Acquisition of Long-Duration, Low-Gravity Slosh Data Utilizing Existing ISS Equipment (SPHERES) for Calibration of CFD Models of Coupled Fluid-Vehicle Behavior

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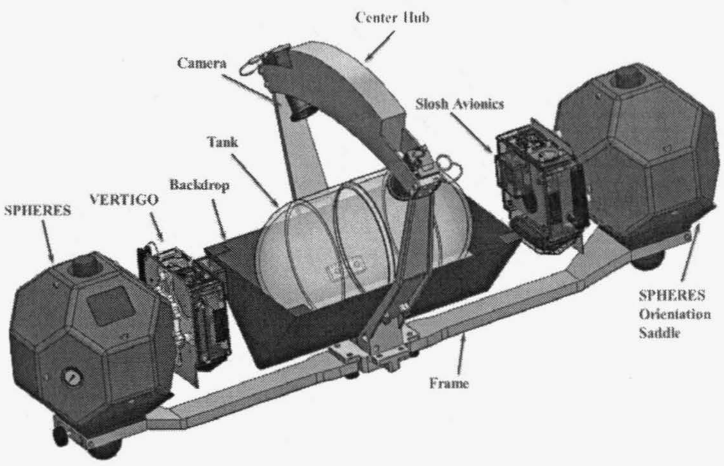
Extended Abstract

Accurate prediction of coupled fluid slosh and launch vehicle or spacecraft dynamics (e.g., nutation/precessional movement about various axes, attitude changes, ect.) requires Computational Fluid Dynamics (CFD) models calibrated with low-gravity, long duration slosh data. Recently completed investigations of reduced gravity slosh behavior have demonstrated the limitations of utilizing parabolic flights on specialized aircraft with respect to the specific objectives of the experiments. Although valuable data was collected, the benefits of longer duration low-gravity environments were clearly established. The proposed research provides the first data set from long duration tests in zero gravity that can be directly used to benchmark CFD models, including the interaction between the sloshing fluid and the tank/vehicle dynamics.

To explore the coupling of liquid slosh with the motion of an unconstrained tank in microgravity, NASA's Kennedy Space Center, Launch Services Program has teamed up with the Florida Institute of Technology (FIT), Massachusetts Institute of Technology (MIT) and the NASA Game Changing Development Program (GCD) to perform a series of slosh dynamics experiments on the International Space Station using the SPHERES platform. The Synchronized Position Hold Engage Reorient Experimental Satellites (SPHERES) testbed provides a unique, free-floating instrumented platform on ISS that can be utilized in a manner that would solve many of the limitations of the current knowledge related to propellant slosh dynamics on launch vehicle and spacecraft fuel tanks. The six degree of freedom (6-DOF) motion of the SPHERES free-flyer is controlled by an array of cold-flow CO2 thrusters, supplied from a built-in liquid CO2 tank. These SPHERES can independently navigate and re-orient themselves within the ISS. The intent of this project is to design an externally mounted tank to be driven inside the ISS by a set of two SPHERES devices (Figure 1). The tank geometry simulates a launch vehicle upper stage propellant tank and the maneuvers replicate those of real vehicles. The design includes inertial sensors, data acquisition, image capture and data storage interfaces to the SPHERES VERTIGO computer system on board the flight article assembly. The design also includes mechanical and electronic interfaces to the existing SPHERES hardware, which include self-contained packages that can operate in conjunction with the existing SPHERES electronics.

The SPHERES-Slosh investigation is computer controlled and requires only minimal interaction with the ISS crew. Once the package is on station, an ISS crewmember takes the hardware out of the storage container and assembles a few pieces to complete the system. Once this operation is complete, the SPHERES units (already on station) are attached on both ends of the assembly. The SPHERES are integrated using a clamp system that rigidly attaches the CO2 tank to the testbed frame. Finally, the cameras and IMUs are connected to the VERTIGO computer system to form the completed system.



Once the unit is fully assembled, it is ready for research operations to begin. This simply involves an ISS crewmember powering on all units. This includes both SPHERES units and the SPHERES Laptop computer. Once all units are up and running, the entire assembly is placed in the center of the ISS module and allowed to free float. The ISS crewmember runs the software on the SPHERES Laptop which commands the SPHERES to perform a pre-specified set of maneuvers. After the test run is complete (5 minutes approx.), the unit is reoriented to the center of the module and a new test begins. Provided our allotted mission time allows, these tests continuously run until the on-board memory is full, or the CO2 propellant aboard the SPHERES runs out. At this point, the crewmember attaches the hard drives to the SPHERES Laptop computer and downloads all of the test data for transmission back to earth.

The principal goal of this inverstigation is to acquire long duration slosh data consisting of both video and position data. Since liquid propellants normally constitute a large percentage of the vehicle's mass, it is important to predict the effects they will have on the vehicles trajectory. In other words, a vehicle with liquid propellants will move differently from the same vehicle using solid propellants. This is caused by the forces imparted to the vehicle as the liquid moves around inside the tanks. This investigation will use video cameras to photograph the liquid inside a clear tank. At the same time, Inertial Measurement Units (IMU) will measure the position of the system as a function of time. This will generate enough data to quantitatively determine the differences between a tank with liquid and one without. The data will also be used to benchmark CFD models currently in use.

Undergraduate and graduate (MS and PhD level) students from the Florida Institute of Technology (Florida Tech) and the Massachusetts Institute of Technology (MIT) are actively involved in the liquid slosh dynamics research project onboard ISS. At Florida Tech 5 undergraduate students, 3 graduate students and 2 faculty members are involved. At MIT several undergraduate students, 1 graduate student, 1 research scientist and 1 professor are involved in the project. In addition to college-level student participation, several outreach activities specifically geared toward elementary and high school students are being prepared in conjunction with this effort. The SPHERES slosh dynamics project serves as a lesson module and provides examples for existing STEM (Science, Technology, Engineering and Mathematics) programs already in place at local elementary and high schools in Brevard County, Florida. Besides producing a rich set of CFD calibration data, this experiment will engage and inspire elementary and high school students to explore careers in science and engineering.

Currently, the project is on schedule to launch during increment 37-38 aboard a SpaceX Falcon 9 vehicle. This third ISS resupply mission by SpaceX is called SpaceX-3 and is scheduled to Launch at the end of September 2013. Operations on board the ISS will commence in early 2014.