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

J. Miller\textsuperscript{a,b}, E. Christiansen\textsuperscript{c}, J. Hyde\textsuperscript{b}

\textsuperscript{a}University of Texas at El Paso, 500 W. University Blvd., El Paso, TX 79968
\textsuperscript{b}Jacobs, NASA Johnson Space Center, Houston, TX 77058
\textsuperscript{c}NASA Johnson Space Center, Houston, TX 77058

19 NOV 2019
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.
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.

\[ \alpha[\phi, \psi] = \arccos \left( \sqrt{1 + \tan[\phi]^2 + \tan[\psi]^2} \right) \]
The experimental data is collected to assist in validation of numerical simulations.

Impact: -2 $\mu$s to 28.5 $\mu$s

Simulation: 0 $\mu$s to 30 $\mu$s
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
• 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

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