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Experimental and Numerical Study of Submillimeter-Sized Hypervelocity Impacts on Honeycomb Sandwich Structures

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Abstract

This paper deals with hypervelocity impacts of submillimer-sized debris on honeycomb sandwich panels. These debris, which are mostly present within the low Earth orbit, indeed represent a real threat for spacecrafts and satellites. In fact, for debris large enough to be tracked, pre-determined debris avoidance manoeuvre is usually conducted to prevent any damage. Submillimer-sized debris, however, are too small to be identified and therefore spatial structures must be protected against such threat. Honeycomb structural panels and whipple shields have been used as primary shielding against orbital debris impact. The protection capability is usually estimated using Ballistic Limit Equations (BLE). These data have been built from experimental tests on whipple shield protection and transposed to honeycomb sandwich panels.
In the case of Whipple shield, the debris cloud generated at the impact on the bumper sheet expands until reaching the rear wall. BLE for Whipple shields only depends on materials properties, protection geometry, angle of incidence and impact velocity. For honeycomb sandwich panels, the debris cloud is partially channelled within honeycomb cells, thus limiting its radial expansion. The channelling effect is thus a function of the honeycomb cell geometry. The honeycomb BLE presented by the Centre d'Etudes de Gramat (CEG) in 2008 has been introduced in order to take into consideration such effect.
The present study proposes to extend the results of the CEG. The main approach is to consider the relative dimensions between the projectile diameter and the honeycomb geometry in order to evaluate the perforation risks of submillimer-sized hypervelocity impacts. The impact process on honeycomb sandwich panel has first been modelled using commercial hydrocode LS-Dyna using hybrid Lagrange and Smooth Particle Hydrodynamics (SPH) solvers. The numerical model has been validated through several hypervelocity impacts experiments carried out at Thiot Ingenierie Shock Physics Laboratory at velocities up to 9.3 km/s. This model has then been used to define a ballistic curve which defines the critical projectile diameter of a specific sandwich panel subjected to submillimer-sized debris impact. The results are finally compared to the ones obtained by the CEG leading to an updated estimation of the protection capability of honeycomb sandwich panels.

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1. Introduction

In the beginning of space exploration, meteorite impact constitutes one of the major threat to space vehicles. Currently, due to the increasing number of space debris in the low earth orbit [1], space debris collision has become the main threat to near earth space structures. Space debris are man-made fragments consisting of different materials (plastic, metal …) from the destruction or collision of space launcher, rockets and satellites. The debris size ranges from submillimeter size to a few tens of centimetre with a velocity from a few km/s to 15 km/s.

Avoidance manoeuvre is not feasible for small debris (millimetre size) since they cannot be detected by radars. Thus, protective shield must be installed near to critical area of the spacecraft to withstand such threat. Whipple shield is widely used [2-4] on spacecraft: an aluminium bumper is placed at a specific distance from the wall of the spacecraft to fragment the debris in order to reduce the damage of the rear wall. Such solution is capable to protect from impact of space debris of size below 10 mm. This protection capability is commonly estimated using ballistic limit equation (BLE) (Fig. 1) which defines the critical projectile diameter beyond which the shield is not effective. Three main regimes can be considered:

- "A" ballistic regime: projectile is not fragmented, the higher the velocity; the more important is the damage to the rear wall.
- "B" intermediate regime: projectile is fragmented and the debris cloud expands until reaching the rear wall; the higher the velocity, the higher the radial expansion reducing the damage to the rear wall.
- "C" hypervelocity regime: projectile and front plate are potentially vaporised, the critical diameter decreases with the velocity

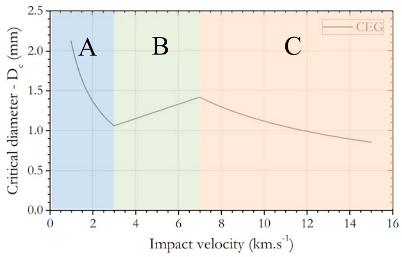

Fig. 1: BLE for a typical whipple shield [5]

Honeycomb structure are recently introduced as a spacecraft shield; their protection capability is initially considered as equivalent to whipple shield. However, for honeycomb sandwich panels, the debris cloud is partially channeled within honeycomb cells [5-8], thus limiting its radial expansion. The ballistic limit equation presented by the Centre d'Etudes de Gramat (CEG) [5] has been introduced in order to take into consideration the presence of honeycomb. This BLE has been defined from simulation with millimeter sized projectiles.

The aim of this work is to study the effect of submillimeter sized projectile with a specific modelling in order to refine the work published by Sibeaud et al. [5] The first part of this paper is dedicated to the development of a numerical model, the second is devoted to the validation of this model through two impact experiments and the third details the simulations performed to predict an updated ballistic curve.