Liquid Propellant Manipulated Acoustically

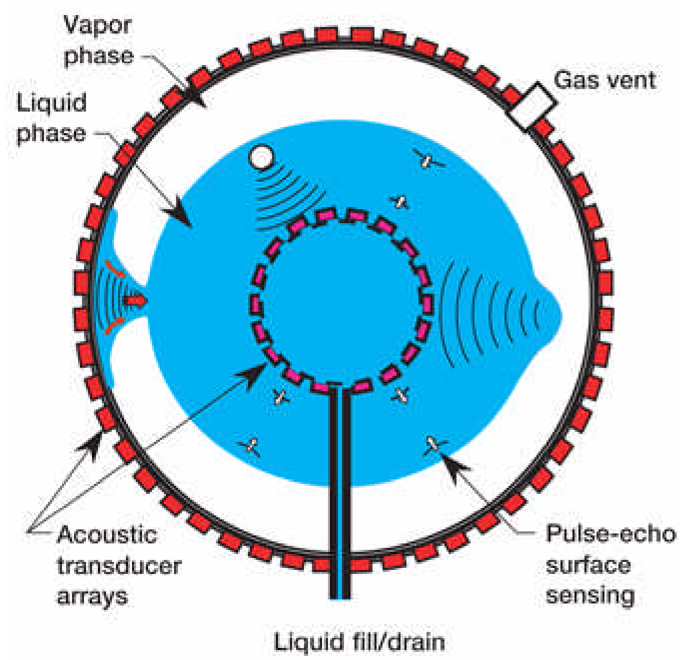
Fluids are difficult to manage in the space environment. Without gravity, the liquid and gas do not always remain separated as they do in the 1g environment of Earth. Instead the liquid and gas volumes mix and migrate under the influence of surface tension, thermodynamic forces, and external disturbances. As a result, liquid propellants may not be in a useable location or may even form a chaotic mix of liquid and gas bubbles.

In the past, mechanical pumps, baffles, and a variety of specialized passive devices have been used to control the liquid and gas volumes. These methods need to be carefully tuned to a specific configuration to be effective. With increasing emphasis on long-term human activity in space there is a trend toward liquid systems that are more flexible and provide greater control. We are exploring new methods of manipulating liquids by using the nonlinear acoustic effects achieved by using beams of highly directed high-intensity acoustic waves.

One effect is acoustic radiation pressure, which will be used to manipulate gas bubbles and liquid gas interfaces. It can be used to propel and control the position of gas bubbles and could force separate bubbles to coalesce. It may also be used to suppress free-surface sloshing.

Another effect is acoustic streaming, which has been proven to create liquid currents without nozzles or mechanical propellers. Acoustic streaming can be used in a variety of ways, including in agitation liquids to suspend solid particles or to annihilate thermal gradients to suppress propellant boiloff. Acoustic radiation pressure and acoustic streaming can be combined to create liquid fountains that can transfer liquids over long distances. The system will employ acoustic phased arrays to steer and focus the acoustic beams electronically, making it possible to operate on multiple targets as needed.

Acoustic manipulation will be enhanced by the addition of acoustic imaging. This technique is akin to medical ultrasound and sonar. Acoustic imaging will be coupled with the manipulation techniques that will allow the system to both "see" as well as "act" on selected targets. This acoustic "smart tank" will be able to both map the contents of the propellant tank and control its behavior. This approach lends itself to automated control or control by remote operators.



Acoustic "smart tank."

Long description of figure A number of acoustic functions are combined in the "smart tank." The spherical tank is novel in that the liquid is centered about a central hub with a jacket of gas or vapors. The jacket serves as an added layer of insulation, dramatically reducing the heat transfer through the tank walls. The central hub provides a means of filling and draining the liquids. An outer and inner band of transducer array elements can be used to transfer the liquid to the hub, drive out gas bubbles, and stabilize the liquid mass on the hub. Acoustic pulse echo sensing tracks the surface position, and radiation pressure forces the liquid to remain centered.

In the first year of this research, the NASA Glenn Research Center has been working with Dr. Adin Mann of Iowa State University to develop a nonlinear acoustic model. This analytical model will aid us in the design of the acoustic devices and arrays, and it will predict radiation pressure and acoustic streaming. This information will then be used create fluid dynamic and thermodynamic models using existing computational fluid dynamic codes.

Glenn has also been designing a general purpose 64-channel acoustic liquid manipulation (ALM) acoustic phased-array system. This system is computer controlled and can be programmed to by a simple laptop to synthesize a variety of acoustic beam configurations and power levels. This system will be tested in laboratory tanks and with microgravity aircraft test models.

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Headquarters program office: Funded by SRF at Glenn
Programs/Projects: SRF