Preliminary Results from the Modal Propellant Gauging Experiment on New Shepard P9

Kevin M. Crosby[1], Taylor Peterson[1], Cassi Bossong[1], Bennett Bartel[1], Celestine Ananda[1], Nicholas Bartel[1], Megan Janiak[1], Sheila Franklin[1], and Rudy Werlink[2], Carthage College, Kenosha, WI, USA, [2]NASA Kennedy Space Center, Florida, USA (corresponding author: kcrosby@carthage.edu)

Introduction The Modal Propellant Gauging (MPG) experiment is one of several emerging approaches to low-gravity liquid propellant gauging. MPG provides real-time, non-invasive (no tank penetrations), gauging of both cryogenic and earth-storable propellants by measuring the "added-mass" effect of liquid on the resonant mode frequencies of thin-walled tanks subject to acoustic excitation.

MPG has been demonstrated in 1-g on a variety of subscale and flight-hardware propellant tanks, including a hot-fire test of the Methane-LOX system onboard the Morpheus Prototype Lander, pressure and thermal cycle tests on a Space Shuttle OMS tank, and the Orion ESM propellant tank (qualification unit), and various composite tanks with both cryogenic propellant simulants and water. MPG has also been extensively tested on parabolic flights, across three different flight campaigns.

While liquid mass gauging resolutions of less than 1% have been obtained under 1-g conditions with equilibrated liquid masses, parabolic flights do not provide sufficient time to achieve equilibrium surface configurations in zero-g with reasonable tank sizes. To achieve equilibrated liquid surface configurations in zero-g requires access to microgravity for time-scales on the order of minutes. In the present work, we report initial results from the first low-gravity tests of the MPG system with equilibrated liquid configurations aboard the Blue Origin New Shepard spacecraft.

MPG Overview MPG implements experimental modal analysis (EMA) to measure surface acoustic modes on the outer wall of the propellant tank. A broad-band acoustic excitation is applied to the tank wall and resonant modes are excited and acquired via patch transducers. The analysis software associates the modal shapes and peak frequencies with the contained liquid mass using the added-mass model of fluid-structure interactions.

Experimental Hardware The experimental hardware flown on P9 is shown in Fig. 1. Three small, transparent, polycarbonate cylindrical tanks are filled with water at different fill fractions. Actuation and response sensing is via thin PZT patch transducers applied to the outer wall of the propellant tanks. Two GoPro cameras image the tanks during the flight. The experimental volume is enclosed in a secondary containment vessel surrounded by LED panels to provide glare-free lighting of the tanks for imaging of liquid surfaces. A control system located beneath the secondary containment vessel contains the Data Acquisition System (DAQ), electrical power system (EPS), white noise generators (WNG), and piezo amplifiers. The control system was designed to be flight-like in terms of power and mass constraints, and to demonstrate the ability to perform high-data-rate signal acquisition in space using COTS components.

Data Acquired on P9 The primary objectives of the present flight experiment were to (1) validate the assumptions of the FSI added-mass model for associating modal peak shifts with liquid mass in zero-g, and (2) validate CFD and Surface Evolver models of liquid reorientation time and surface configurations for the subscale model tanks used in the experiment. These objectives were met through both video imaging of liquid surfaces in the transparent tanks and continuous acquisition of modal response during launch, zero-g surface reorientation, and while the liquid surfaces were in stable zero-g configurations.

Summary of Results Analytical and finite element modeling of predicted MPG gauging results in zero-g will be compared to experimental data from NS P9. CFD and Surface Evolver modeling of the zero-g liquid surface shape(s) are validated by P9 video data and used to inform the FSI model for modal frequencies and shapes. Forward work on MPG in subsequent suborbital and parabolic flight testing will be discussed.

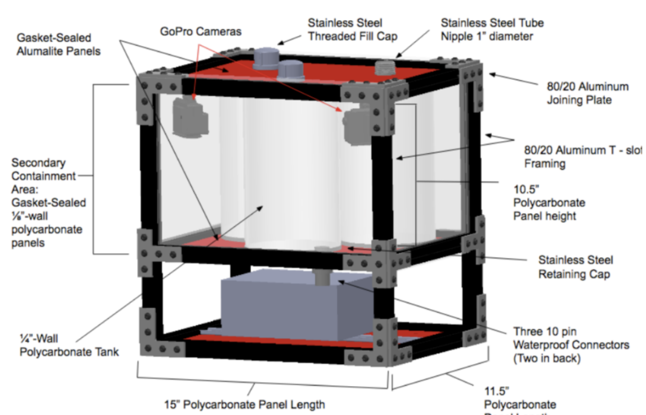

Figure 1: Double-locker MPG payload experiment schematic.