Abstract

Spacecraft and associated onboard equipment undergo substantial dynamic loading during various mission phases. The activation of pyrotechnic devices induces severe high-frequency shocks transmitted throughout the entire structure, also known as "pyroshocks". These shocks could potentially lead to mission failure and inflict safety-critical damages. Consequently, verification tests for aerospace equipment are necessary to prove the resistance of the equipment to impulsive loads.

Qualification requirements are typically expressed in terms of the shock response spectrum acceleration, and they can easily vary since distinct launch vehicles induce different shock response spectrum profiles. Laboratory tests thus aim to replicate real conditions of a shock environment while ensuring repeatability and safety. To achieve this, the majority of test facilities often exploit impacting objects (e.g., hammers or projectiles) launched onto resonant plates, which in turn support the component under examination.

Recent studies have increasingly focused on developing numerical analyses to predict the shock responses of these structures. Currently, the calibration process relies on empirical techniques causing substantial costs and downtime. This PhD thesis delineates several objectives, aiming to introduce innovative approaches to pyroshock testing from both theoretical and experimental perspectives. In addition to an initial literature review that entirely describes the state of the art, the main contributions of this work are outlined below.

Firstly, a novel approach developed in the frequency domain has been introduced. On this basis, effective parametric models have been developed both for the simulation of pyroshock tests and for the optimization of the design of test facilities. These models demonstrate notable accuracy and flexibility, effortlessly and efficiently satisfying the variable SRS requirements. This operational efficiency

translates into reduced calibration times, entailing significant economic benefits. The proposed models exhibit varying degrees of complexity and computation times. They range from a multi-degree of freedom system model to the implementation of an embedded computer-aided design modeler, integrated with a finite element solver, and a genetic algorithm optimizer. Insights into contact mechanics for defining impulses and various optimizations to enhance test performance are encompassed.

Secondly, an extensive dataset has been gathered to facilitate a comprehensive exploration of parameters in shock tests employing a resonant plate. These data were acquired at the Marcus Wallenberg Laboratory for Sound and Vibration Research (MWL) in collaboration with the KTH Royal Institute of Technology. This dataset has enabled an investigation into the influence of experimental configurations on test outcomes, specifically in terms of the shock response spectrum. Furthermore, these data have been crucial in validating predictive models employing a digital twin. The research incorporates an in-depth analysis of shock physics, involving a comparative assessment between simulated and measured force profiles. This comparative study provides valuable insights into the complexities of shock dynamics.

Finally, the last contribution concerns the design and development of the Politecnico di Torino test facility. Taking advantage of the developed models and acquired knowledge, a specialized test facility for conducting pyroshock tests with resonant plates has been successfully designed. The key components of this test facility include a structural portal frame to uphold the resonant plate and an excitation apparatus, which can take the form of either a pneumatic gun or a pendulum. This test facility stands as the application of the outcomes of the previous research, allowing the controlled experimental simulation of pyroshock tests.