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PREDICTING PERFORATION AND RUPTURE OF COMPOSITE OVERWRAPPED PRESSURE VESSELS FOLLOWING AN ORBITAL DEBRIS PARTICLE IMPACT

Abstract

Most spacecraft have at least one pressurized vessel on board. Because of the serious damage that might result following an on-orbit space debris particle impact, a primary design consideration is the anticipation and mitigation of that damage. Considerable effort has been expended in the study of flat unstressed spacecraft components under conditions intended to simulate those of a debris particle impact. However, pressurized tank walls will develop bi-axial stress fields. Numerous challenges have limited the testing conducted using pressurized elements, especially composite overwrapped pressure vessels (COPVs). To address this issue, a program was undertaken to characterize the hypervelocity impact response of COPVs. Depending on COPV design and impact / operating conditions, a COPV impacted at hypervelocity may experience either only relatively shallow damage; a through-hole, perhaps with localized liner cracking or composite peeling; or catastrophic failure (rupture). While a puncture and the resulting leak could de-stabilize an orbiting spacecraft, an on-orbit rupture could not only lead to spacecraft loss, but for human missions, possibly loss of life. Whether or not a structural element is perforated is typically characterized by a ballistic limit equation (BLE). Similar to a BLE, a rupture limit equation (RLE) can be used to characterize whether or not rupture would occur following a perforating impact. In a risk assessment that considers the various failures that might occur following debris impact, both types of equations are required. Here we present the development of these two types of equations for COPVs impacted by hypervelocity particles. The RLE is designed to differentiate between regions of operating and impact conditions that, given a perforation, would result in either a rupture or only a relatively small hole or crack. Similarly, the BLE is constructed so that it distinguishes between impact and operating conditions that would result in a front side puncture (without rupture) from those that would not. Data from over 50 impact tests on 3 different types of COPVs are pooled together and used in the development of the RLE and the BLE. Operating conditions were parameterized as the hoop stress in the tank, while impact conditions were parameterized using momentum. A comparison of the RLE and the BLE with experimental results shows that both equations are able cleanly separate the regions of rupture from non-rupture, and perforation from non-perforation. As such, the equations presented are both highly accurate in predicting the response of the COPVs and impact conditions considered.