Paper ID: 16256
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SPACE DEBRIS SYMPOSIUM (A6)
Hypervelocity Impacts and Protection (3)

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BULLETPROOFING SATELLITES: MODELING THE PHYSICS OF HYPERVELOCITY IMPACTS

Abstract

Spacecraft and satellites in Low Earth Orbit can collide with small objects such as micrometeorites and man-made space debris at speeds over several thousand miles per hour. While the masses of such objects are relatively low, the kinetic energy transferred in these hypervelocity impacts (HVI) can be quite lethal, destroying orbital components in failure modes unseen in conventional studies. Even impacts in the low-hypervelocity regime can generate shock pressures in millions of pounds per square inch and deform materials at incredibly high strain rates. The strength of a spacecraft's materials is thus small compared to the stresses of impact, and even metals and high strength composites behave like fluids. The rapid compressions in such impacts increase temperatures by hundreds of degrees, melting common aerospace materials. Higher velocity collisions often vaporize targets, and the temperatures and pressures of extreme HVI can force targets into a plasma state briefly. The high pressures and small timescales of such an event are ideally modeled by explicit finite element schemes, and the fluidic response of the materials involved can be effectively simulated using hydrocodes. The proposed research uses an advanced explicit finite element scheme to examine fully three dimensional models of hypervelocity impacts involving particles of varying shapes and sizes at various incidence angles and speeds. Both meshed and meshless methods are used to fully model the projectile and shield failure, and variations in the propagation and subsequent damaging effects of debris. The fluidic response and phase change of the interaction is directly modeled, and variations in this response are analyzed with respect to shockwave velocities within the shield material. Various advanced failure models are implemented, and compared to experimental results for validation. Damage to aerospace composite structures is modeled, as well as damage to multiple sequential interfaces as a simulation of a Whipple shield. In addition to using traditional qualitative validation methods of prior studies, such as debris cloud and impact crater size comparison, it is proposed that the quantitative results of new experimental tests using laser vibrometers and ultrasonic sensors be directly compared to simulated results to ensure that the underlying physical response of HVI are being effectively modeled. Investigating various models for both projectile and shield failure gives a comprehensive picture of secondary impacts by debris. By analyzing the fundamental physical processes of material failure in HVI, researchers can design more effective shielding for astronauts and mission critical components.