Bubble-free pumping of liquids in space

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Fourth CCF experiment on the ISS successfully completed

Pumping fuel with no bubbles is no problem at the filling station around the corner, but it certainly is in the microgravity environment of space. The fourth and final series of the Capillary Channel Flow (CCF) experiments on the International Space Station (ISS), which began on 5 August 2014, has just come to an end. In this collaborative project between NASA and the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR) Space Administration, researchers have been investigating the flow behaviour of liquids in microgravity to gain important insights for spaceflight technology – as well as for applications on Earth, such as in biomedicine.

How do liquids behave in microgravity?

Problems arising from the formation of air bubbles can occur in any system on board space vehicles that contains a liquid, such as drinking water containers, toilets or fuel tanks. This does not happen in a car's fuel tank, as the fuel always sits at the bottom of the tank because of Earth's gravity. Hence, it can be pumped to the engine without air being sucked in with it. But in space, fuel in a tank can move around due to the absence of gravity. Where in the tank is the fuel? How can it be transported safely to the thrusters under these conditions, and how can the fuel lines be kept free of bubbles?

Currently, this problem is solved by simply making the tanks larger and filling them with more fuel than is actually needed. However, by doing this, the weight and volume of the space vehicle is increased and, as a consequence, the launch costs. Another option is to install special structures in the tanks to convey the fuel to the outlet as a result of capillary action, where it can then be pumped out.

Fuel channels affect the flow of liquid

This is precisely the focus of the CCF experiment. Science teams led by Michael Dreyer from the Center of Applied Space Technology and Microgravity (Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation; ZARM) at the University of Bremen and Mark Weislogel from Portland State University have been investigating how different shapes of fuel channel and pumping speeds affect the flow of liquids. The focus of the recent experiments has been primarily the phenomenon of wave formation in the channels. The aim was to find out whether the occurrence of waves on the surface of the liquid is connected with the stability of the liquid flow. Furthermore, the scientists have been investigating in even more detail how the separation of gas bubbles and liquid functions in microgravity. During the 37-day campaign, the CCF experiment equipment was remotely operated from control rooms in Bremen and Portland.

The CCF campaign at a glance

Since the CCF experiment equipment was transported to the Space Station in April 2010 on Space Shuttle flight STS 131, four experiments have been carried out:

First campaign – December 2010 to March 2011 (66 days)
The aim of the investigation was to use capillary channels to convey liquid without forming bubbles. This involves the liquid flowing between two plates set parallel to one another at the outlet of the tank. The channel was bound at the top and bottom and open at the sides. The fuel sucked in remained between the plates due to the capillary action and the resulting surface tension. The experiment specifically clarified which flow rates are possible without bubbles being sucked in or the liquid flow breaking down. These are referred to as critical flow speeds.

Second campaign – September 2011 to October 2011 (35 days)
A V-shaped capillary channel was used to investigate how gas bubbles that have already penetrated the liquid are transported back to the surface and thus can be separated from the liquid. A separation strategy was investigated with which a gas/liquid mixture can be automatically separated under microgravity conditions.

Third campaign – June 2013 to July 2013 (40 days)
A V-shaped channel was again used in this series of experiments and the apparatus checked for its functionality. The repeatability of the scientific results was confirmed and additional experiments performed.

Fourth campaign – August 2014 to September 2014 (37 days)
In the final series of experiments, the scientists again investigated automatic phase separation in even more detail under microgravity. To do so this time, they observed flows that contained air bubbles in V-shaped channels of different lengths.

In total, the CCF experiment has been running successfully on the ISS for nearly six months, and has provided an enormous amount of data. Although this has not all yet been evaluated, the most important result for practical applications has already been determined – the theoretical model for calculating flow behaviour in capillary channels under microgravity, which the researchers had already developed, has been confirmed in full by the experiments. Hence, it is now possible for flow behaviour to be reliably calculated using computer models. In addition, the researchers were able to show in tests that air bubbles that already exist in the fluid flow can be automatically removed – even in microgravity – by using specific shapes of channel.

New possibilities for spaceflight technology and biomedicine

The foundations provided by the CCF experiment may be used in future to optimise the design of space vehicles and thus save costs. Improved availability of fuel would also extend the service life of satellites, because they would be able to maintain their position for longer. It is especially important with re-ignitable launcher upper stages that the fuel is in the right place at the right time, so the mission can achieve its goal. However, the knowledge might also be of interest here on Earth, for example in improving liquid flows in biochips for biological health screening and analysis methods.

The CCF experiment was a cooperation between NASA and the DLR Space Administration. The experimental equipment was built by Airbus Defence & Space.

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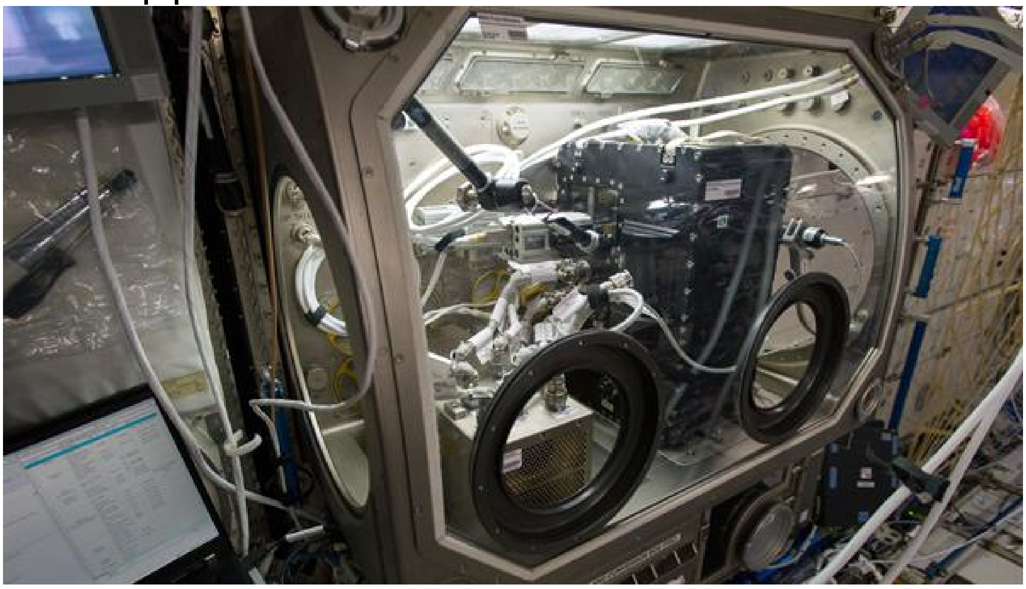
Installing the CCF equipment on the ISS

US astronaut Reid Wiseman installs the Capillary Channel Flow (CCF) experiment equipment in the International Space Station Microgravity Science Glovebox for the fourth series of experiments.

Credit: NASA.

The CCF equipment



The Capillary Channel Flow (CCF) experiment. The experiment module can be seen with the flow channel (black), the cameras that transmit the results directly back to the ground, and the control computer (silver).

Credit: NASA.

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