Contribution ID: **414** Type: **Presentazione orale**

Structural Integrity Assessment of Flexible Aerospace Baffles Comparing Quasi-Static and 2-Way FSI Methods

Friday 4 September 2026 09:15 (15 minutes)

The management of liquid sloshing remains a critical challenge in aerospace engineering, where fuel oscillations can significantly impair the stability and structural integrity of space vehicles. While rigid baffles are traditionally employed to mitigate these effects, flexible Anti-Sloshing Devices (ASDs) offer a promising alternative. They can potentially enhance energy dissipation through fluid-structure interaction (FSI) while granting substantial mass reductions.

However, these performance and weight benefits come with a trade-off: a highly non-linear dynamic response that complicates the design process. Because the baffles deform under fluid forces, predicting flow-induced deformations and internal stresses is paramount to ensure the structural integrity and optimal performance of flexible ASDs.This work outlines a comprehensive design workflow for flexible ASDs in cylindrical tanks.

Leveraging the classic axisymmetric Kirchhoff-Love plate theory for the structural modeling and linear potential flow theory for the fluid domain, the primary objective is to propose a simplified, reliable structural model for the preliminary design phase of both the baffle device and its connection system to the LOX/LH2 tank walls.

To conduct a conservative structural assessment, the fluid-structure interaction is initially decoupled using a quasi-static approach. The maximum hydrodynamic pressure generated by the sloshing fluid, calculated based on classical rigid-baffle theories, is applied statically to the undeformed structure. This fail-safe approximation assumes a worst-case loading scenario, intentionally neglecting the mitigating structural inertial effects and the potential load-relief provided by the baffle's flexibility.

Therefore, a core objective of this study is to systematically investigate whether these established rigid-baffle pressure distributions can be reliably extended to the preliminary structural sizing of flexible ASDs. Consequently, the proposed simplified approach is benchmarked against high-fidelity, 2-way FSI numerical simulations of free-decay sloshing problems, which serve as a robust comparison baseline. A parametric study is conducted by varying the material properties, specifically Young's modulus (E) to cover a wide spectrum of flexibility levels, and the baffle immersion depth relative to the free surface.

Crucially, the investigation encompasses and compares both fully submerged and non-submerged baffle configurations. For the non-submerged cases, the study explicitly investigates the structural integrity of the component under wave impact loads occurring beneath the baffle. Indeed, when the liquid free surface is close to the ASD, wave amplitudes exceeding the clearance result in direct liquid splashing against the structure. As demonstrated by the CFD results, this impact produces a highly localized pressure pulse with an amplitude significantly exceeding the standard maximum slosh pressure, characterized by a time scale much shorter than the primary slosh period. While slosh loads periodically excite the baffles at low frequencies, splash-loads impose abrupt, severe stresses that must be rigorously accounted for to prevent localized structural failure.

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Session Classification: Modellazione

Track Classification: Modellazione