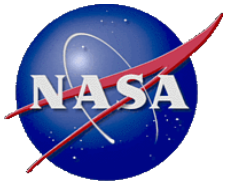
National Aeronautics and Space Administration



Status of NASA Research on Projectile Shape Effects-CFRP Impact Experiments

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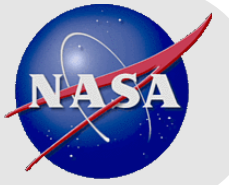
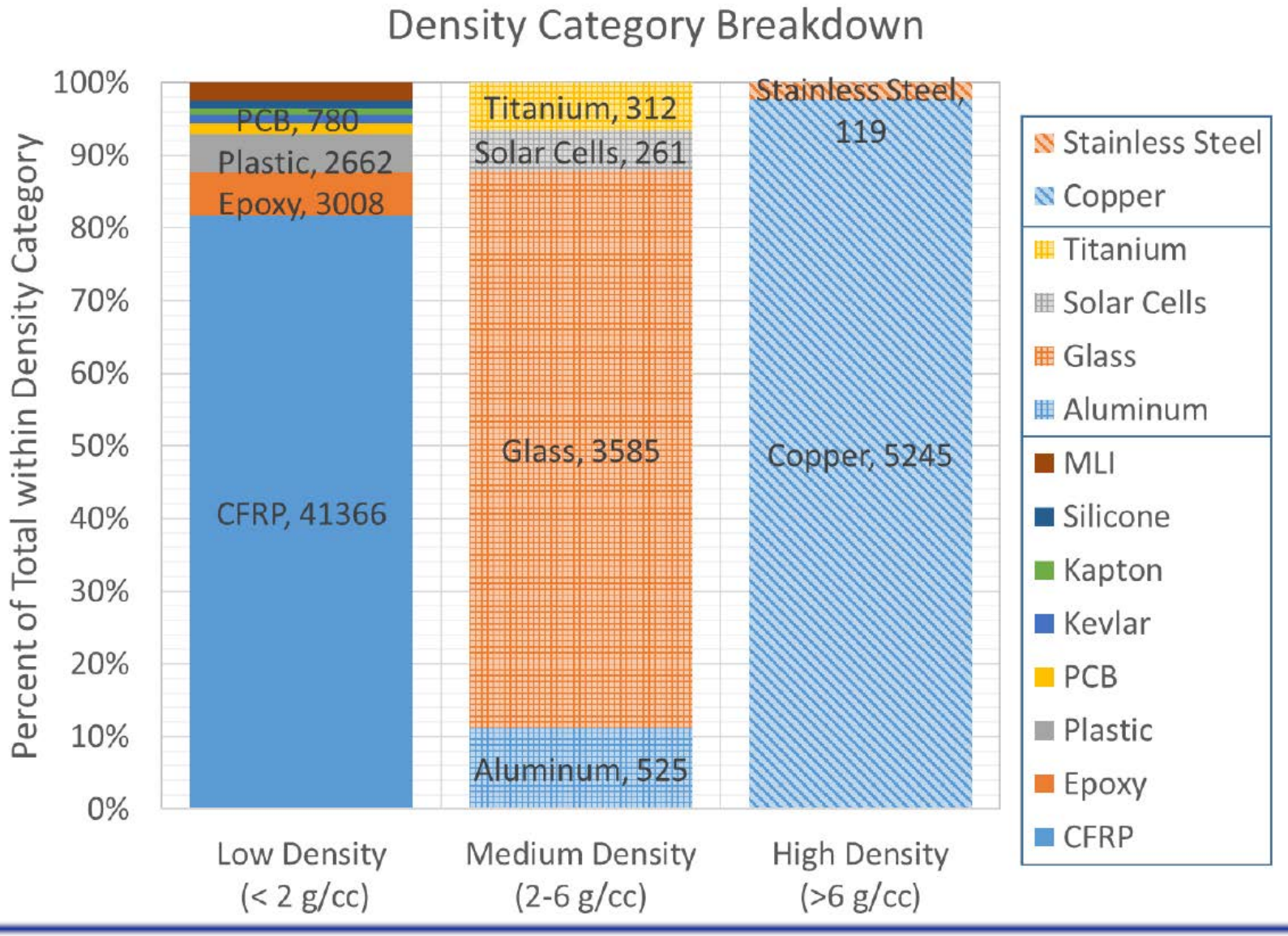
Orbital debris fragment shape study

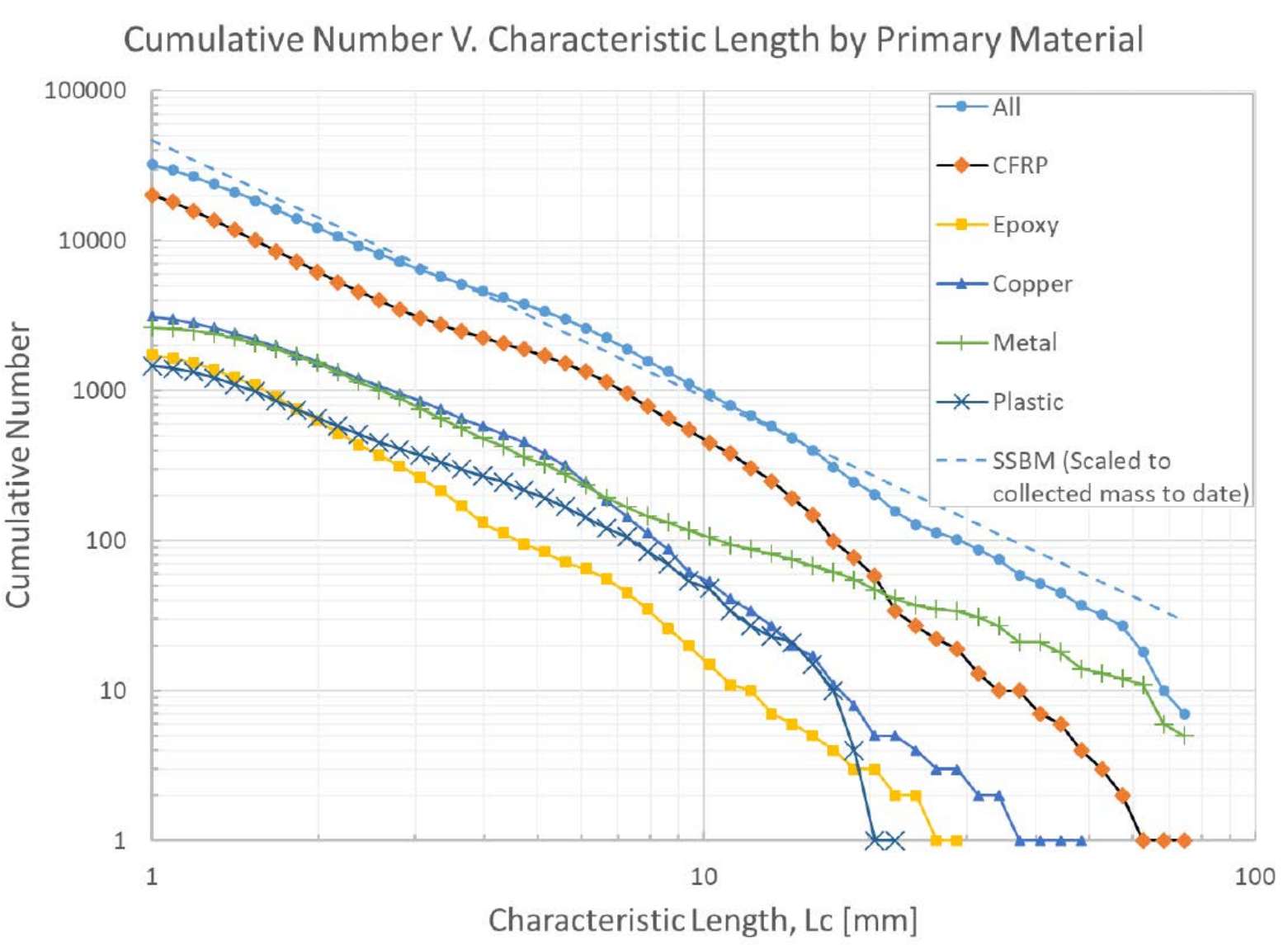


- **Efforts have continued in expanding the understanding of the implications of shaped CFRP materials.**
- **Impact experiments have been performed for validation data of numerical simulation models.**
  - Multiple Length to Diameter L:D ratios have been considered
  - For each general L:D ratio an aluminum Whipple shield with an external thermal blanket have been bracketed (obtained a pass and fail for the considered shield)
  - Diagnostics have been developed to determine the orientation of projectile at impact
- **Numerical simulations compare well with obtained experimental data.**

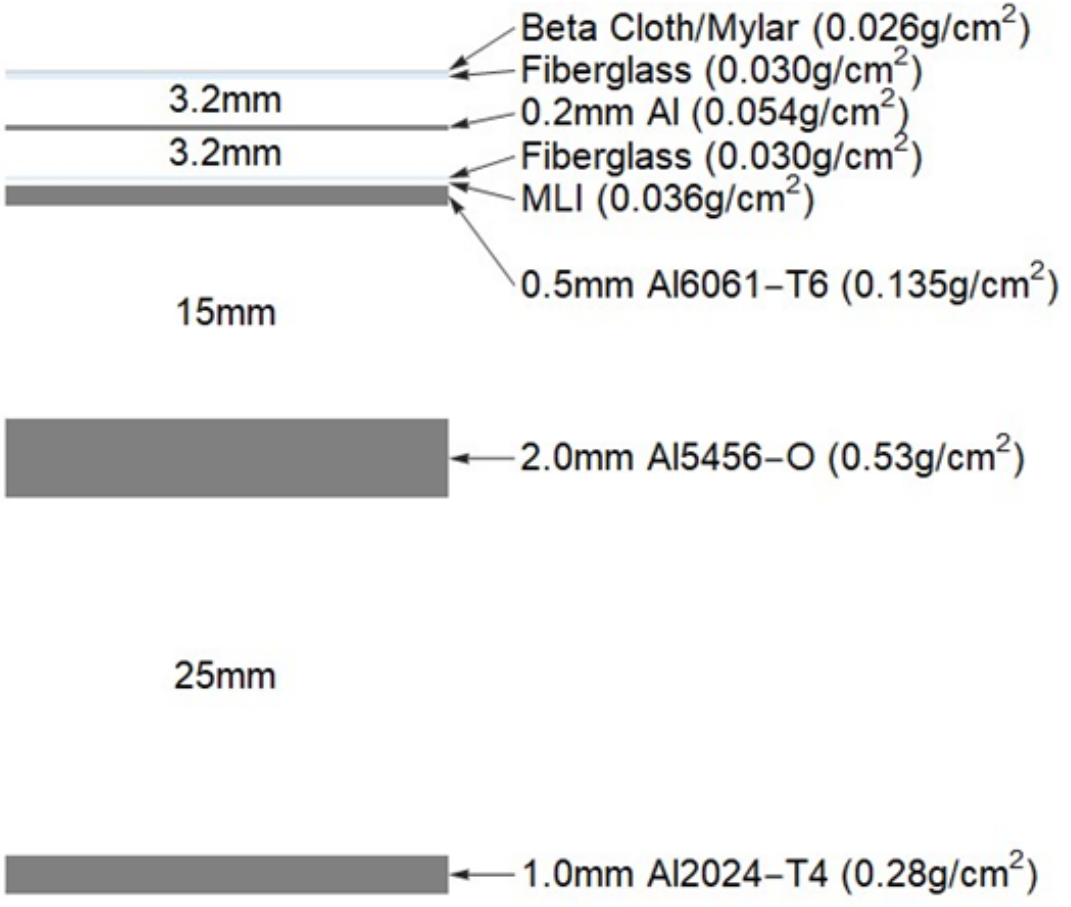
CFRP is a major debris component of a modern satellite break-up



CFRP is the principal component of untrackable debris from a modern satellite break-up

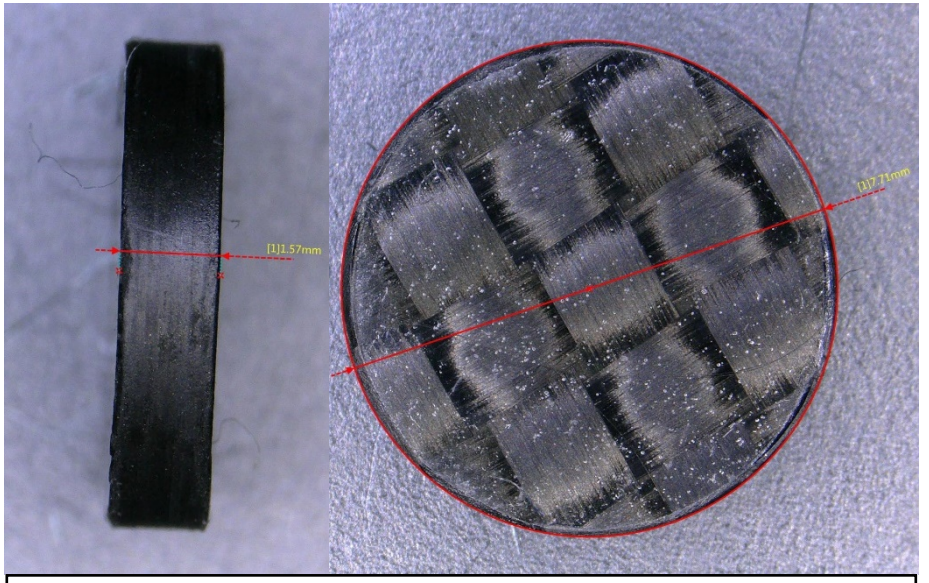


Impact experiments used a realistic Whipple shield with an external, thermal-blanket

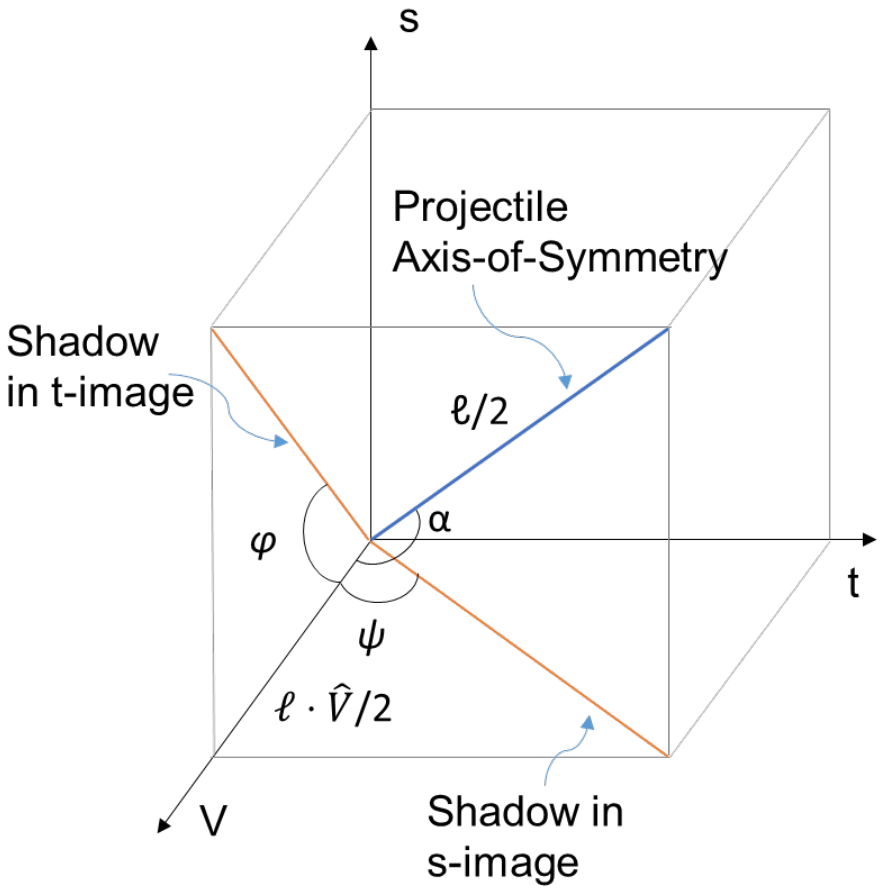


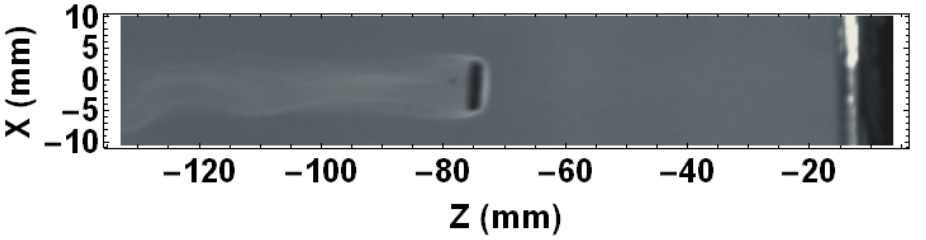
Schematic for experimental layup (layers scaled by mass; separations to scale), which represents a previously considered shield. [Lyons2013, Davis2013]

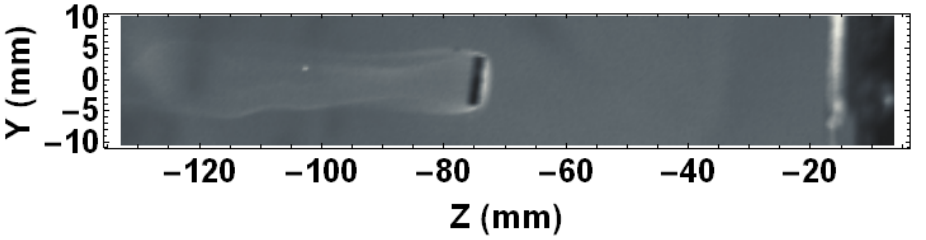
HITF19206 considered an L:D of 1:5 projectile with a diameter of 8 mm

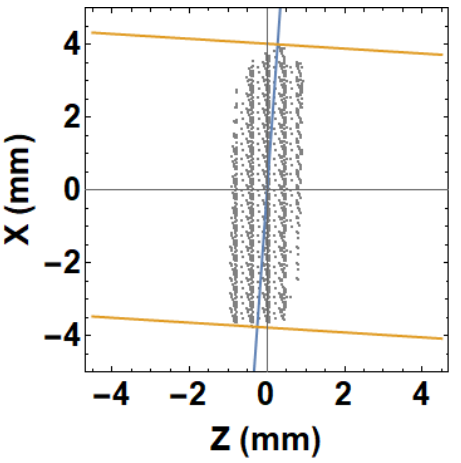


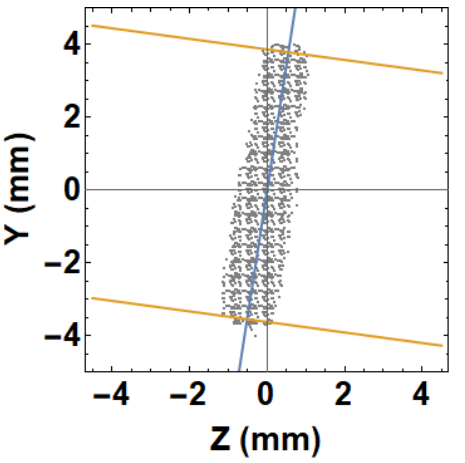
Orthogonal videocameras have been used to determine the projectiles orientation at impact







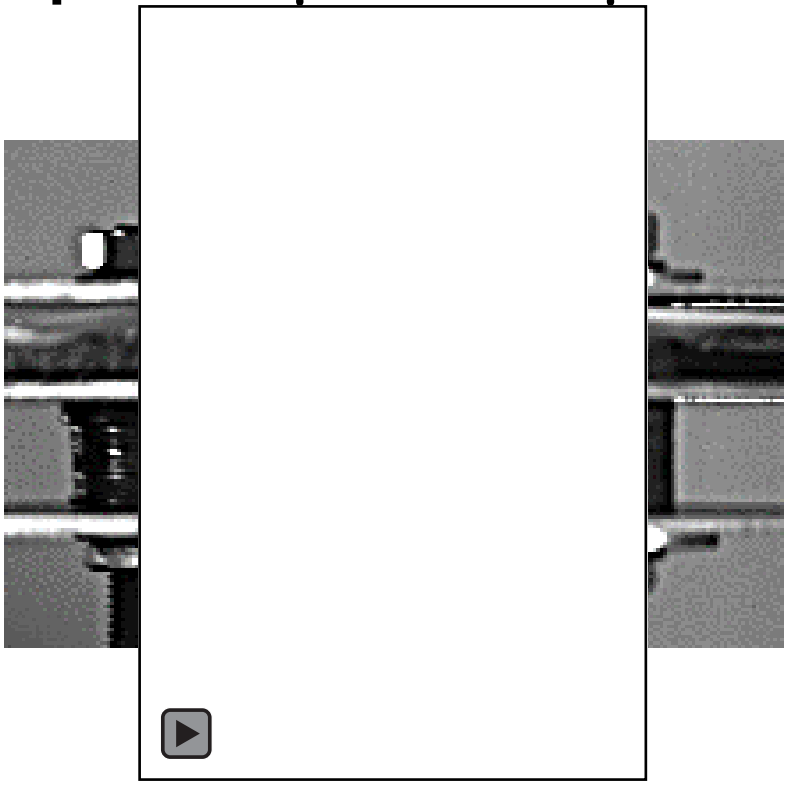




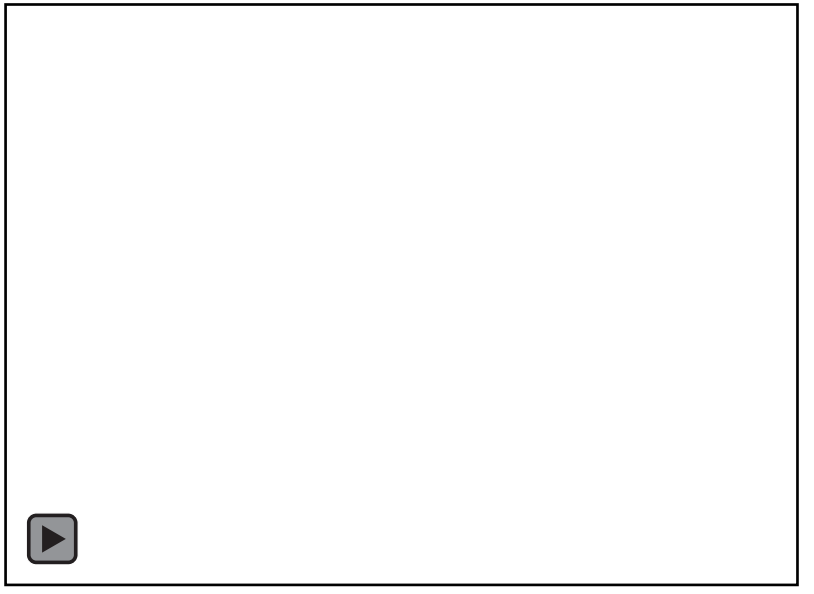
$$\alpha[\phi,\psi] = ArcCos\left[\sqrt{\frac{1}{1+Tan[\phi]^2+Tan[\psi]^2}}\right]$$

The experimental data is collected to assist in validation of numerical simulations

Impact: -2 μs to 28.5 μs

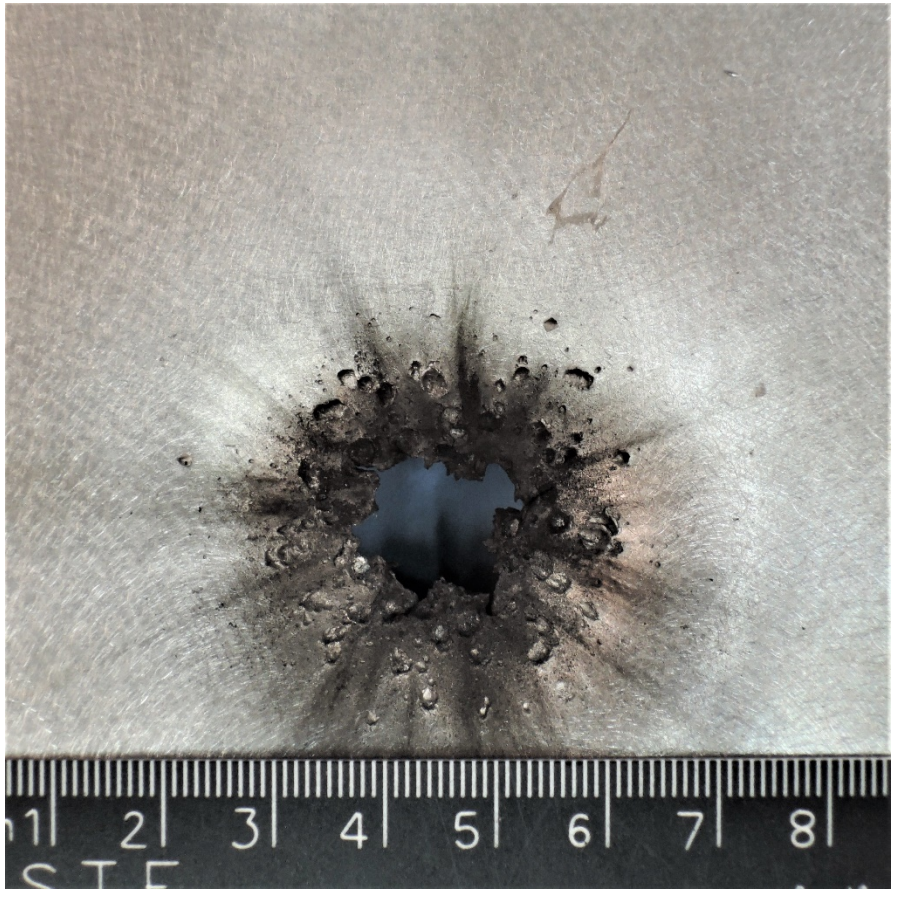


Simulation: 0 μs to 30 μs

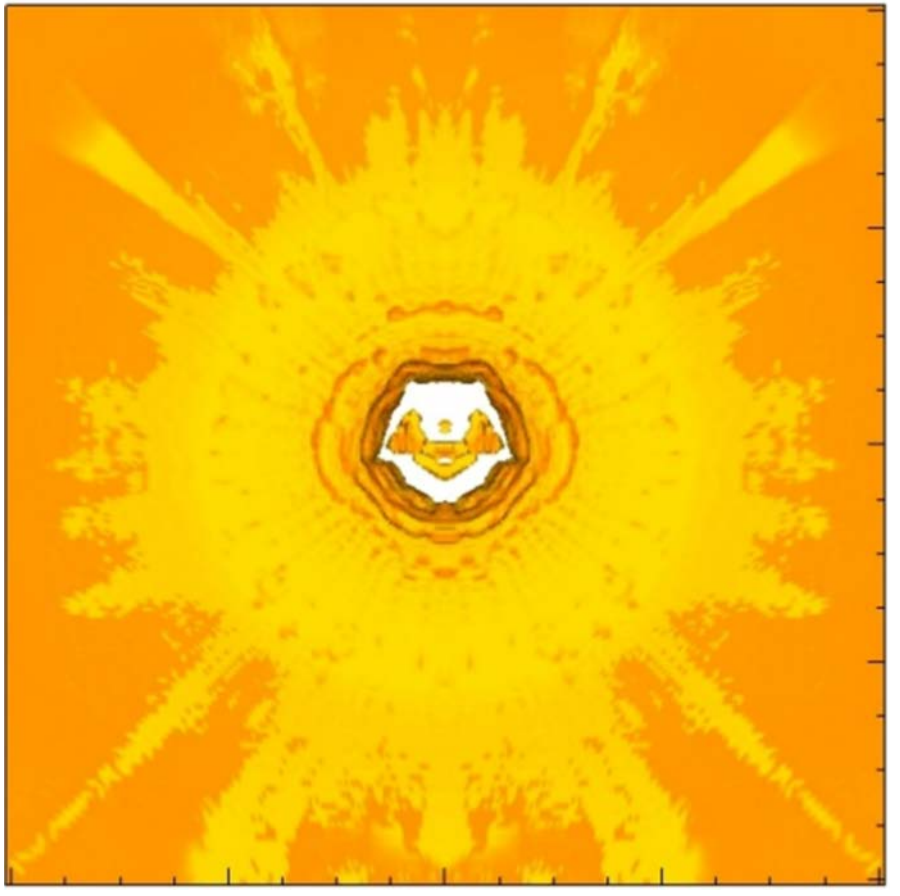


Comparison of the HITF19206 rear wall from experiment and simulation

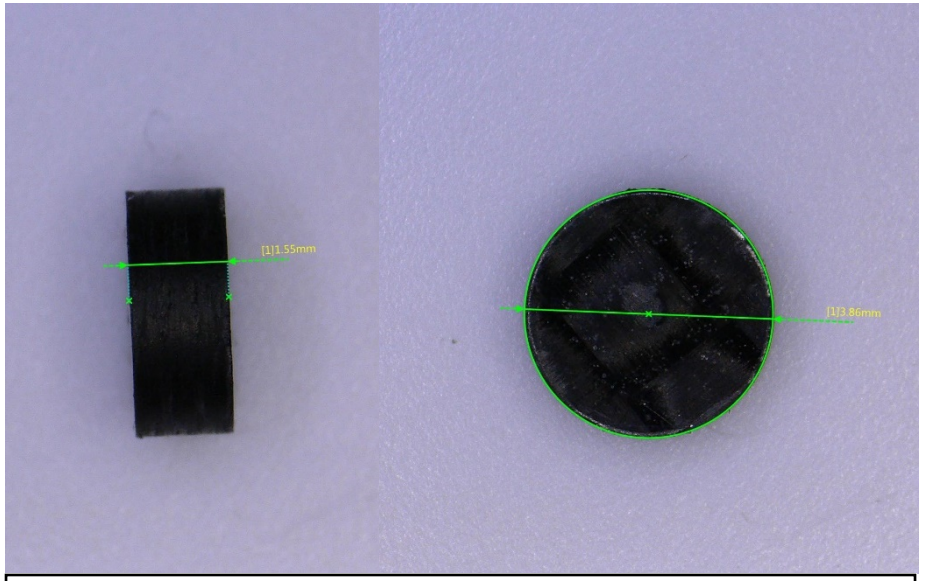
Rear wall from HITF19206

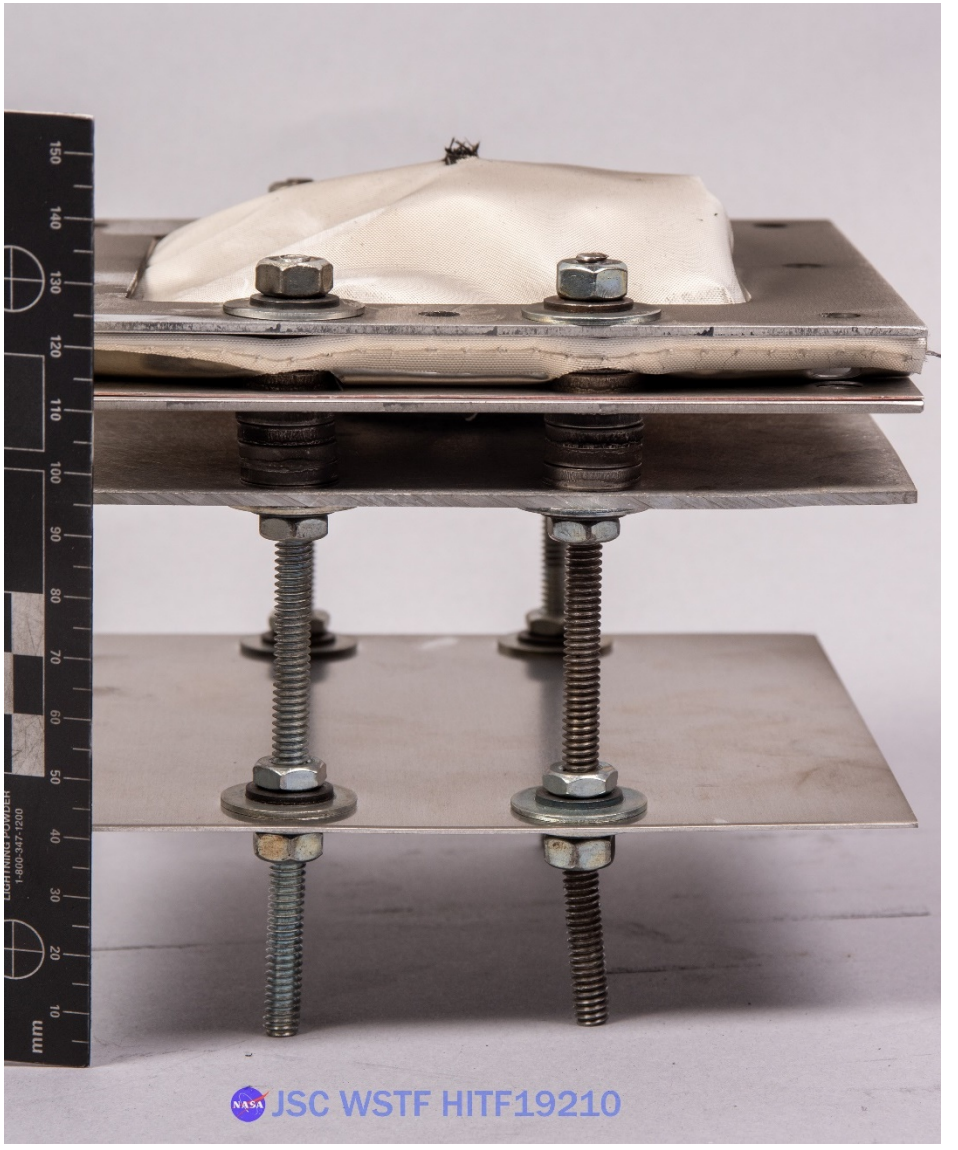


Simulated rear wall damage for HITF19206



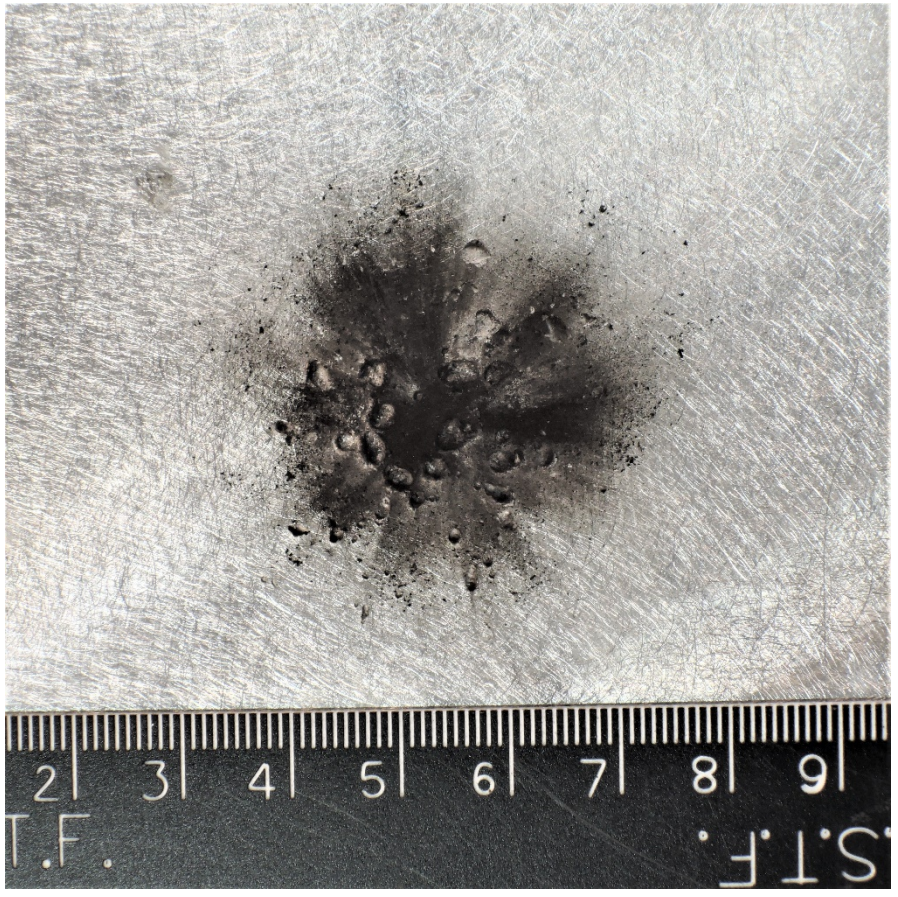
HITF19210 considered an L:D of 1:2.5 projectile with a diameter of 4 mm



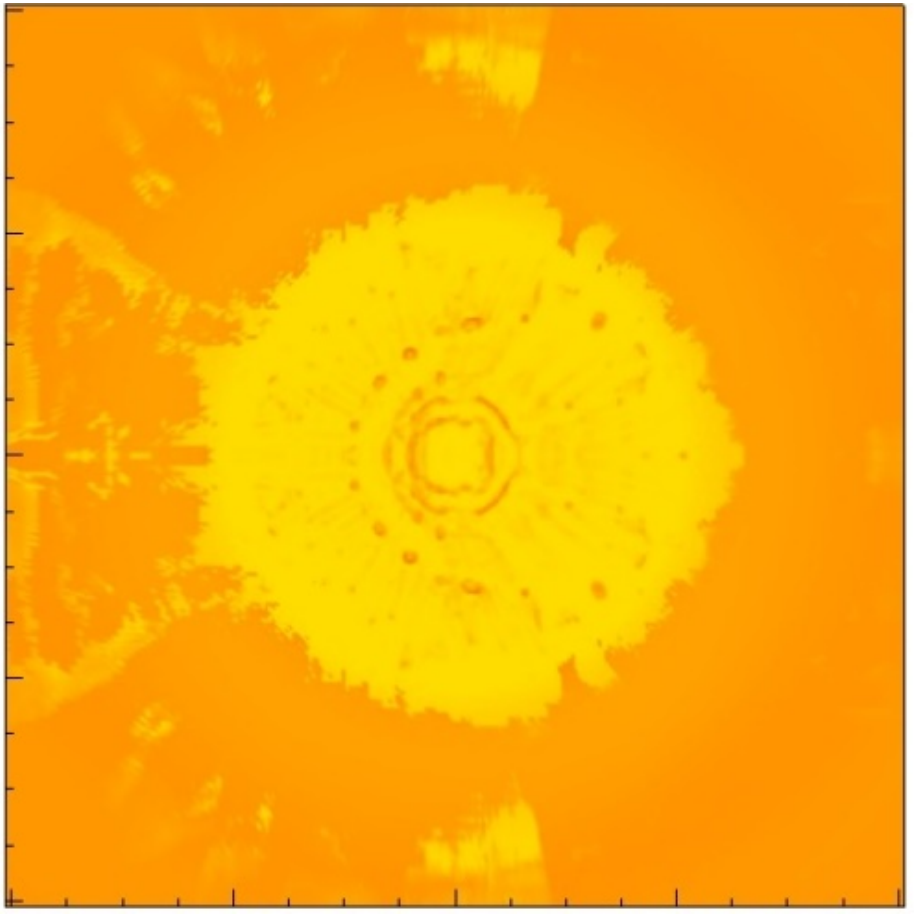


Comparison of the HITF19210 rear wall from experiment and simulation

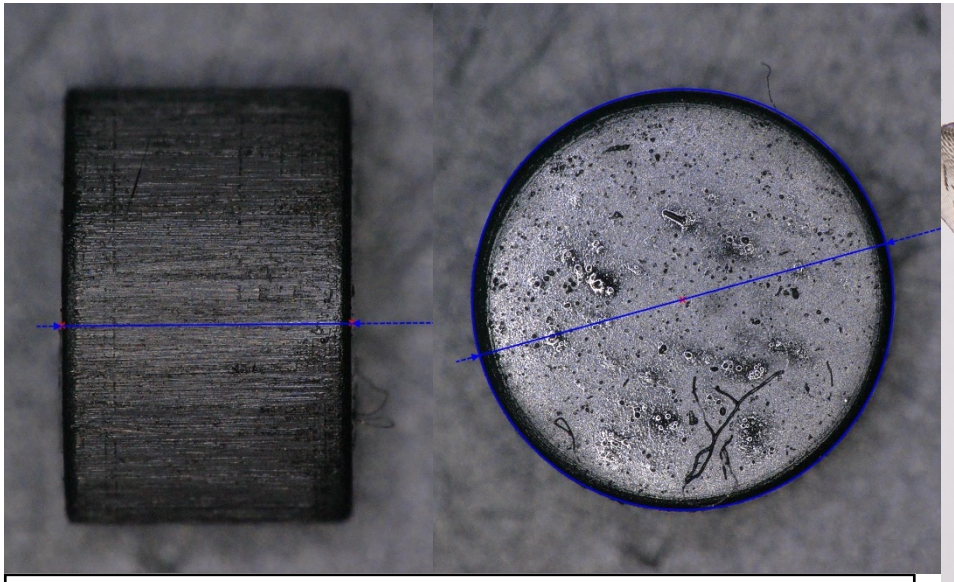
Rear wall from HITF19210

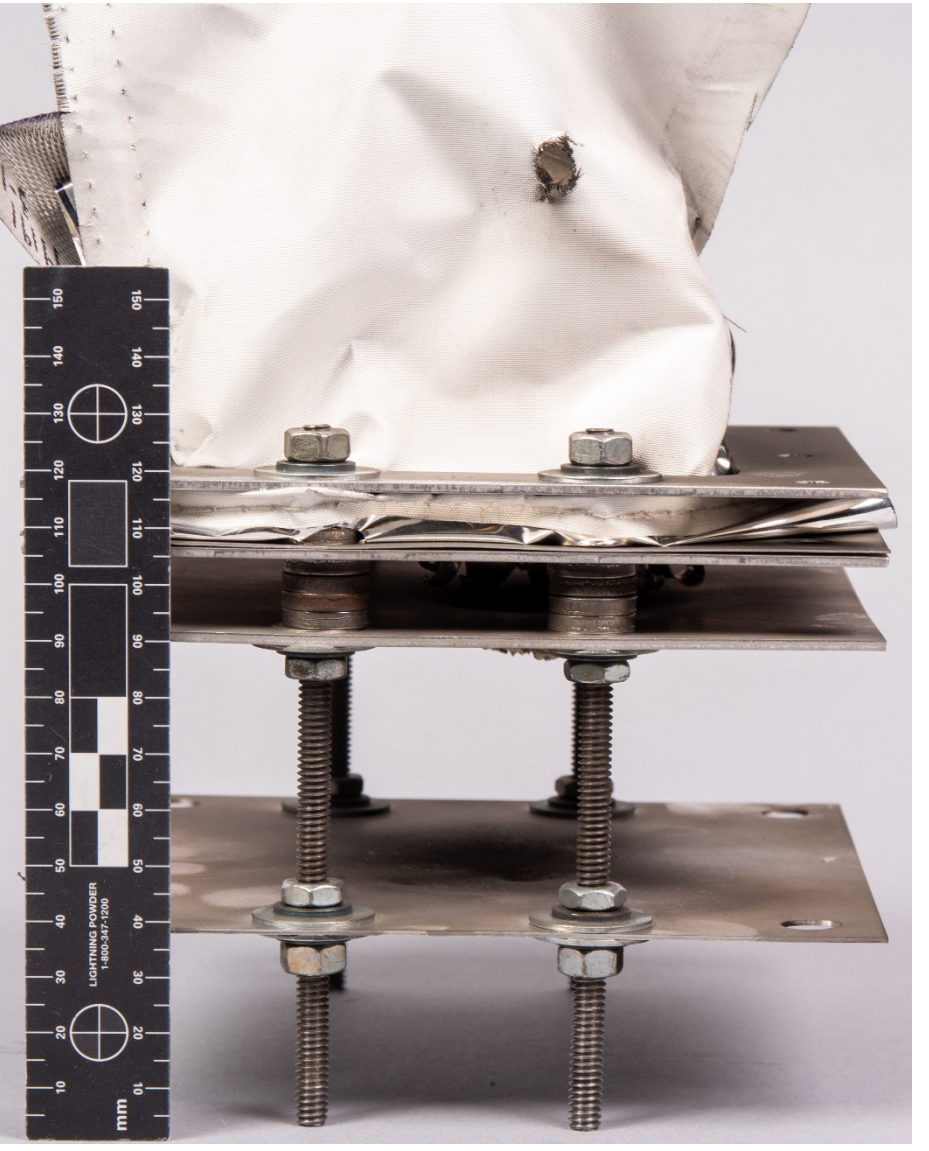


Simulated rear wall damage for HITF19206



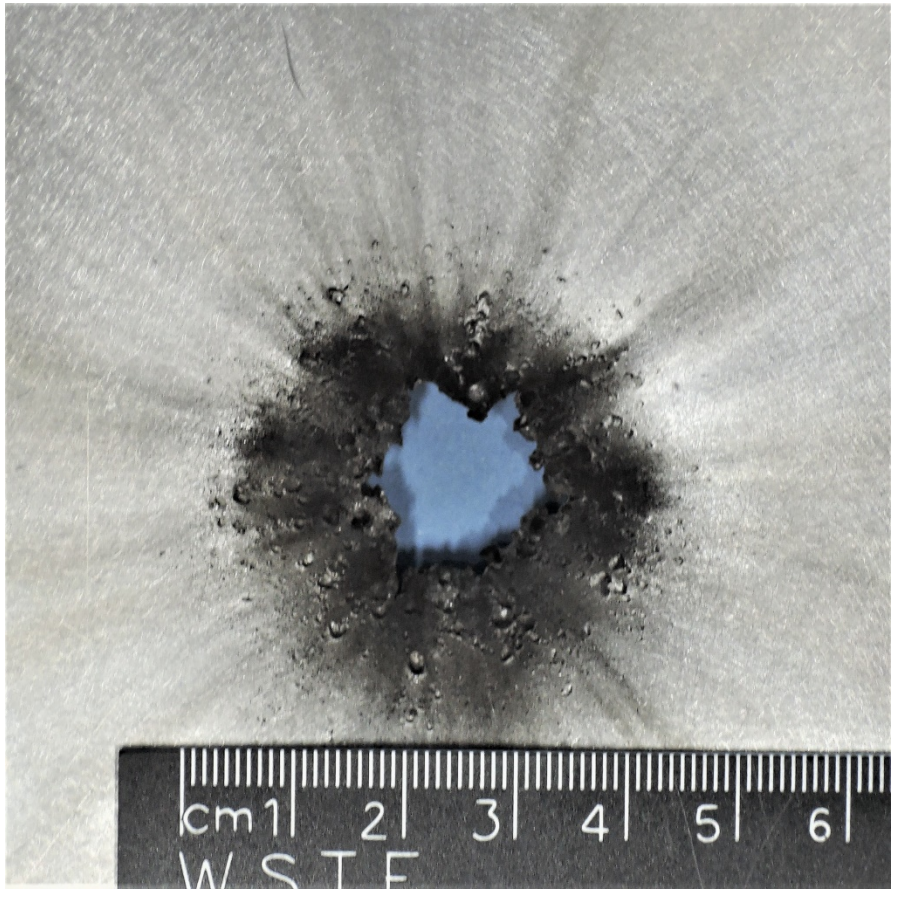
HITF19191 considered an L:D of 2:3 projectile with a diameter of 5 mm



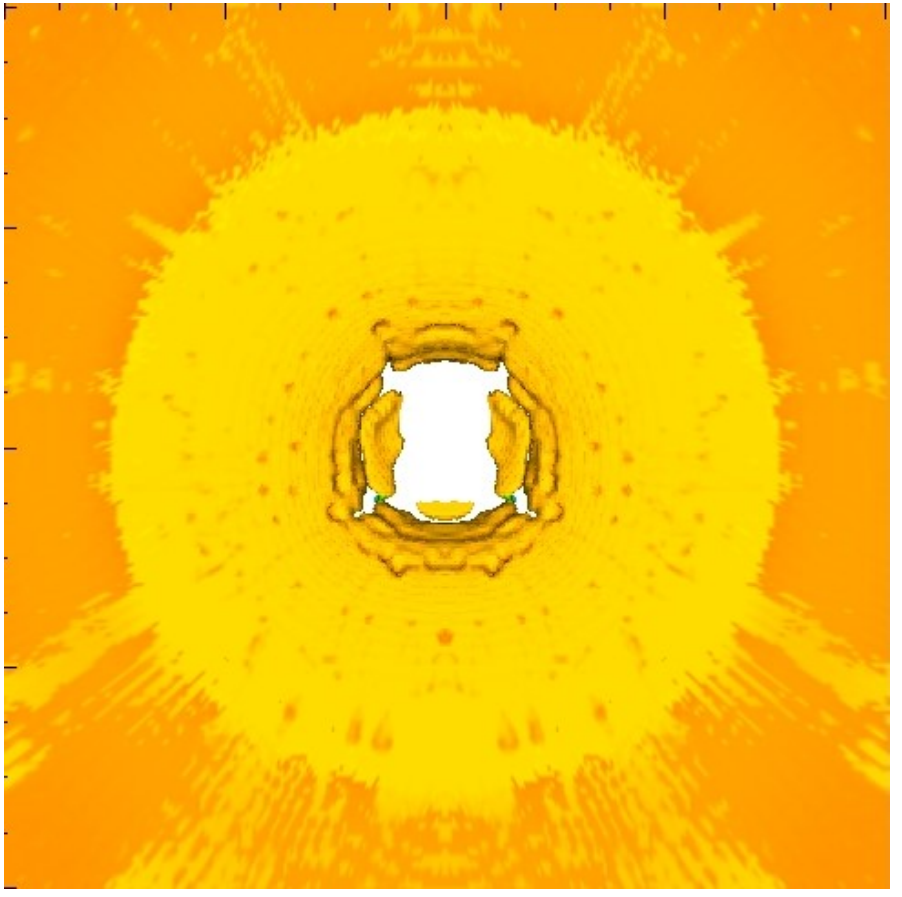


Comparison of the HITF19191 rear wall from experiment and simulation

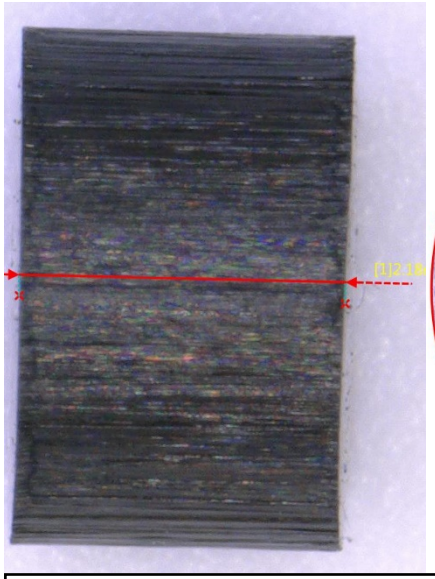
Rear wall from HITF19191

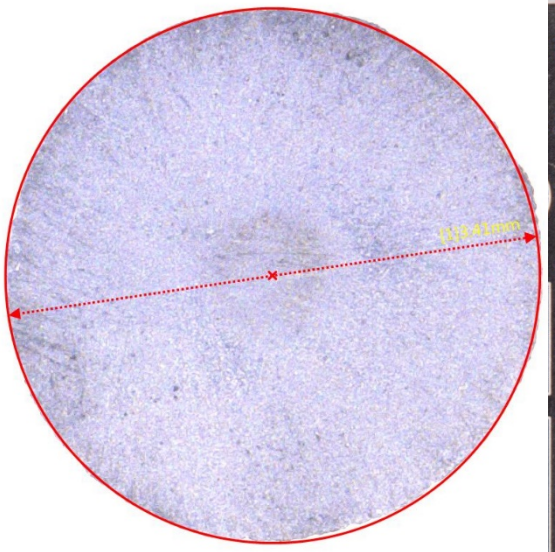


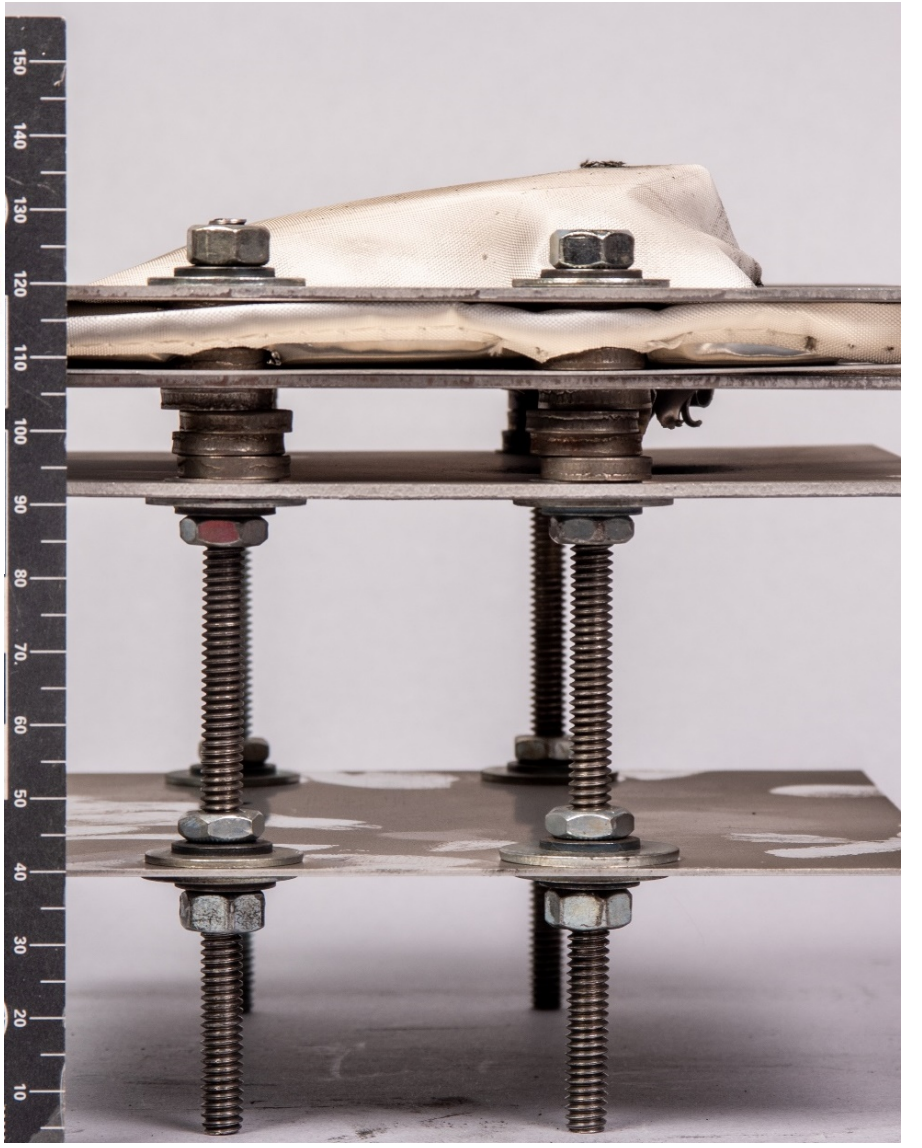
Simulated rear wall damage for HITF19191



HITF19201 considered an L:D of 2:3 projectile with a diameter of 3.45 mm

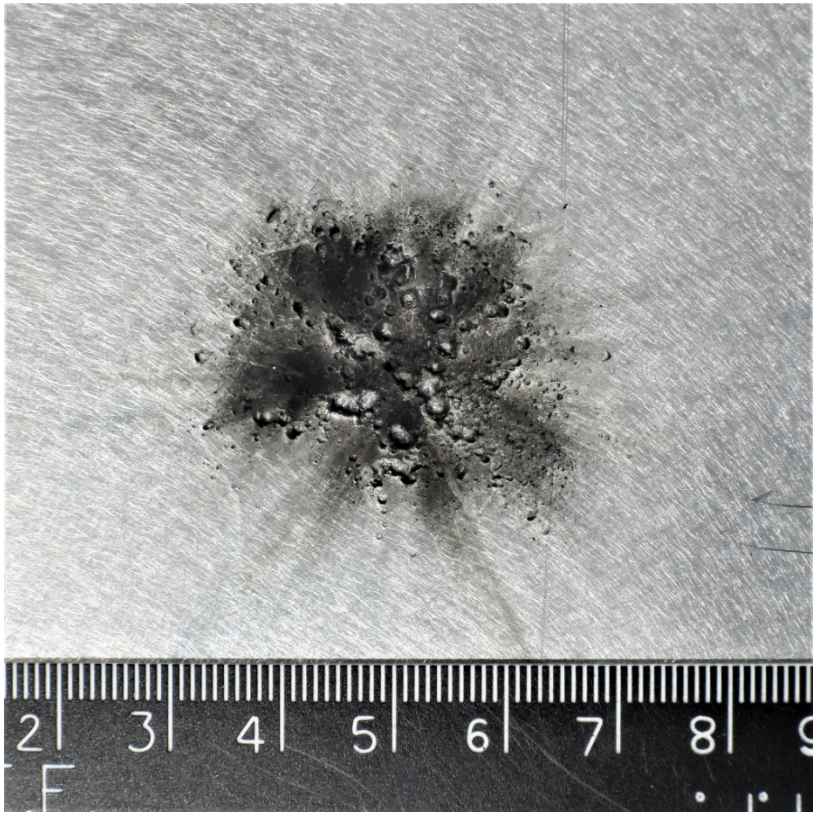






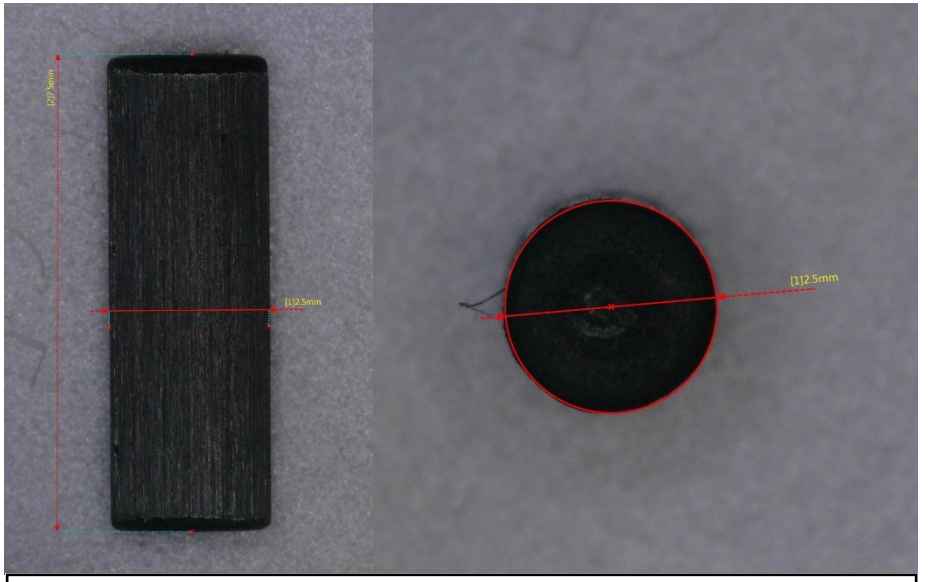
Comparison of the HITF19201 rear wall from experiment and simulation

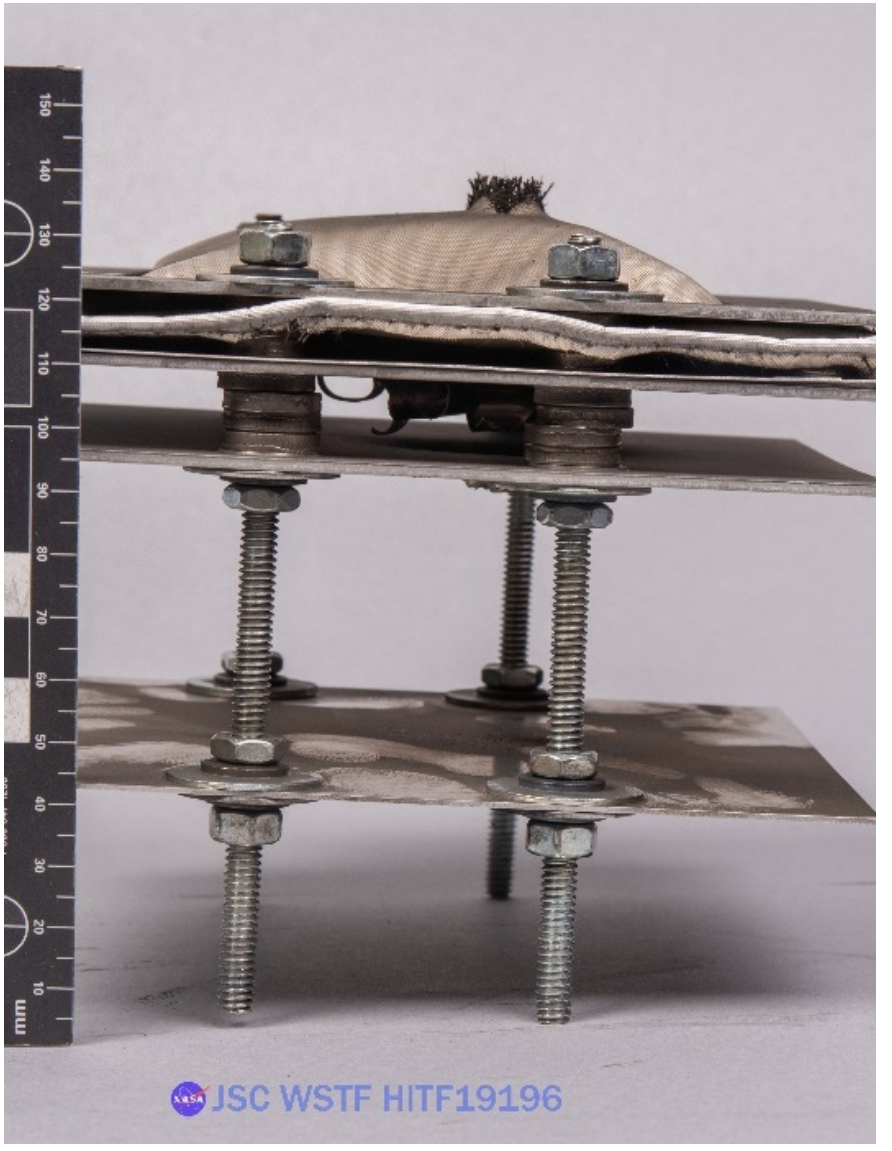
Rear wall from HITF19201



Simulated rear wall damage for HITF19201

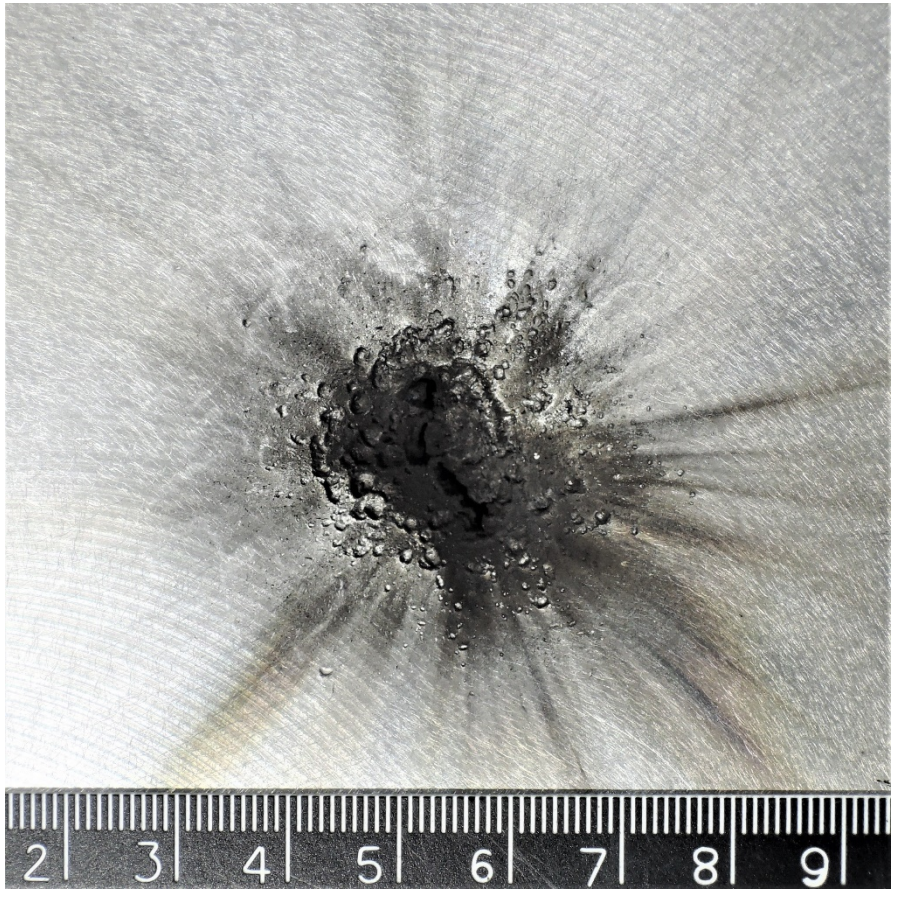
HITF19196 considered an L:D of 3:1 projectile with a diameter of 2.5 mm



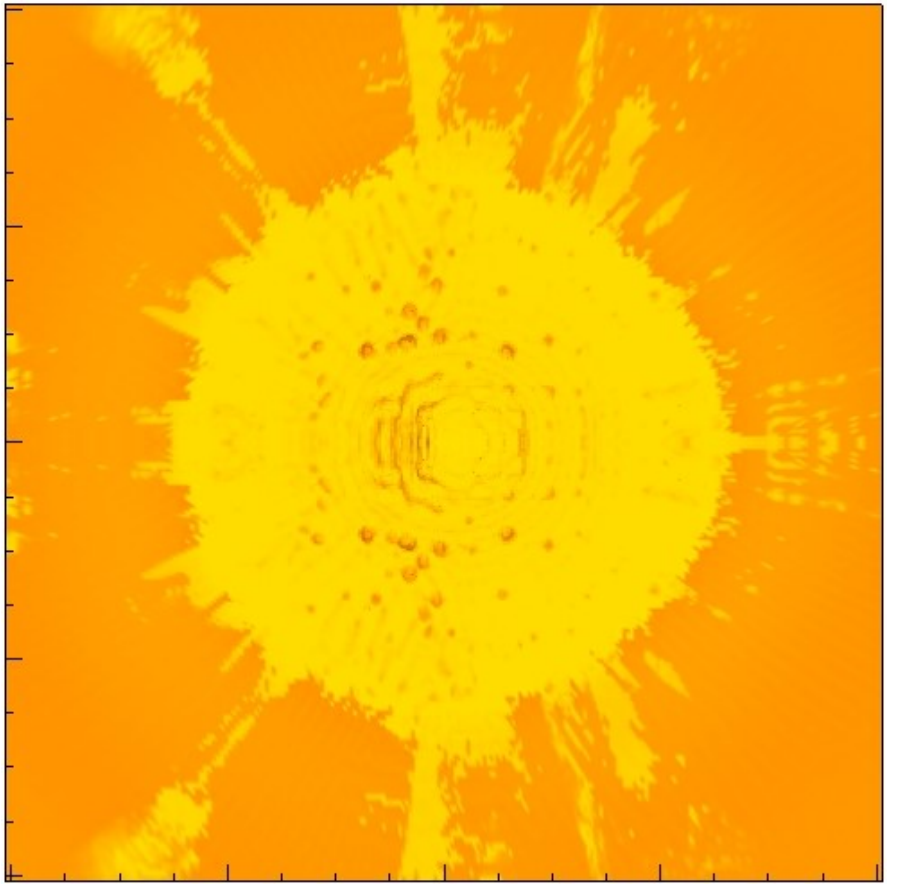


Comparison of the HITF19196 rear wall from experiment and simulation

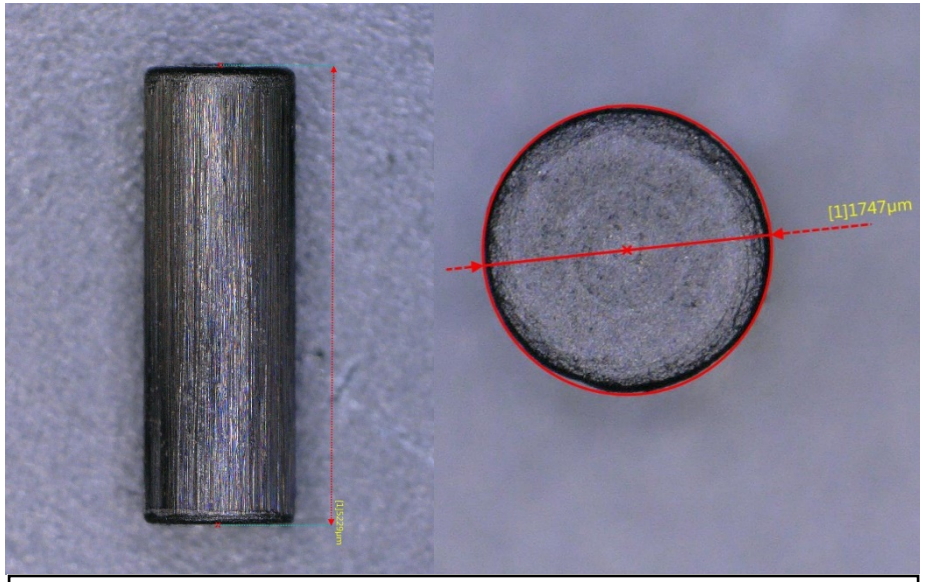
Rear wall from HITF19196

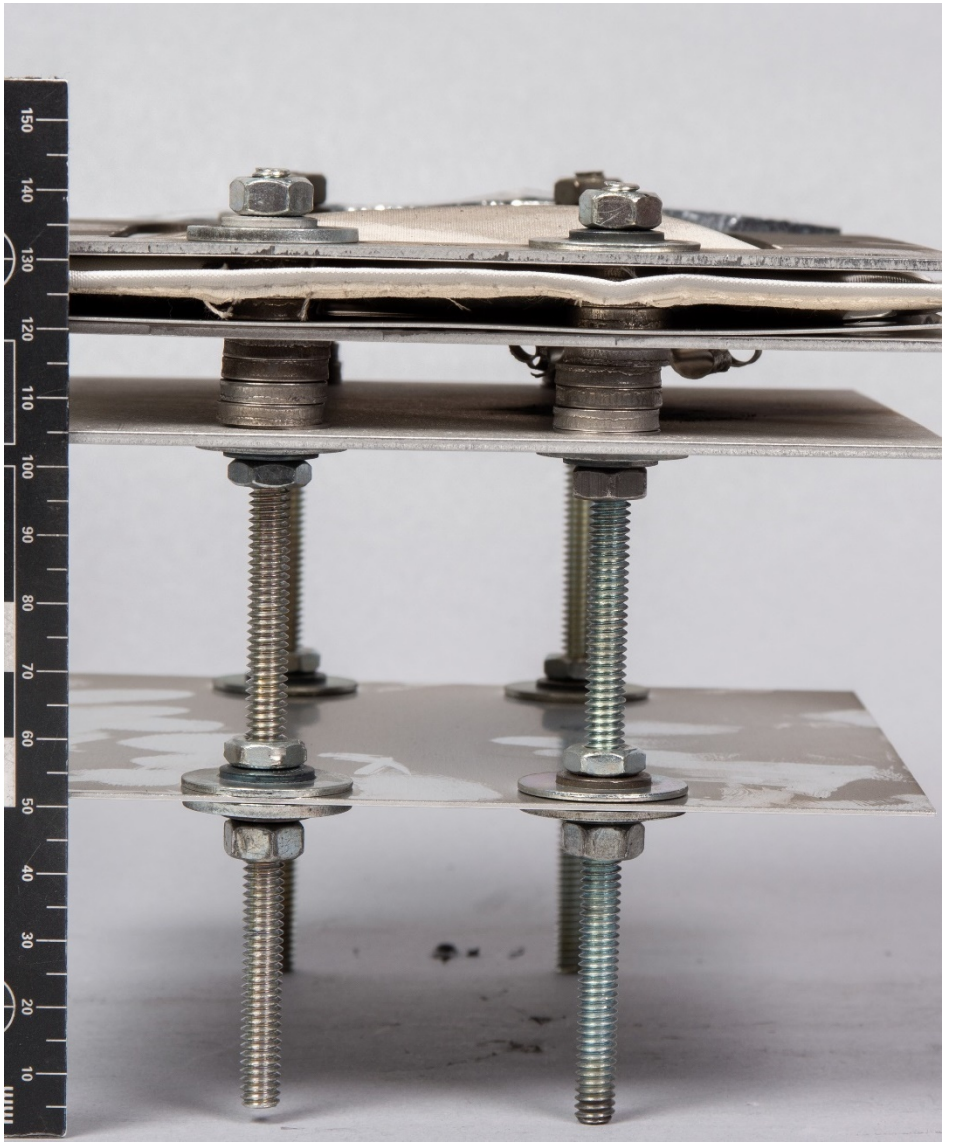


Simulated rear wall damage for HITF19196



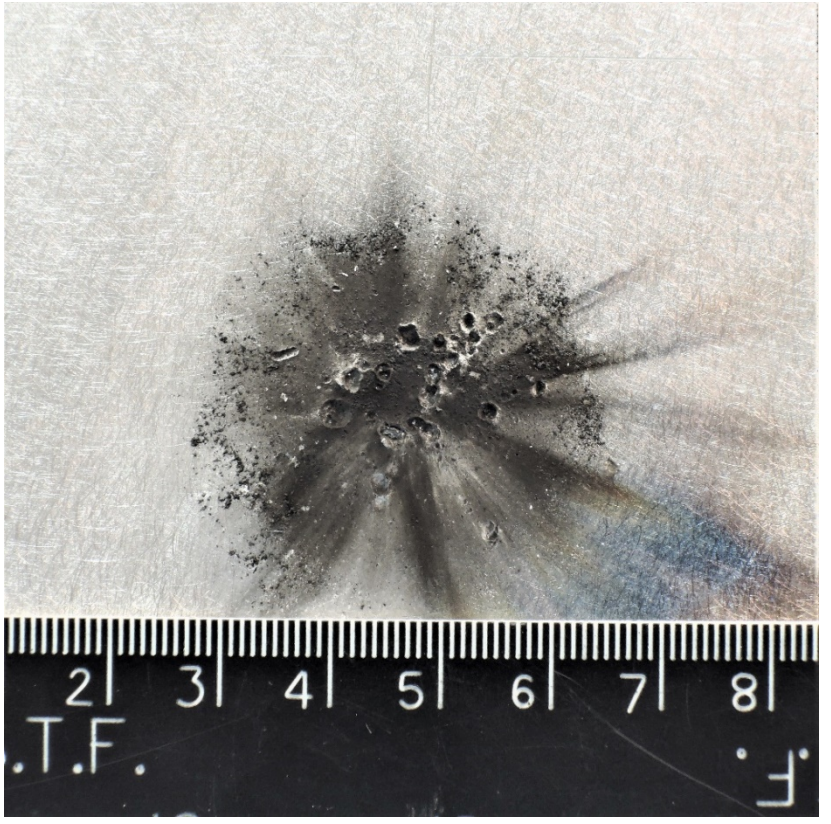
HITF19204 considered an L:D of 3:1 projectile with a diameter of 1.75 mm



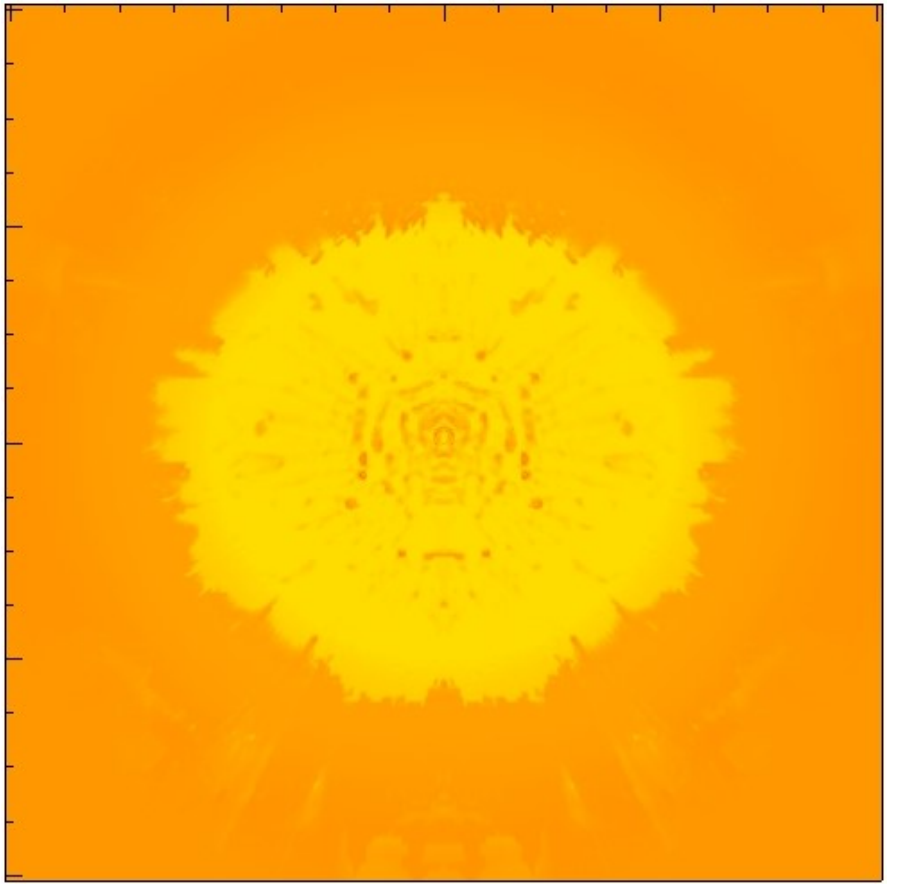


Comparison of the HITF19204 rear wall from experiment and simulation

Rear wall from HITF19204

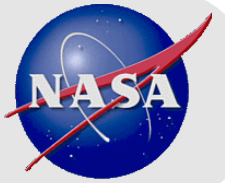


Simulated rear wall damage for HITF19204



Orbital debris fragment shape study future work

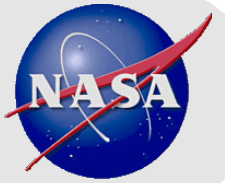
- **Continue to cross-evaluate numerical simulations and obtained data for model effectiveness.**
- **Tighten some of the open questions from the first round of testing and then expand materials.**
  - Add data on some of the configurations into the Whipple shield with an external thermal blanket and work to improve some of the projectile launch and flight characteristics
  - Consider other shields of importance to ISS and Artemis
- **Develop obliquity models and improve models to include impact speed.**



Material that covers additional shots

BACKUP SLIDES

Eleven impact experiments have been performed with CFRP projectiles



Cylindrical CFRP with Varied L/D Ratios									
HITF Number	Projectile Length (mm)	Projectile Diameter (mm)	Projectile L/D	Projectile Mass (g)	Impact Speed (km/s)	Impact Angle (°)	Attack Angle (°)	Critical Length (mm)	Status
HITF19191	3.3	5.0	0.66	0.1007	6.94	0	13.1	2.56	Fail
HITF19192	3.3	5.0	0.66	0.1002	6.99	0	24.7	2.51	Fail
HITF19193	3.3	5.0	0.66	0.0999	6.96	0	18.8	2.54	Fail
HITF19195	7.5	2.5	3	0.0570	6.97	0	69.9	9.97	Fail
HITF19196	7.5	2.5	3	0.0572	6.99	0	47.7	11.31	Fail
HITF19198	1.6	7.86	0.204	0.1163	6.95	0	60.3	0.46	Fail
HITF19201	2.18	3.41	0.639	0.0327	6.94	0	64.2	5.27	Pass
HITF19204	5.23	1.75	2.99	0.0204	7.00	0	81.2	21.47	Pass
HITF19206	1.57	7.71	0.204	0.1170	5.96	0	9.1	0.82	Fail
HITF19207	1.55	7.59	0.204	0.1170	6.63	0	17.2	0.79	Fail
HITF19210	1.55	3.86	0.402	0.0302	6.63	0	14.9	3.66	Pass