Sloshing Analysis in Micro Gravity aboard a CubeSat

A Proposal for Utilizing Particle Imaging Velocimetry

Author

JEAN-CARL KELLER, M.SC.

After my beachelor degree on mechatronic systems, I followed up with a master degree on applied sciences with its main emphasis on mechatronic systems in Space Applications at the University of Applied Sciences Augsburg (UASA), Germany.

During my studies I was part of the student rocket team "HyComet" (Hybrid Composite Experimental Rocket) where we build a hybrid sounding Rocket within the DLR STERN program. In this team I came in first contact with CubeSat's and was instantly excited.

The was project was initiated by Prof. Dr. André Baeten (UASA) and is called "CEOSAT" – (Composite Experimental Orbital Sloshing Analysis Testbed) Its main goal is to analyse sloshing aboard a spacecraft to gather detailed data for liquid simulations and predictions. The Secondary goal is to minimize structure weight by utilizing carbon fiber reinforced plastics (CFRP) and therefore maximizing payload weight, and size.

In my master thesis, my research concentrated on measuring methods for sloshing liquids in micro gravity.

Sloshing Analysis in Micro Gravity aboard a CubeSat

A Proposal for Utilizing Particle Imaging Velocimetry

Abstract

This poster gives a quick overview of ongoing sloshing experiments and then goes into the advantages of particle imaging velocimetry against other methods used for liquid sloshing analysis in micro gravity. The result will be a small sized yet capable method for analyzing liquid sloshing in micro gravity, aboard a CubeSat.

State of the Art

Since sloshing is not a new subject for spaceflight, a lot of tests campaigns were conducted in the past to analyze the behavior of liquids in microgravity and the influence of flight stability and guidance. The latest experiments where the Dutch
Sloshsat Flevo, a 100kg satellite flown in 2005 [1], the NASA SPHERES experiment aboard the ISS [2] and the French CNES FLUIDICS experiment also aboard the ISS [3].

The ongoing experiments are based on different measuring methods. Sloshsat Flevo consists of multiple capacitive sensors to acquire the wetting as well as micro anemometers for the velocity of the liquid and fine height sensors for the height. SPHERES and FLUIDICS both using a vision-based method combined with force or motion feedback sensors. The vison-based methods rely on comparison between a simulated picture and a picture from the experiment. This approach has the downside of reflection on the tank and inaccuracies due to the human factor in analysis.

A 3D-Model of the actual experiment could be helpful to digitally compare a simulation to an experiment in greater detail, as well as register velocities and free-floating liquids.

Particle Imaging Velocimetry (PIV)

PIV is a vision-based method that uses particles within a volume to picture flows and turbulences of liquids or gasses. The particles are illuminated with a bright light source and then photographed with typically four cameras. The particle distribution is then reconstructed with the Multiplicative Algebraic Reconstruction Technique (MART) to generate a volumetric 3D-replication. [4]

Advantages of a CubeSat

CubeSats offer high opportunities combined with low cost and fast development cycles, therefore, CubeSats have a low financial risk. This makes it possible to proof a concept with low budget. For example, the Sloshsat Flevo mission failed partially due to loss of the wetting sensors. But due to its expensive hardware, building a second satellite was not possible. So, the scientists have to use the incomplete data for their research. A CubeSat on the other hand, costs only a fraction of the price of a large satellite, to build and to launch, so multiple satellites can be launched if one fails or to accomplish different tasks.

Miniaturization and implementation of PIV in a CubeSat

To place all the necessary components of the satellite-bus inside a CubeSat, additional to the payload, the CubeSat needs to be at least two units long (2U). Figure 1 shows a rendering of a possible arrangement of the PIV payload and the satellite-bus with (1) being an illumination source for the tank, (2) an 80mm spherical, translucent tank, (3) the four cameras needed for PIV and (4) the main electronic stack of the satellite bus.

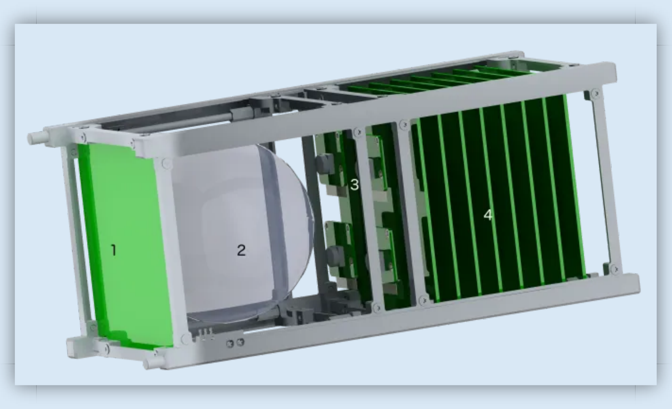

Figure 1: Rendering of a possible arrangement of the payload inside a 2U CubeSat

Conclusion

PIV is a promising method to gain detailed measurements of sloshing liquids and compare it with a three-dimensional simulation. It can be used on a small scale in a CubeSat or can be scaled up for larger satellites. It can also be used on sounding rockets or drop-towers with the major advantage of using a larger tank and not space certified electronics. This makes it even cheaper to do research on this topic.

PIV is a commonly used method and it is more on a scientific approach than photogrammetry or picture by picture comparison, because it is made specific for fluid dynamics analysis. All parameters (wetting, velocity and height) can be examinated with one existing program, so the workflow can be simplified with an established software.

References

[1] J. J. M. Prins, "Facility for liquid experimentation and verification in orbit," Rio de Janeiro, 6.10 2000, p. 36.

[2] S. Chintalapati, C. Holicker, R. Schulman, E. Contreras, H. Gutierrez, and D. Kirk, "Design of an Experimental Platform for Acquisition of Liquid Slosh Data aboard the International Space Station," presented at the 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Atlanta, Georgia, Jul. 2012, doi: 10.2514/6.2012-4297.

[3] A. Dalmon *et al.*, "Comparison Between the FLUIDICS Experiment and Direct Numerical Simulations of Fluid Sloshing in Spherical Tanks Under Microgravity Conditions," *Microgravity Sci. Technol.*, vol. 31, no. 1, pp. 123–138, Feb. 2019, doi: 10.1007/s12217-019-9675-4.

[4] "Thomographic PIV, Volumetric Flow Field Imaging – the ultimate solution for quantitative flow visualization." LaVision, Apr. 2015.