AAE SPECIAL SEMINAR

Capillary Flows: from Laplace's Notebook to SpaceX Starship

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Abstract

In 1851, the Russian mathematician A. Y. Davidov declared the theory of capillary phenomena essentially closed, brought by his predecessors to "such a level of perfection that there is hardly anything more to be gained by its further investigation". A hundred and seventy-five years later, the position of a single bubble still determines whether a rocket engine restarts in orbit.

Davidov's confidence was premature, though not unfounded. The mathematical foundations trace back to Laplace, and late-twentieth-century derivations have led to eminently practical design rules for a variety of systems. But Davidov could not foresee the space revolution and the practical challenges it would bring to the study of capillary flows. To paraphrase A. D. Myshkis (1976), their modern study is driven largely by increasingly demanding applications. Today, that drive still challenges our understanding of the field.

Low-gravity fluid physics can be seen as the space equivalent of microfluidics. On Earth, capillary forces take over only when the system shrinks, which is why interfacial physics has largely belonged to the microfluidics community. Removing gravity opens the same regime on propellant tanks the size of a building.

This seminar follows that idea through several space systems built on recent fundamental capillary fluid physics research, from a propellant management device for CubeSat cold-gas propulsion where a patch heater initiates and sustains ullage positioning (NASA TechFlights) up to the very large SpaceX Starship vessels, subject to previously ignored self-gravitation effects (NASA BPS). Applications to large-scale liquid mirror telescopes (DARPA Zenith) and next-generation toroidal propellant tanks (NASA BPS) are also covered. Past and upcoming technology maturation experiments in drop towers, parabolic flights, and suborbital vehicles are discussed alongside the analytical and numerical tools that support their design and analysis.

Davidov didn't take long to reconsider. In the 1852 translation of his work, he struck his own sentence and settled for "a high level of perfection". The change left room for improvement, and the field still uses it. With some luck, you will leave this seminar persuaded that low-gravity fluid mechanics holds much more than the capillary equation.

Biography

Dr. Alvaro Romero-Calvo is an assistant professor in the Daniel Guggenheim School of Aerospace Engineering at the Georgia Institute of Technology, where he leads the Low-Gravity Science and Technology Laboratory. His group conducts a broad range of microgravity and low-gravity research, supporting the development of next-generation space systems and the study of the fundamental physical phenomena behind them. As PI and Co-PI of multiple federally funded projects with NASA, DARPA, and industry partners, Dr. Romero-Calvo's research has advanced new phase separation, propellant management, life support, adaptive optics, lunar surface, and heat transfer technologies. His team conducts fluid physics experiments across multiple low-gravity platforms, including drop towers, parabolic flights, and suborbital rockets, to bring promising new technologies closer to commercial infusion.

Dr. Romero-Calvo's contributions have been recognized with his selection as a NASA Innovative Advanced Concepts (NIAC) Fellow, the ASGSR Thora Halstead Young Investigator Award, and media coverage in Popular Science, Science News, Physics Today, and other international outlets. He also serves as a member of the NASEM Committee on Biological and Physical Sciences in Space, Chair of the AIAA Gravity-Dependent Science and Technology Technical Committee, and Vice-Chair of COSPAR's Commission G.

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