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Parametric instability of pressurized propellant tanks

 Jochen Albus^{a,*}, Stefan Dieker^b, Huba Öry^c, Andreas Rittweger^a
^aEADS Space Transportation GmbH, Bremen, Germany^bReimerdes and Dieker Ingenieure GbR, Bremen, Germany^cRWTH-Aachen University, Germany

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Abstract

Pressurized propellant tanks might become dynamically unstable with detrimental dynamic responses if a dynamic excitation leads to a coupling of pressure oscillations (especially due to the response of axisymmetric modes) with very low damped ovalizing modes. This phenomenon can be described and identified as the so-called *parametric instability*. During the dynamic qualification test campaign of the new Ariane 5 Cryogenic Upper Stage ESC-A, a parametric instability was observed for sinusoidal tests under certain test conditions with low static pressure in the propellant tank. The parametric instability was identified and an analytical simulation was performed that confirmed the instability. During flight, harmonic excitations might occur due to pressure oscillations within the solid rocket booster. However, the application of the analytical model on flight conditions indicates that the flight behaviour will be stable. This was confirmed by results from additional tests. This paper describes the phenomenon of the parametric instability of pressurized propellant tanks and presents an analytical methodology to assess the risk of the occurrence of a parametric instability.

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1. Introduction

During the dynamic qualification test campaign of the new Ariane 5 Cryogenic Upper Stage ESC-A (Fig. 1), an instability of a propellant tank response was observed. The sinusoidal excitation of the lower interface of the upper stage ESC-A (sinusoidal sweep) yields a sudden increase of a tank response for a certain frequency. The test was stopped.

It was found that two tank modes exist near the same frequency: an axial mode (wavenumber 0) and an ovalizing mode with wavenumber 12. The circumferential

displacement of the tank shell of these modes are plotted in Fig. 2.

By test assessment and analytical investigations, the phenomenon was identified as parametric instability. As a consequence, it was detected that this tank behaviour depends on the inner pressure. During the first tests, where instability occurs, the differential pressure of the tank was 0.5 bar. During the flight phase, in which a harmonic excitation might occur due to pressure oscillations within the solid rocket booster (second acoustic booster mode), the static tank differential pressure p_0 is above 2.0 bar.

Further analytical investigations and tests became necessary in order to examine whether or not the tank response will be stable during flight.

In this paper, the phenomenon of the parametric instability will be first explained by an Euler beam analogy. Besides the Euler beam analogy, the

* Corresponding author.

E-mail addresses: jochen.albus@space.eads.net (J. Albus),
stefan.dieker@dieker-bremen.de (S. Dieker),
h_oery@ilb.rwth-aachen.de (H. Öry),
andreas.rittweger@space.eads.net (A. Rittweger).