Propellant Slosh in the Orion Service Module

Kimberly Schultz, Amber Bakkum, Kevin Crosby & Carthage Microgravity Team
Carthage College Department of Physics August 2010

Introduction

In fluid dynamics, slosh refers to the movement of liquid inside a hollow object. We examine these dynamics in a scale-model of the Orion Service Module (SM) down-stream hydrazine propellant tank. The SM is a component of the Orion crew lunar return vehicle, and part of NASA's Constellation Program (Fig. 1).

Given that a substantial portion of the initial weight of the SM is fuel, understanding the fluid dynamics in the SM tanks is critical [1]. **Our research goal is to validate computational models produced by Lockheed Martin for propellant slosh during spacecraft maneuvers.**

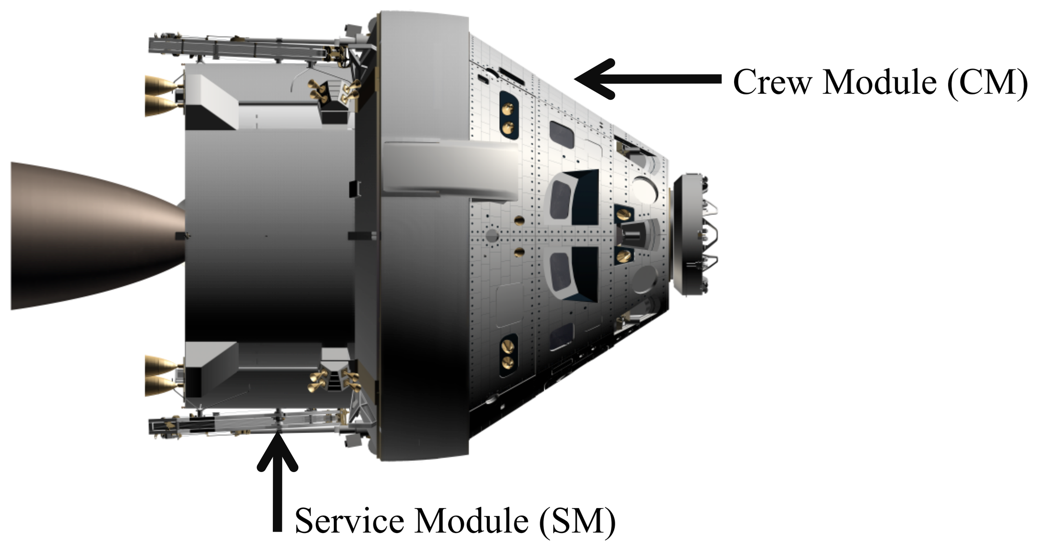

Figure 1: Orion Vehicle

Research Objectives:

(1) Carry out a *linear slosh analysis* to identify frequencies of the anti-symmetric slosh modes.
(2) Establish the equilibrium *free-surface configuration* of propellant – **What shape does the propellant volume take in zero-g?**

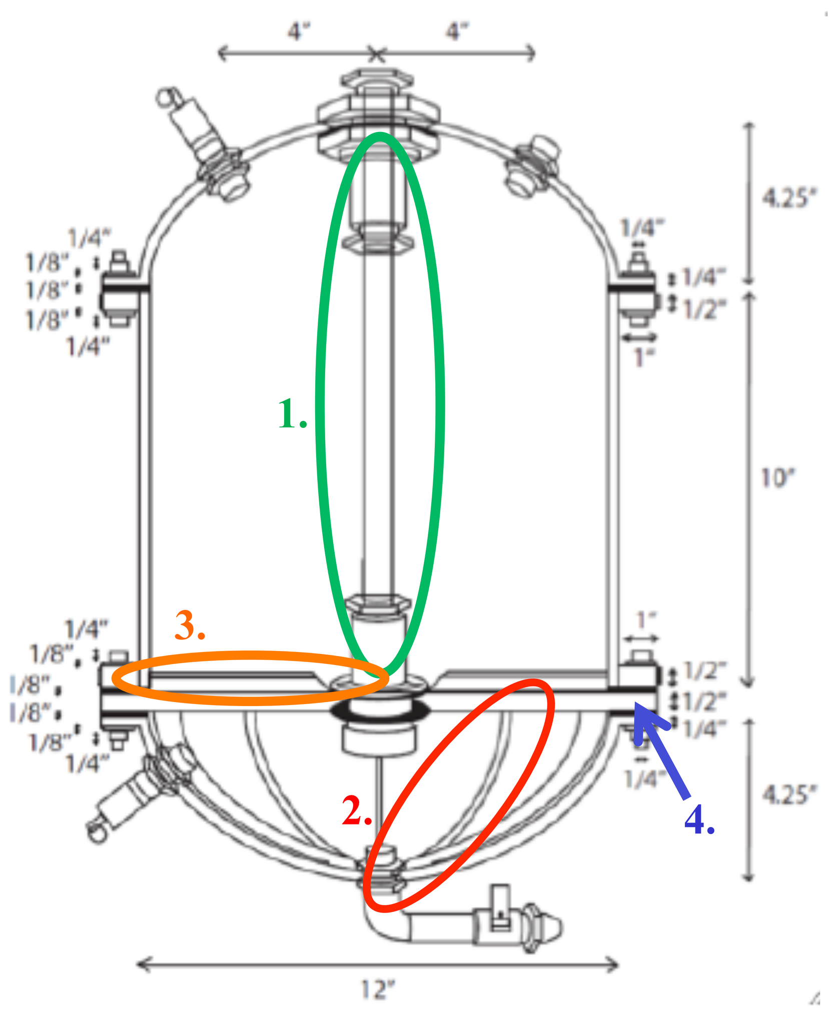

Figure 2: Tank Design

Model Tank Design

The tank design preserves the geometry of the Orion SM propellant tank to a 1/6 linear scale (Fig. 2). The tank is cast acrylic and Lexan for visual observation of the fluid motion. The simulated propellant used was 60% ethanol/water mixture.

Internal Structures:
1. Mass gauging probe
2. Eight radial vanes
3. Eight radial stiffeners
4. The propellant management device (PMD)

Methods

We carried out experimental, theoretical, and computational investigations of slosh dynamics:

Experimental Data
•Through the NASA Systems Engineering Educational Discovery (SEED) Program, our model tank was flown on a zero-gravity aircraft to simulate a zero-g environment, shown in Fig. 3.
•A linear slosh analysis was carried out using video data collected via three mini DV cameras and correlated with accelerometer data.

Figure 3: Zero-g Parabolic Flight with model tank

Computational Modeling
Using FLOW-3D, a computational fluid dynamics (CFD) program, the natural slosh frequencies and zero-g configurations in both the full scale tank and the model tank are studied.

•Natural Slosh Frequencies: For a given fill-fraction and gravity level, the tank experiences an impulsive load. Fluid oscillation frequencies are then measured. Martian, Lunar, 1-g, and 2-g acceleration data are shown in Fig. 6.
•Zero-g Free Surface Configuration: Simulations study the free surface configurations and formation time for varied initial fluid levels (Fig. 4 & Fig. 5).

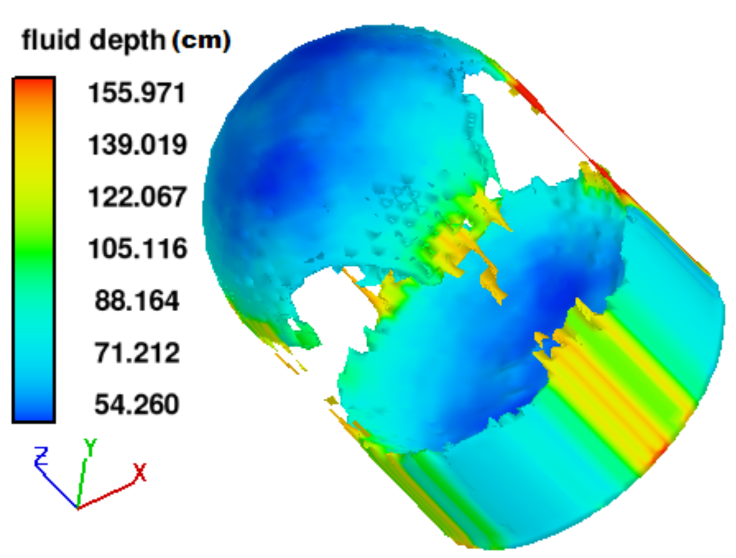

Figure 4: Full-scale tank in its zero-g surface configuration

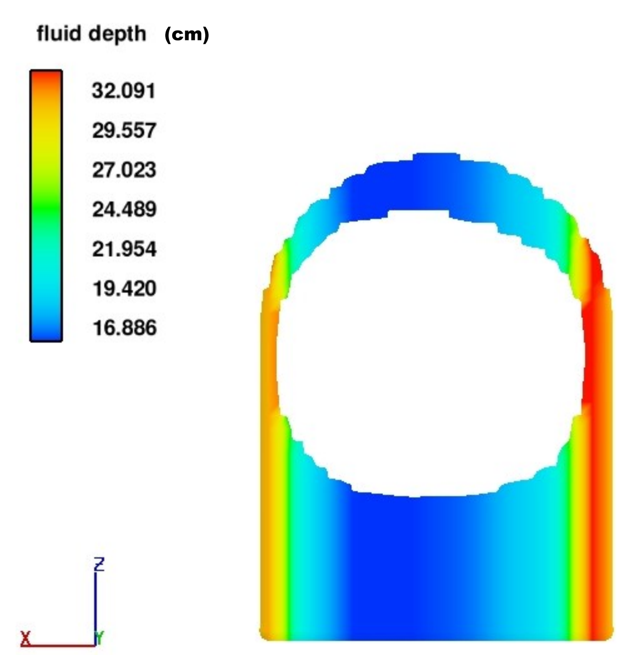

Figure 5: Cross-section of model tank in its zero-g surface configuration

Results & Analysis

A *Linear Slosh Analysis* examines the lowest resonant slosh frequencies present in the tank. Anti-symmetric slosh frequencies are shown in Fig. 6 for a range of fill fractions (ratio of fluid surface height *h* to tank radius *R*). Solid lines in Fig. 6 are predicted curves derived from velocity flow potential theory.

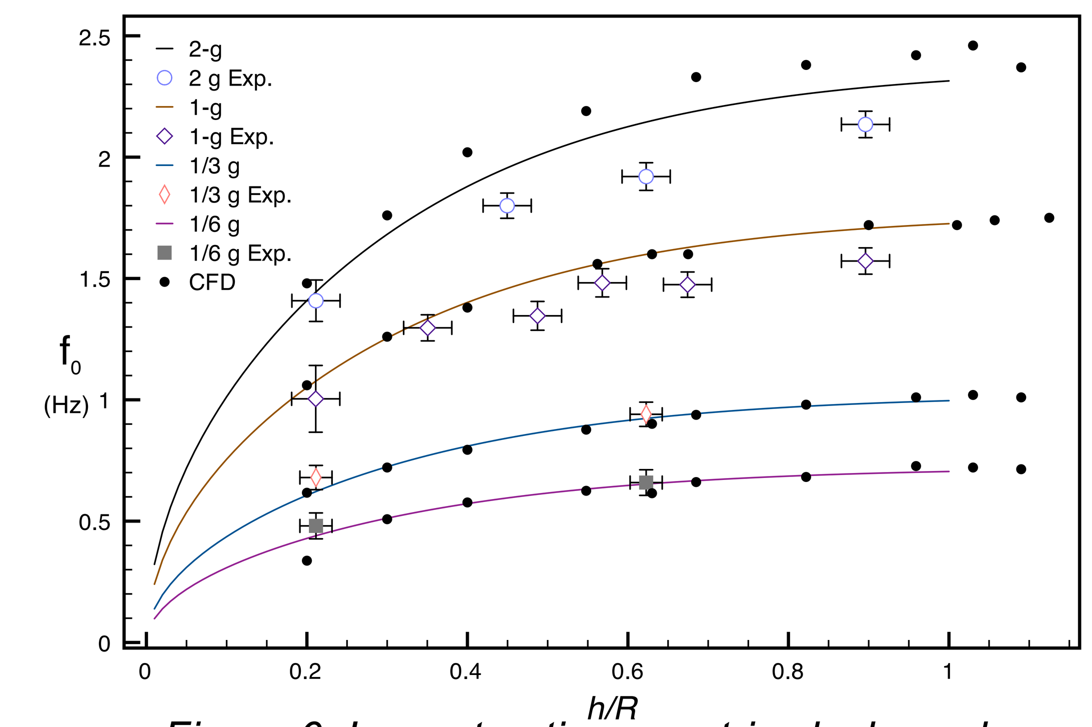

Figure 6: Lowest anti-symmetric slosh-mode frequencies plotted against tank fill-fraction.

Key Results

Our flight data and CFD analysis suggests that:
•Propellant in full-scale tank should take up to 3400 seconds to reach equilibrium configuration after impulsive acceleration (orbital maneuvers, etc.)

•Equilibrium Free-surface configuration of propellant consists of two separated fluid volumes. **This is a new and *unanticipated* result.**

These results have potential impact on considerations of both propellant management & gauging, and future tank design. Our team continues to investigate the free-surface topology of propellant in the Orion SM tanks with a re-flight proposal of a modified experiment that will more directly address zero-g fluid configurations.

References

[1] Vreeburg, Jan P.B. "Spacecraft Maneuvers and Slosh Control", in IEEE Control Systems Magazine, June 2005.

[2] Dodge, F., and Garza, L., Experimental and Theoretical Studies of Liquid Sloshing at Simulated Low Gravity, Trans. ASME J. of Appl. Mech., 34 (1967).

Acknowledgements

• Carthage Microgravity Team: Amber Bakkum, Stephanie Finnvik, Isa Fritz, Bradley Frye, Cecilia Grove, Katelyn Hartstern, Samantha Kreppel, Emily Schiavone, Kimberly Schultz, Kevin Crosby & Jonathan Braun
•Carthage SURE Program; NASA Microgravity University; Wisconsin Space Grant Consortium; Lockheed Martin