HYPERVELOCITY IMPACT ON HONEYCOMB TARGET STRUCTURES: EXPERIMENTAL PART

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ABSTRACT

This paper reviews some experimental works carried out at the CEG on hypervelocity impact damage of unmanned spacecraft honeycomb structures. Square shaped sandwich panels were fabricated from 0.8 mm aluminium or carbon composites facesheets and 20 mm aluminium honeycomb cores. Five targets were tested against aluminium spherical projectiles at nominal velocities of 5.7 km/s. The targets were placed both at normal and 45° incidence. Double exposure flash radiography was used to characterise the debris cloud generated by the impact. Ongoing post mortem analysis of targets and witness plates will provide invaluable reference data for further modelling activities.

1. INTRODUCTION

The study presented in this paper was conducted under the umbrella of the CNES (Centre National d'Etudes Spatiales, ie French Space Agency) long-term assessment project on satellite vulnerability in earth orbit environment. The Centre d'Etudes de Gramat (CEG) is in charge of developing a software suite called PLEIADES devoted to the global vulnerability of spacecraft orbiting around the Earth. The threats considered in this programme are the numerous orbiting debris which may affect the satellite's mission as a result of hypervelocity impact onto the spacecraft external walls. For mass efficiency reasons, relating to load carrying capabilities, these walls consist mainly of honeycomb sandwiches which therefore provide the primary protection against such threats for critical equipments accommodated within the spacecraft. This paper presents the initial effort aimed at characterising the ballistic properties of such shielding. The ongoing modelling programs, including the use of computer simulation, will be presented later on.

2. IMPACT CONFIGURATIONS

Two types of honeycomb sandwiches made of aluminium or carbon composites facesheets were defined and tested using the CEG's Persephone double stage light gas gun. Two impact configurations for each kind of target were defined both at normal and 45° incidence. The targets consisted in panels of 150 mm width and 150 or 190 mm long respectively. In order to record the debris prints generated by the perforation process, a 4 mm aluminium witness plate was hold steadily to the target at a line of sight distance of 150 mm downrange from the rear facesheet as shown in figure 1 and 2.

The target consisted in 20 mm aluminium honeycomb cores assembled with 0.8 mm aluminium and carbon fibres composites facesheets, all together glued. The diameter of the hexagonal core cell was 4 mm. Volumetric and areal densities of these components are summarised in table 1. Carbon composite facesheets are fabricated with stacked plies oriented at 0° ; 45° ; -45° ; 90° / 90° ; -45° ; 45°; 0°. Such targets prove to be 22 % lighter than their aluminium counterpart. It is therefore legitimate to compare their capabilities to withstand hypervelocity impact.

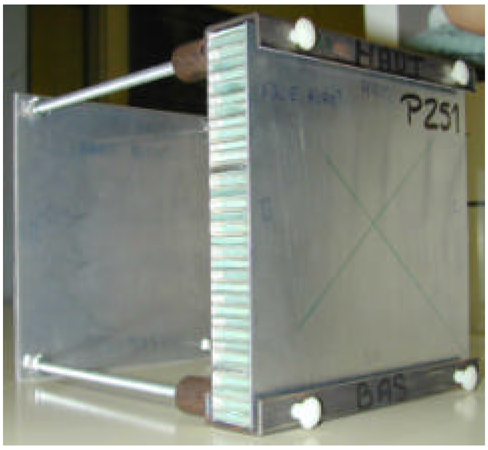

Fig. 1. : target assembly at normal incidence.

Table 1: Volume and areal densities of components

	Face sheet		Honeycomb Type 4-40		Structural panel	
	Al	C	Core Al	Glue BSL312	Al	C
ρ (g/cm³)	2.8	2	0,050	-	-	-
A (g/cm²)	0.224	0.160	0.1	0.015	0.578	0.450

Pure aluminium spherical projectiles of 7 mm diameter were launched at nominal impact velocities of 5.7 km/s.

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The impact tests have been conducted using the Persephone double stage light gas gun in operation at the CEG (Loupias et al., 1994).

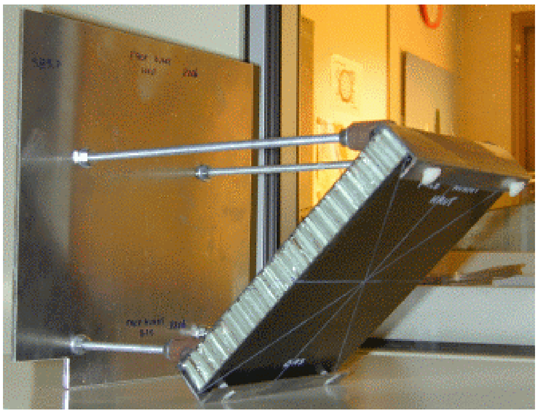

Fig. 2. : target assembly at 45° incidence.

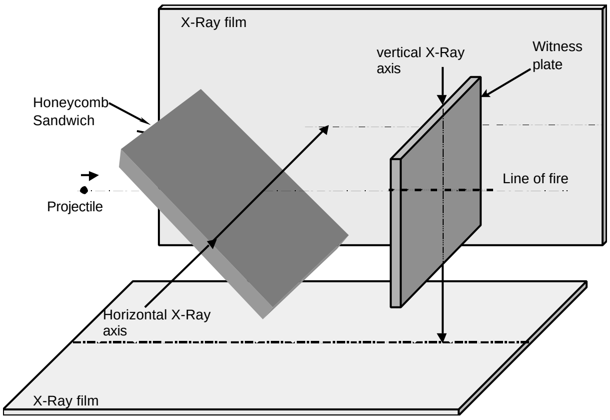

Fig. 3. Sketch of experimental configurations at the gun muzzle (shown here at 45°).

3. EXPERIMENTAL RESULTS

The accuracy at impact did not allow the aiming of the projectile at one particular location on the target. Yet due to the relative diameters of the projectile and the hexagonal honeycomb cell, it was possible to ignore the actual point of impact location on the target, with respect to the honeycomb core pattern.

Two x-ray channels–not represented here- were used before impact on the target to ensure an accurate measurement of the projectile velocity. Taking advantage of the separation distance from the honeycomb panel rear facesheet to the witness plate, which represents some internal equipment of the spacecraft, another pair of X-ray channels were located on orthogonal axis, tangent to these two plate and perpendicular to the theoretical line of fire in order to allow the determination of the post perforation debris cloud shape expansion dynamics (see figure 3).

Unexpected X-Ray triggering failure required that a total of five experiments had to be performed, including three firings at normal incidence. It is not the purpose of this paper to make full comparisons of the ballistic protection of the various target designs but instead to collect as many experimental data as possible for each firing to allow for future code validation to be exercised with confidence. Nevertheless preliminary comparisons will be realised between normal and 45° and also between carbon composite and aluminium facesheets panels. Each firing performed is then illustrated with a complete set of figures including X-ray views of the debris cloud and impact crater patterns on the different plates recovered after the tests (fig. 4 to 8). The observed damages on the plates have been reported in table 2 as well as front-end debris velocities which have been calculated for all firings where possible. Delay times were measured from the time of impact on the front facesheet of the panel.

4. PRELIMINARY ANALYSIS

As explained above, the primary objective of this first set of experiments was not to determine the ballistic limit a the sandwich panel as a function of the projectile mass and impact velocity but instead provide some insight in the perforation and damaging mechanisms for such widely used structural components in the space industry. Anticipating the need for future code validation, it was therefore found of fundamental importance to provide reference visualising in order to correlate the fragment distribution with the impact crater pattern on the witness plate.

One of the most significant difference from what was described in earlier work (Sibeaud *et al.,* 2003) when looking at the X-Ray pictures (figures 4 to 7) is the inhomogeneous fragmentation distribution within the debris plume emerging from honeycomb panels. Lethal fragments lying at the fore-end of the debris cloud seem to survive the penetration phase as a consequence of material channelling through the hexagonal cells. Moreover, the rear cloud portion appears clearer than its front end, expressing that a much lower density of fragment is expected in this region. Furthermore, X-Ray pictures appear slightly denser for aluminium facesheets panels, especially at 45° incidence, indicating the difference in mass and material repartition within the cloud.

Post-mortem pictures of the panels (Figures 9 to 11) show clearly that the fragments generated after perforation of the front facesheet have been absorbed within the honeycomb structure, resulting therefore in huge deformation cavities in this latter component. Outlet diameters more than ten times the projectile diameter have been experienced in targets at normal incidence. The oblate shape of such cavity under 45° incidence does not seem to originate from the inclination itself although its longest dimension (height) comes out

roughly in the cosine ratio. The overall cavity has actually moved off centre in the downward direction where the major fraction of the debris bubble emanating from the front facesheet keeps interacting with the honeycomb structure. The most powerful residual fragments can be seen (X-Ray pictures in figures 7 and 8) along the proximity of the initial projectile path. The highly fragmented part of the debris cloud is mostly ejected toward the normal from the hole entrance which can be seen also on the witness plate (figure 12).
An other interesting feature is the nearly hexagonal geometry of the cavities in the honeycomb and rear facesheets, closely related to the elementary cell structure.
The energy absorption process sounds typical of the one already experienced with a highly porous heat shielding material (porosity of 84%) subjected to hypervelocity impact (Loupias *et al.*, 1997). Cavities of much greater diameter than those measured in the backing plate had been produced within the porous material and explanations proposed through numerical simulations. We have got presently the same kind of situation in the honeycomb structure which is comparable to a 98% porous aluminium. The exit hole in the rear facesheet is similarly smaller than the maximum highlighted in the honeycomb.

Table 2: Kinematics of experimental configurations

Shot# (Target facesheet material)	Incidence	Projectile Velocity (m/s)	Axial velocity of debris cloud (m/s)
P251 (Al)	0°	5744(*)	NM
P254 (C)	0°	5557	4730
P259 (Al)	0°	5818	4380 (est.)
P260 (Al)	45°	5660	3840
P261 (C)	45°	5566	4630

(*): nominal value, all other were measured

However, the honeycomb structure does not bring protection alone. Front and rear facesheets contribute as well but appear to respond differently under high incidence impact. At normal incidence, the rear carbon composite facesheet is subject to delamination (see figures 10 and 11) which turns in complete disruption under oblique impact, underlying the brittle nature of this material compared to aluminium. Examination of the witness plates (figure 12) reveals the influence of such brittleness in terms of resulting damage. The witness plate was not perforated with the aluminium facesheets honeycomb panel at 45°, but it was with the carbon composite facesheets. Such difference is consistent with the 20% higher axial cloud velocity recorded with the carbon. This velocity difference is limited to 8% at normal incidence. Quoted figures should be further analysed with the help of hydrocode numerical simulation and therefore must not be taken as are because of impact velocity difference from one configuration to another one.
Extra analysis of effects on downrange plates should also be performed in the near future in order to provide the necessary reference data for the planned modelling effort.

Table 3: Characteristics of damages in Honeycomb structure (HC) and witness plate (WP) – Crater means 'no perforation'

Shot#	Max. Damage extent in target			Diam. of perforations in WP (mm)
	Front facesheet Perfo.	HC panel	Rear facesheet	
P251	Φ 12	Φ 75	Φ 25	4 holes normal 8↑17→, Φ 25 ; 13 ; 7 2 craters Φ 5 ; 4
P254	Φ 11	Φ 74	33↑ 31→	4 holes normal Φ 11 ; 9 ; 9 ; 6 12 craters 2 holes with cracks
P259	Φ 12	Φ 74	38↑ 33→	3 holes normal 12↑17→ ; Φ 14 ; 6 8 craters; 1 surface deformation
P260	Φ 25	110↑ 72→	88↑ 89→	Multiple craters max. Φ 4 12 surface deformations
P261	19↑ 16→	110↑ 78→	disrupted	1 hole normal Φ 4 1 hole Φ 4 with spalling 11 craters

(arrows indicate the direction of measurements)

5. CONCLUSION AND PERSPECTIVE

Hypervelocity impact of projectiles onto honeycomb structural panels designed for spacecraft provides significant challenge for both the numerical and the material algorithms to be developed for computer codes. Therefore, all five tests presented here as a piece of work initiated by the CNES (Sibeaud *et al*., 2004) provide useful data towards the perspective of a preliminary modelling effort. Smaller projectiles will have also to be considered with the help of previously published data and analysis (Taylor *et al*., 2003; Turner *et al*., 2001).

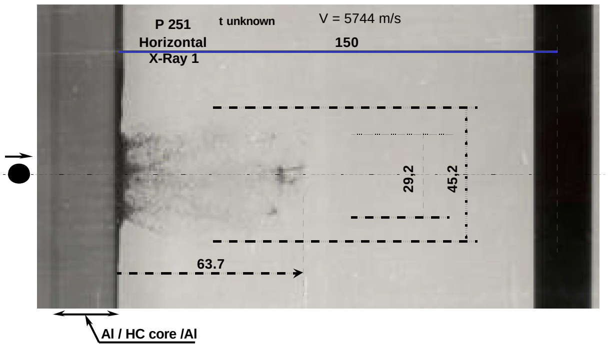

Fig. 4. Flash X-Ray radiograph taken during shot #P251. Honeycomb structure with aluminium facesheets.

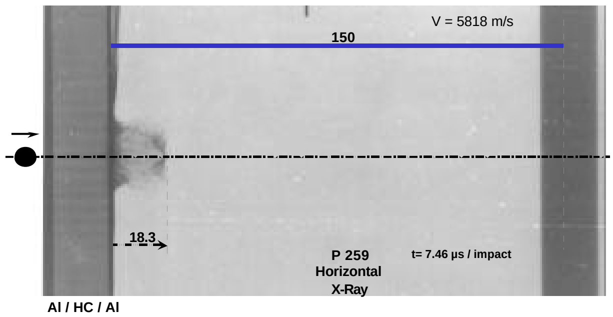

Fig. 5. Flash X-Ray radiograph taken during shot #P259. Honeycomb structure with aluminium facesheets.

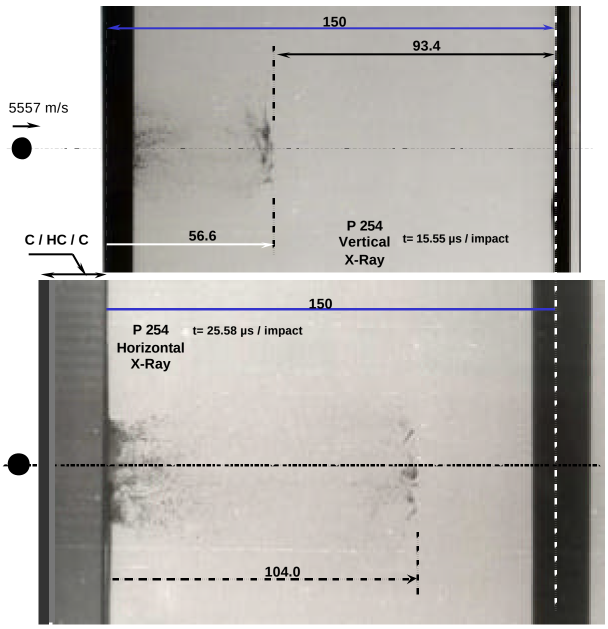

Fig. 6. Flash X-Ray radiographs taken during shot #P254. Honeycomb structure with carbon composite facesheets.

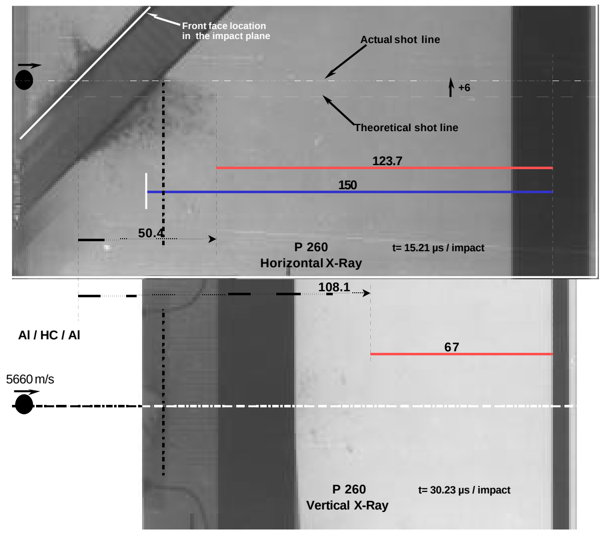

Fig. 7. Flash X-Ray radiographs taken during shot #P260. Honeycomb structure with aluminium facesheets.

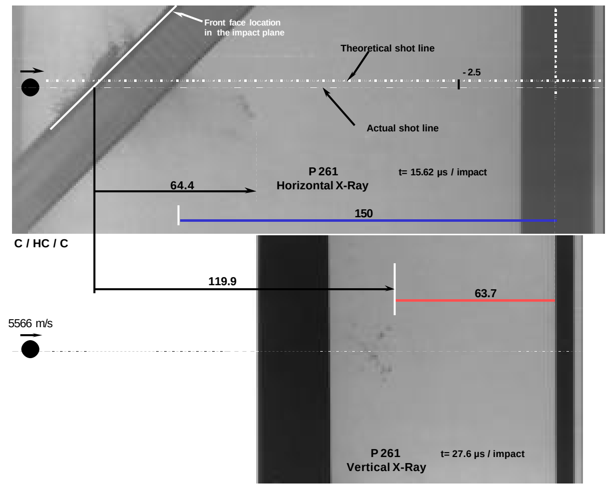

Fig. 8. Flash X-Ray radiographs taken during shot #P261. Honeycomb structure with carbon composite facesheets.

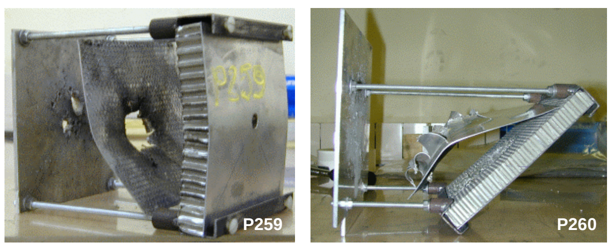

Fig. 9. Post shot targets. Aluminium facesheets panels at normal and 45° incidence.

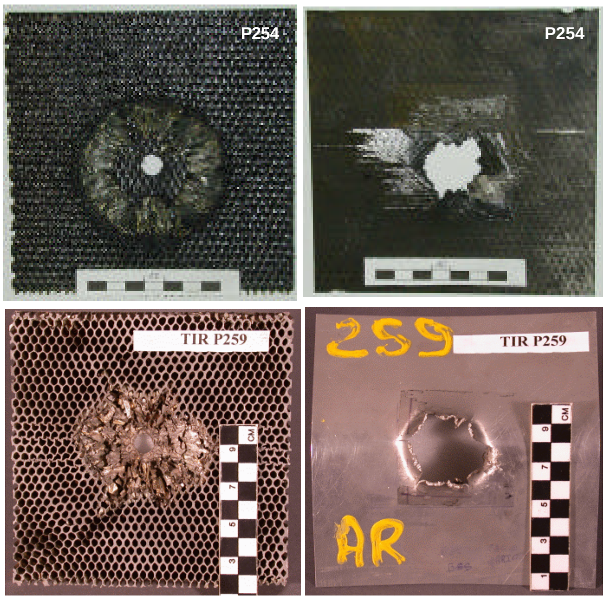

Fig. 10. Honeycomb structure and rear facesheet damage at normal impact incidence as viewed from the witness plate– Top: carbon composite facesheets; bottom: aluminium facesheets.

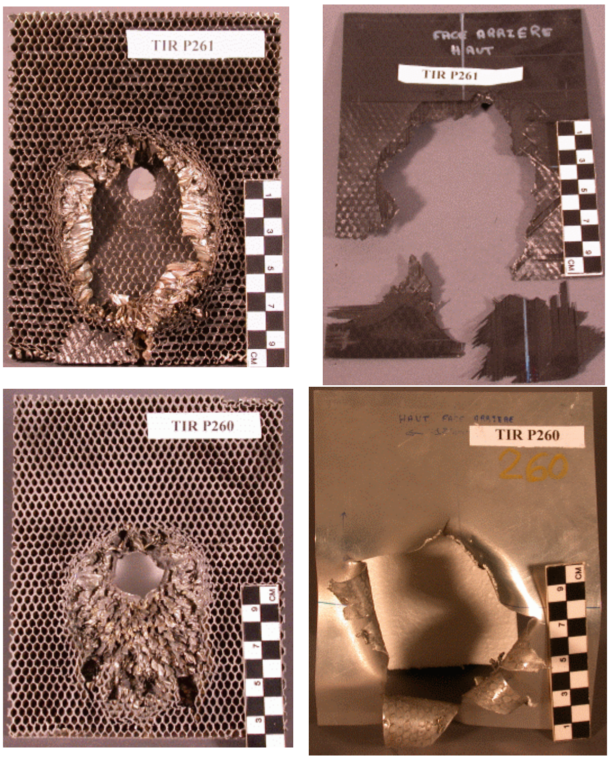

Fig. 11. Honeycomb structure and rear facesheet damage at 45° impact incidence as viewed from the witness plate – Top: carbon composite facesheets; bottom: aluminium facesheets.

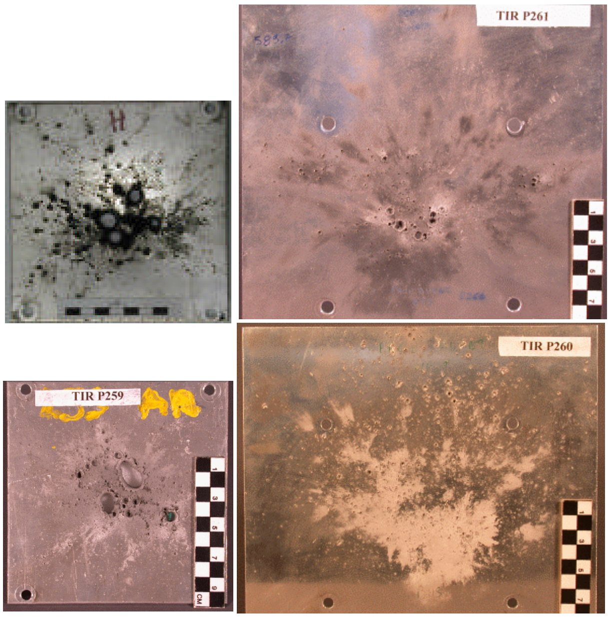

Fig. 12. Witness plates as seen from projectile – left: normal incidence; right: 45° incidence; top: carbone composite facesheets; bottom: aluminium facesheets.

6. ACKNOWLEDGEMENT

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