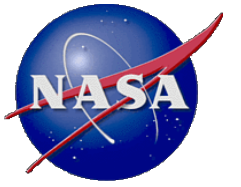
National Aeronautics and Space Administration



Status of NASA Research on Projectile Shape Effects

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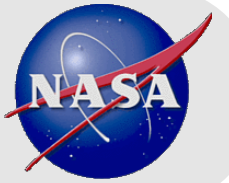
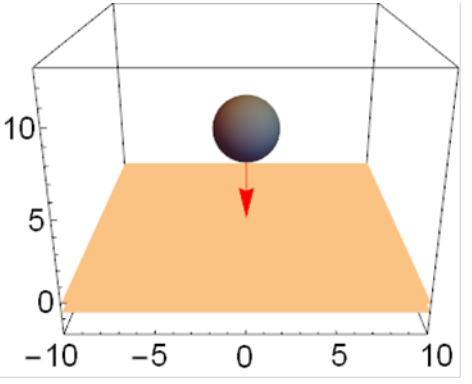
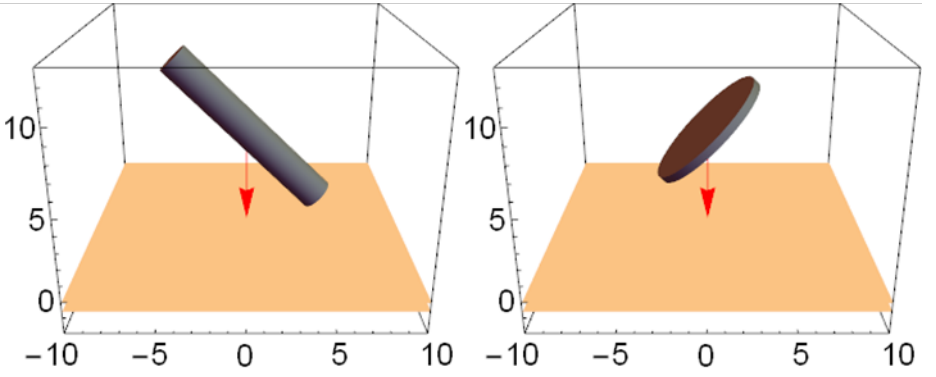
Orbital Debris Fragment Shape Study



- **Task Plan**
  - Assess ballistic limits for cylindrical rod-like and plate-like projectiles using hydrocode simulations and hypervelocity impact test results
    - Target types/failure criteria:
      1. General and specific single-wall materials (metals and thermal protection materials)
      2. General and specific multi-wall shields (Whipple shield, stuffed Whipple shield, etc)
    - Assess projectile density effects: low-density (graphite-epoxy), medium density (aluminum) and high-density (steel)
    - Assess impact velocity effects
    - Assess projectile orientation effects
    - Assess impact obliquity effects

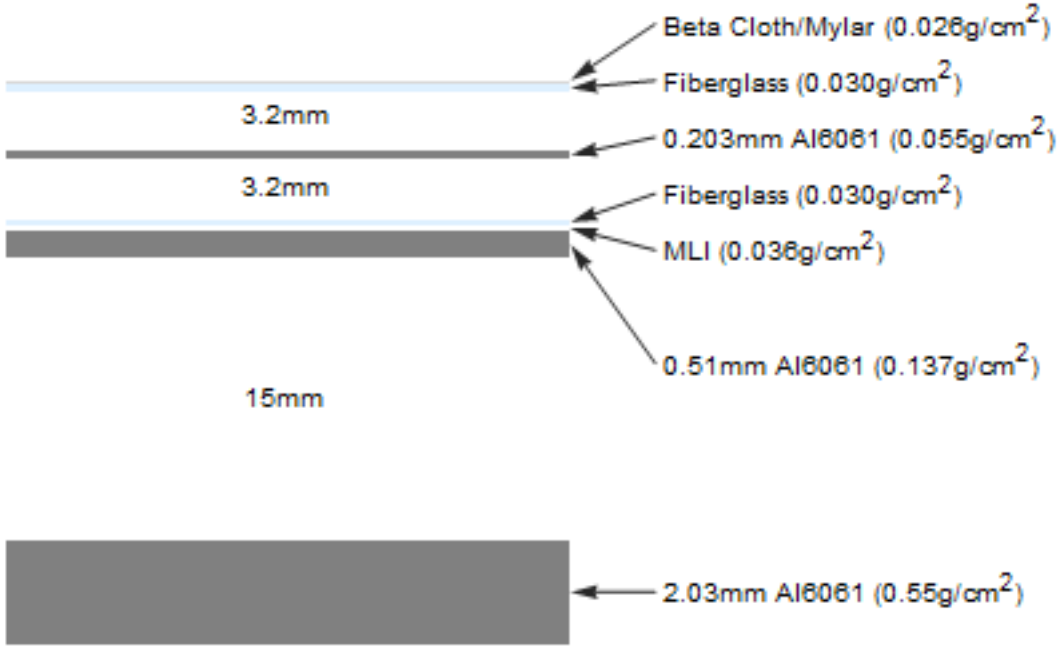
Even extending to axisymmetric shapes adds variables that greatly expand parameter space

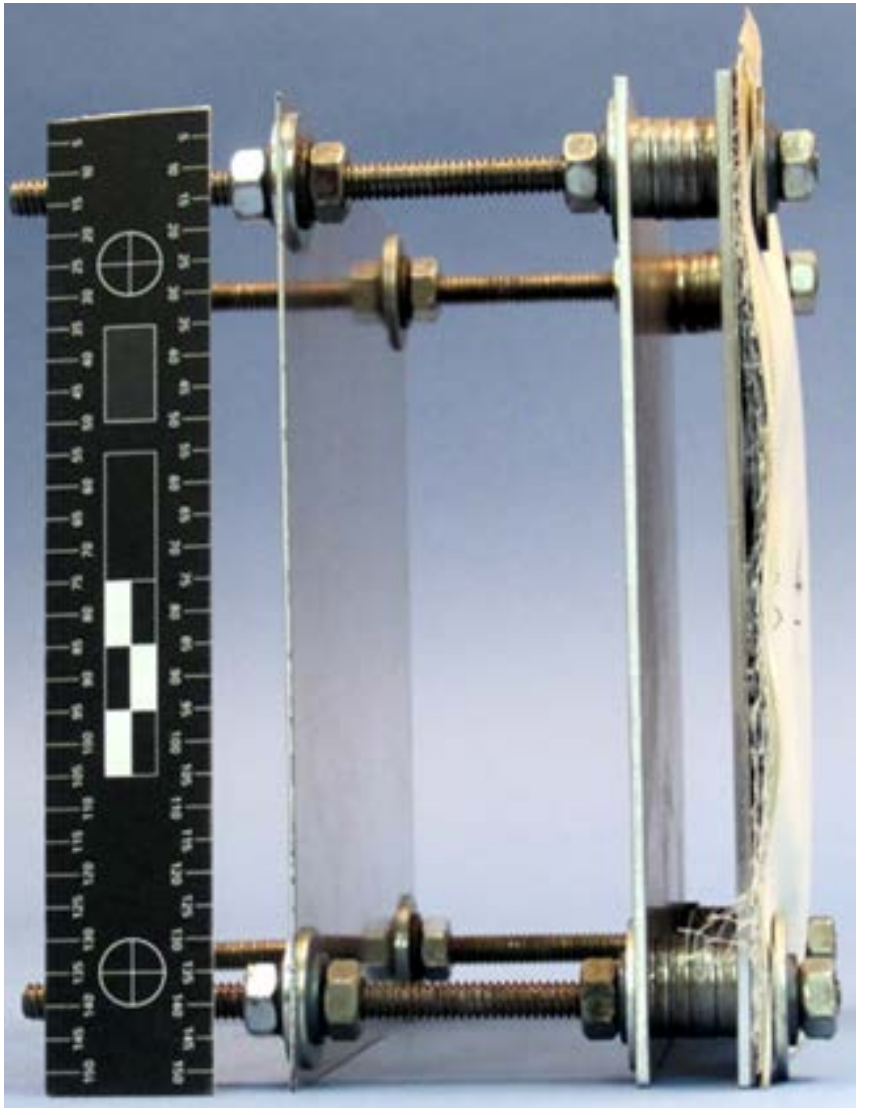




Non-spherical shapes add additional ballistic variables: $\mathcal{B}[\mathcal{D},\mathcal{L},U,\theta,\mathcal{M},\varphi,\psi]$

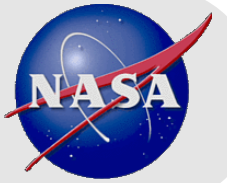
Simulations explored a Whipple shield with a blanket for preliminary shape effect findings



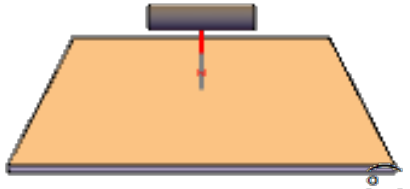


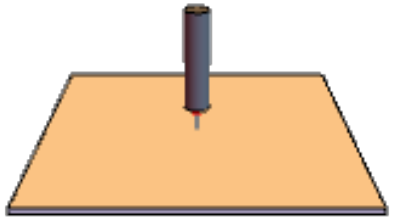
Schematic for numerical simulation (layers scaled by mass; separations to scale), which represents a previously considered shield. [Lyons2013, Davis2013]

The critical cylinder mass to critical sphere mass highlights regions needing exploration

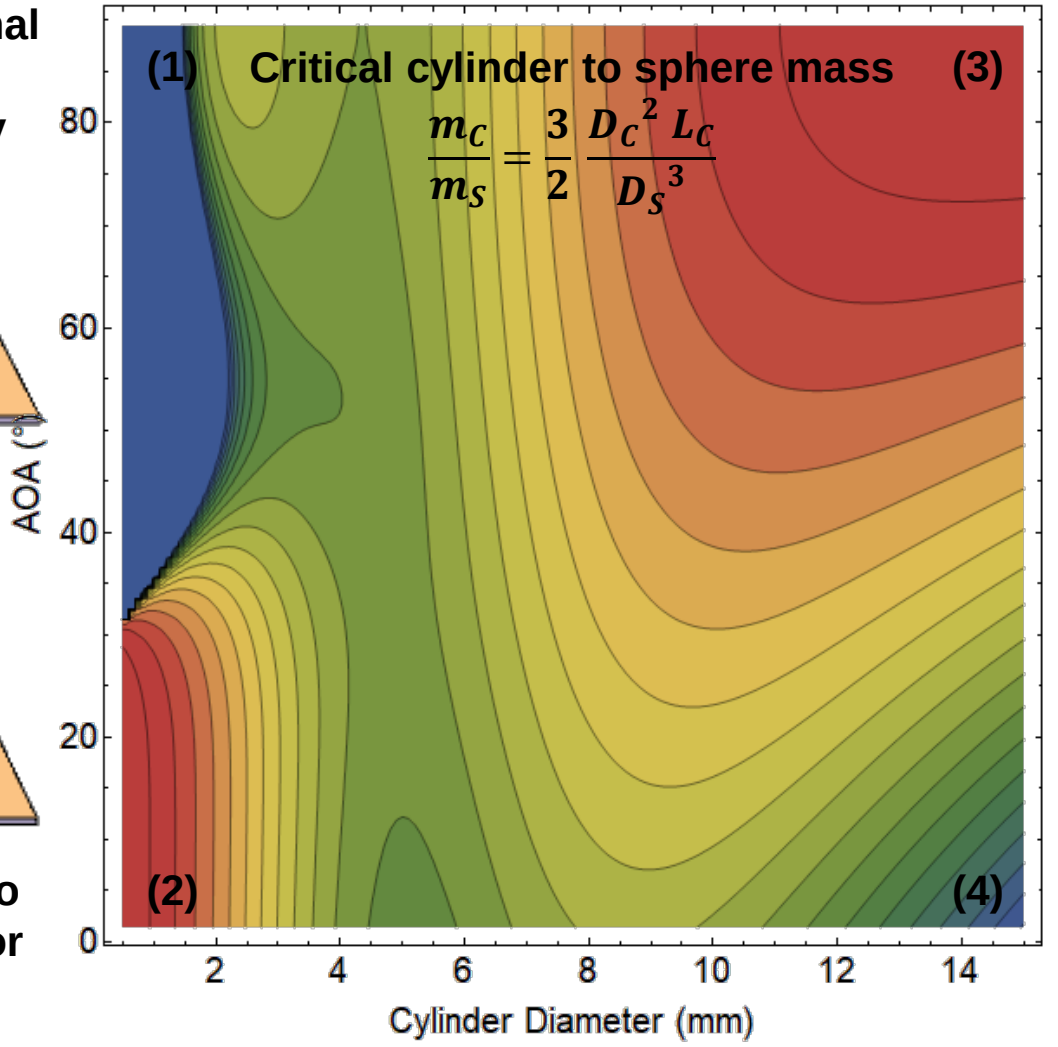


1) Rods orthogonal to the velocity vector are weakly penetrating

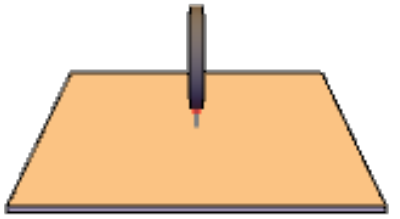


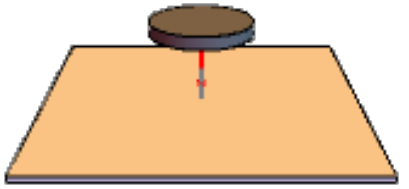


2) Rods aligned to the velocity vector are highly penetrating



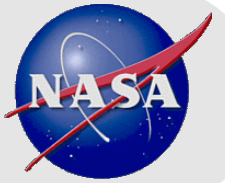
3) Plates orthogonal to the velocity vector are highly penetrating





4) Plates aligned to the velocity vector are weakly penetrating

Orbital debris fragment shape study recommendations



- **Due to the complexity of shape effects on ballistic performance of shields and spacecraft materials/hardware, it is recommended that debris populations be limited to a few, no more than three, categories**

  (1) Rod-like orbital debris – Evaluated in hypervelocity tests and MMOD risk assessments as cylinders with length/diameter (L/D) = 3

  (2) “Chunky” orbital debris – Evaluated in hypervelocity tests and MMOD risk assessments as either spheres or cylinders with L/D =1

  (3) Plate-like orbital debris – Evaluated in hypervelocity tests and MMOD risk assessments as cylinders with L/D = 1/3