Multi-Mission Earth Entry Vehicle Development by NASA's In-Space Propulsion Technologies (ISPT) Project

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Presentation to the IPPW-9 Session 6B

21 June 2012

Acknowledgements

- The Multi-Mission EEV work under ISPT is performed by a team of engineers and specialists at NASA-Langley and NASA-Ames, under the leadership of David Anderson at NASA-GRC (ISPT Program Manager) and Gordon Johnston at NASA-HQ (ISPT Program Executive).
- Thanks to the core team members and coauthors (in blue):
  - Rob Maddock
  - Jamshid Samareh
  - Rick Winski
  - Artem Dyakanov
  - Anjie Baker
  - Parul Agrawal
  - Kerry Zarchi
  - Jose Aliaga
  - Steve Sepka
  - Tom Squire
  - Raj Venkatapathy
  - Matt Gasch
  - Jay Feldman
  - Lou Glaab

  - NASA-JSC and WSTF, for their micrometeoroid analysis and testing
  - NASA-MSFC, for their radiation analysis and testing
  - VT CRASH Lab and LaRC structural testing group
  - And others….

Outline

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- Programmatic Status
- Analysis Investments
  - Finite Element Modeling
  - Thermal Soak Model
- Testing Investments
  - Foam Impact
  - Space Environmental Effects
- Thermal Protection Systems
- Scanning Techniques
- Summary

Background

- Due to planetary protection concerns, the Mars Sample Return (MSR) Earth Entry Vehicle (EEV) has to be the most reliable spacecraft ever flown
  - Probability of failure currently required to be $<1 \times 10^{-6}$
  - This may be revised in the future, based on new knowledge
- The *Multi-Mission* EEV concept is to use the design features of the MSR EEV on other missions to gain confidence and increase reliability.
  - Inherently stable aerodynamic shape (60˚ sphere cone) reorients to nose-forward during entry in case of release perturbation
  - No parachute – the capsule is designed to survive impact
  - Heritage Carbon Phenolic TPS leverages DoD testing database
- Since 1999, investments have been made in detailed design and developmental testing

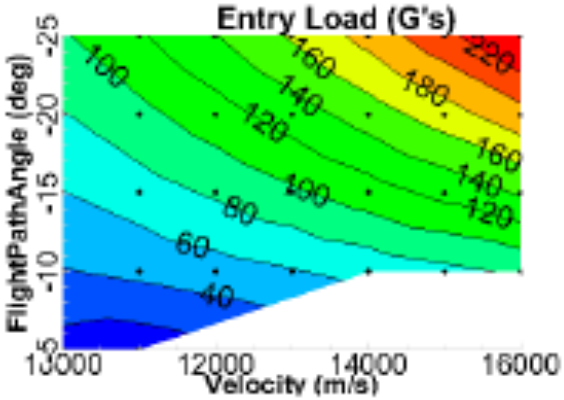


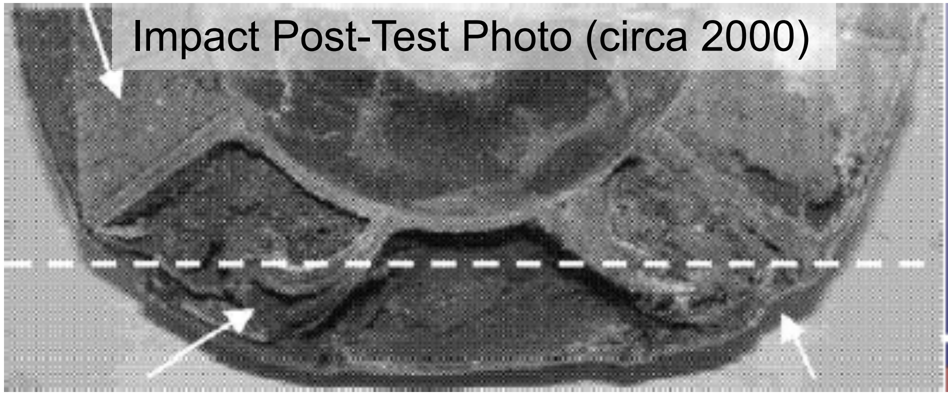

Current Programmatic Status

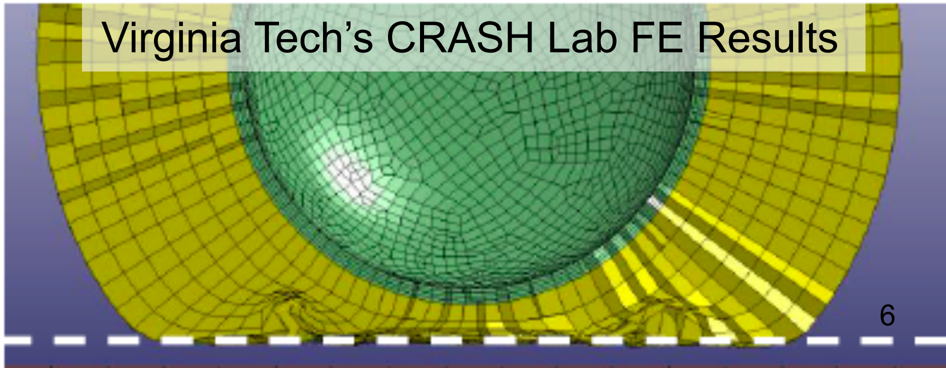
- **The pre-Project efforts for Mars Sample Return have had varying intensity levels for the past 15+ years.**
  - **Technology investment planning has alternated with mission and architecture design.**
  - **The last significant technology planning effort was in 2008, and the "3-mission" architecture has been the baseline since that same timeframe.**
- **The Planetary Sciences Decadal Survey calls for a number of sample return missions in the next decade:**
  - **Comet Surface Sample Return**
  - **Lunar South Pole-Aitken Basin Sample Return**
  - **Mars Sample Return**
- **Discovery and New Frontiers solicitations are expected in 2015 and 2016, respectively.**
- **Technologies must be developed to support viable proposals**
- **Current ISPT investments are modest ($1-$3M/year) and are focused on analysis tool development and model validation testing**

ISPT's Analysis Investments

- **Multi-Mission Systems Analysis for Planetary Entry (M-SAPE) tool development enables <u>rapid</u> MDO assessment (see Maddock, Samareh)**
  - EEV mass, size, and design parameters for a range of missions
  - Multiple fidelities of trajectory simulation, structural and TPS sizing
- **Goal is to release the tool and train users in time for proposal development and evaluation**
- **Efforts in 2012 on thermal soak model and impact model**
  - Basic structural model established
  - NASTRAN parameterized to rapidly generate grids



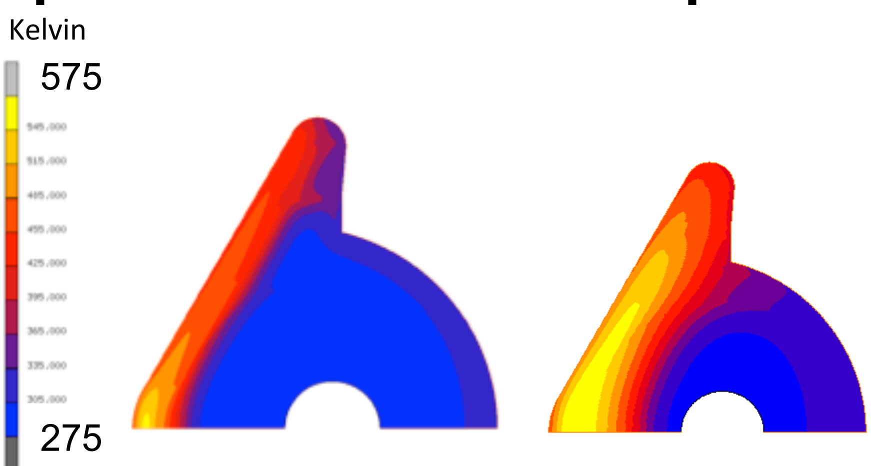

Impact Post-Test Photo (circa 2000)


Virginia Tech's CRASH Lab FE Results

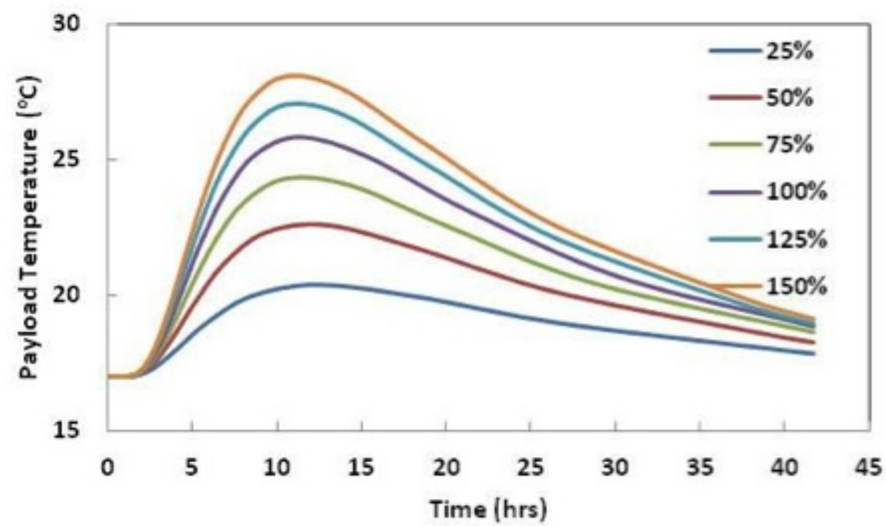
Thermal Soak Analysis

In-Space Propulsion Technologies (ISPT)

- **Maintaining the scientific payload at the desired temperature is a key requirement**
  - Different materials and thicknesses may be required, affecting mass
  - Thermal soak may drive recovery timeline and method
- **Thermal soak model has been developed and is being parameterized for incorporation into the M-SAPE tool**



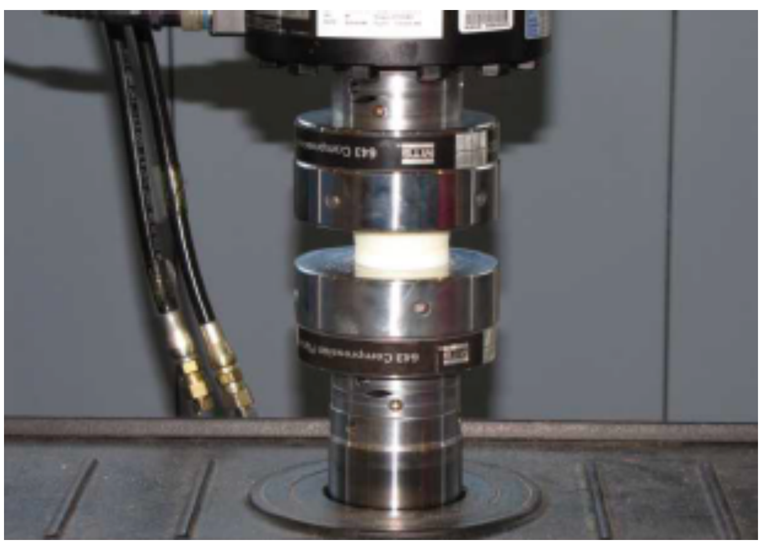
1.6 m diameter   0.9 m diameter

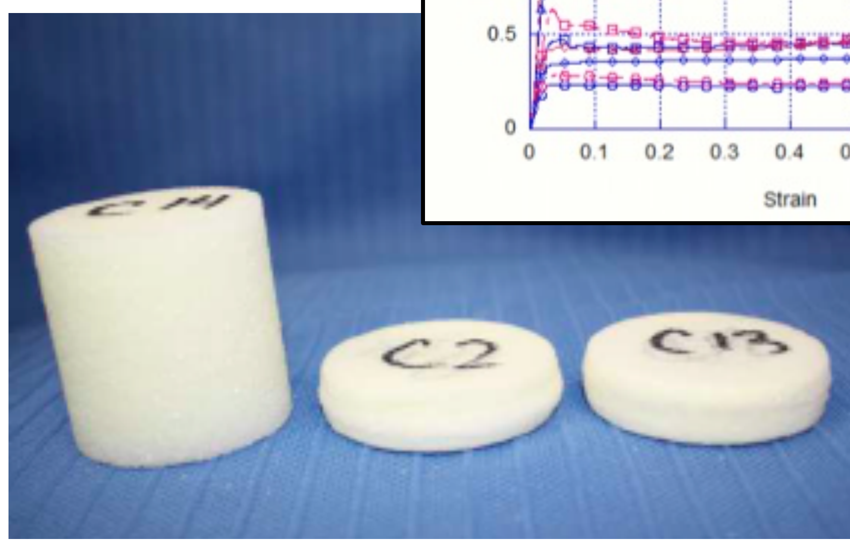


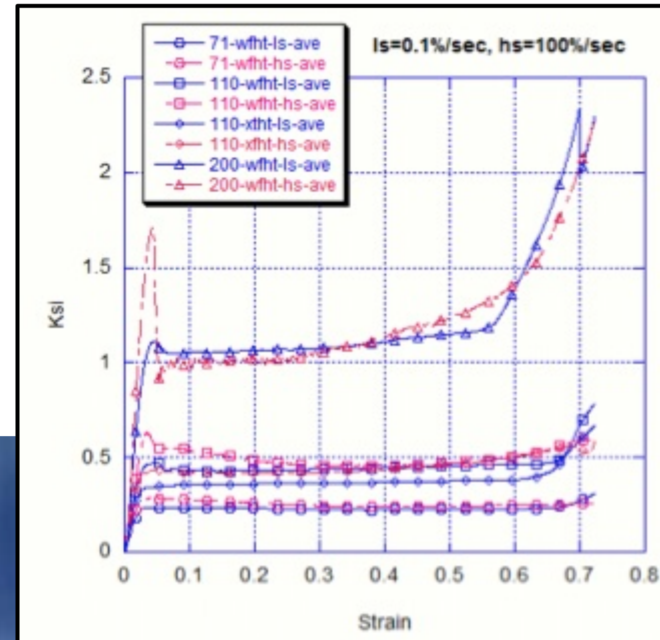
Analysis results will be presented in detail at the AIAA 43rd Thermophysics Conference in New Orleans this month. See Agrawal, et al. "Thermal Soak Analysis for Earth Entry Vehicles."

ISPT's Testing Investments

- **Ground testing is used to validate component models:**
  - Foam behavior
  - Foam thermal properties
  - Impact response
  - Aerodynamics
- **Thermal properties testing is conducted on impacted and un-impacted foam**

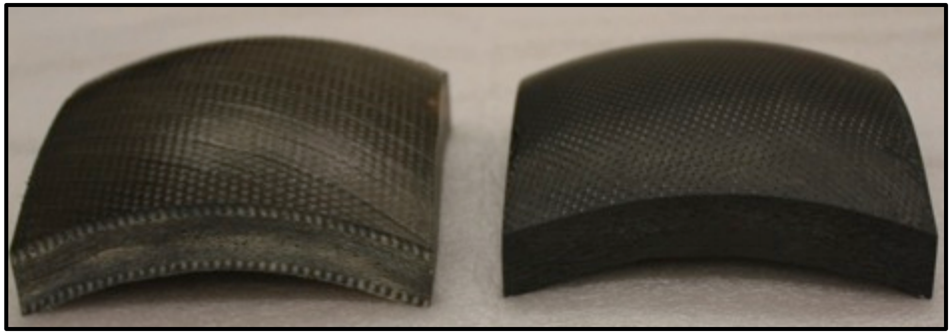


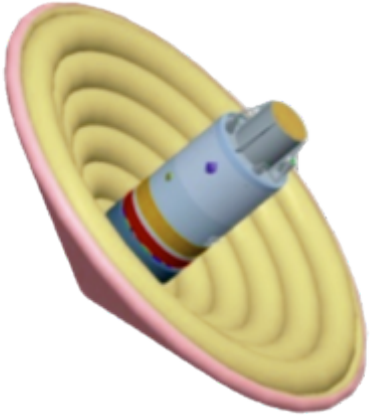


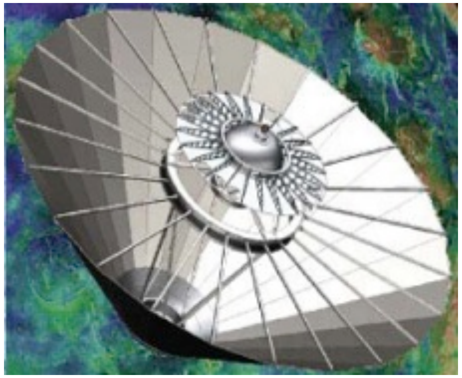


EEV Forebody TPS Materials

- **Throughout past EEV work, assumed that only heritage carbon phenolic could meet the planetary protection requirements of MSR, due to its large DoD performance database.**
- **Space-grade chop-molded carbon phenolic (nosecap) has limited suppliers; industry sustainability is an issue**
- **Carbon Phenolic and Beyond Workshop #2 was held in April at NASA-Ames**
  - Alternates to heritage CP (other precursors)
  - Other TPS materials (like 3-D woven)
  - Alternative architectures (e.g., lower ballistic coefficient)





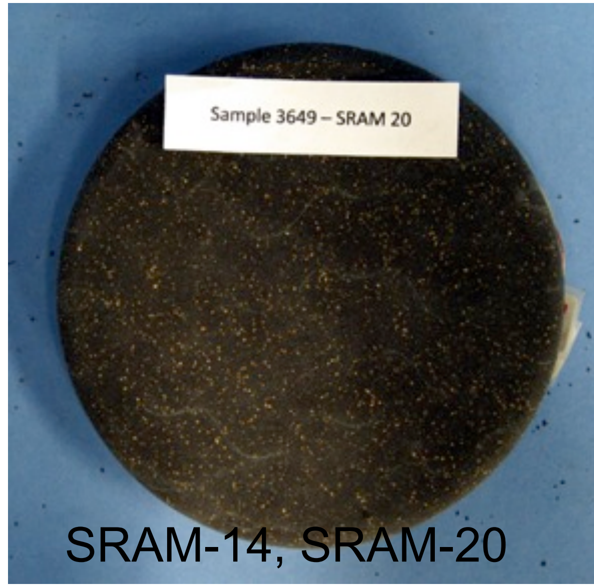


TPS Space Environmental Effects Testing

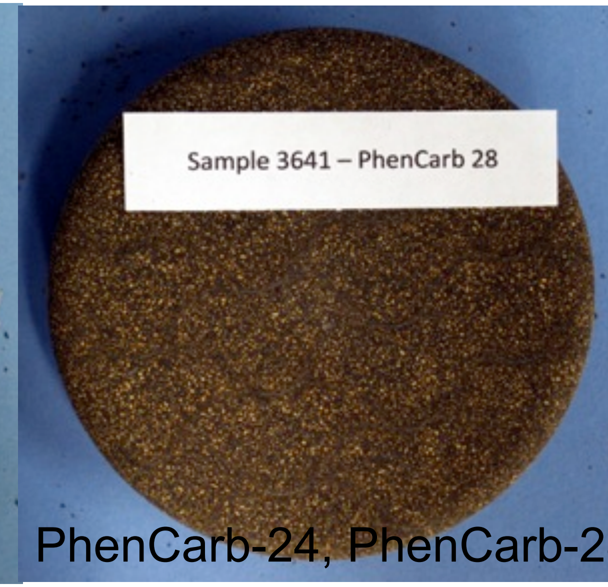
- **Goal is to mature more robust, efficient thermal protection system (TPS) materials as far as possible, on the ground**
- **Exposure to sequential space environments will raise the TRL and uncover unforeseen issues**
- **Analyses determined proper exposure environments based on outer planets mission, to be representative of challenging deep space environments**
  - Micrometeoroid: 7 km/s (backshell hit most likely on EEV)
  - Cold Soak: near-cryogenic
  - Radiation dose: Van Allen, GCR and solar flare
- **Arcjet testing follows, at levels representative for the MSR EEV. Durations are specified to stress the materials.**

TPS Materials Considered

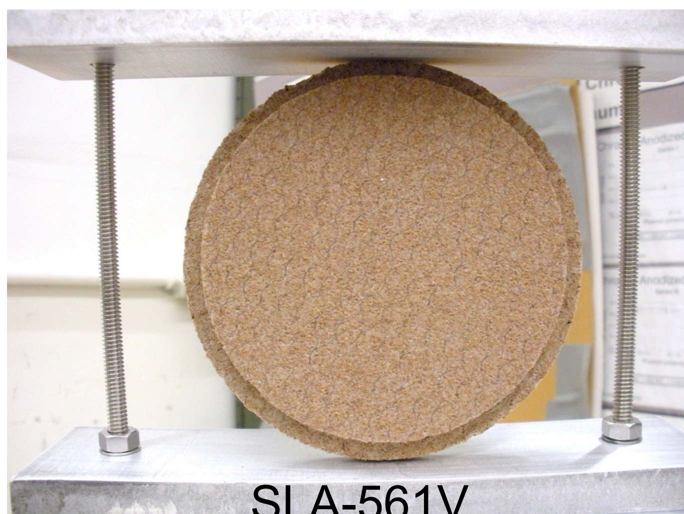
- **Materials tested have been either used historically or matured through ISPT funding**
- **Range of densities suitable for backshell and forebody**
- **TPS materials:**
  - **SRAM**
  - **PhenCarb**
  - **SLA-561V**
  - **Carbon-Carbon**



SRAM-14, SRAM-20



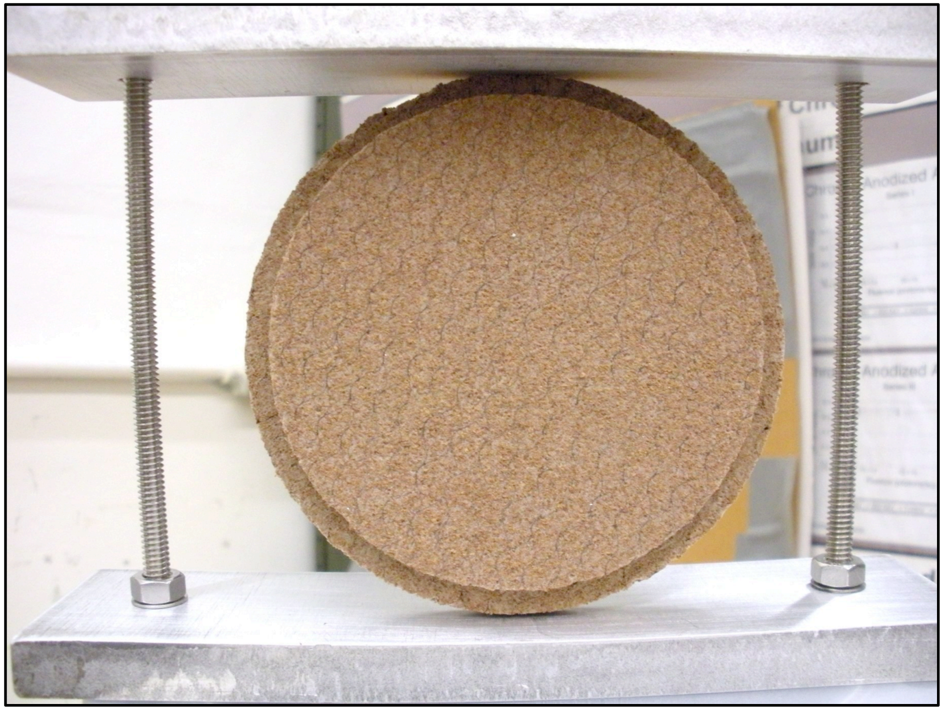
PhenCarb-24, PhenCarb-28


SLA-561V


Advanced C-C

Typical Radiation Exposure Results

- **Exposed the materials to 2 MeV electrons, to a total fluence of 3.0×10^{14} electrons/cm^2 using a National Electrostatics Corporation Model 7.5SH Pelletron accelerator – a simulated dose for a Titan cruise**



Pre-Exposure SLA-561V

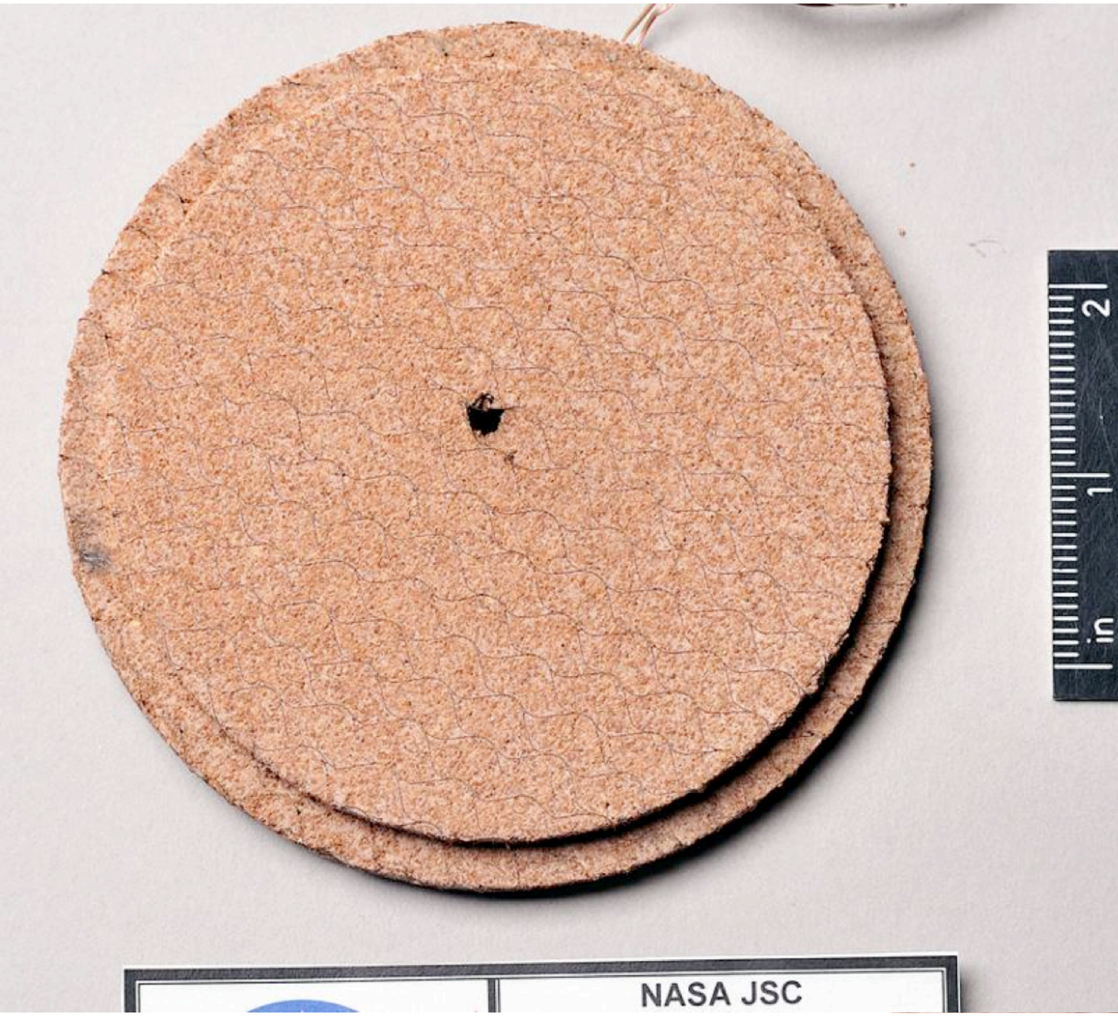
Post-Exposure SLA-561V

Impact Test Matrix Summary (LMSSC)

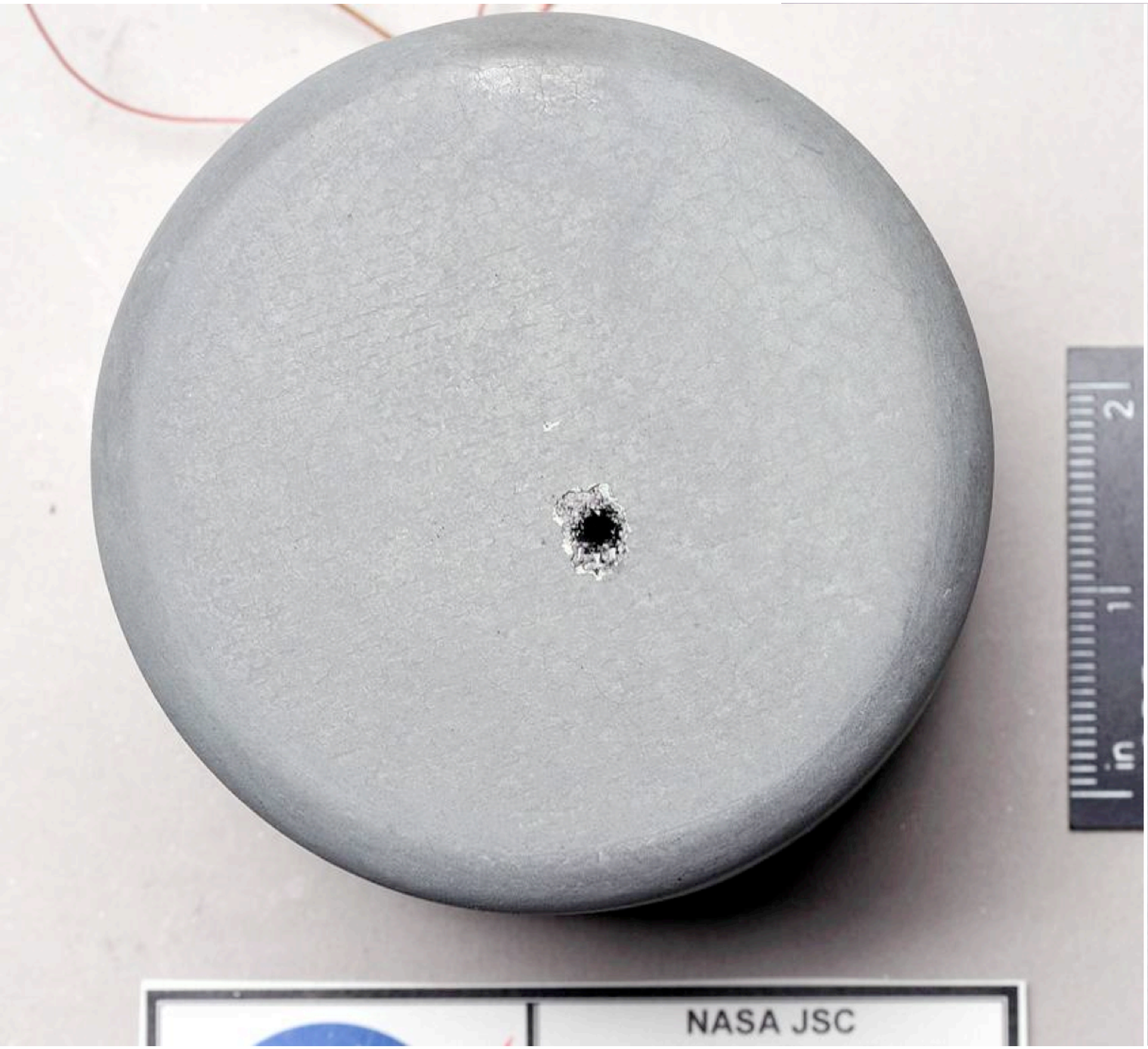
Test No.	Target Type	Tile Diameter/ Thickness (inches)	Projectile Material	Projectile Diameter (mm)	Impact Velocity (km/s)	Impact Angle (deg)	Comments
LMA Cold Impact							
21	LMSEE SLA-10	4.5 / 0.5	Glass	1.0	7.0	0	Sample 7
22	LMSEE SLA-10	4.5 / 0.5	Glass	1.0	7.0	60	Sample 8
23	LMSEE SLA-10	4.5 / 1.0	Glass	1.0	7.0	0	Sample 3
24	LMSEE SLA-10	4.5 / 1.0	Glass	1.0	7.0	60	Sample 5
25	LMSEE CC-10	4.0 / n/a	Glass	1.0	7.0	0	Sample 1
26	LMSEE CC-10	4.0 / n/a	Glass	1.0	7.0	0	Sample 2
27	LMSEE CC-10	4.0 / n/a	Glass	1.0	7.0	60	Sample 5
28	LMSEE CC-10 Coated	4.0 / n/a	Glass	1.0	7.0	0	Sample 10
29	LMSEE CC-10 Coated	4.0 / n/a	Glass	1.0	7.0	60	Sample 12
LMA Irradiated Cold Impact							
30	LMSEE SLA-10	4.5 / 0.5	Glass	1.0	7.0	0	Sample 9 Exp 12/28/10
31	LMSEE SLA-10	4.5 / 0.5	Glass	1.0	7.0	60	Sample 11 Exp 12/30/10
32	LMSEE SLA-10	4.5 / 1.0	Glass	1.0	7.0	0	Sample 4 Exp 1/3/11
33	LMSEE SLA-10	4.5 / 1.0	Glass	1.0	7.0	60	Sample 6 Exp 1/4/11
34	LMSEE CC-10	4.0 / n/a	Glass	1.0	7.0	0	Sample 4 Exp unknown
35	LMSEE CC-10	4.0 / n/a	Glass	1.0	7.0	0	Sample 6 Exp unknown
36	LMSEE CC-10	4.0 / n/a	Glass	1.0	7.0	60	Sample 7 Exp unknown
37	LMSEE CC-10 Coated	4.0 / n/a	Glass	1.0	7.0	0	Sample 9 Exp unknown
38	LMSEE CC-10 Coated	4.0 / n/a	Glass	1.0	7.0	60	Sample 11 Exp unknown

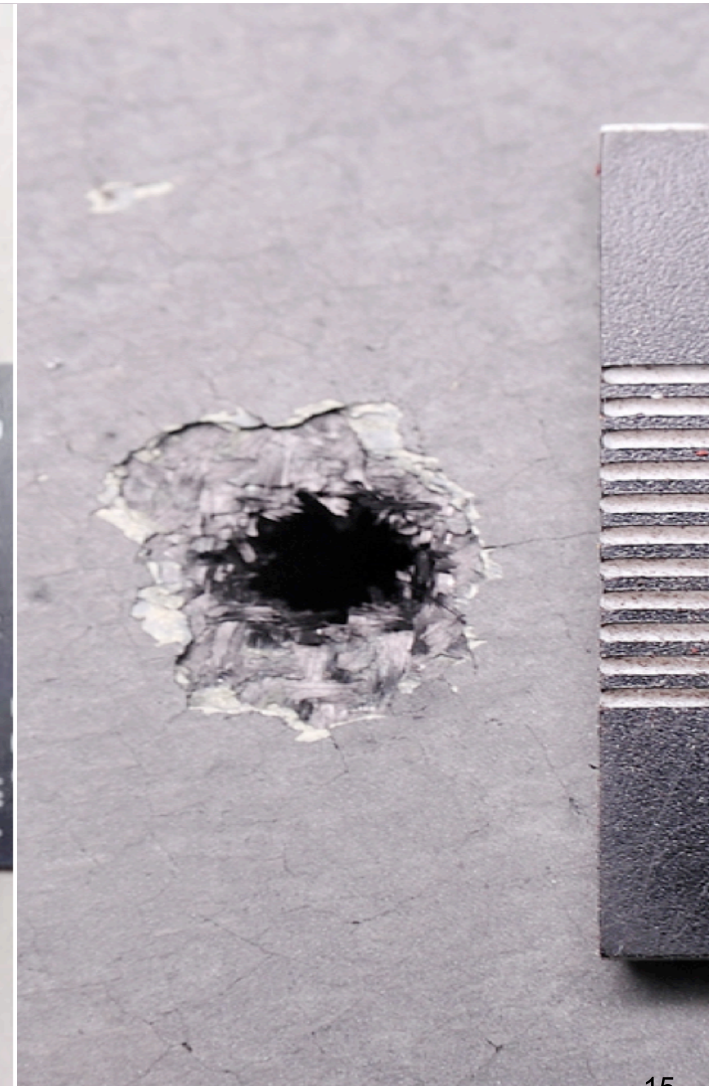
SLA-561V, 0 deg Impact

Low-Density (16 lb/ft^3) Material

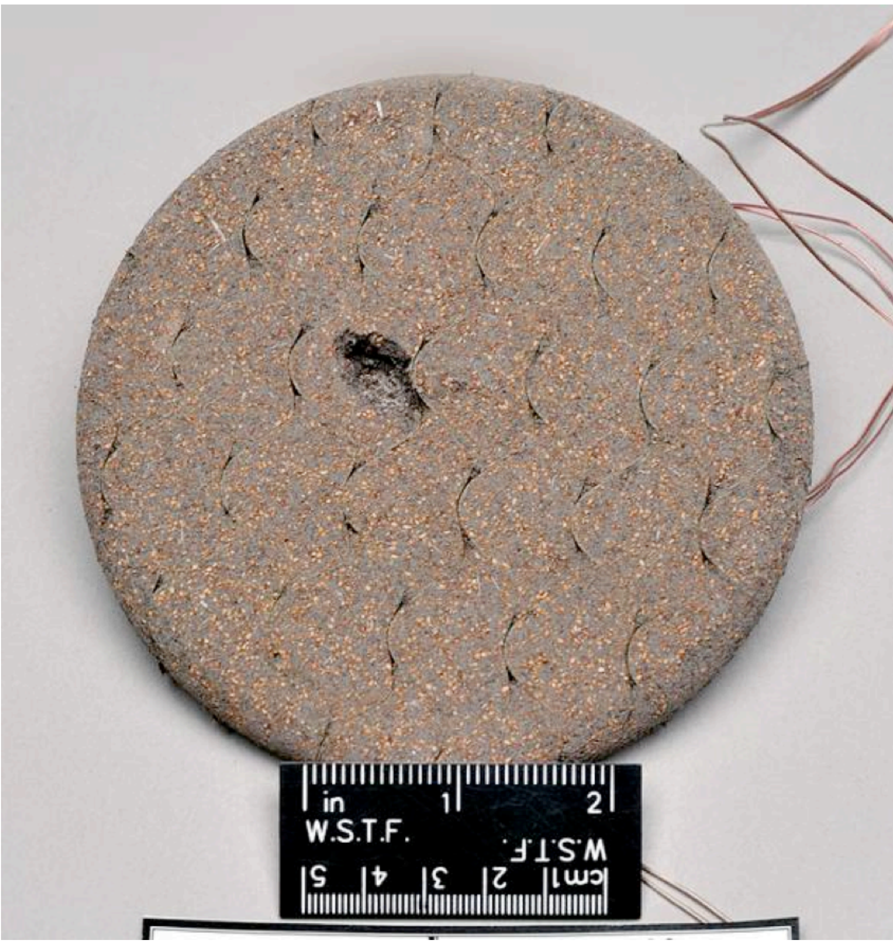


Coated Carbon-Carbon with Calcarb Insulator, 0 deg Impact

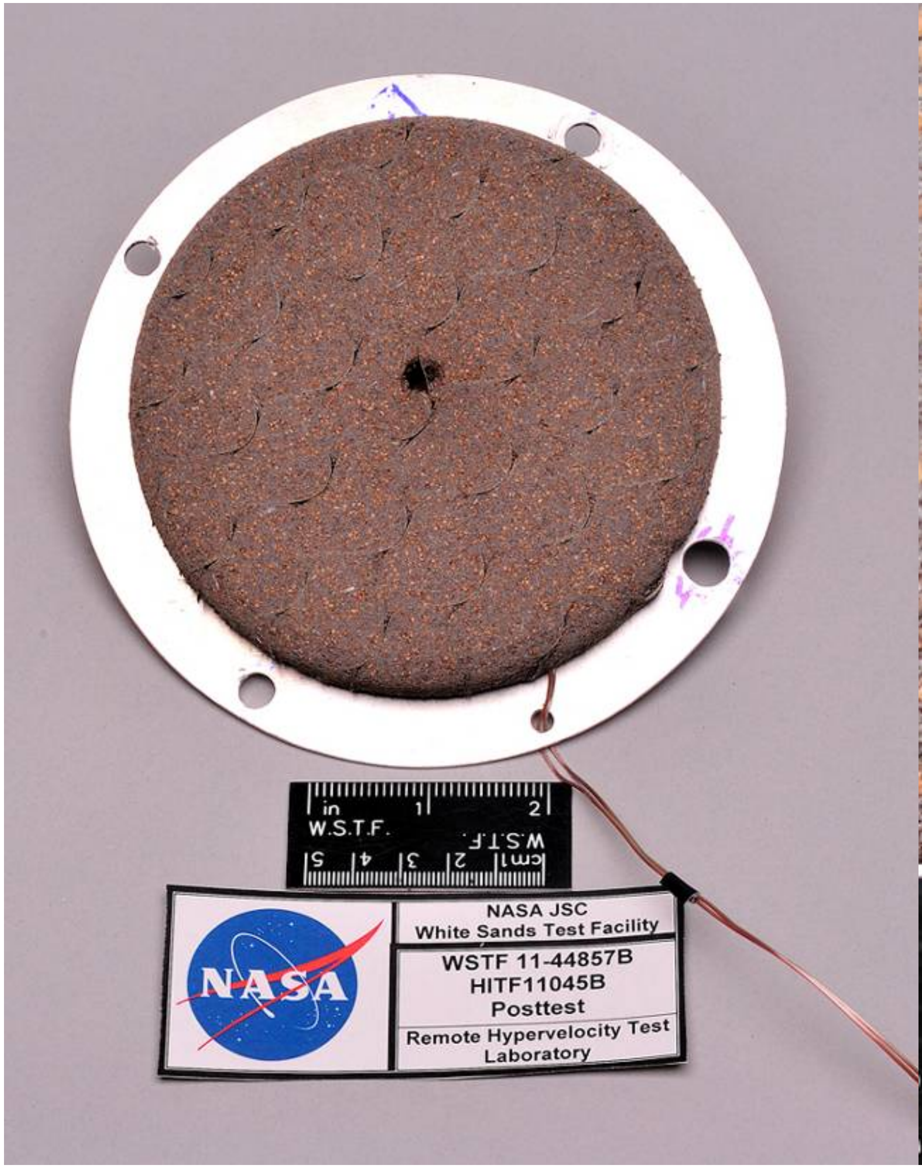




SRAM-14, 60 deg Impact
Low-Density (14 lb/ft^3) Material

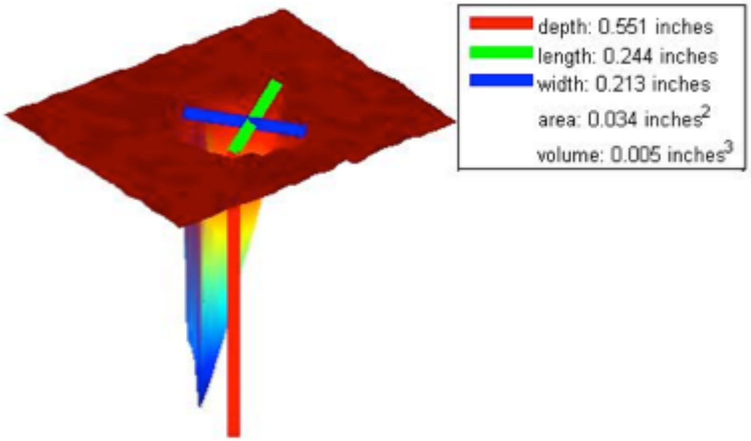


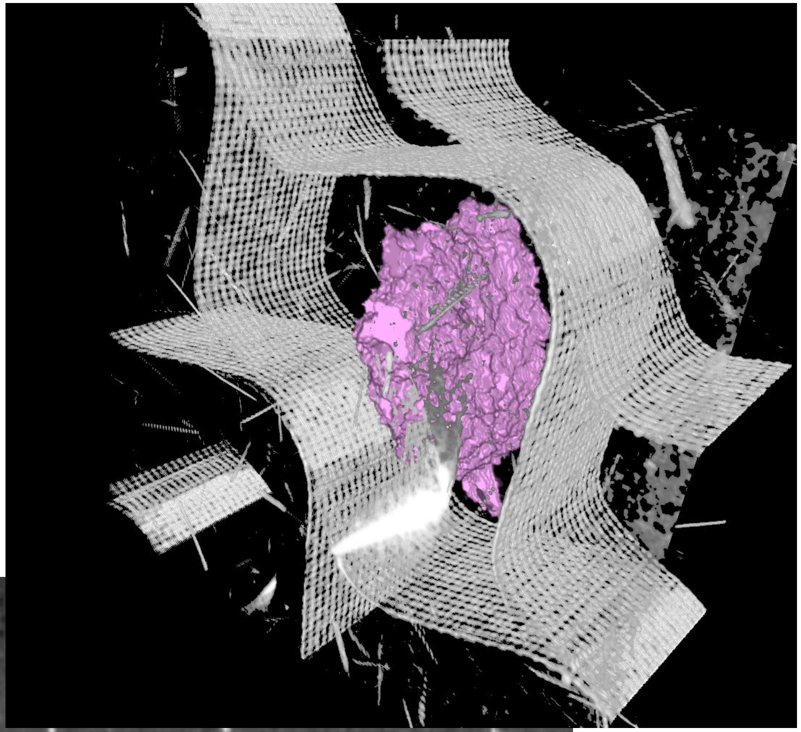
SRAM-20, 0 deg Impact
Low-Density (20 lb/ft^3) Material

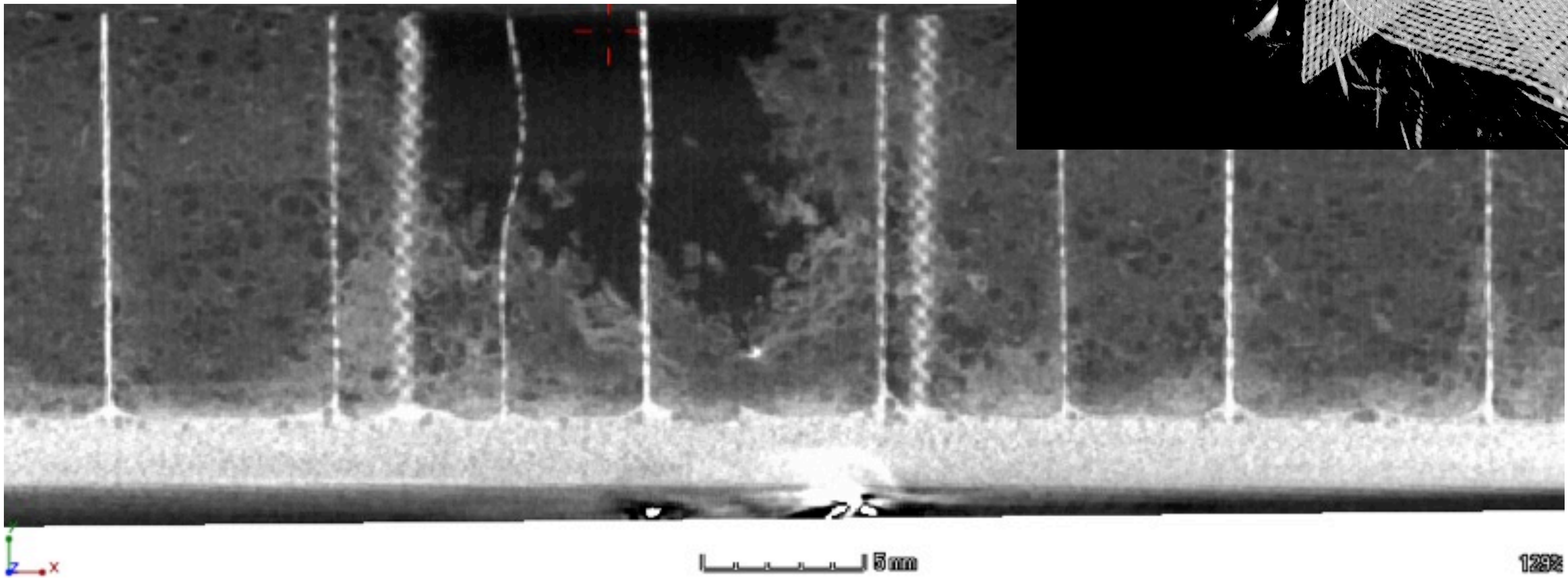


Cavity Scanning Techniques

Laser Scanning Results







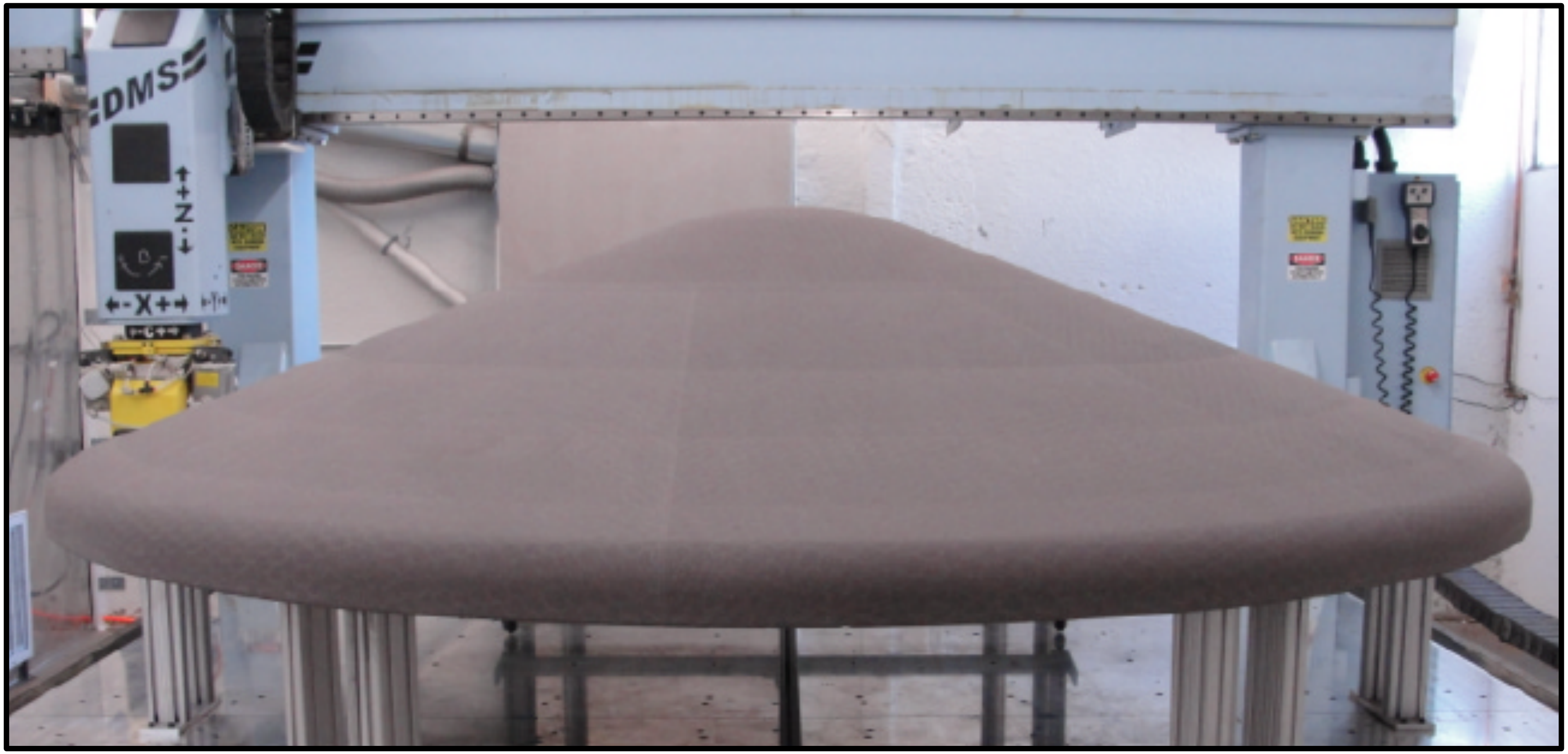
Backshell: ARC AHF Arc Jet Testing

- **Backshell materials (SRAM-17, SRAM-20, SLA-561V) were exposed to 60 W/cm^2 for 100 seconds**
- **No appreciable change in surface cavity shape**
- **Post-test scanning will reveal in-depth changes**

Summary

- A passive, chuteless, aerodynamically stable design is the most reliable, efficient configuration for an EEV.
- Significant progress is being made in advanced tools and testing to mature the EEV design for use in Discovery and New Frontiers proposals
  - Other sample return missions can benefit from common design principles
  - Use on previous missions will build reliability in the MSR EEV
- MMOD, arcjet, foam impact, and spin tunnel testing ongoing in FY12
- Wind tunnel, and arcjet on additional materials, starting in FY12 and continuing into FY13

Update: Large Article Manufacturing



ARA's 2.65-meter, 70˚ SRAM-20 heatshield over ATK very high-temperature structure---ready for CT scanning