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Predicting the Perforation Response of Honeycomb Sandwich Panels Using Ballistic Limit Equations

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Man-made debris from previous spacecraft missions poses a serious threat to spacecraft that are launched to operate in Earth orbit because it can strike such spacecraft at extremely high velocities and consequently damage mission-critical systems. Most satellites are constructed with honeycomb sandwich panels as their primary structural elements. To be able to perform a risk analysis, it is important to know, in the event of such a meteoroid or orbital debris particle impact, whether or not the impacting particle or parts thereof will exit the rear of the sandwich panel. A recently developed set of ballistic limit equations for two different types of honeycomb sandwich panels are studied to determine how well they perform when they are applied to systems that are outside of the database that was used to develop them. It was found that these ballistic limit equations are fairly conservative; they successfully predicted sandwich panel perforation in nearly all of the tests that resulted in perforation, while allowing approximately half of the nonperforating tests to be incorrectly labeled as tests with a perforation. This indicates the likelihood that use of these equations in design applications could result in overly robust shielding hardware.

Nomenclature

d_c = critical projectile diameter for failure of rear wall, cm
d_p = projectile diameter, cm
K_{MLI} = adjustment factor for multilayer insulation
K_{S2} = adjustment factor for scaling standoff distance S_2 in the hypervelocity regime
K_{tw} = adjustment factor for equipment cover plate thickness t_w in the hypervelocity regime
K_{3D}, K_{3S} = ESA triple-wall ballistic limit equation fit factors for the hyperballistic and ballistic velocity regimes, respectively
S_1, S_2 = standoff between first and second, and second and third bumper, where third bumper = backwall, cm
t_b = thickness of the inner/second bumper (the rear face sheet in the case of a honeycomb sandwich panel), cm
t_{ob} = thickness of the outer bumper (the front face sheet in the case of a honeycomb sandwich panel), cm
t_w = thickness of third bumper/back wall/equipment cover plate, cm
V, V_n = impact velocity and its normal component ($V \cdot \cos\theta$), respectively, km/s
V_{t1} = transition velocity between ballistic and shatter velocity regimes, km/s
V_{t2} = transition velocity between shatter and hypervelocity regimes, km/s
$V_{t1,n}$, $V_{t2,n}$ = normal component of $V_{t1} \cdot \cos\theta$ and $V_{t2} \cdot \cos\theta$, respectively, km/s
α, β, γ, δ, ε = fit parameters for the Schäfer–Ryan–Lambert ballistic limit equation
θ = impact angle (0 deg is a perpendicular impact on the target surface), deg
ρ_{ob}, ρ_p = volumetric density of the outer bumper and the projectile, respectively, g/cm^3
$\sigma_{y,\text{ksi}}$ = yield stress of the equipment cover plate, ksi

I. Introduction

The near-Earth space environment is cluttered with man-made debris from previous spacecraft missions into that environment as well as with naturally occurring meteoroids. This debris poses a serious threat to spacecraft that are launched to operate in Earth orbit because it can strike such spacecraft at very high velocities and consequently damage mission-critical systems. As a result, as a spacecraft design evolves, the spacecraft designers must be aware of the response of various spacecraft components and structural elements under high-speed impact loading conditions. Precautions must be taken to ensure that a spacecraft's operation and functional units are not compromised when it is struck by an orbital debris particle or by a meteoroid.

Most satellites launched into Earth orbit are constructed with honeycomb sandwich panels (HC/SPs) as their primary structural load bearing elements. A typical honeycomb sandwich panel is shown in Fig. 1. Behind such panels are located spacecraft components that are appropriate for the particular spacecraft or satellite mission and function (e.g., electronics, avionics, fuel cells, pressure vessels, etc.).

To be able to perform a risk analysis for a particular satellite under a specific mission profile, it is important to know more than just whether or not the satellite will be struck by a meteoroid or an orbital debris particle. It is equally important to know, in the event of such an impact, whether or not the impacting particle (or its remnants) will exit the rear of the HC/SP (i.e., whether or not the ballistic limit of the HC/SP will be exceeded).

Although the response of a multiwall system with monolithic flat panel walls under high-speed particle impact has been studied extensively over the past 50 years or so, the extent of the effort to study HC/SPs under similar impact conditions has been much more limited. The issue of whether or not the ballistic limit of a HC/SP will be exceeded under a given set of impact conditions has been

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