26 / 18	no	1 / 10	54 / 67
Cylinder, leeward max	LI-900	2 / 2	no	0 / 0	3 / 5

Mid L/D
10 x 29 m



Location on COBRA 14297 Vehicle	Rigid TPS	q (W/cm^2) A / E	Margin q?	Pressure (kPa) A / E	Shear (Pa) A / E
Windward cylinder	PICA	174 / 63	no	13 / 13	175 / 114
Nose, max	LI-900	26 / 10	no	1 / 1	29 / 21
Cylinder side, max	LI-900	26 / 11	no	1 / 1	28 / 21
Leeward cylinder	LI-900	1 / 1	no	0 / 1	2 / 4

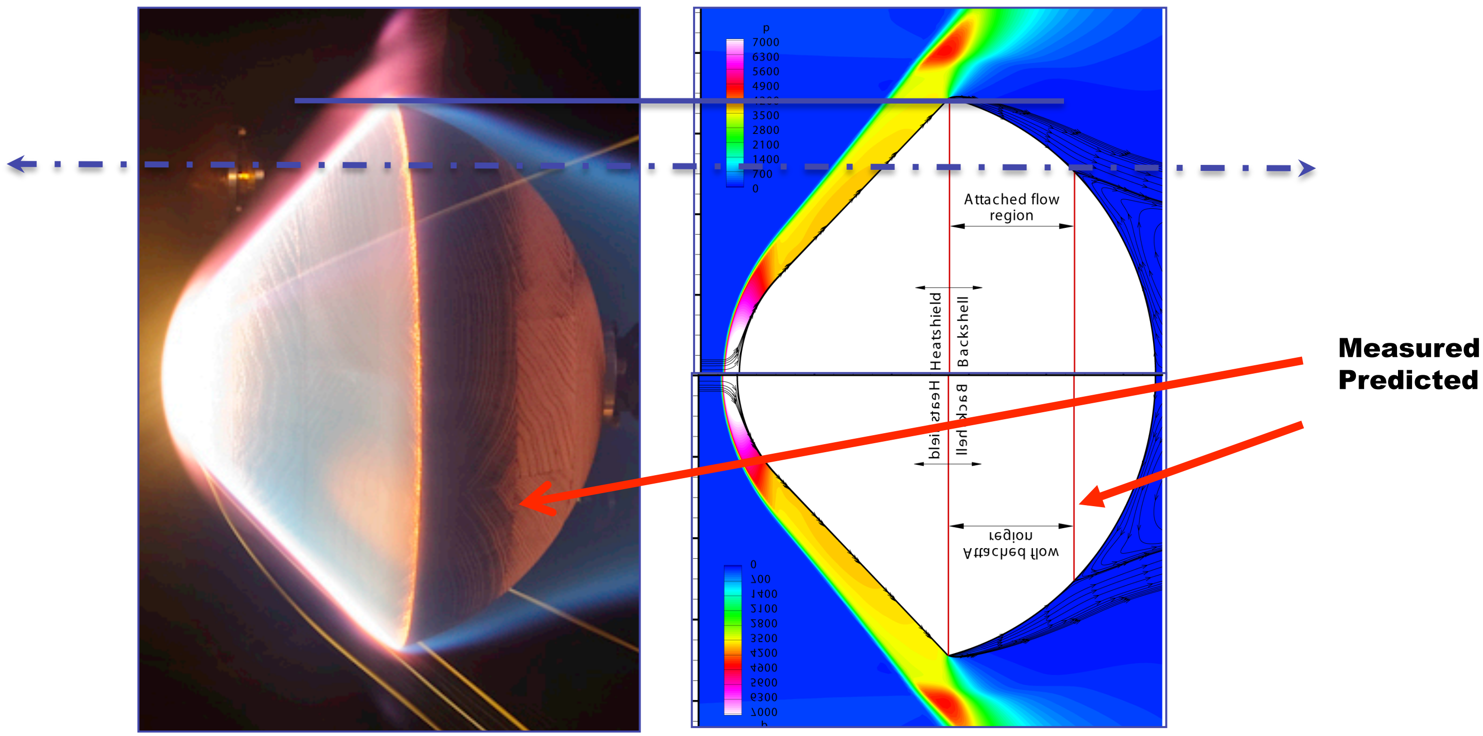
COBRA
14297



Analysis of heat rates suggest flexible TPS should be considered mid L/D vehicles

Data in charts are representative for max heat load locations

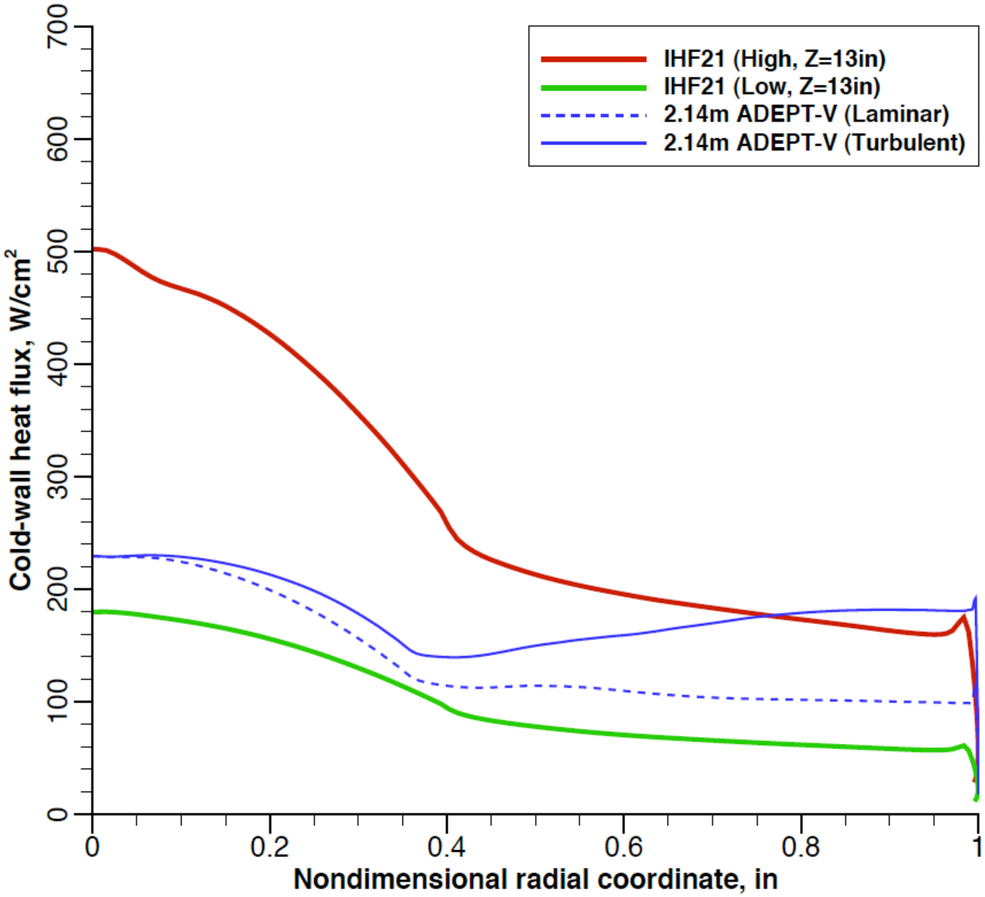
Going Beyond Standard Arcjet Testing: SPRITE and Validated Pre-Test CFD Predictive Capability

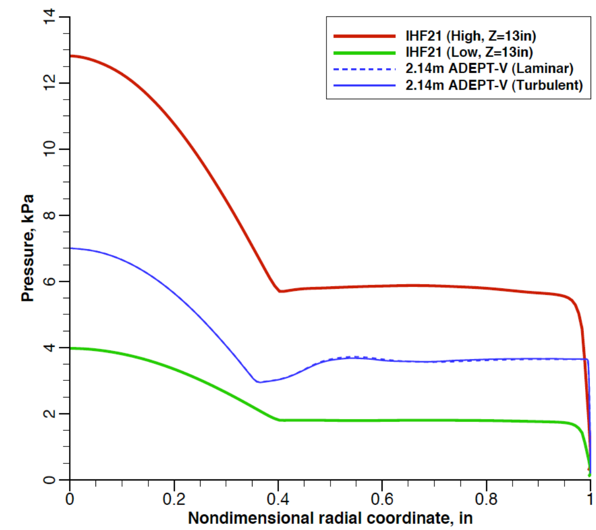


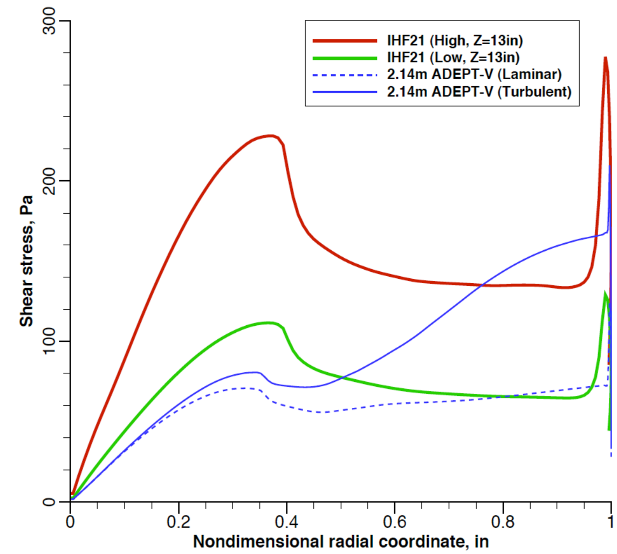
- **Excellent agreement in char pattern between DPLR CFD & arc jet test**
  - **Nozzle shear – Shock layer interference gave SPRITE max diam.**
  - **Attached flow on aft body**

SPRITE: (Small Probe Reentry Investigation for TPS Engineering)

Comparison of SPRITE Flex and ADEPT Aerothermal Conditions for Venus

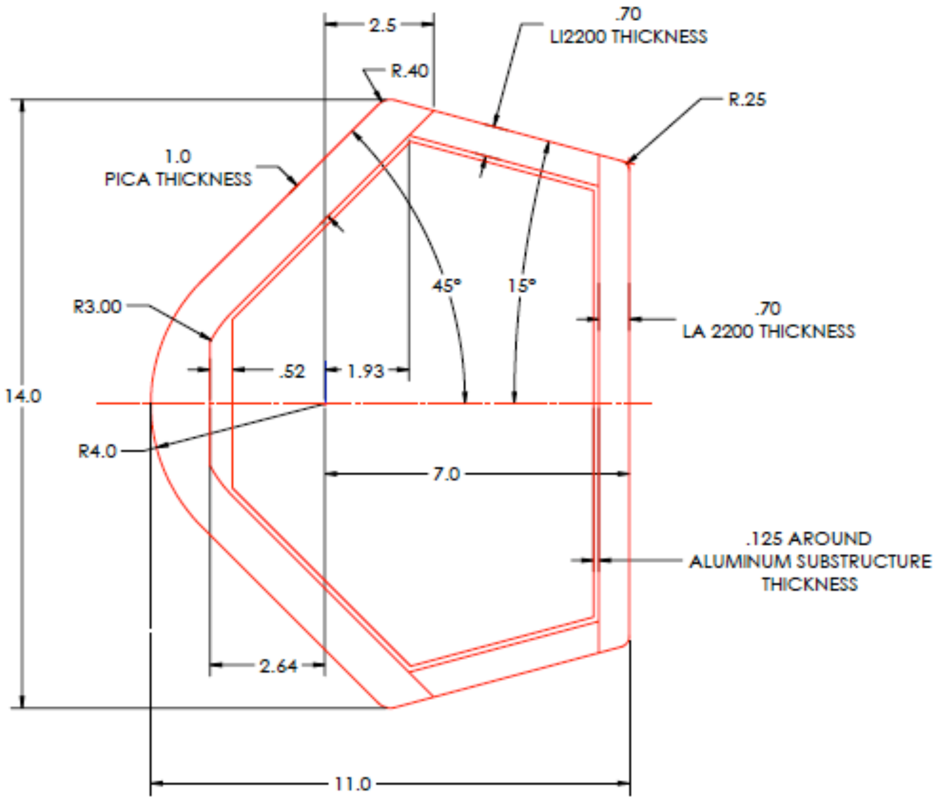


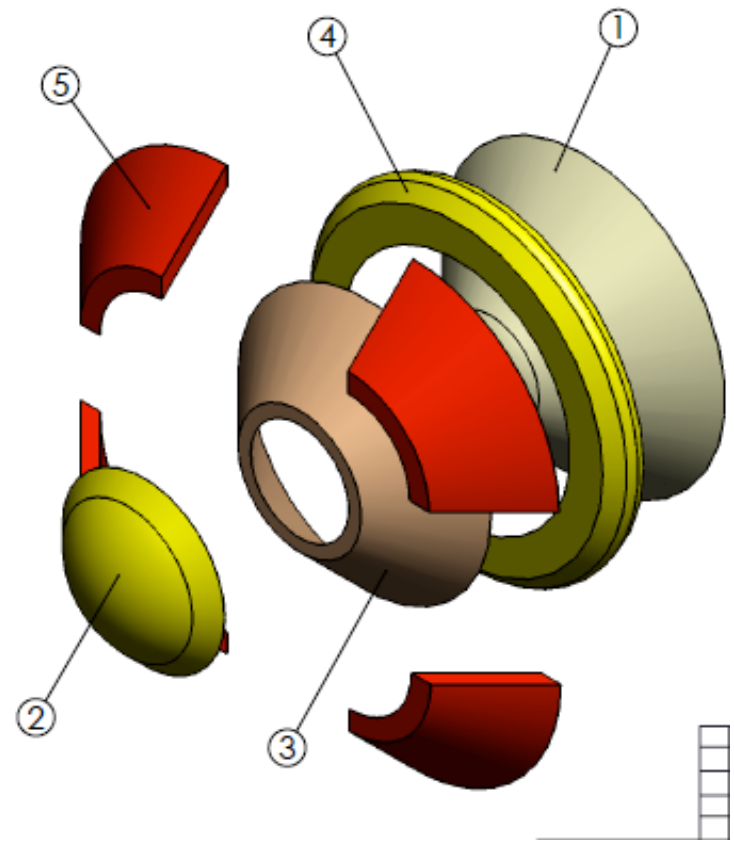




SPRITE goes beyond conventional approach and enables combined environment (qdot, pressure and shear) arcjet testing

SPRITE – Conformal Arcjet Testing





Instrumentation

- Pyrometery
- TC stacks
- High Speed Video
- Full Scale Calorimetry

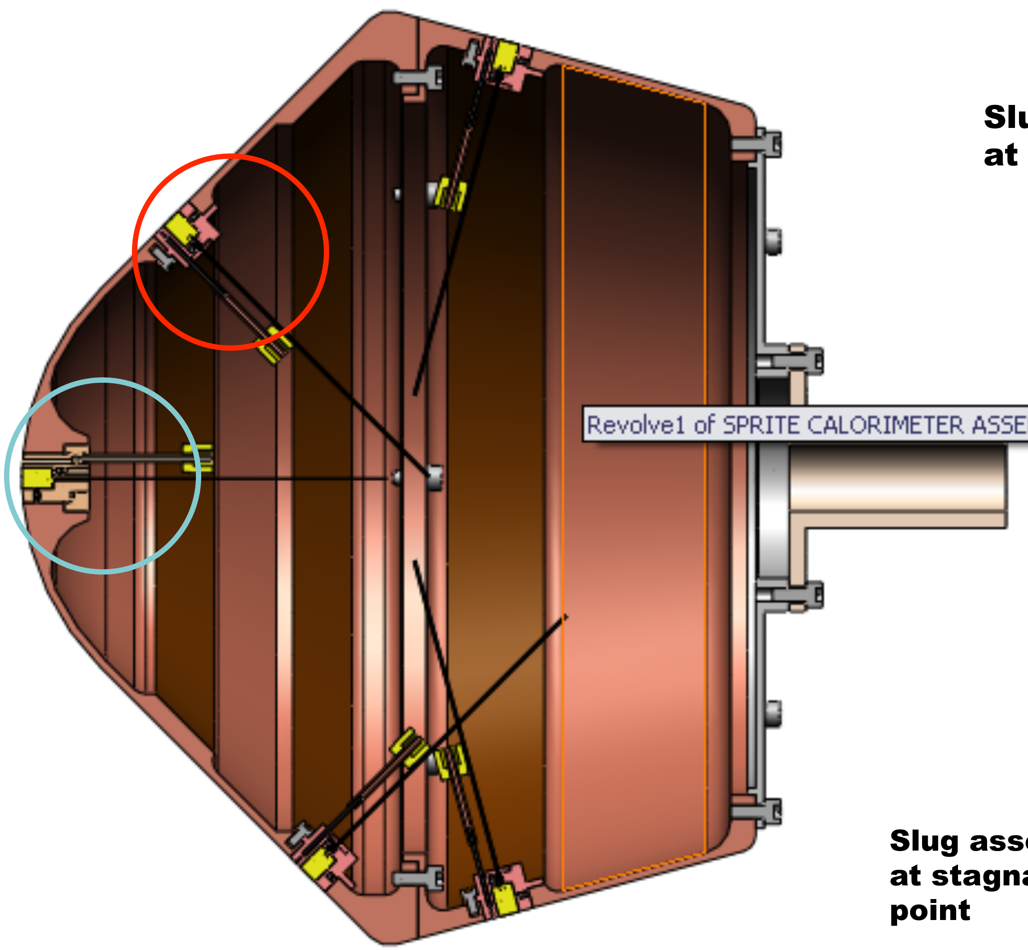
Data

- Temperature as function of time
- Acreage and seam performance in combined qdot, pressure and shear environment
- Recession

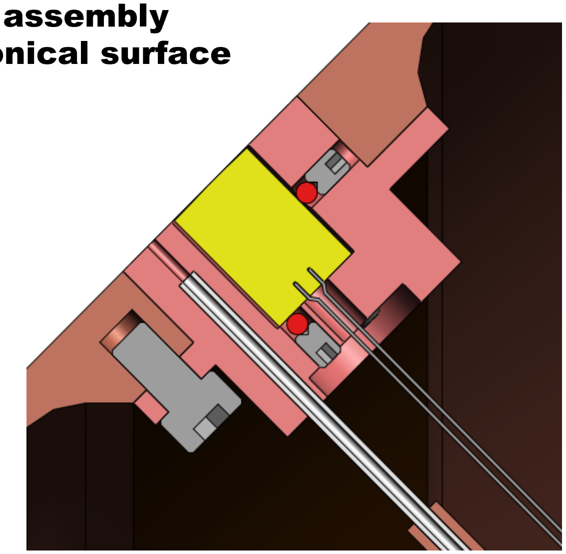
Use of Data

- Thermal Response Model
- Understand TPS performance for conformal TPS applications

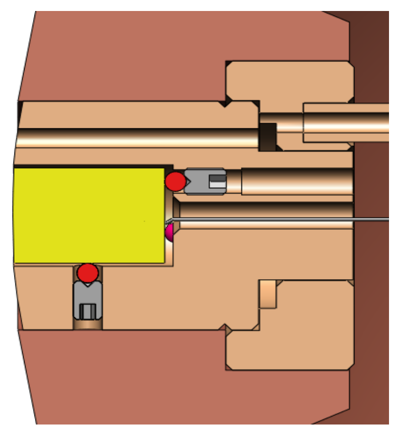
Cu SPRITE Calorimeter for Conformals – Full Scale



Slug assembly at conical surface



Slug assembly at stagnation point



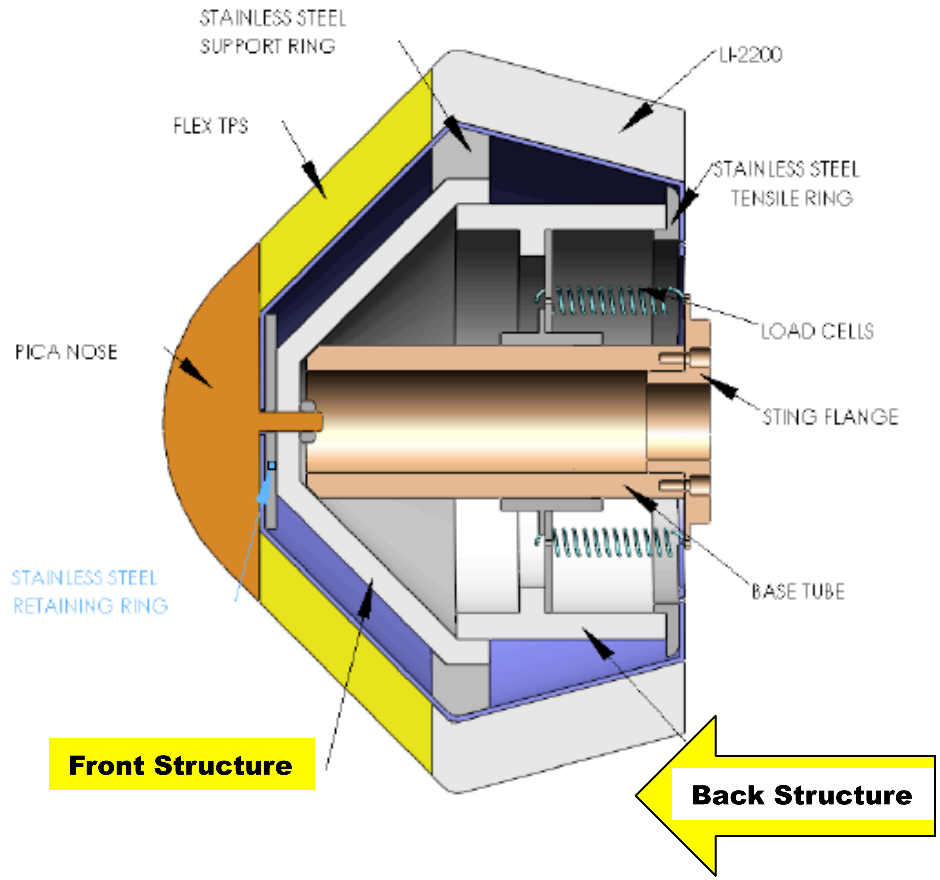
SPRITE-Flex Arcjet Testing

Objective

Determine performance of flexible ablators (acreage, seams and permeability) with "structure" in flight-simulated <u>combined</u> environments (qdot, pressure, shear <u>and</u> tensile loading).

Note

Current design under NASTRAN analysis to allow for flight-like biaxial tensile loading on the flex ablator and its "structure"



Summary and Recommendations

- Flexible ablator technology is cross cutting and game changing
  - **Cross cutting for deployable and conformal (rigid – body) TPS applications.**
  - **Enabling for the game-changing Mars 23 m HIAD and ADEPT deployable decelerators, the smaller EFF Mars HIADS and for the revolutionary ADEPT missions to Venus & Saturn (Venkatapathy, et. al. IPPW-8 session 4)**

Peak ballpark environments of interest are
Deployables ~ (300 W/cm^2, 14 kPa pressure and shear of 300 Pa)
Rigid bodies ~ (700 W/cm^2, 150 kPa pressure and shear of 500 Pa)
Dual heat pulse capability needed for human and robotic Mars missions using aerocapture

- Future system analysis studies of rigid vehicles should consider:
  - ***Flexible ablators as an option for conformal TPS on rigid entry vehicles***
  - ***Flexible TPS (HIAD insulating baseline material) and Shuttle blankets should be considered for lower heat flux areas on future mid L/D Human Mars Mission vehicles.***

- Plans for innovative SPRITE arcjet testing of flexible ablators and conventional testing (puck/wedge/swept cylinder) are being developed as a part of OCT sponsored maturation of flexible ablators

Acknowledgements

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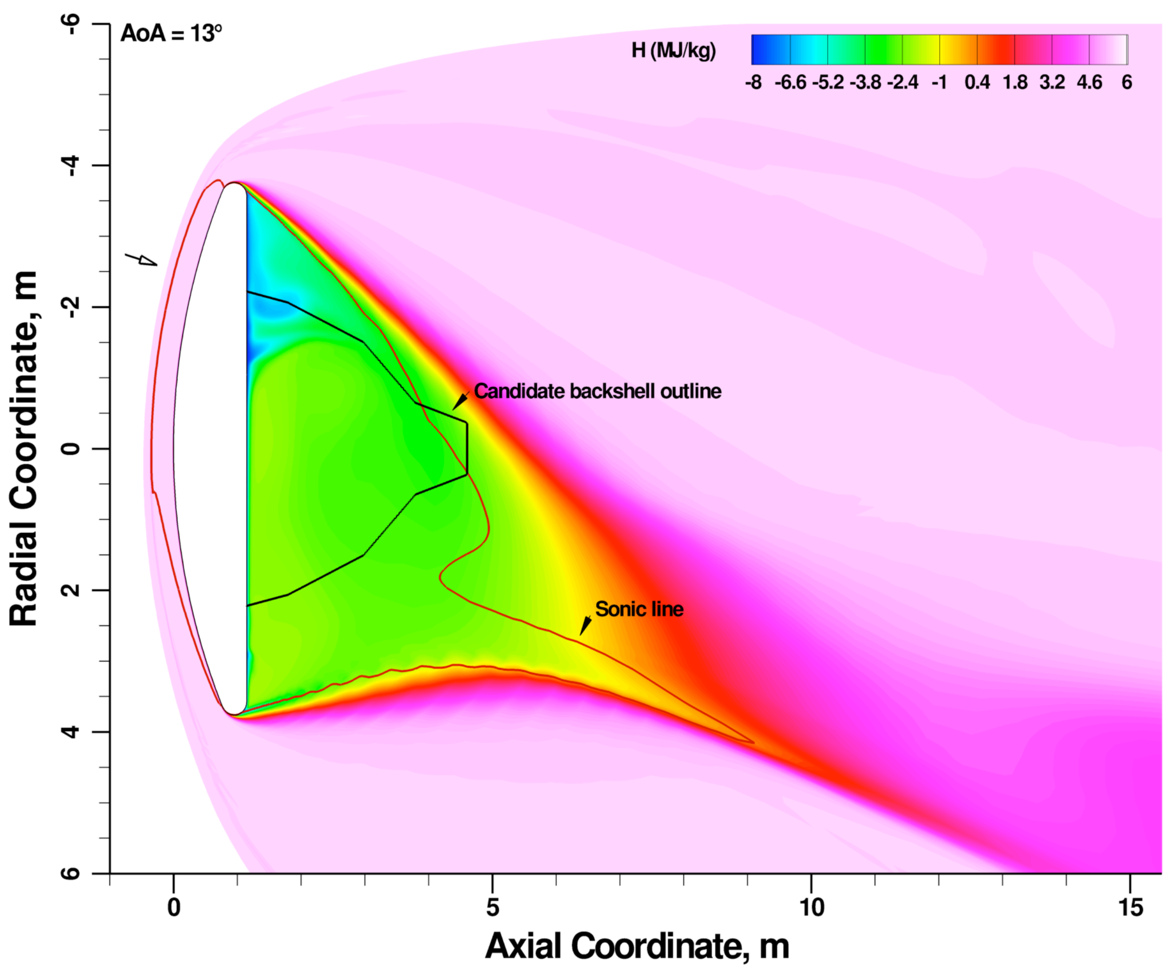
- **Imelda Terrazas-Salinas**

BACKUP

Design Issue for Deployables: Balancing of H/S Diameters, Heat Rate, Vehicle Controllability and Aft body Shear Impingement



7.5 m Ablative deployable: Mars 2018 H/S With 4.5 m diam x 1.67 stretched aftbody

HIAD with insulatative TPS would be ~ 15 m Diam.