Flexible Ablators: Applications and Arcjet Testing

J. O. Arnold, E. Venkatapathy. R. A. S. Beck, M.K. McGuire;
NASA Ames Research Center

D. K. Prabhu; *ERC Inc/NASA Ames*

S. Gorbunov; *Jacobs Technology/NASA Ames*

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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

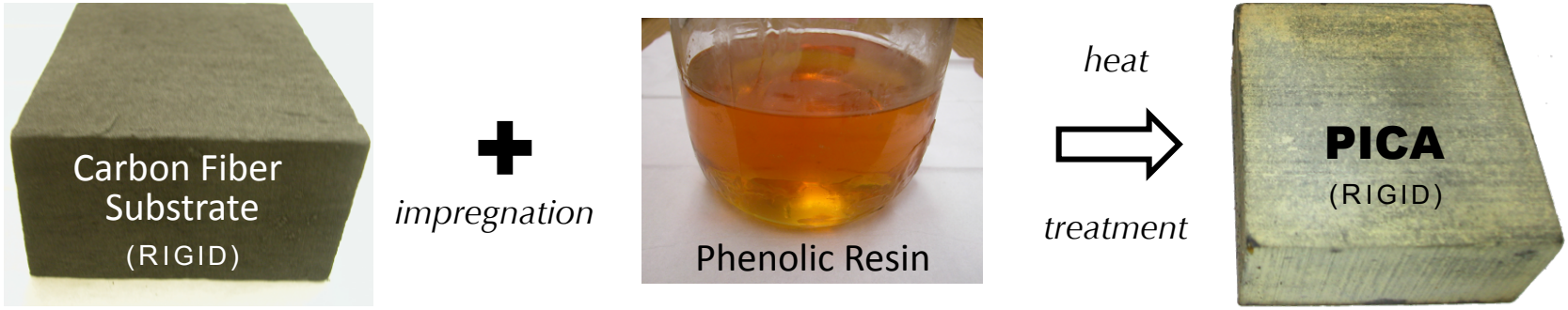
- **Testing: Going beyond standard puck and wedge testing**

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

- **Summary & Recommendations**

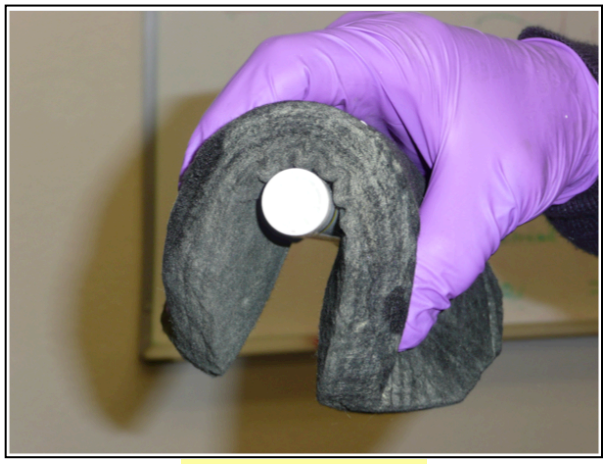
What are Flexible Ablators?

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



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

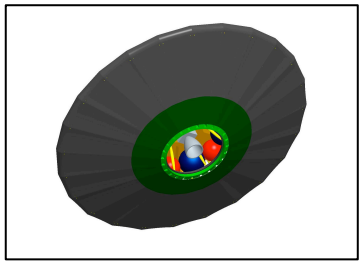
SIRCA-flex

Potential Applications for Flexible TPS: Deployables

Entry Vehicle Concept	Location	q (W/cm^2) 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

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

HIAD[1] Concept
(23 m diameter)



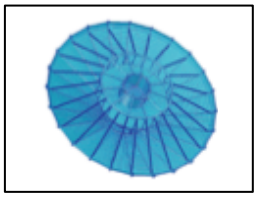
ADEPT[2] Concept
(23 m diameter)

Entry Vehicle Concept	Diameter (m)	Location	q (W/cm^2)	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/cm^2)	Margin q?	Pressure (kPa)	Shear (Pa)
ADEPT, Venus	Peak Forebody	230	no	7	210
ADEPT, Saturn	Peak Forebody	295	no	11	245



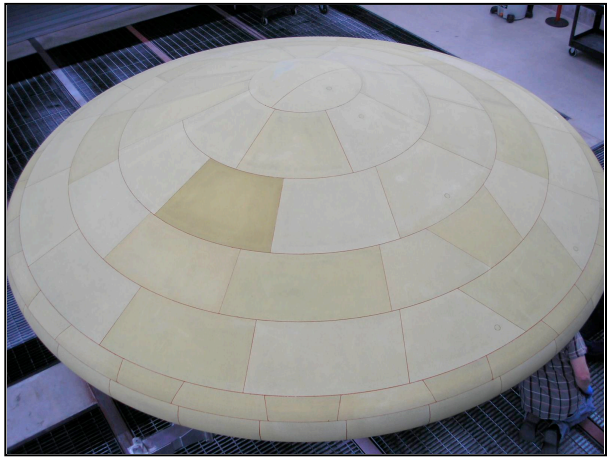
ADEPT Concept
(2.14 m diameter)

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

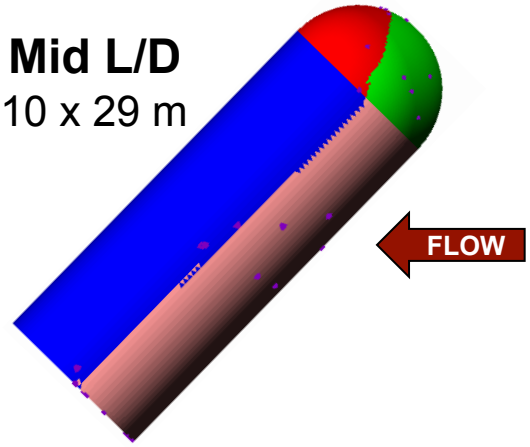
Potential applications for Heavy Mars Down-mass Concepts

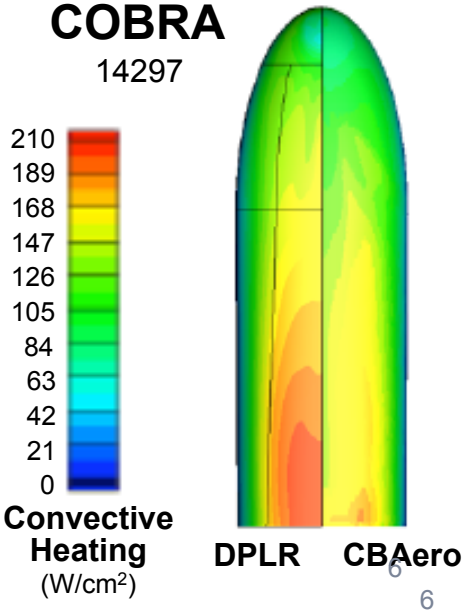
Location on Max L/D Vehicle	Rigid TPS	q (W/cm^2) A / E	Margin q?	Pressure (kPa) A / E	Shear (Pa) A / E
Windward cylinder	PICA/LI-900	437 / 130	YES	24 / 17	512 / 266
Windward cylinder	PICA/LI-900	301 / 87	no	21 / 15	373 / 194
Nose, max	LI-900	26 / 11	no	1 / 1	30 / 21
Cylinder side, max	LI-900	26 / 18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

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

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

Data in charts are representative for max heat load locations





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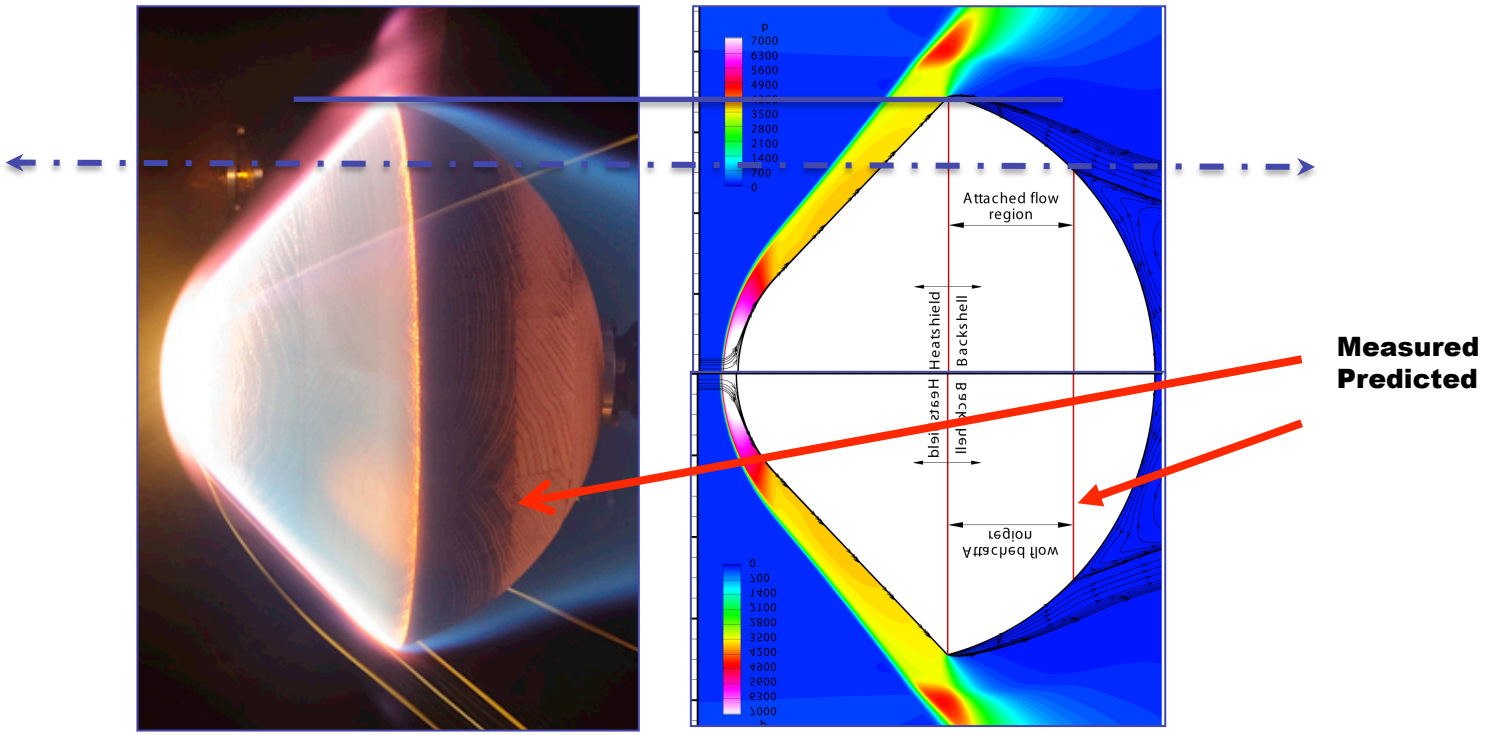
Going Beyond Standard Arcjet Testing: SPRITE and Validated Pre-Test CFD Predictive Capability



- 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

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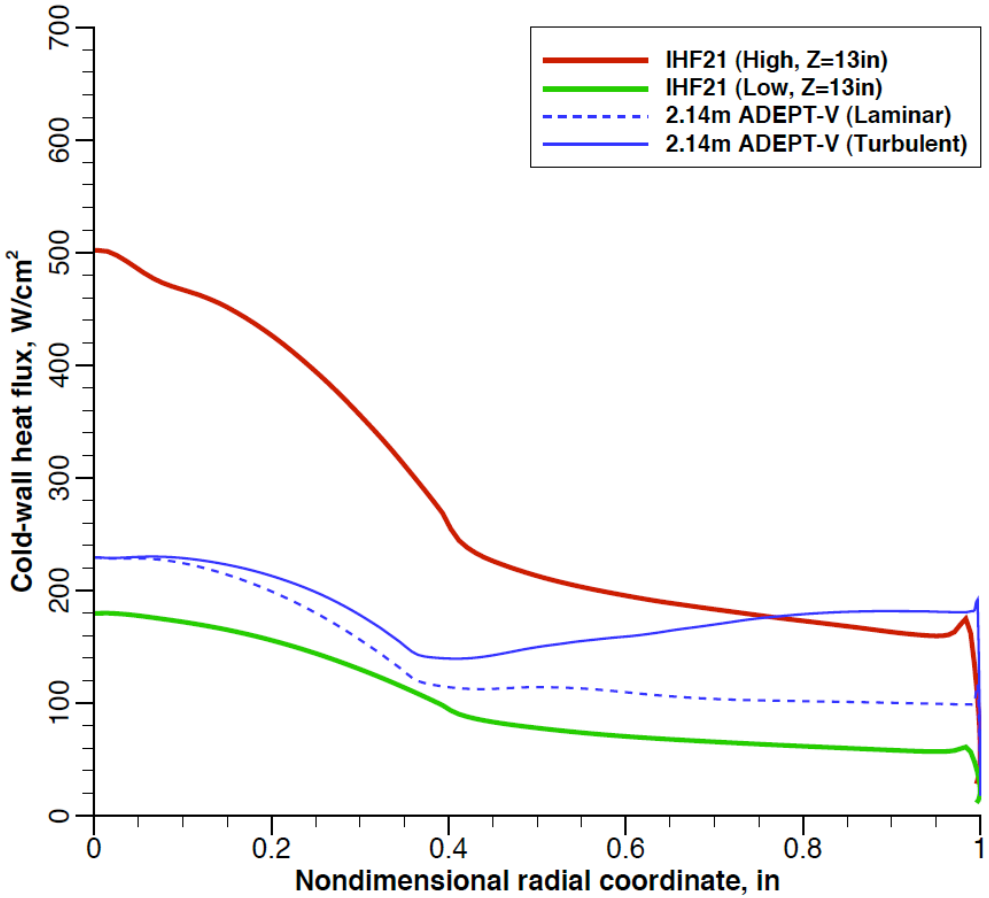
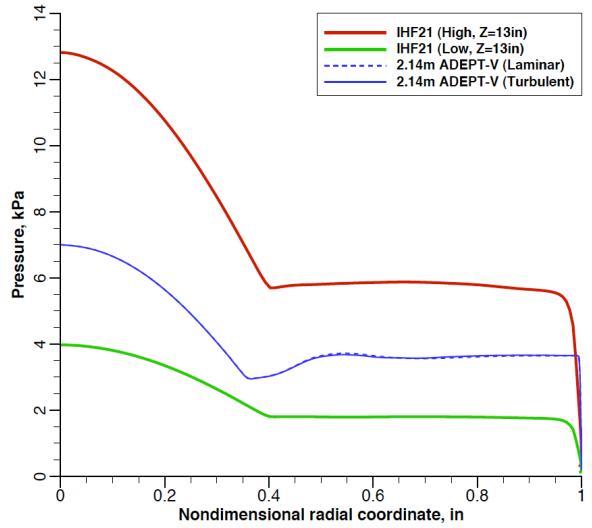
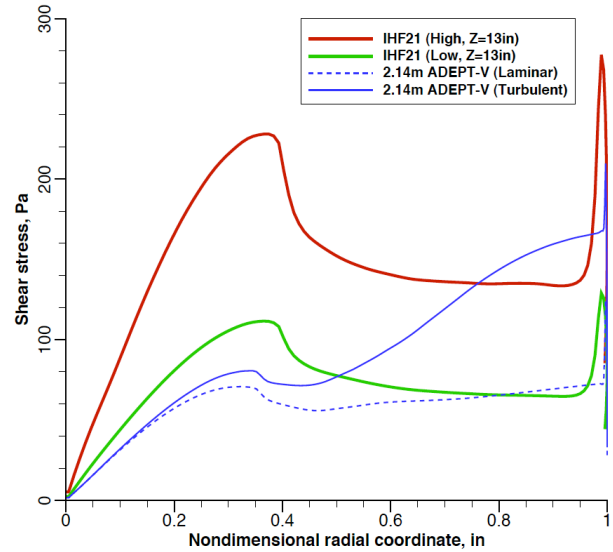
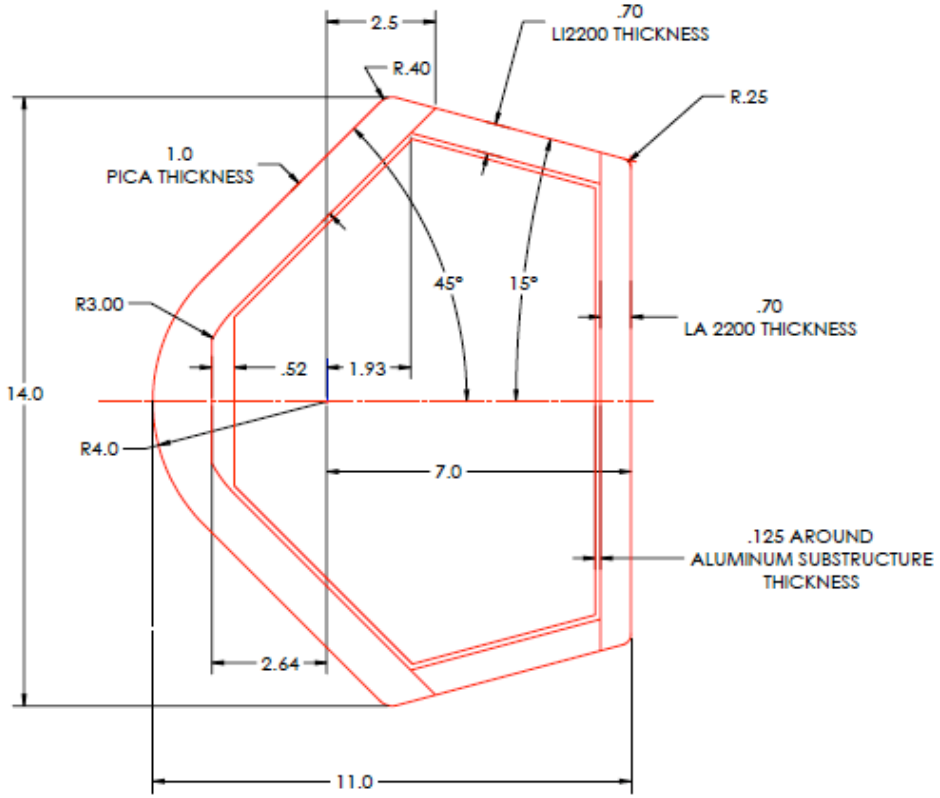


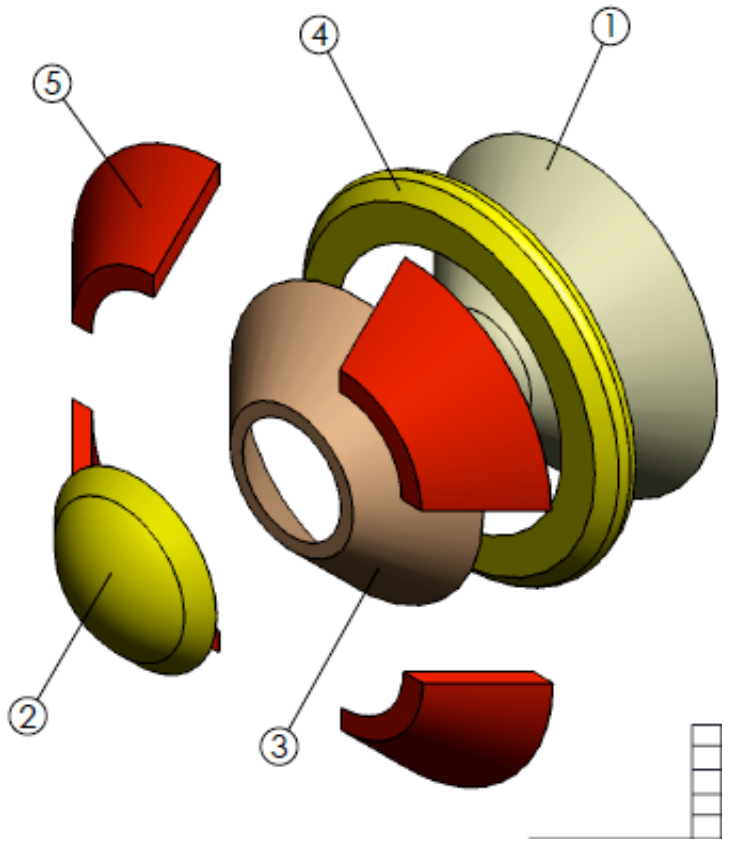




SPRITE goes beyond conventional approach and enables combined environment (qdot, pressure and shear) arcjet testing

SPRITE – Conformal Arcjet Testing





Instrumentation

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

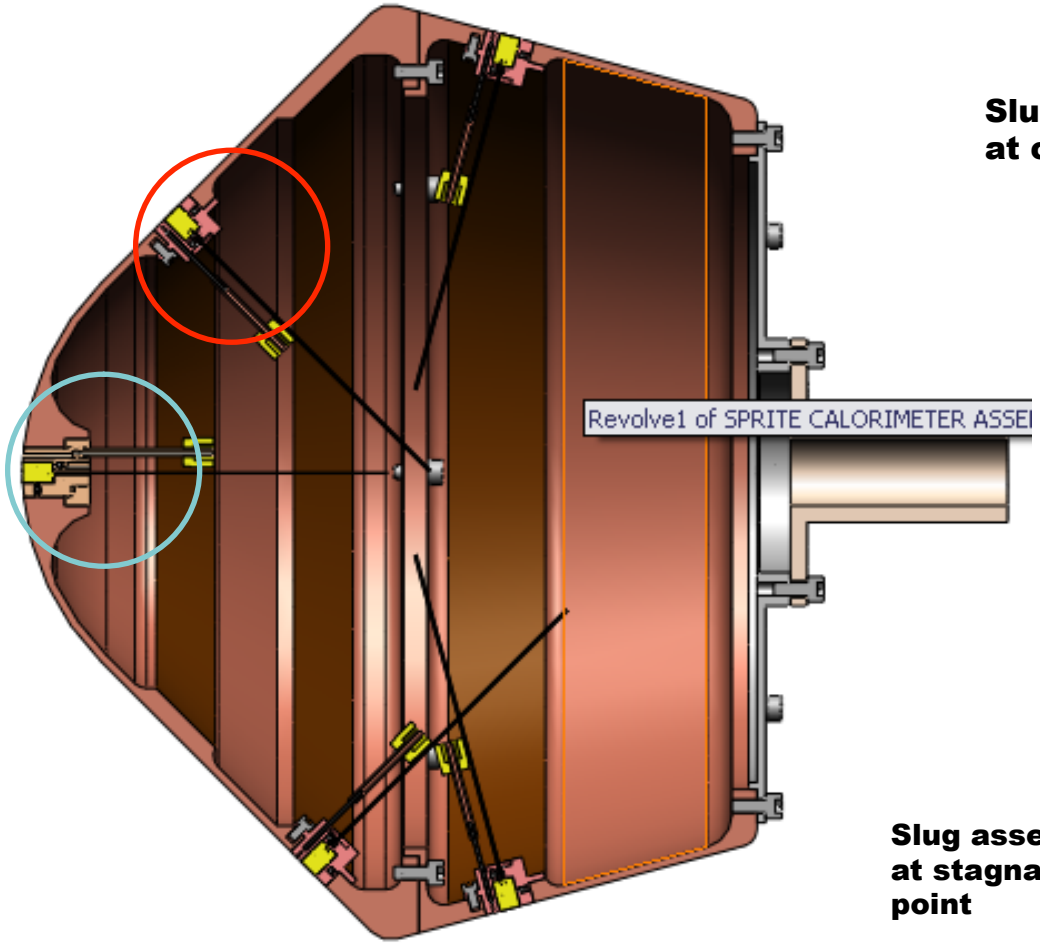
Data

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

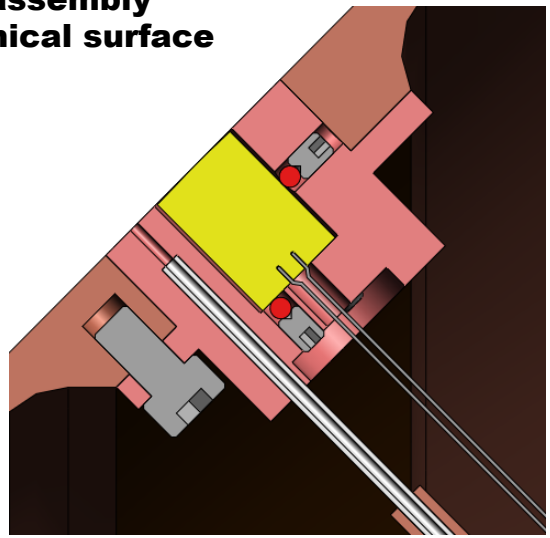
Use of Data

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

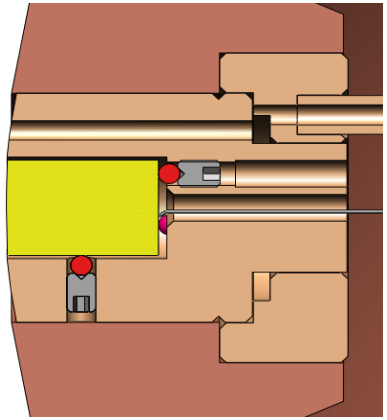
Cu SPRITE Calorimeter for Conformals – Full Scale



Slug assembly at conical surface



Slug assembly at stagnation point



SPRITE-Flex Arcjet Testing

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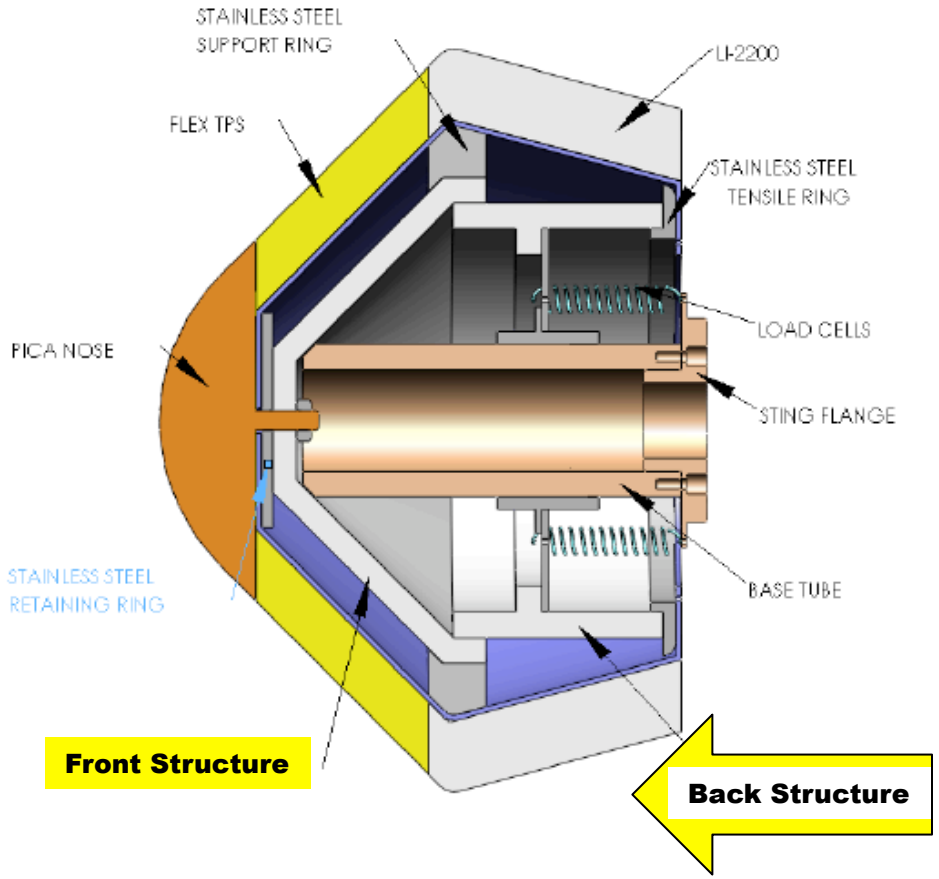
Objective

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

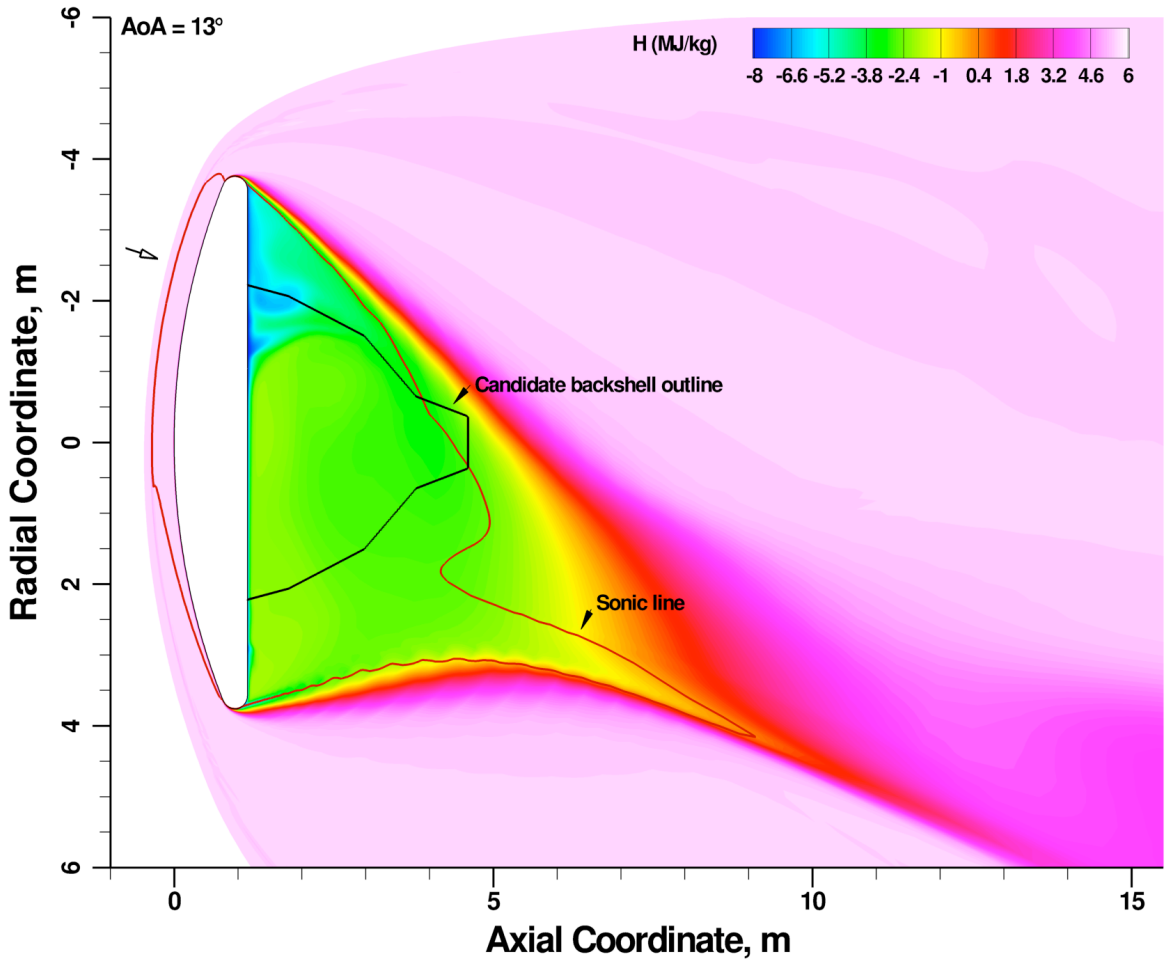
- Plans for innovative SPRITE arcjet testing of flexible ablators and conventional testing (puck/wedge/swept cylinder) are being developed as a part of OCT sponsored maturation of flexible ablators

Acknowledgements

- **Steve Del Papa and the JCS arcjet testing crew**
- **Alan Covington and Howard Goldstein**
- **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.