It’s all about fluids

By

R. Balasubramaniam, Case Western Reserve University/NASA GRC, ramaswamy.balasubramaniam-1@nasa.gov

Ralph Fritsche, NASA KSC, ralph.f.fritsche@nasa.gov

Mohammad Kassemi, Case Western Reserve University/NASA GRC, mohammad.kassemi@nasa.gov

Gioia Massa, NASA KSC, gioia.massa@nasa.gov

Brian Motil, NASA GRC, brian.j.motil@nasa.gov

Mark W. Weislogel, IRPI, LLC, [mmw@irpillc.com](mailto:mmw@irpillc.com)

Abstract:

The focus of this white paper is to put sufficient resources towards the development of a design guide and tools for the handling of fluids within the unique environment of space and educating the community on those principles. The role of fluids is ubiquitous to all space processes and science experiments. This area is still identified by the technology developers as critical as a host of problems have occurred.

Introduction

The role of fluids is ubiquitous to all processes needed for manned space exploration as well as conducting science experiments in a manner like that performed in a terrestrial environment. The ability to transport heat, reactants and products is accomplished via both natural and force convection, diffusion, and the imposition of other forces that can attract, repel, or align molecules and fluid elements in a desired manner. Many space systems and biological processes rely significantly on the ability to reliably predict and control the position and flow of liquid and gasses. As such, the decadal survey conducted in 2000 [1] identified a research approach for the development of multiphase flow and heat transfer technology as one of the four programmatic considerations. However, this emphasis was lost after the 2003 Columbia Disaster and NASA changed its focus to the human exploration of space. Unfortunately, this area is still identified by the technology developers as critical as a host of problems have occurred. The focus of this white paper is to put sufficient resources towards the development of a design guide and tools for the handling of fluids within the unique environment of space and educating the community on those principles.

In the early days of the space program, the principal focus was on the management of large liquid volumes in propellant tanks. Large quantities of propellant needed to be loaded onto launch vehicles, conditioned, and reacted in a controlled manner in the rocket engine. Even though propellant loading occurs in a terrestrial environment, for the upper stages, conditioning, flowing, and reacting the propellants are initiated in the microgravity environment. To a lesser extent, the ability to use convective heat transfer for both thermal management and power generation was explored. Implementation of the heat transfer applications were limited to primarily to capillary based heat pipes and single-phase flow loops.

While there is still intense interest in propellant storage and transfer for fuel depots and rockets powered by nuclear power for extended manned deep space missions and two-phase heat transfer for the Rankine power cycle for Nuclear Electric Propulsion, many additional challenges have been faced by the aerospace community and designers ranging from food preparation to water reclamation and purification, to conducting scientific experiments in the unique environment of space.

With the reduction of gravity in the space environment, the dominance of the buoyancy force is greatly diminished, and other forces such as surface tension and electrostatic forces, and surface properties and geometries play a larger role in governing the behavior.

Over the years, NASA approached the academic and industry communities in a variety of forums [2], [3], [4], [5], [6], [7], [8], and [9]. Despite the advocacy for NASA to adopt an integrated approach for the conduct of research on multiphase flow and heat transfer technology for the human exploration and development of space [1], relatively little is currently known about the effect of gravity on multiphase systems and processes even though these systems are necessary for power production, propulsion, and life support. The subsequent decadal survey [10], identified the ability to position and flow liquids and gases for purposes of using both the sensible and latent heats as both Applied Physical Science (AP1 and 2) and Translation to Space Exploration Systems (TSES 1, 2, 6 and 14). Most recently, one report, [11] pointed out that the even though extensive modeling and simulation capability exists for terrestrial two-phase Rankine power cycle, there are “additional risks associated with handling a two-phase flow in zero gravity.”

IN 2015, NASA released [Technology Roadmaps](https://www.nasa.gov/offices/oct/home/roadmaps/index.html) which were then reorganized into the [2020 NASA Taxonomy](https://www.nasa.gov/sites/default/files/atoms/files/2020_nasa_technology_taxonomy.pdf) that identified the reliable control of fluids for spacecraft propulsion (TX01), power (TX03), life support (TX06) and thermal management (TX14).

Unfortunately, despite all this advocacy and limited research, problems have been encountered with the implementation of the fluid handling systems aboard the International Space Station as well as some of the scientific research that has been conducted:

* Gas bubbles in the feedwater for the Water Processing Assembly have been occasionally detected and the feedwater was diverted to the wastewater bus due to gas detected in the feedwater [12].
* Gaseous oxygen was detected in the feedwater and allowed to go into the rotary separator instead of the wastewater stream [13].
* Extra water is necessary to remove trapped gas bubbles from kinked water lines [14].
* Containment of the water associated with crew hygiene activities [15].
* Leakage of water into the helmet of an astronaut during an extravehicular activity (EVA) [16].
* Thermal cycling of samples has resulted in the nucleation of dissolved gas bubbles that impact science measurements [17].
* The release of microdroplets during pipetting operations into the crew cabin [18].
* Difficulties in maintaining the correct level of hydration and aeration for plant growth through the different levels of plant maturation have required additional monitoring and activities by the crew [19].

Ultimately, many of the difficulties may be attributed to “real” as opposed to idealized systems. For example:

* Science experiments that use “pure” as opposed to “contaminated” fluids that alter the surface tension and contact angle of the fluid.
* Surfaces that are contaminated by the residue of cleaning and other dirty fluids.
* Surface finishes and pinning edges that restrict the desired fluid motion.
* Dissolved gasses that are released out of a liquid solution because of the change in solubility either due to an increase in temperature or drop in pressure.
* Low pressure and recirculating zones within a flow conduit that trap gas pockets only to release them later into the flow stream.

Proposal:

The development of the necessary design considerations and tools is necessary to avoid the future occurrence of these problems. While comprehensive handbooks similar to those assembled for terrestrial systems [20] are highly desired, even a monograph and correlation approach [21], [22], and [23] for microgravity systems can provide insights for an apprentice engineer and rough approximations. Detailed computational fluid dynamic modeling, including tools such as the [Surface Evolver](http://facstaff.susqu.edu/brakke/evolver/evolver.html) and an [interface tool](https://www.irpillc.com/expertise/computation-modeling/), and [Ansys FLUENT](https://www.ansys.com/products/fluids/ansys-fluent/ansys-fluent-trial?utm_source=google&utm_medium=ppc&utm_campaign=fluent&utm_content=&utm_term=ansys%20fluent&campaignid=7013g000000HRoOAAW&creative=563877134841&keyword=ansys%20fluent&matchtype=e&network=g&device=c&gclid=Cj0KCQiA2ZCOBhDiARIsAMRfv9K_4WneVqilx0IHHIMb34jDORZohqXPRwRSd-iqtsni4m9iUTbHi4caAt-ZEALw_wcB) should be developed for a wide range of flow and static conditions to account for solubility, thermal conditions and geometries. While the Surface Evolver and its interface tool is available as “freeware,” the source code was written decades ago, and substantial improvements may be made to streamline the execution. Furthermore, the use of FLUENT is cost prohibitive especially when efforts are made to take advantage of using its parallel processing capability.

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