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Acceleration fields induced by hypervelocity impacts on spacecraft structures

D. Pavarin[a,*], A. Francesconi[a], R. Destefanis[b], M. Lambert[c], A. Bettella[a], S. Debei[a], M.De Cecco[a], M. Faraud[b], C. Giacomuzzo[a], P.C. Marucchi-Chierro[b], G. Parzianello[a], B. Saggin[d], F. Angrilli[a]

[a]*CISAS University of Padua, Via Venezia 15, 35131 Padova, Italy*
[b]*ESA ESTEC, Postbus 299, NL-2200AG Noordwijk, The Netherlands*
[c]*ALENIA SPAZIO Torino Str., Antica di Collegno, 253 10146 Torino, Italy*
[d]*Politecnico di Milano Polo di Lecco Via Marco D'Oggiono 18/A, 23900 Lecco, Italy*

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Abstract

This paper presents an overview of the hypervelocity impact test campaign ongoing in the frame of the ESA contract ‘‘spacecraft disturbances from hypervelocity impact’’. The project aims at analyzing the propagation of shocks due to hypervelocity impacts from the external shell of a spacecraft to its internal components. The object of the study is the GOCE satellite, which has been recognized to be very sensitive to small disturbances because of its payload that has been designed to measure even very low acceleration levels. In the first step presented hereafter, the test campaign has been focused on the qualification of the background environment inside the impact chamber and on the determination of the vibration levels induced by perforating and non-perforating hypervelocity projectiles on simple aluminum plates. The results currently obtained and a preliminary data analysis will be presented in the following.

Keywords: Shock; Hypervelocity impact; GOCE; Vibration

1. Introduction

Space debris and meteoroids are a well-known source of possible damage for satellites. Nevertheless, among the potential effects induced by hypervelocity impacts on a spacecraft, mainly direct structural damage has been investigated so far. However, some experiments have recognized that the shock environment induced by hypervelocity impacts could be close to what is generated by explosive devices as Pyros [1,2], being therefore a real threat for equipment and instrumentation. The induced vibration environments have been studied by means of acoustic emission by Prosser et al. [3,4] but its full characterization, as suggested for example by NASA [5], has not been yet performed.

*Corresponding author. Tel.: +39 049 8276854; fax: +39 049 8276855.
E-mail address: daniele.pavarin@unipd.it (D. Pavarin).

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The characteristics of the vibration environment induced by a hypervelocity impact are under investigation in the frame of the ESA contract "spacecraft disturbances from hypervelocity impact" [6]. The object of this study is the gravity field and steady-state ocean circulation explorer (GOCE) satellite, because of its very accurate gradiometer, that is very sensitive to even very small external disturbances [7,8].

The present study is focused on the analysis of the structural propagation of transient disturbances on typical satellite jointed panels, particularly close to the GOCE ones. Beyond assessing the potential risk to the GOCE mission, the study aims also at the identification of a general numerical and experimental verification criterion allowing reliable prediction/characterization of the vibration environment induced by hypervelocity impacts to generic spacecrafts. A general overview of the study is provided by Pavarin et al. [6].

The study is based on an extensive hypervelocity impact campaign aiming at providing data about the vibration field induced on structures representative of the real spacecraft configuration. The test matrix has been divided into preparatory tests, tests on simplified targets and tests on complex targets. The main structure of the test matrix is presented in the following. In particular, preparatory tests are focused on the analysis and control of the background environment and on the determination of the acceleration ranges on different parts of simple and complex targets to proceed with the instrumentation set-up.

The analysis of the background noise is a fundamental step since the test environment inside the vacuum chamber is not vibration-free. Many effects related to the gun shooting determine vibrations, which could be propagated to the target providing a background noise, which is an interfering input for the measurements. Moreover, some noise sources can provide a signal so strong that could completely overlap the vibration environment induced by the impacting projectile, especially far away from the impact site and after structural joints. Thus, background noise must be carefully analyzed and possibly reduced. Several tests have been conducted to qualify each single source of the background perturbations. Details of these tests are provided in the following. Determination of the expected vibration envelope for different targets configurations is also a fundamental preliminary step to proceed with a careful instrumentation definition and set-up. Several hypervelocity tests have then been conducted leading to a preliminary assessment of the expected vibration envelope on simple aluminum targets.

2. Experimental set-up

2.1. The light gas gun

The test campaign is conducted at CISAS hypervelocity Impact facility. The facility is based on a high-frequency two-stage light gas gun [9,10]. The main gun characteristics are reported in Table 1. Projectiles are carried by sabots, which are aerodynamically separated inside the flight chamber. The normal operation pressure inside the flight chamber is between 4 and 7 kPa of inert gas. The speed of the projectile is measured through the acquisition of three different signals during and at the end of its flight path. Two signals are acquired when the projectile, together with sabots, transits through two laser beams. The smallest projectile detectable is a 0.6 mm sphere flying at 5 km/s, a third signal, acquired by a photodetector looking at the target (light impact sensor), is generated by the light emitted during the impact of the projectile onto the target. The uncertainty on velocity measurements is calculated according to ISO guidelines [11]. Depending if the projectile is shaded or not by sabots fingers, the total uncertainty ranges from 0.5% to 2%.

Table 1
Main gun characteristics, the projectile mass does not include the sabot

First stage			Second stage				Barrel		Projectile	
Vol. (dm^3)	Gas	Press. (Mpa)	Diam. (mm)	Length (m)	Gas	Press. (MPa)	Diam. (mm)	Length (m)	Mass (mg)	Vel. (km/s)
3	He	0.1–20	35	3	H_2	0.1–0.5	4.76, 6	1.5–2.5	1–60	5.5