

# DESIGN AND GROUND VIBRATION TESTING OF AN EXTERNAL DROP-TANK FOR FUEL SLOSH STUDIES ON A DYNAMICALLY SCALED DELTA WING

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## ABSTRACT

Historically, Saab performed Ground Vibration Tests (GVT) on varied configurations, including fluid-filled drop tanks, to provide data for Finite Element Model correlation and verification. Currently, Saab utilizes dummy drop tanks for ground vibration testing to eliminate the hazards of fuel handling and to mitigate mass asymmetries caused by non-uniform fill levels or internal fluid migration. Discrepancies observed between test configurations using fluid-filled tanks and recent results using dummy tanks have inspired a deeper investigation into the sloshing-induced effects on the structural dynamic characteristics and eventually the flutter boundaries.

The KTH-NASA dynamically scaled aeroelastic model featuring external stores and control surfaces was used as the platform for the new stores. This model was originally developed for transonic flutter testing in the NASA Transonic Dynamics Tunnel. A set of modular external drop tanks was designed for the flutter model, able to hold either a liquid payload ("Wet") or rigid mass equivalents ("Dry"). A cylindrical shape was chosen for the drop tanks, for geometrical similarity with existing drop tanks and for ease of construction, using acrylic pipes. The primary structure consists of an acrylic cylinder with an inner diameter of 110 mm and an outer diameter of 120 mm, with additional parts 3D-printed out of PolyLactic Acid (PLA) plastic.

The liquid used for the Wet case is water. The rigid mass equivalents for the Dry case are FDM-printed in PLA plastic in four length wise-sections, to limit the part size to allow for printing and to minimize the impact on lengthwise stiffness. The ability of FDM 3D-printers to deposit material infill in a lattice structure means that a heavier material (PLA) can be used to accurately model the density and CoG of a lighter material (water). Rigid equivalents have been constructed for 100%, 75% and 50% fill levels, and color-coded to identify the test configuration in post-test analysis. At 100% fill level the payload represents ~250% of the structural mass.

The wing-store system was mounted to a rigid test wall at a Saab facility. Structural excitation was provided by electrodynamic shakers. Single-axis accelerometers were distributed across the wing (Z-direction) and the tank (Y- and Z-directions). Two excitation locations were used, at the rear-most end of the tank structure and at the rear-most end of the wing tip pylon. Excitation was conducted over a frequency range of 4–64 Hz. While swept-sine excitation was initially attempted, it induced significant transient effects due to the phase lag between the structural motion and the internal fluid response. To ensure the fluid-structure system reached a steady-state periodic response, a stepped-sine approach with a 200-cycle delay prior to measurement at each frequency increment was implemented. At lower frequencies, excitation force levels were constrained by the high-amplitude displacements of the primary wing bending modes. Any additional increase in force made the shakers reach the stroke length limit, and interrupted the test by accelerometer overload.

For the 100% fill level case, the wing bending modes (Mode 1 and Mode 5) are consistent between the wet and the dry cases, but there is a slight frequency shift for the modes involving a torsional motion of the wing. For the 50% case, the frequency shift of the modes grows larger, resulting in 10-20% higher frequencies than for the Dry case. Interestingly, Mode 3 (Wing Torsion and Store sway) of the "Dry" case is not observed in the "Wet" case at the 50% fill level, see Figure 1. For the remaining modes, the impact on modal damping is limited for all excitation levels and methods. This might be related to the constrained amplitude of the excitation, since the highest damping regime is associated with chaotic movement of the liquid which was not achieved during testing.

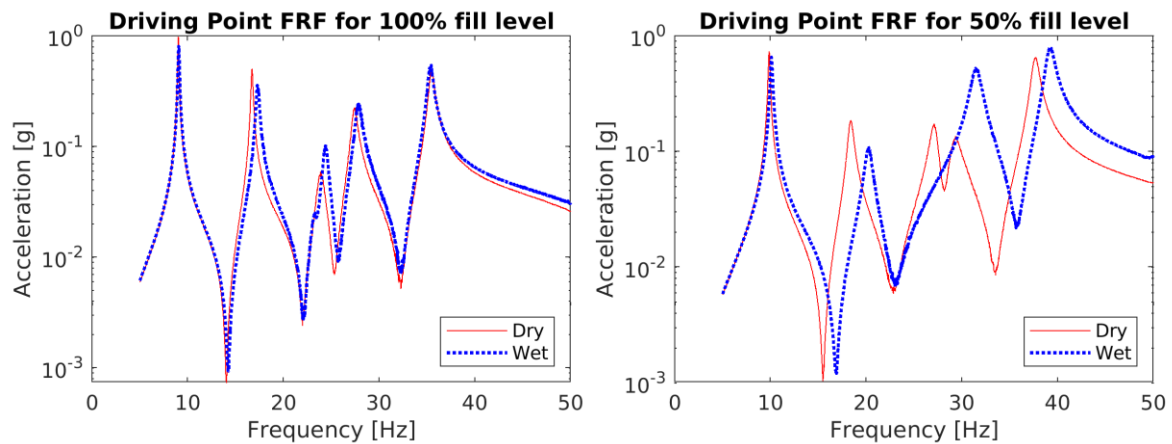


Figure 1. Driving point FRF for 100% and 50% fill levels, comparing the Dry and Wet cases.

Flutter predictions have been made using the experimental mass and stiffness data, together with linear unsteady aerodynamics in ZAERO and solved using ZAEROs built in g-Method. The results show a significant impact on critical flutter velocity for Mach numbers between 0.5 and 0.9, due to the increased frequency separation between Mode 1 and Mode 2 for the Wet case, resulting in a higher critical flutter velocity. As the experiment has kept all other variables fixed, this impact is directly related to the free-surface effects of the liquid payload.

This investigation suggests that utilizing rigid "Dry" dummy drop tanks provides a conservative but inaccurate baseline for flutter clearance as the presence of a liquid payload with a free surface impacts the aeroelastic stability boundaries. In practice the impact is probably less pronounced as drop tank are usually engineered to minimize free surface movement using e.g. foams, baffles, and other partitions.

Future studies aim to evaluate computationally effective methods to include the effect of sloshing in industrial flutter clearance calculations, using this set of measurements as a benchmark.