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Hypervelocity impact damage to polymer matrix composite structures in Space

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The use of composites in the design of spacecraft structures and satellite components has increased over the last four decades as fibre reinforced polymer matrix composites offer significant advantages over metals due to their high specific strength, stiffness and low coefficient of thermal expansion. A major concern involving the use of lightweight fibre reinforced composites in Space is their vulnerability to hypervelocity impact (HVI) damage from micrometeoroids and orbital debris (MOD).

In this investigation, experimental ground-based HVI tests were employed to simulate the damage from MOD impacts on composite structures used in Space, specifically carbon fibre/PEEK composites, the class of composites used in the construction of Canada's Space Station Remote Manipulator System (SSRMS). Three series of HVI tests were performed on AS-4 carbon fibre/PEEK composite laminates to study the effects of varying laminate thicknesses (16 and 24 plies), projectile diameters (1-3.57 mm), impact velocities (2.71-714 km/s), projectile densities (1.14-7.86 g/cm^3) and impact angles (0, 30 and 45 degrees) on the damage to the composite. In addition, a series of tests exploring the shielding effect on the witness plate of a stand-off layer of Nextel fabric was also performed. Parameters investigated in this study were equivalent entry and exit crater diameters, front and rear (spall) surface delamination damage zones, and primary (projectile) and secondary (target) debris cloud dispersion cone angles.

The entry crater diameter was found to be primarily dependent on the diameter of the impacting projectile. A design model was developed that predicts the crater diameter for hypervelocity impacts on composite laminates for a given projectile diameter. The predictive model is in excellent agreement with experimental results and can be applied to a wide range of composite target lay-ups, fibre and matrix materials, and laminate thicknesses, and for a diverse range of projectile materials, densities, diameters and energies. The normal incidence primary and secondary debris cloud dispersion cone angles were quantified as a function of a non-dimensional parameter that includes impact velocity, projectile diameter and target thickness. A turning angle for the deflected primary debris was defined for oblique incidence impacts.