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*
and
S. Gorbunov; *Jacobs Technology/NASA Ames*

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Outline: Flexible Ablators and Testing

- What are flexible ablators? Details in paper for 21st AIAA Decelerator Conference May 23-26 2011 by Beck, et. al.
- Limits of performance (qdot, pressure and shear) not yet defined.
- Potential applications to near/far term human and robotic missions.
- Brief discussion re deployables: Balance between heat shield diameter, heat rate, controllability, and aft-body shear impingement.
- Bonding of flexible ablators to rigid aeroshells for conformal apps.
- Going beyond puck and swept cylinder testing: Plans to use the new SPRITE Arcjet testing approach for flexible ablators.
- Summary: Flexible ablators are game-changing and cross-cutting.

What Are Flexible Ablators ?

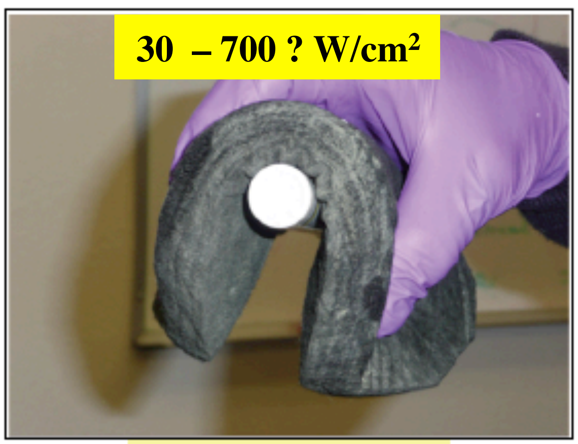
Rigid Ablators

- Phenolic Impregnated Ceramic Ablator (PICA)
- Silicone Impregnated Reusable Ceramic Ablator (SIRCA)

Flexible Ablators

Substrate/reinforcement	+	Matrix	=	*Flexible* Ablator
Flexible Felt [silica] [carbon]	+	Resin* [silicone] [phenolic]	=	TPS [SIRCA-flex] [PICA-flex]

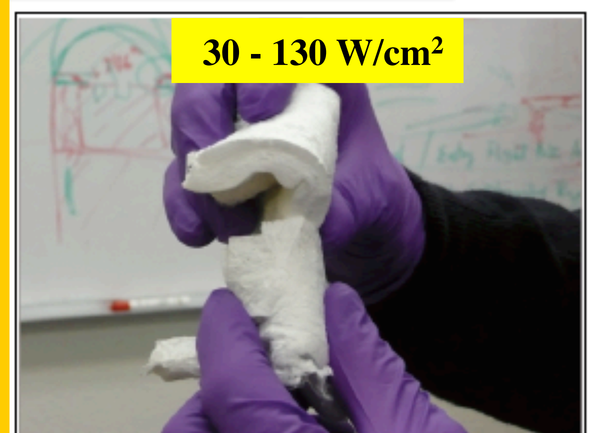
**resin is mainly responsible for the pyrolysis process*



PICA-flex

Initial range of heating Explored. Arcjet tests on PICA-flex at 526 W/cm^2 (CW) and 35.4 kPa.

The perf. limits of flexible ablators for heat rate, shear and pressure are not yet defined.

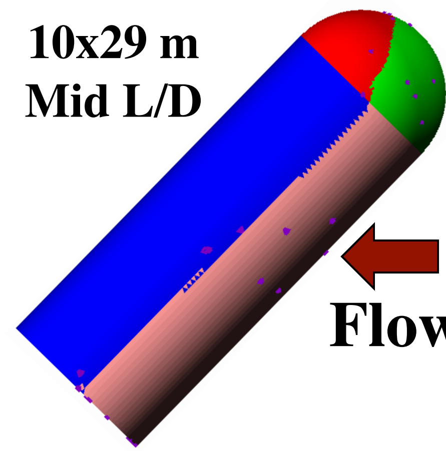


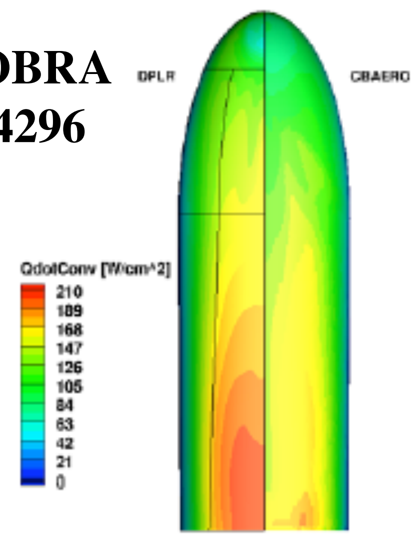
SIRCA-flex

Potential Conformal Applications for Flexible TPS (1/2)

(Representative data at max heat load location)

Vehicle	Location	q, A/E W/cm^2	Margin q , (Y/N	Pressure A/E, kPa	Shear, A/E, Pa
EDL SA Mid L/D	Windward Cylinder	**437/130**	Y	**24/17**	**512/266**
"	"	301/87	N	21/15	373/194
"	Nose, Max Non ablator	26/11	N	1/1	30/21
"	Cylinder side Max non ablator	26/18	N	1/10	54/67
"	Cylinder, Leeward max	2/2	N	0/0	3/5
COBRA HMM 14297	Windward Cylinder	**174/63**	N	**13/13**	**175/114**
"	Nose, Max Non ablator	26/10	N	1/1	29/21
"	Cylinder side Max non ablator	26/11	N	1/1	28/21
"	Leeward Cylinder	1/1	N	0/0	2/4





Denotes Potential Flexible Ablator Application

Observations Re TPS for Human Mars Missions: Conformal Applications

- Rigid PICA atop LI-900 used for 2009 ELD-SA study for mid L/D while COBRA used rigid PICA on windward cylinder. Heat rate ranges suggest flexible ablators may be used for cylinder and nose TPS rather than rigid ablators. Their imitations for these conformal applications in terms of dual heat pulse, pressure, shear and thickness remain to be answered.

- EDL-SA 2009 mid L/D and COBRA studies used Shuttle tile solutions for non-ablating nose and leeward cylinder locations.

- Obvious advantage of flexible TPS is manufacture-ability, major reduction of piece-parts and elimination of TPS material-structure integration issues.

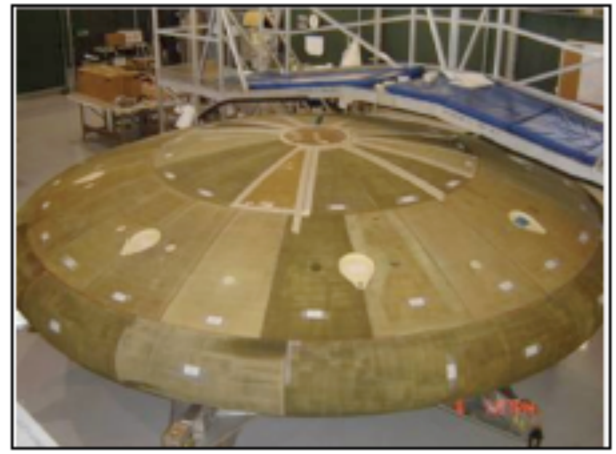
- **Recommend: Future studies consider flexible ablator solution for windward locations. For locations with qdot < 30 W/cm^2, study the new "insulating" flexible TPS being developed for HIADs/HEART and existing Shuttle AFRSI and FRSI.**

Potential Conformal Applications for Flexible TPS (2/2)

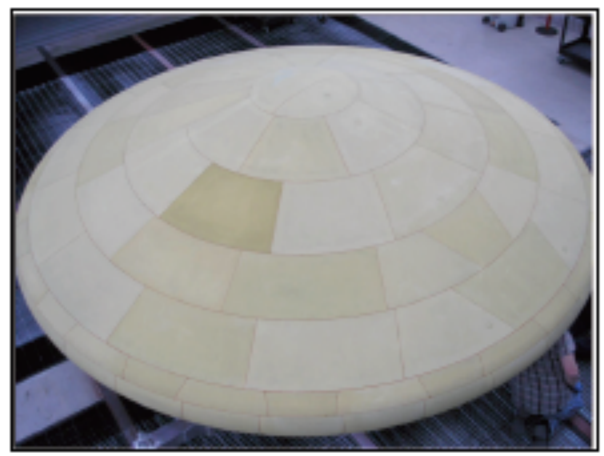
	Vehicle	Location	q, W/cm²	Margin q , (Y/N	Pressure kPa	Shear, Pa
	Orion, ISS Return	Shoulder, Point 21	65	N	101	88
➡	Orion, Lunar return	Shoulder, Point ?	**433**	N	**101**	**146**
➡	MSLi May 2010	Max on Forebody	**128/88**	**Y/N**	**32/25**	**129/83**
➡	Mars maxc Sept. 2010	Shoulder	98	N	19	137
	"	Dish	69	N	24	43

➡ **Denotes Potential Flexible Ablator Application**

Flexible, ablative TPS might be used in conformal mode on Orion to mitigate rigid PICA integration issues and as an alternative to PICA for future MSL-class rigid aeroshells. Limitation on pressure for Orion remains to be addressed (101 vs 35 kPa tested).



Orion 5 meter PICA MDU



MSL 4.5 meter PICA HS #2

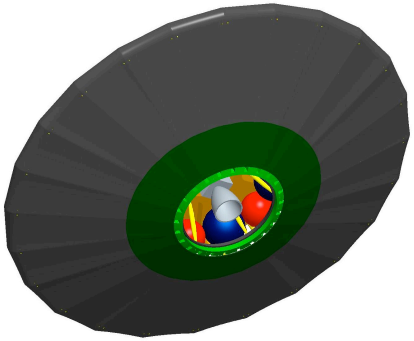
Potential Deployable Applications for Flexible TPS (Representative data at max heat rate locations)

Flexible ablators are enabling for all entries

Vehicle	Location	q, A/E W/cm^2	Margin q , (Y/N	Pressure A/E, kPa	Shear, A/E, Pa
EDL SA/ ADEPT 23 m diam.	Peak forebody	**106/32**	Y	**11/8**	**42/25**
"	"	67/21	N	9/6	27/16
EFF 6 m diam. direct entry	Peak forebody	223/NA	Y	14/NA	287/NA
EFF 8 m diam. direct entry	"	**171/NA**	Y	**10/NA**	**207/NA**
EFF 10 m diam. direct entry	"	134/NA	y	7/NA	162/NA
ADEPT-Venus 45°, 2.13 m S-cone	Peak forebody	**230/NA**	**N**	**7/NA**	**210/NA**
ADEPT-Saturn, 45°, 2.13 ,m S-cone	Peak Forebody	**495/NA**	**N**	**11/NA**	**245/NA**

EDL – SA 2010 EFF study showed this 7.2 km/sec entry speed, 8 m HIAD system using PICA-Flex ablator to be capable of delivering 3.4 mT to Mars' surface via direct entry with an arrival mass of 7.2 mT. This compares well to the Viking-entry technology capability capped at ~ 1.2 mT payload delivery (MSL). <u>This 8m diameter HIAD is ½ the size of one using "insulating" TPS.</u>

23 meter HIAD



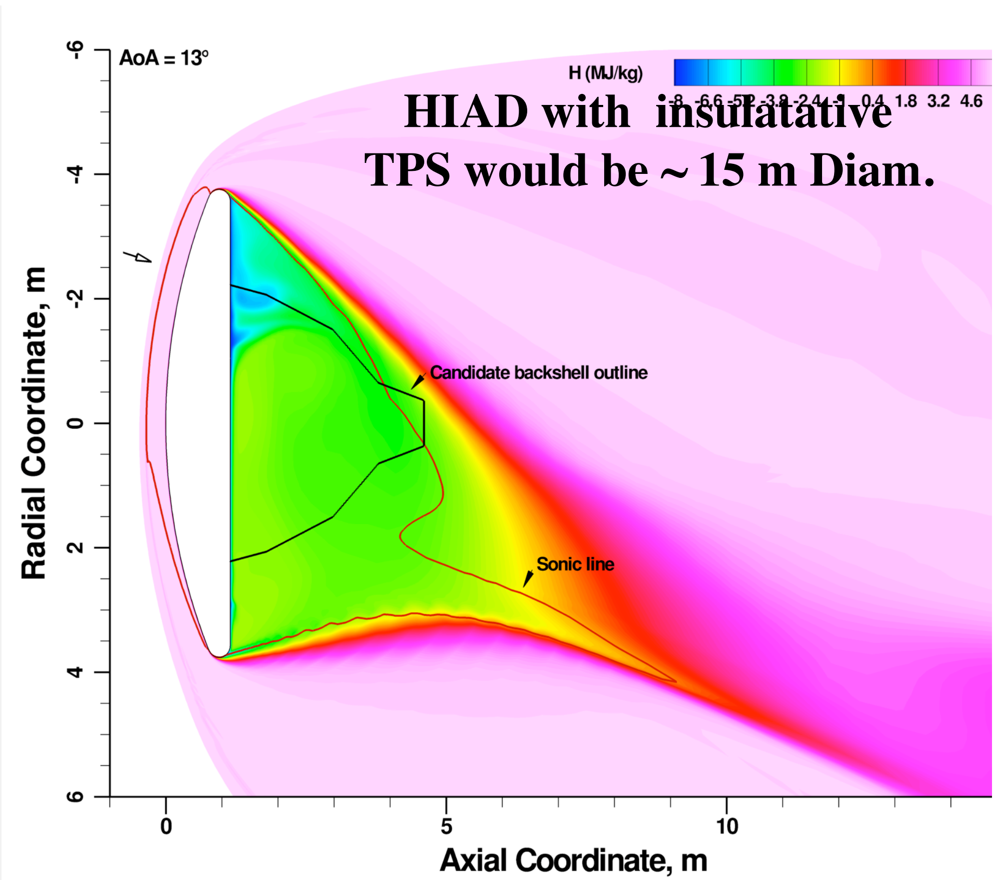
23 meter ADEPT

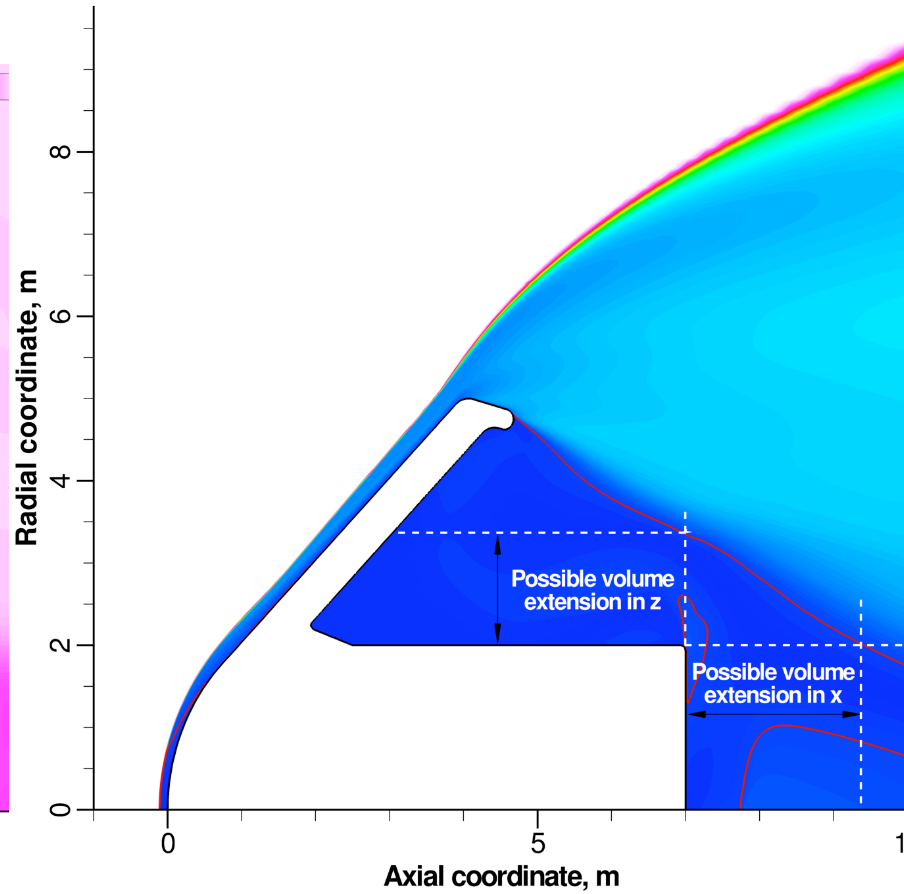
ADEPT - Saturn

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

10 m ADEPT – Venus H/S Possible payload envelope

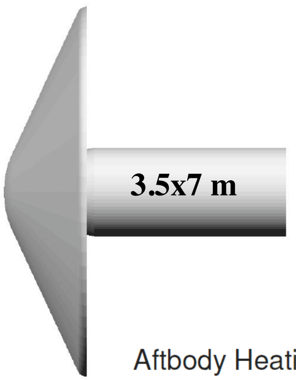




Aft-body Impingement from EFF Analysis by Dave Kinney/ARC

Entry Systems & Technology Division

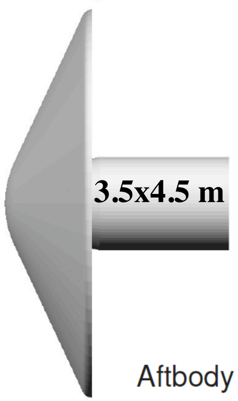
Aerocapture



- Mach 31
- 0.01338 bars
- 17.6° AoA

α < 39°

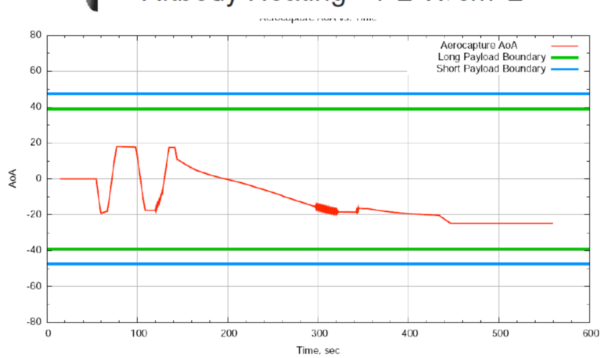
Aftbody Heating ~1-2 W/cm^2



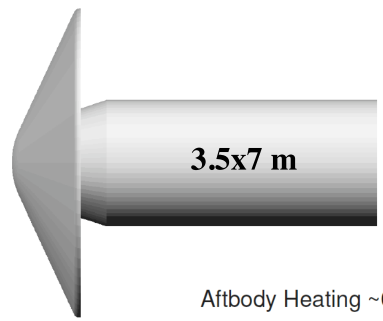
Drawings NOT To Scale

α < 47°

Aftbody Heating ~1-2 W/cm^2



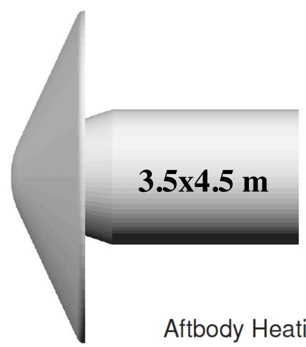
Entry



- Mach 14.621
- 0.012692 bars
- 0 – 20° AoA

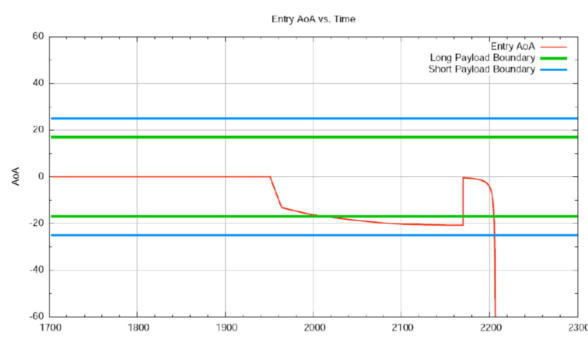
α < 17°

Aftbody Heating ~0.5 - 1 W/cm^2



α < 25°

Aftbody Heating ~0.5 - 1 W/cm^2



Summary

- 13.5 m dia. HIAD allows larger AoA range during heating than that for HAID of 8 m diameter.
- EFF Studies Limited HIAD diameters to be 8 m to avoid issues of aft-body heating.
- Kinney EFF study suggests aft body heating is low (0.5-2 W/cm^2) for AoA limiting bounds.

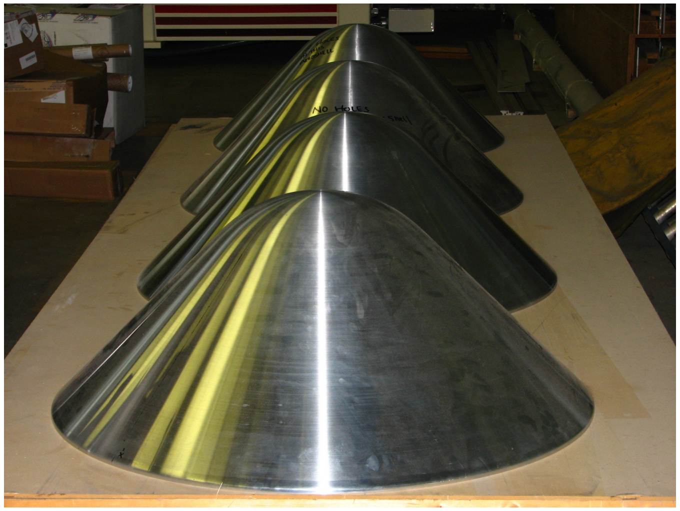
Observations Regarding Deployable, Size Controllability and Aft-body Heating

- 7. 5 meter diameter, flexible ablator-enabled deployable with 4.5 m diameter x1.67 long stretched MSL aft body and a ~ 3.3 mT payload capability would be very interesting candidate for future Mars missions (MSR?)

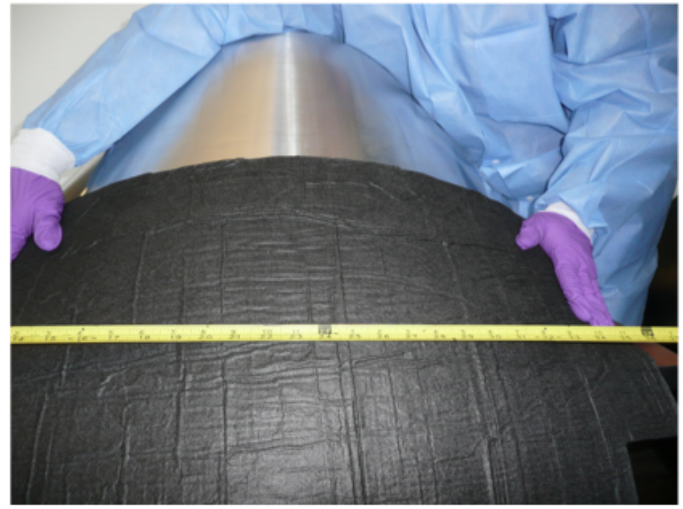
- Large HIADS using insulatating TPS mitigate concerns regarding aft-body shear layer impingement, but this trades against vehicle controllability issues as discussed in the EDL-SA EFF TM.

- **Recommend: Future system analysis trades of forebody TPS mass as function of H/S diameter versus aft-body protection against shear layer heating.**

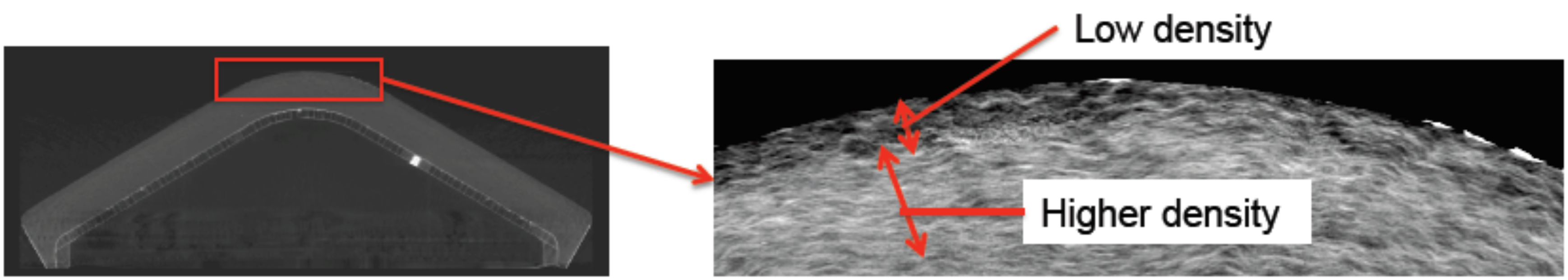
Future FLEX MDU and NDE Testing



0.91 M base dia. MDU shells



Felt mock-up on MDU shell

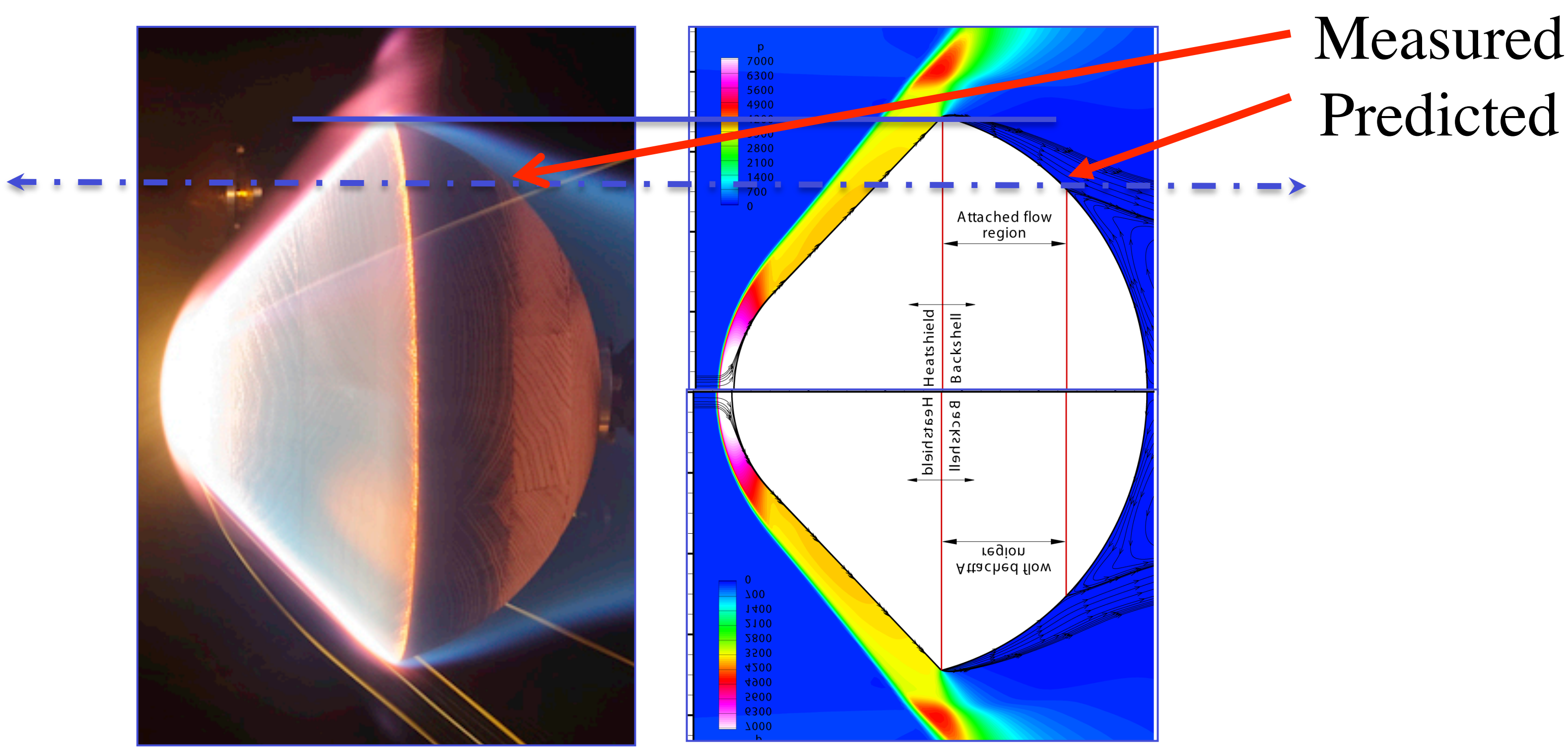


X-ray computed tomography slice PICA's density variations in the flown Stardust heat shield

Initial approach: Direct bonding with RTV. Also plan to use backscattering and 2-d pressure pads for development

Going Beyond Standard Arcjet Testing: SPRITE

- Excellent agreement in char pattern between simulation & arc jet test



• The dashed line shows the comparison between pre-test predicted location of flow separation as compared to the feature (un-charred region) captured in arcjet test of a red oak model.

Arcjet Conditions on SPRITE

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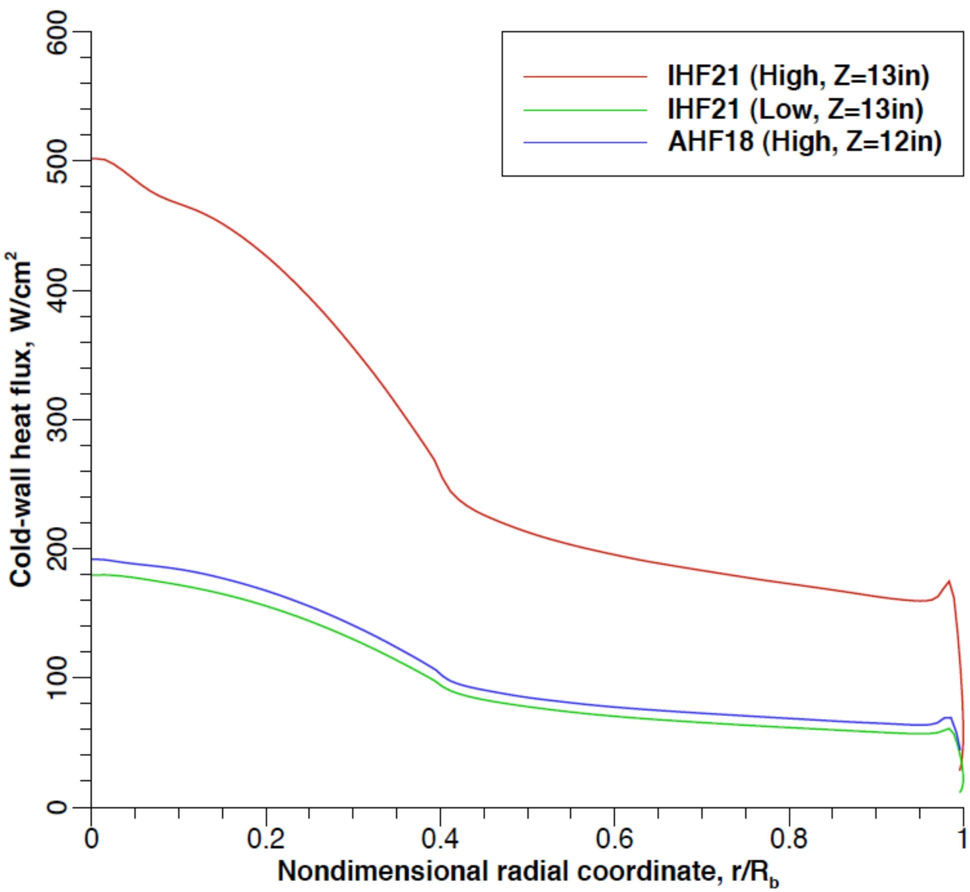
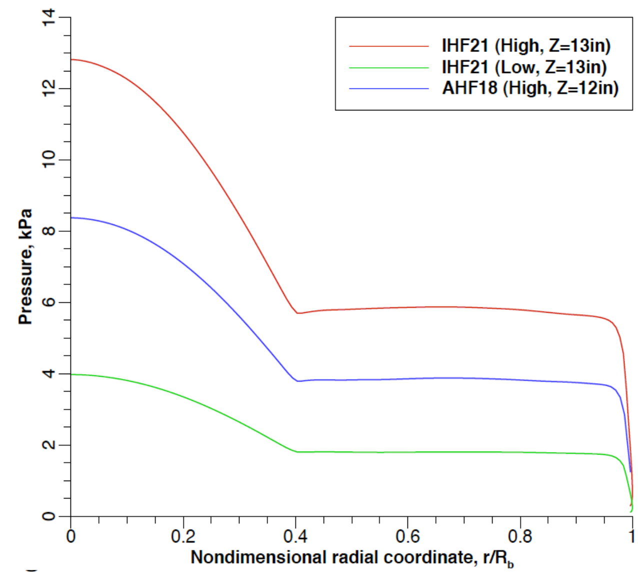
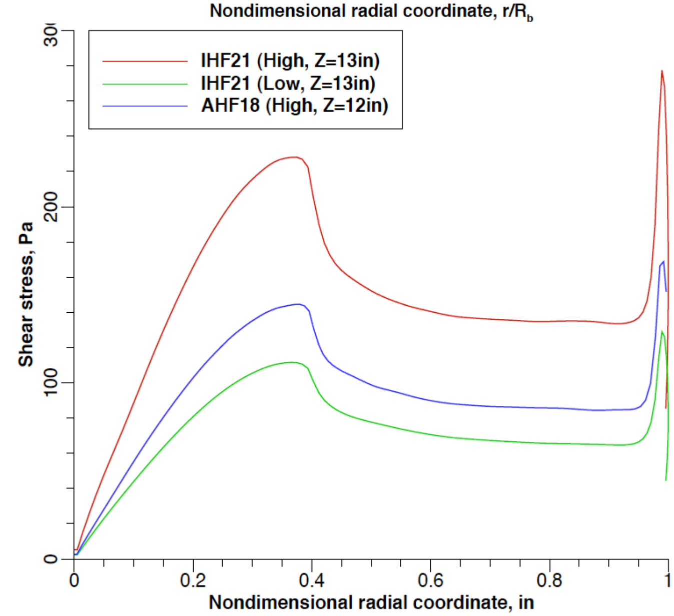
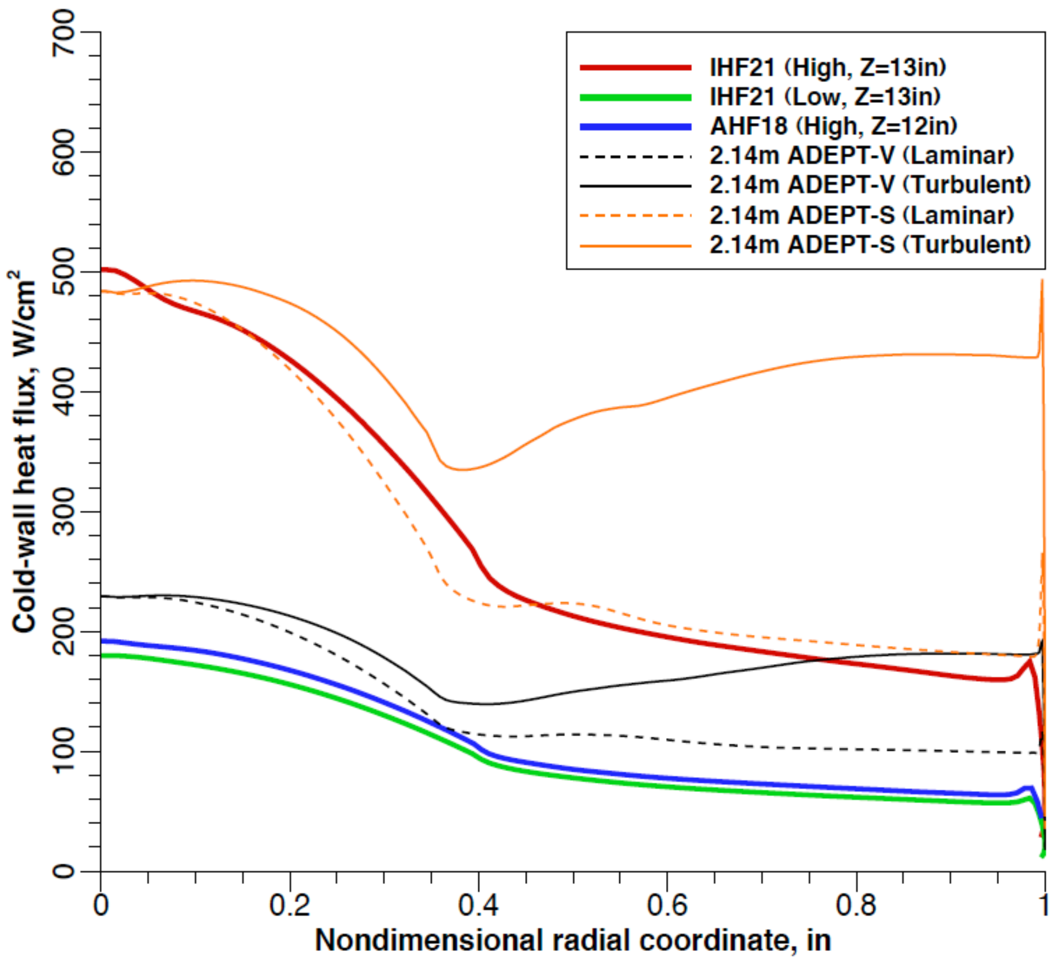
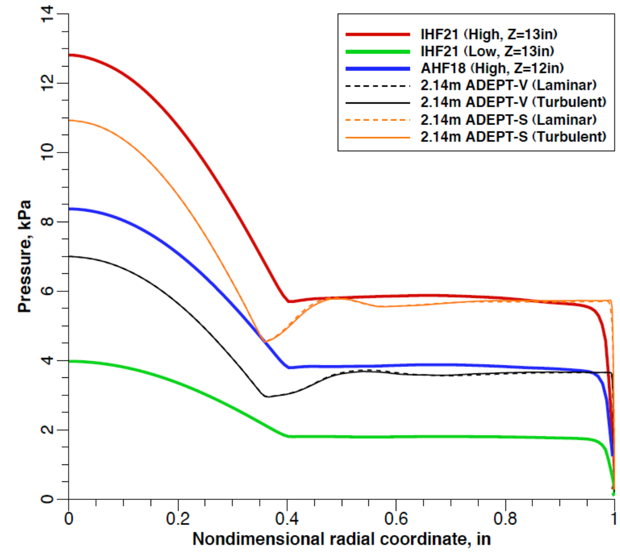


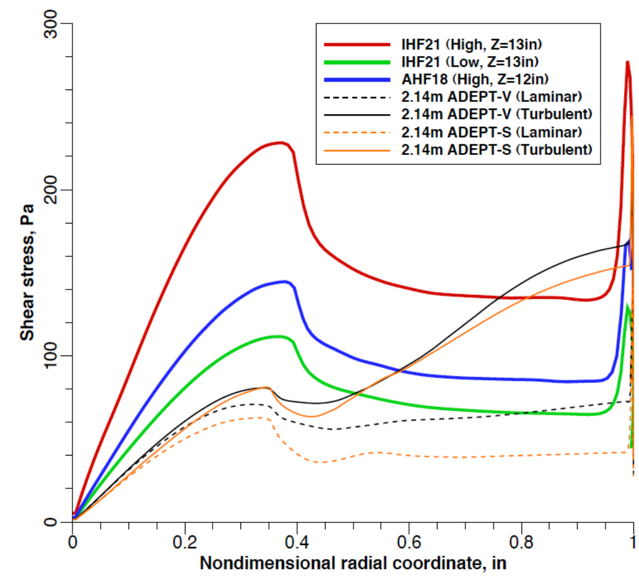




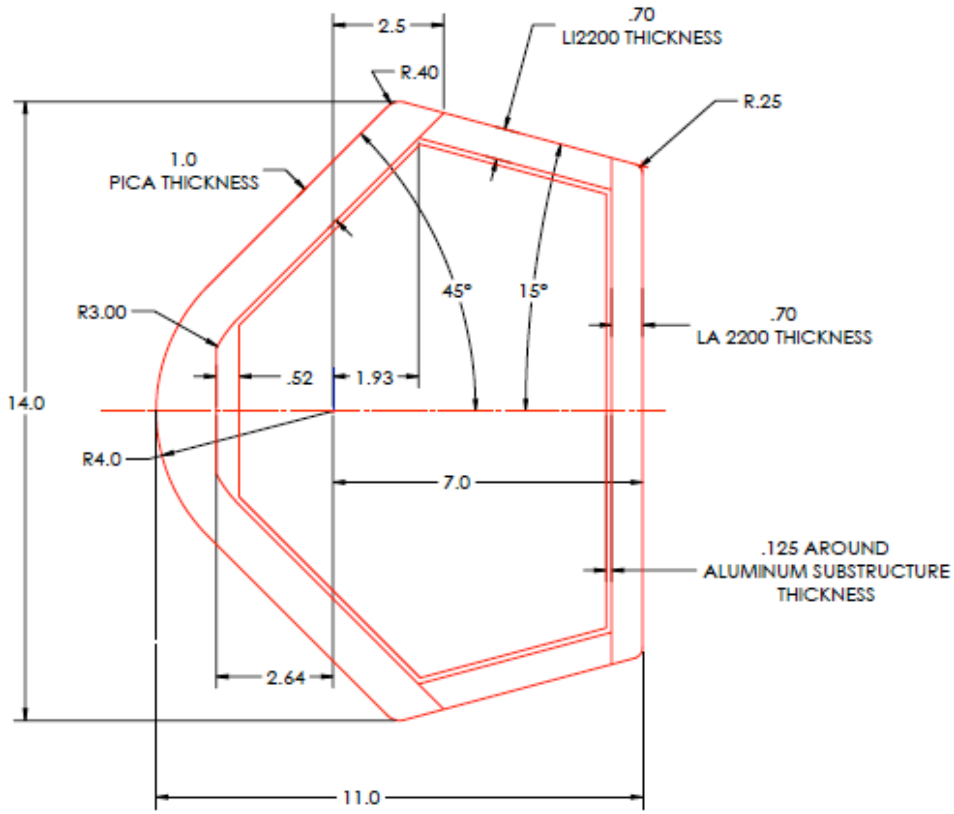
Comparison of SPRITE and ADEPT Flight Conditions (Venus and Saturn)

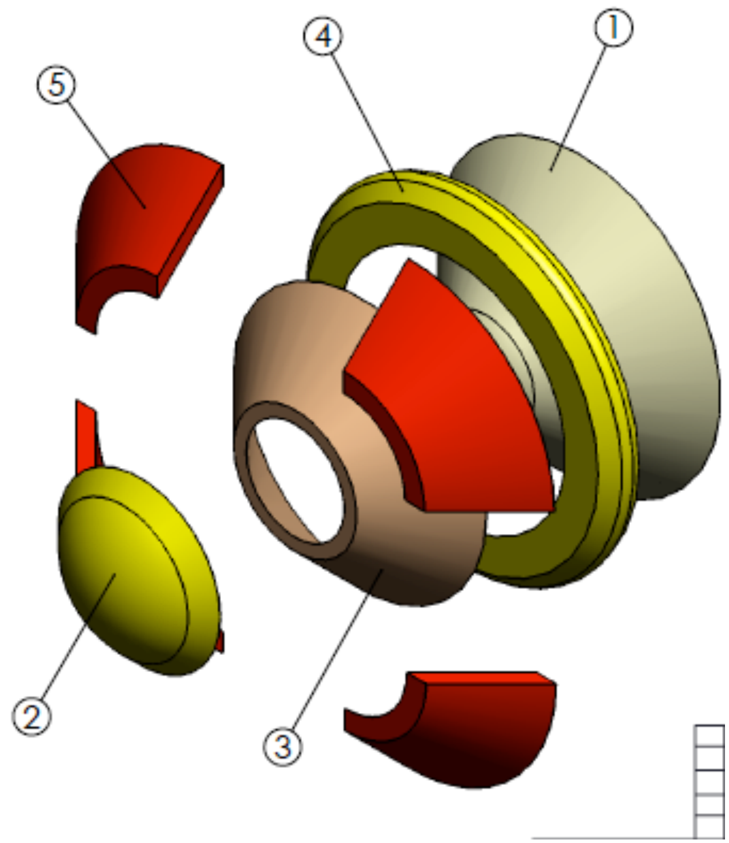






SPRITE – Conformal Arcjet Testing





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

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

Use of Data
- Thermal Response Model
- Material Performance Envelope for Conformal TPS applications

TC Stack Development for Flexible TPS

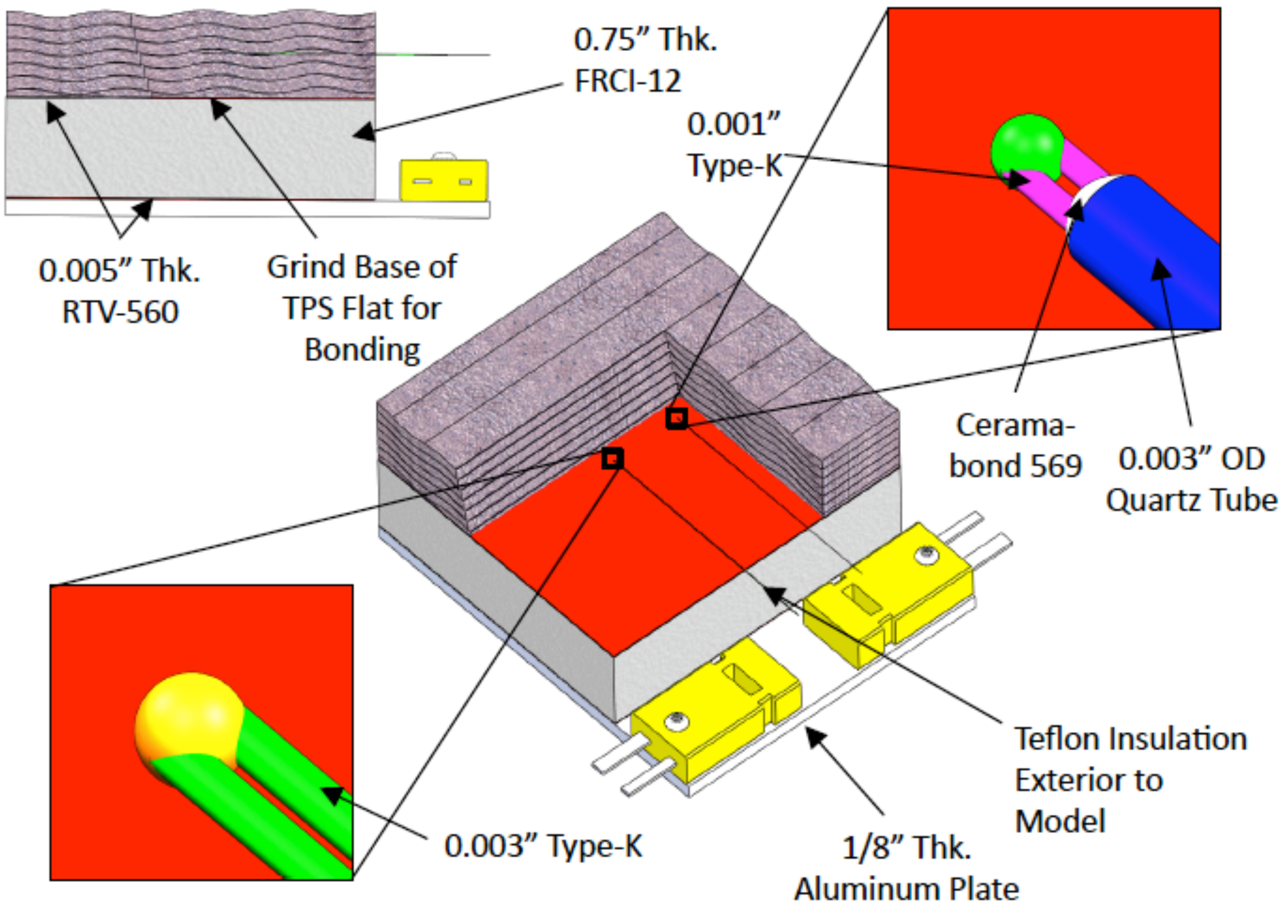
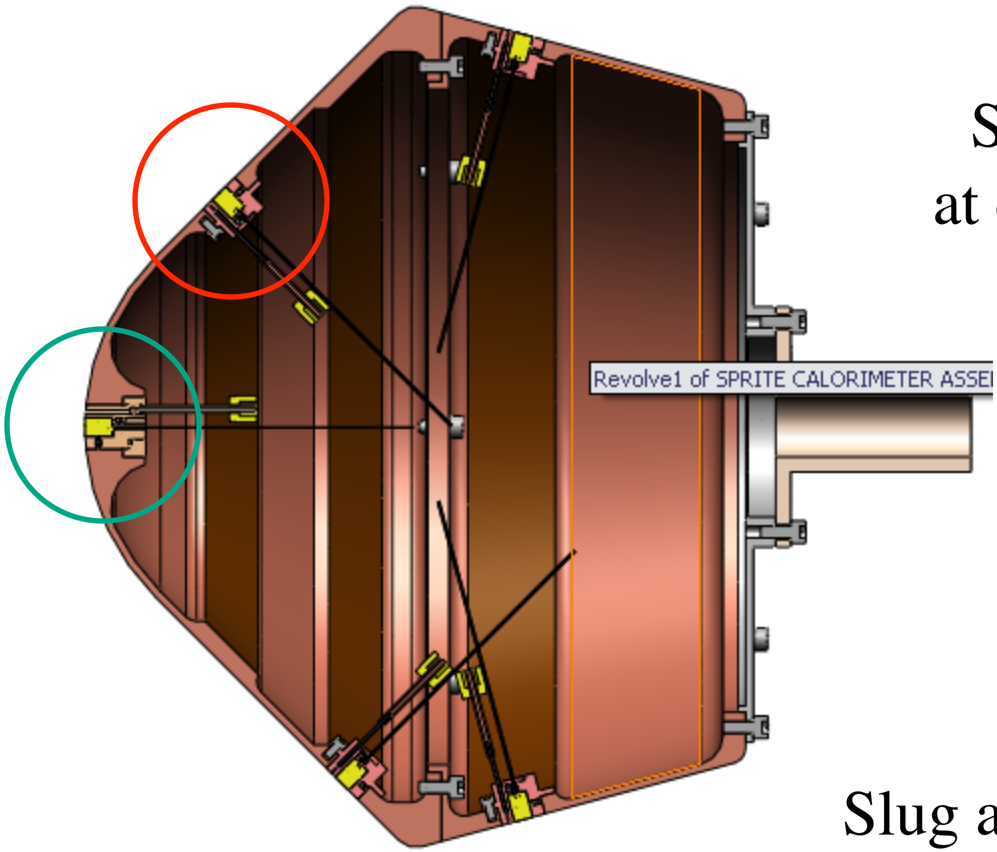
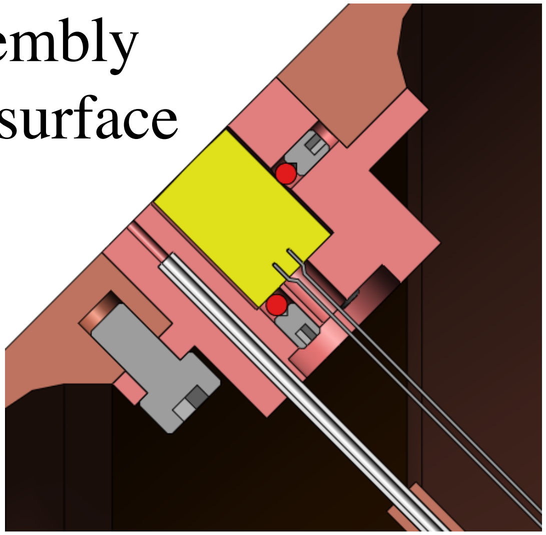


Chart courtesy of G. J. Hartman and J. Mach

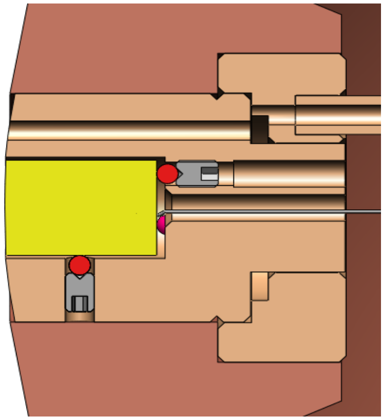
Cu SPRITE Calorimeter – Full Scale



Slug assembly
at conical surface



Slug assembly
at stagnation
point



Sergey
Will update materials

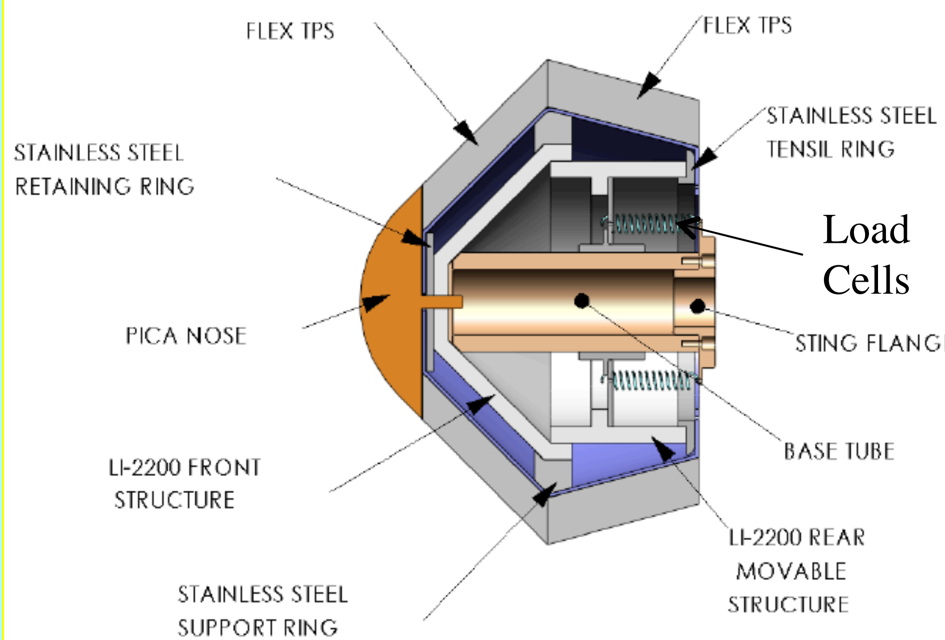
SPRITE-Flex Arcjet Tes

Objective

Determine performance of flexible ablators (acerage, seams and permeability) in flight-like <u>combined</u> environments (qdot, pressure, shear <u>and</u> tensile loading).

Note

Current design uses no longitudinal Ribs. Fore conical section in tension so flexible ablator will assume a slight catenary shape



Instrumentation

- **Pyrometery (OML & IML)**
- **Strain Gages**
- **High Speed Video**
- **Internal Pressure gages**
- **Full scale calorimetry**

Data

- **OML and IML temperature and internal pressure and tensile loading as function of time**
- **Video of acreage & seams.**
- **Post-test recession**

Use of Data

- **Check of Thermal Response Model**
- **Material and Seam Performance Envelope for Flexible TPS Apps**
- **"Structural" performance and permeability definition**

Summary

- Analysis has shown that flexible ablator technology is cross cutting for rigid and deployable TPS applications. Also, it is enabling for the game-changing 23 m HIAD and ADEPT deployable decelerators.

- Future mission studies should consider:
  - Trades for H/S diameter versus qdot versus need for aft-body size in terms of vehicle controllability, TPS mass and manufacture-ability.
  - Flexible ablators as option for conformal TPS on rigid heat shields.
  - Flexible TPS (HEART insulating baseline material) and Shuttle Blankets should be considered for future mid L/D Human Mars Mission vehicles.

- Plans innovative for SPRITE arcjet testing of flexible ablators and conventional testing have been developed. Testing will begin under Office of the Chief Technologist funding in Fiscal Year 2012.