Capillary Flow Experiment, Capillary Flow Experiment – 2

The primary objective of Vane Gap (VG) experiments was to determine equilibrium interface configurations and critical wetting conditions for interfaces between interior corners separated by a gap. Secondary objectives were to determine critical wetting transient as well as validating numerical predictions of the large length scale discontinuous or near discontinuous wetting phenomena.

Capillary Flow Experiments overview

The Capillary Flow Experiments were a suite of fluid physics flight experiments designed to investigate large length scale capillary flows and phenomena in low gravity. The CFE's data was crucial to the Space Exploration Initiative, particularly as it pertained to fluids management systems including fuels and cryogen storage systems, water collection and recycling, thermal control systems, and liquid state materials processing.

NASA's current plans for exploration missions anticipate the use of larger liquid propellant masses than have ever flown on interplanetary missions. Under low-gravity conditions, capillary forces can be exploited to control fluid orientation such that such large mission-critical systems perform more reliably.

CFE was a fundamental scientific study that yielded quantitative results from safe, low-cost, short time-to-flight, handheld fluids experiments. The experiments studied phenomena that could not be studied on the ground such as dynamic effects associated with a moving contact boundary condition, capillary-driven flows in interior corner networks, and critical wetting phenomena in complex geometries.

Specific applications of the results centered on fluids challenges in propellant tanks. Knowledge gained has the potential to help spacecraft fluid systems designers increase system reliability, decrease system mass, and reduce overall system complexity.

CFE encompassed three experiments with two unique experimental units per experiment. There were multiple tests per experiment. Each of the experiments employed parametric ranges and test cell dimensions that could not be achieved in ground-based experiments.

All units used similar fluid injection hardware, had simple and similarly sized test chambers, and relied solely on video for highly quantitative data. Silicone oil was used for these tests. Differences between units were primarily fluid properties, wetting conditions, and test cell geometry. Experiment procedures were simple and intuitive.

Capillary Flow Experiment-2 overview

The Capillary Flow Experiment-2 consisted of 11 fluid modules with unique geometries designed to test capillary flow in the microgravity environment. The first type of CFE-2 fluid module was the Interior Corner Flow module. There were nine modules each with a different interior corner angle and geometry.

The second type of CFE-2 fluid module was the Vane Gap module. There were two of these modules, each had a different cross section profile. The CFE-2 fluid modules were set up in the Maintenance Work Area aboard the International Space Station (ISS) and were operated by an ISS crew member. The capillary flow data was in video format and was recorded by the MWA camera and downlinked to the ground for data analysis.

CFE Interior—ICF

Spontaneous capillary flows in increasingly complex containers were designed to determine important transients for low-g propellant management. Significant progress was made for cylindrical containers, but many practical systems involve containers with tapered geometries.

The test cells' irregular polygonal cross section of the test cells provides particular design advantages in preferentially locating the liquid where desired. Passive capillary flow in such containers is called imbibition and cannot be tested on the ground for large three-dimensional geometries with "underdamped fluids"—a most common characteristic of low gravity fluids systems.

Equations governing the process are known but have not yet been solved analytically to date because of a lack of experimental data identifying the appropriate boundary conditions for the flow problem. Experimental results will guide the analysis by providing the necessary boundary condition(s) as a function of container cross section and fill fraction.

The benchmarked theory can then be used to design and analyze capillary devices such as three-dimensional vane networks and tapered screen galleries for bubble-free collection and positioning of fuels for satellites**—**an important and outstanding problem for propellant management aboard spacecraft.

CFE Vane—VG

A complicated critical wetting condition arises between interior corners that do not actually touch, such as in the gap formed by a vane and tank wall of a large propellant storage tank **—**a commonality in practice, **—**or near the intersection of vanes in a tank with a complex vane network. Two CFE units investigated this phenomenon using a right cylinder with an elliptic cross section and a single central vane that does not contact the container walls.

The vane was rotated, varying the angle between the vane and the wall and also varying the size of the vane-wall gap. The vane is slightly asymmetric so that two gaps can be tested per container. All static interface shapes recorded by video were compared quantitatively with shapes computed using an algorithm.

A major goal of this experiment was to carefully observe all interface configurations during the vane's rotation and test the repeatability and reversibility of the critical wetting phenomena.

CFE Contact—CL

Two CFE units studied a fundamental and practical concern for low-gravity fluid phenomena—the impact of the dynamic contact line. The contact line-controlled interface shape, stability, and dynamics of capillary systems in low gravity.

The CFE–CL experiments provided a direct measure of the extremes in behavior expected from an assumption of either the free or pinned contact line condition. The two units were identical except for their respective wetting characteristics.

Related documents

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Publications

Journal Publications

• Chen, Y., Weislogel, M. M. & Nardin, C., "Capillary-driven flows along rounded interior corners," J. Fluid Mech. 566(2006), 235-271.

Published Presentations

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• Y. Chen, D. Bolleddula, M. Weislogel, "Capillary Flow in Cylindrical Containers with Rounded Interior Corners," AIAA-2007-167, 45th AIAA Aerospace Sci. Meeting and Exhibit, Reno, Nevada, Jan. 8-11, 2007.

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• (invited) M.M. Weislogel, “Capillary Macrofluidics for Passive Fluids Management on Spacecraft,” Engineering Sciences for Space Exploration, Gordon Research Conference, Les Diablerets, Switzerland, Aug 21-26, 2005.

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Project.Manager¿Robert Hawersaat, NASA GRC

Engineering.team¿ZIN Technologies, Inc.es than have ever flown before. Under low-gravity conditions, capillary forces can be exploited to control fluid orientation so that such large mission-critical systems perform predictably.