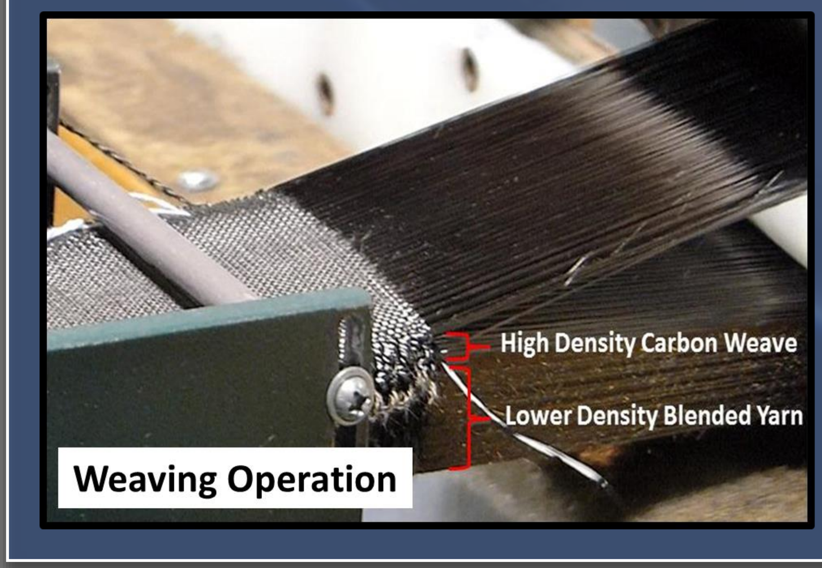
High Velocity Impact Performance of a Dual Layer Thermal Protection System for the Mars Sample Return Earth Entry Vehicle

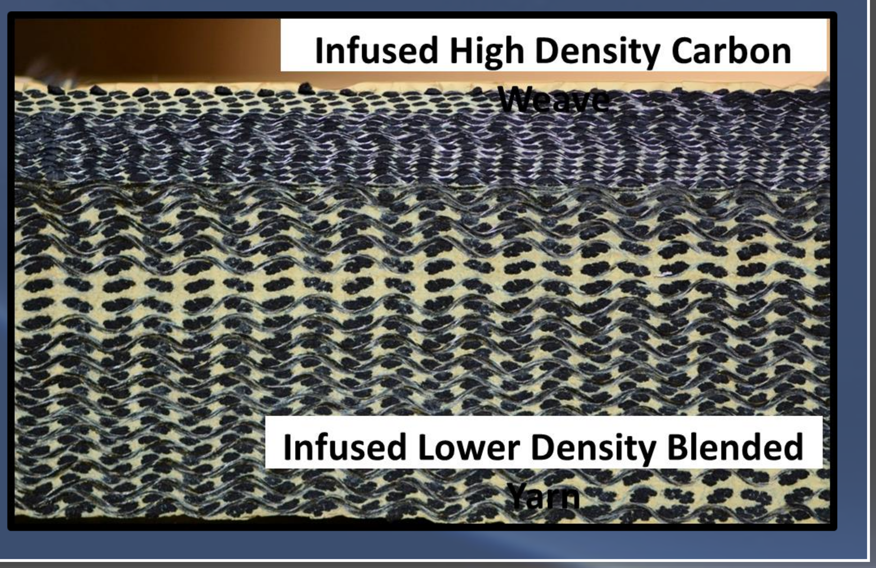
B.J. Libben[1], J.T. Needels[2], D.T. Ellerby[3], J.C. Vander Kam[3], T.R. White[3], P.J. Gage[2], D.K. Robertson[3], A.M. Coates[3]

[1]AMA Incorporated at NASA Ames Research Center, [2]Neerim Corporation at NASA Ames Research Center, [3]NASA Ames Research Center

What is HEEET?

- Heat Shield for Extreme Entry Environment Technology (HEEET) is a Dual-Layer 3-D woven material infused with a low density phenolic resin matrix
- **Recession Layer (RL)**
  - Layer-to-layer weave using fine carbon fiber - high density for recession performance
- **Insulating Layer (IL)**
  - Layer-to-layer weave with carbon phenolic blended yarn - lower density for insulative performance
  - Arc jet tests have shown IL-alone aerothermal capability as well
  - ~30% more recession measured compared to RL



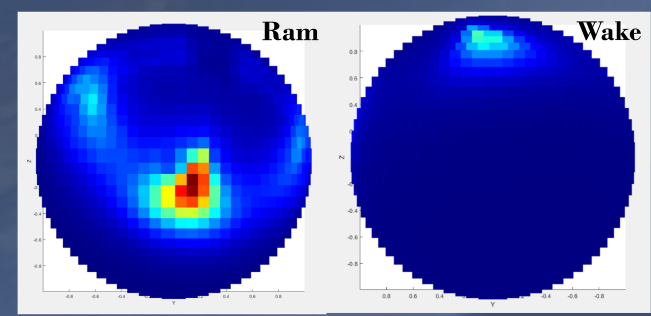


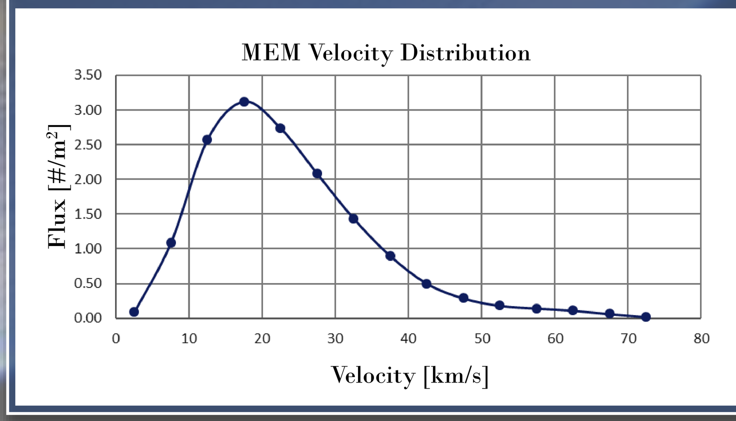
Mars Sample Return Earth Entry Vehicle (MSR-EEV)

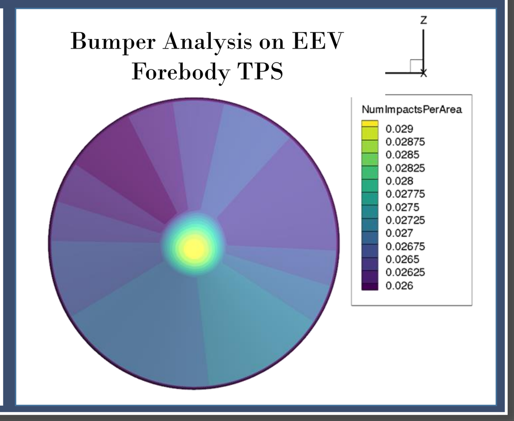
- The MSR-EEV is the last leg of multi-mission effort with the overall objective of robotically collecting samples of regolith from the Martian surface and returning them to Earth for examination
- Planetary protection concerns associated with loss of sample containment puts the MSR-EEV under strict reliability requirements, with off-nominal TPS performance due to MMOD impact being a primary risk driver
- The EEV will be released from its shielded housing about five days prior to Earth entry interface

Meteoroid Environment Modeling

- NASA's Meteoroid Engineering Model (MEM) was used to evaluate the meteoroid flux and velocity distributions along the EEV trajectory
- MEM flux results and the EEV geometry was then used by Bumper to get geometry and trajectory specific risk results

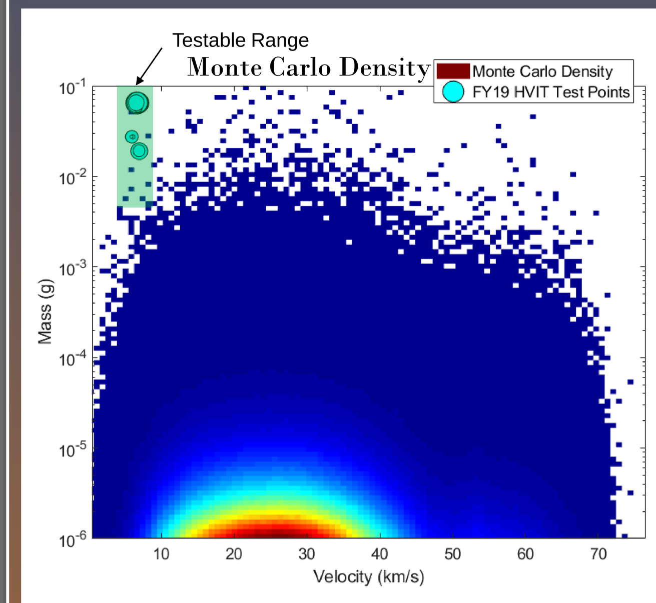


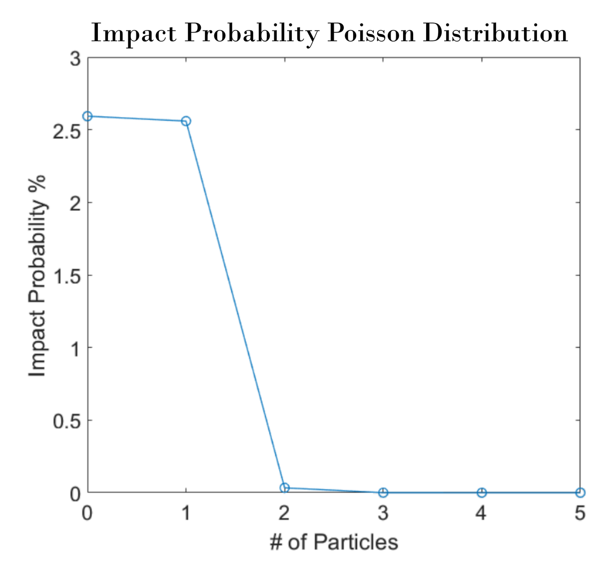


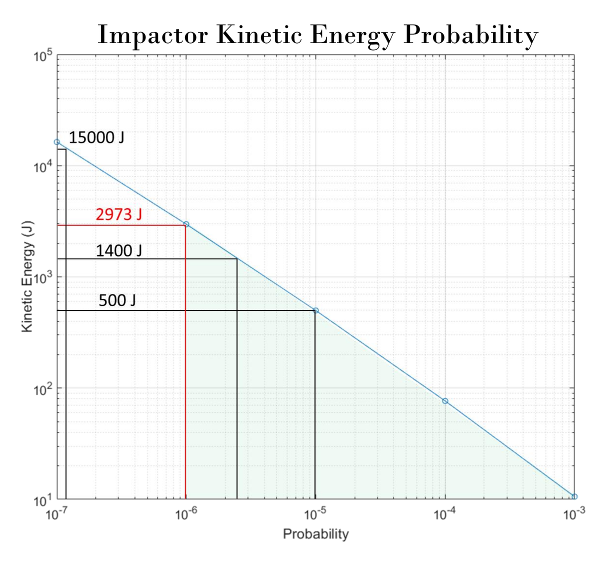


Expected Micrometeoroid Environment

- Since the expected impactor (~25 km/s and 1e-6 g) is far out of ground facility's testable range, Blast Wave Theory's prediction that at a constant kinetic energy, an impactor's crater volume will remain constant is used to allow the testing of relatively high mass projectiles at low velocities
- The probability of an impact event occurring during the mission is calculated using a Poisson distribution on the MEM predicted ram flux to determine the 1e-6 probability impactor







FY19 HVIT Program Test Matrix

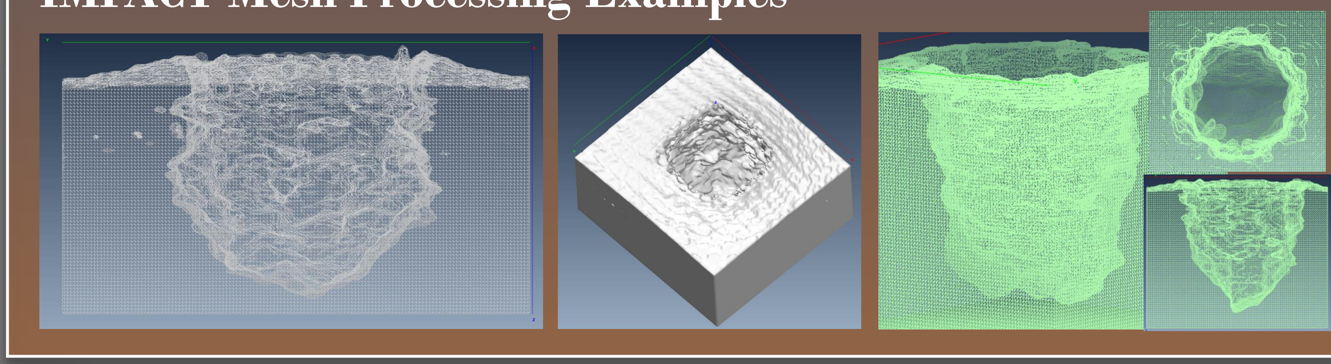
- Hypervelocity testing was conducted using the two-stage light gas guns (LGGs) at NASA's White Sands Test Facility (WSTF)

Factor	Variants			
Backing	0.04" Composite Facesheet		0.375" Al Plate	
Target Material	5 – 13.3 cm [2– 5.35 in] thick PICA	3.18 cm [1.25 in] thick HEEET IL	3.18 cm [1.25 in] thick HEEET 0.13 cm [0.05 in] RL	3.18 cm [1.25 in] thick HEEET 0.26 cm [0.1in] RL
Projectile Material	Nylon		Aluminum	
Impact Angle	0 degree		70 degree	
Energy	Low Energy 500 Joules ~1/100,000 likelihood for 5 days of free-flight		High Energy 1400 Joules ~4/1,000,000 likelihood for 5 days of free-flight	

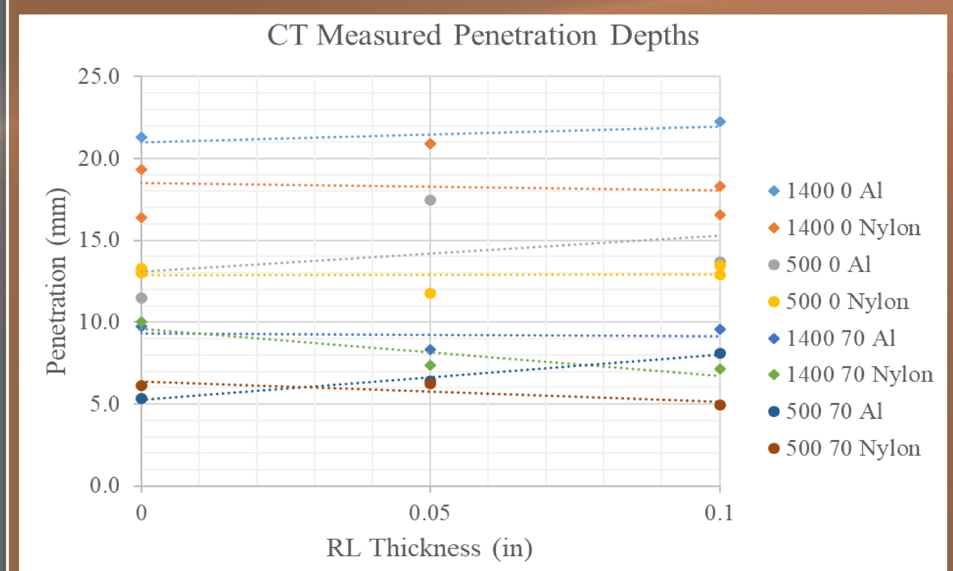
Inspection and Mesh Processing Algorithm for CT scans (IMPACT)

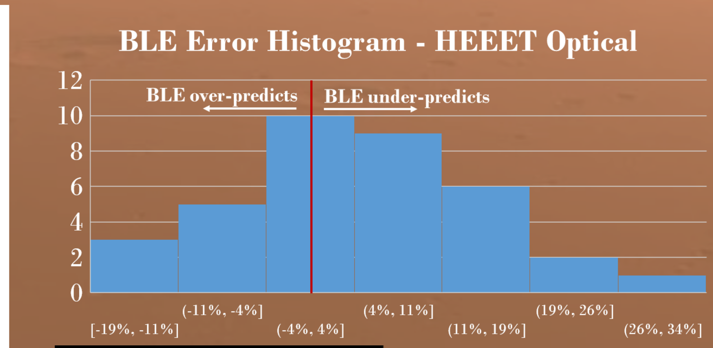
- IMPACT was written to enable enhanced analysis of HVIT crater topology by converting crater CT scans into a geometric mesh to enable measurement of crater volume and cross-sectional area
- This method removes the inaccuracies and limitations of traditional laser measurements due to viewable angles and increases the measurement resolution to the order of 10-100 microns
- IMPACT results will be fed into coupled aerodynamic/thermal response models, which produce an overall risk of failure given a particular form of HVI damage from actual craters

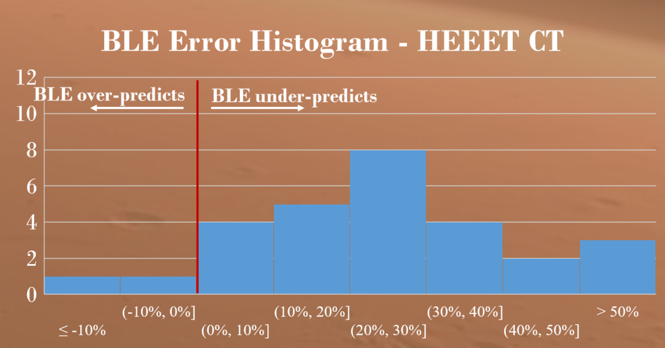
IMPACT Mesh Processing Examples

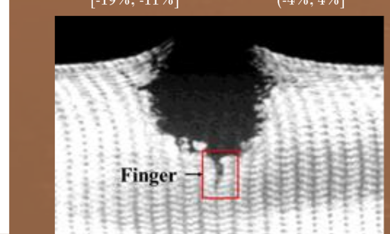


High Velocity Impact Testing (HVIT) Performance



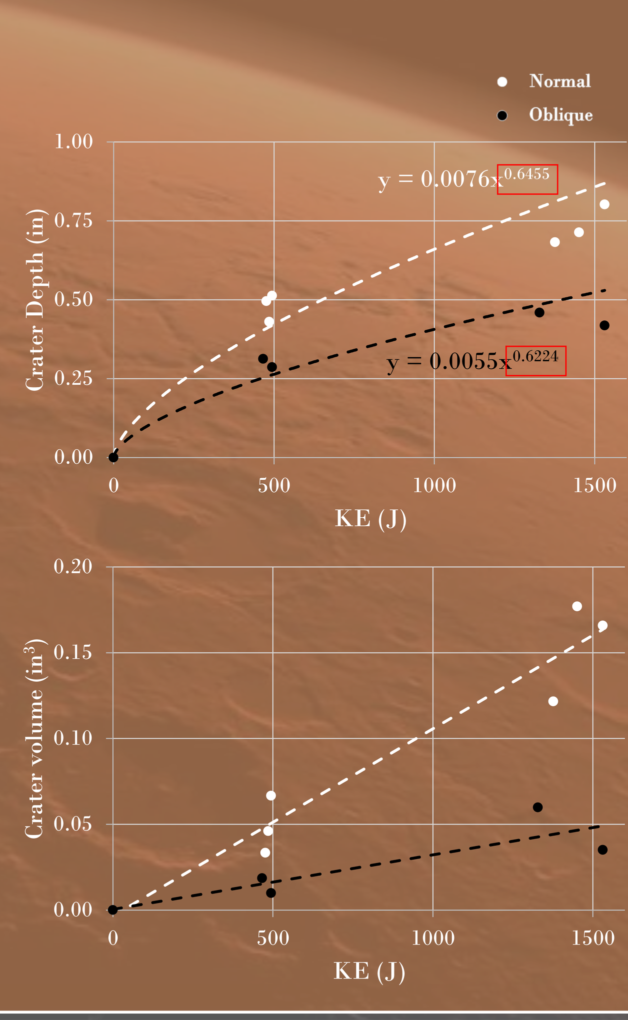




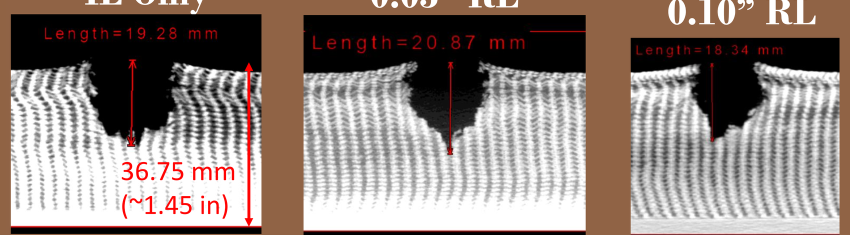


- The HEEET BLE better predicted the optical measurements of the FY19 crater depths due to the BLE being formed off optical measurements
- When comparing BLE predictions against CT scan measured depth, the normal distribution is shifted to a mean error around a 25% under-prediction. This is due to the optical measurements not being able to capture the "finger" features consistently found at the bottom of HEEET HVI craters

Volume Calculations

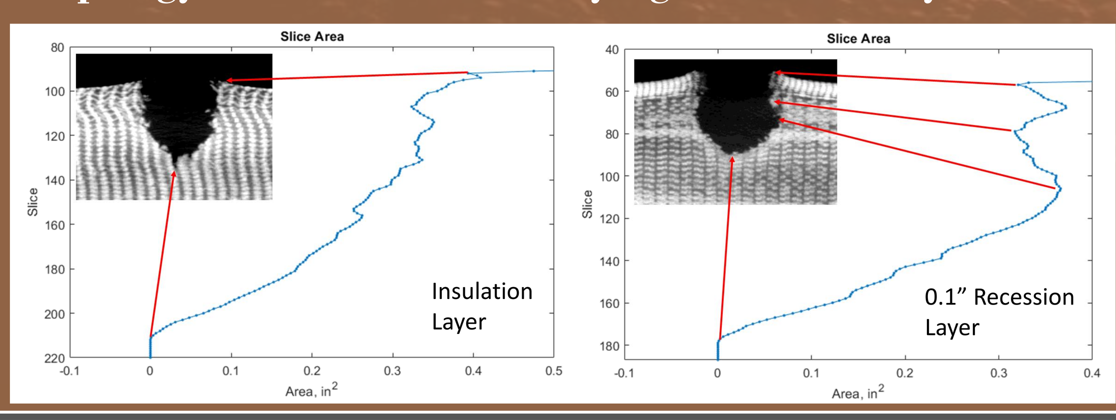


Effects of Varying Recession Layer Thickness



Nylon Projectile	4.78 mm Diameter	~6.7 km/s Velocity	Normal Impact	~1400 kJ Energy

Crater Topology Differences with Varying Recession Layer Thicknesses



Conclusions

- A thin RL does not yield a significant improvement in measured crater depth, meaning it is not a mass-efficient mitigator for MMOD damage
- 1400 J impacts (representing ~8e-5 particle) on HEEET IL are likely flyable, pending thermal analysis
- 15000 J impacts (representing ~1e-7 particle) on HEEET yield un-flyable damage
- HEEET IL alone provides significant MMOD robustness for ~3x the density of heritage PICA
- HEEET BLE (to be updated with new test data) was formed off of full scale RL coupons (~.50" RL) with about half the data points in this test series. This explains the poor predictions the current BLE generates
- A new IL-only HEEET BLE will be generated from the results of this test series