Thermal Imaging Camera Helps Develop New Cryogenic Fuel Tank Design

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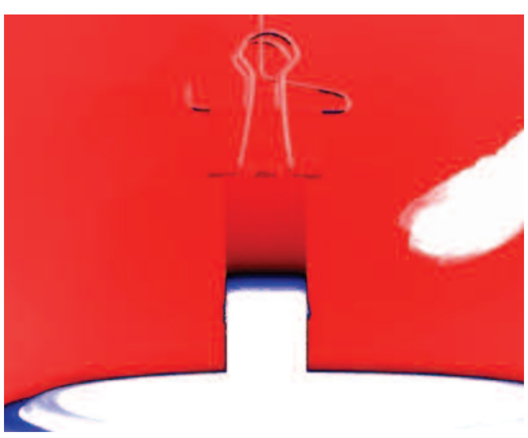
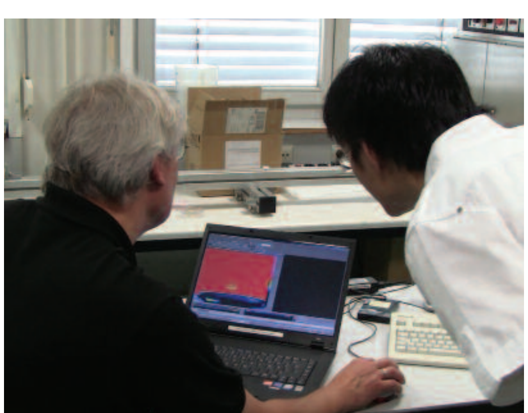
Fuel is a crucial part of space technology, it is necessary to propel the spacecraft but adding more fuel makes the spacecraft heavier and therefore less economic in its propulsion. Spacecraft designers continually face this dilemma. One of the best solutions current technology has to offer is the use of cryogenic fuel, due to its excellent energy to mass ratio. But the volatile character of cryogenic fuels and the absence of gravity in deep space make the use of cryogenic liquids for on-orbit propulsion challenging. But researchers at the German research facility ZARM may find a solution to this problem using a FLIR thermal imaging camera.



Thermal imaging helps to determine the wicking front of a cryogenic liquid.

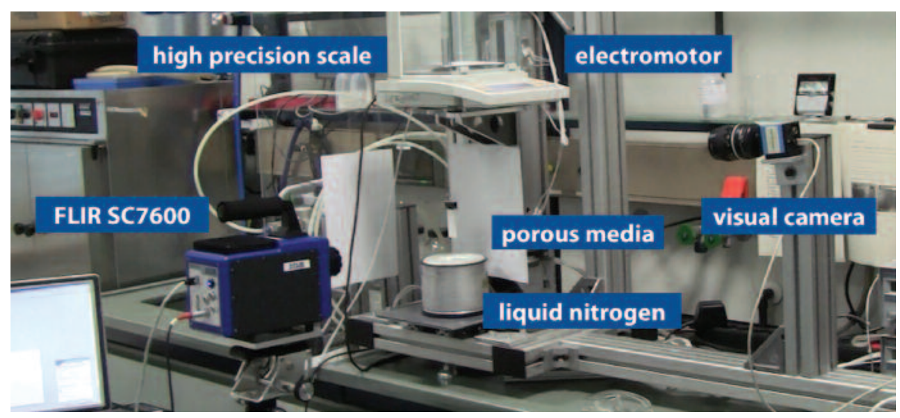


Researchers are fine-tuning the thermal footage using the accompanying FLIR software ALTAIR.

Cryogenic fuels are fuels that have to be kept at extremely low temperatures to maintain them in a liquid state. This makes it possible to store them in large quantities in smaller tanks. The combination of liquid oxygen and liquid hydrogen is the most widely used, since it provides an excellent energy to mass ratio and is also very clean, unlike many noncryogenic fuels which often cause pollution. But the use of cryogenic fuels also poses challenges for spacecraft designers. "One of the challenges is preventing cryogenic fuel in gaseous form from entering the fuel outlet to the engine", explains Ronald Mairose, Head of the Electronic Workshop at the Center of Applied Space Technology and Microgravity (ZARM), a division of the Department of Production Engineering at the University of Bremen. "If that happens cavitations may occur that can cause serious damage to spacecraft components or even complete engine failure."

On earth the gravity can be used to prevent gas from entering the fuel outlet. Due to the difference in density the liquid form of the cryogenic propellant will be positioned in the bottom part of the tank and the gaseous form will rise up in the opposite direction. When the spacecraft has left the earth's gravitational field but is still accelerating the force of the acceleration will have the same effect, but when the engine is switched off in space, the absence of gravity and acceleration make it very difficult to control the positioning and liquid-gas separation of cryogenic fuels. The propellant floats around in the fuel tank in both liquid and gaseous form, making it difficult to safely restart the engine.

Two methods can be used to solve this problem. One method that has been used in the past, arguably the



In this test setup the electromotor is used to dip the porous media in the liquid nitrogen. The high precision scale measures the change in weight and the FLIR thermal imaging camera provides information about the speed with which the liquid nitrogen travels up the porous media.

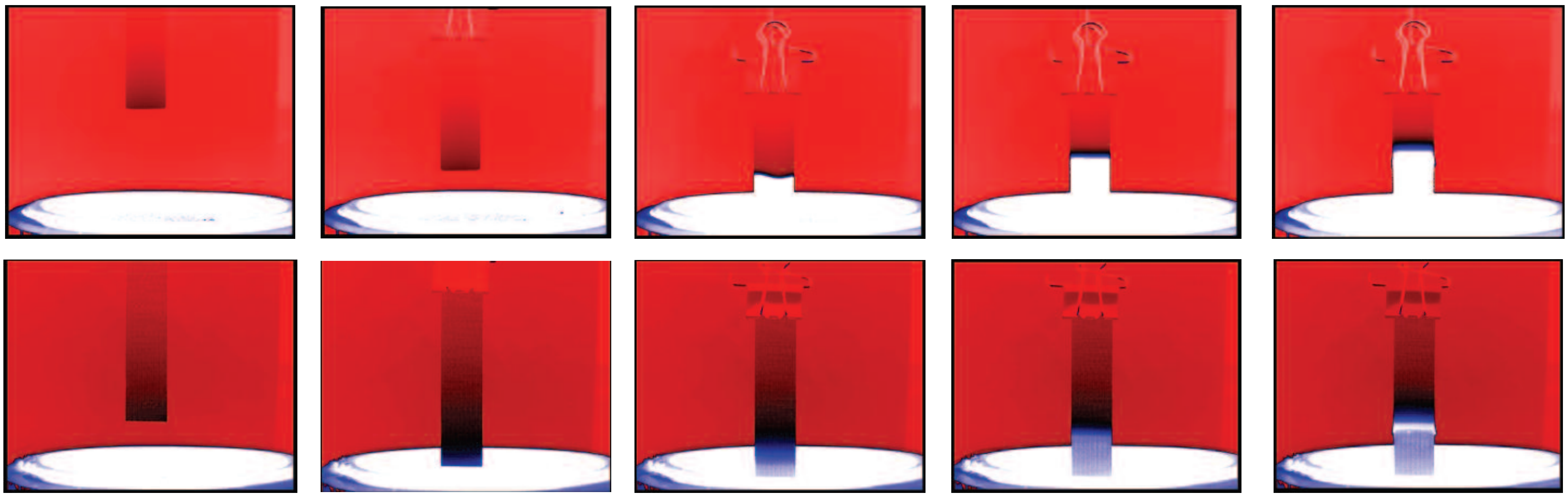
most famous application of this method being the 1969 Apollo lunar landing, is the use of an auxiliary propulsion system to create acceleration. The force of this acceleration positions the cryogenic propellant towards the tank outlet, allowing a gas-free restart. This method has two obvious drawbacks: it increases the overall weight of the spacecraft, something spacecraft designers want to avoid, and its use is limited by the amount of fuel this auxiliary propulsion system contains.

The other method is to utilize porous media, like a woven mesh made of stainless steel, in a Propellant Management Device (PMD). These PMD's are used to hold some of the liquid propellant at the tank outlet. This allows liquids to travel through the porous media, but blocks the passage of gases, ensuring a gas free engine restart. The liquid in the porous media is kept there by an effect called 'wicking'. "Wicking is a common principle for many liquids", explains Mairose. "Everybody who has ever dipped a sugar cube in a cup of coffee has seen this principle in action. The coffee will be sucked into the sugar cube, because the capillary force between the coffee and the sugar is greater than the force of gravity."

"For this method to work the porous media have to contain a sufficient amount of liquid, for if parts are dry gas can pass through tothe engine", explains Mairose. "In other words: the porous media has to remain sufficiently 'wet'. Evaporation might cause the porous media to dry out locally, so this method is currently only used in combination with liquid fuels that evaporate slowly or not at all. Cryogenic liquids are prone to evaporation and their wicking behavior is unknown, so evaporation caused by local temperature change or heat transfer might be stronger than the wicking effect."

Laboratory Tests

Research conducted at ZARM using a FLIR thermal imaging camera has recently led to new insights. The researchers used liquid nitrogen for their set-up, since it is relatively safe if handled properly in a laboratory, but also similar in its physical properties to other cryogenics, especially liquid oxygen. The researcher currently responsible for the conduction of these tests is Ming Zhang, research assistant at ZARM. "A porous glass frit or stainless steel mesh is dipped in a Dewar flask filled with liquid nitrogen", explains Zhang. "If the liquid nitrogen travels up this porous media in a similar manner to the way coffee travels up a sugar cube, then this would



This sequence of thermal images shows the wicking test result for the woven mesh made of stainless steel.

prove the wicking behavior of cryogenic liquids."

The ZARM research facility owns a FLIR SC7600 thermal imaging camera that proved to play a pivotal role in this research. "We struggled to accurately determine exactly how far the liquid nitrogen travels up the porous structure. At first we used visible light cameras but this proved to be inaccurate. Not only is it difficult to see how far the nitrogen travels up the porous media, the visible light camera also only shows the superficial progress of the liquid nitrogen, the progress on the inside of the porous media is not shown."

Visualizing the wicking process with the FLIR SC7600

The FLIR SC7600 thermal imaging camera provided the solution. "Due to the large temperature difference between the liquid nitrogen and the room temperature the liquid nitrogen travelling up the porous media shows up clearly in the thermal image", explains Zhang. "And the liquid nitrogen that travels up the porous media on the inside influences the surface temperature of the porous media, allowing the thermal imaging camera to accurately show how far the liquid nitrogen has progressed up the porous media on the inside as well." The thermal data recorded with the FLIR SC7600 thermal imaging camera show that the liquid nitrogen does travel up the porous media. "It was previously unknown whether cryogenic liquids would display wicking and how this would be affected by evaporation until we performed these tests", Zhang adds.

Gas-free engine restarts with wicking

The information from the thermal imaging camera is combined with the readings from a high precision scale that measures the increase in weight of the porous sample as the liquid nitrogen travels up the porous media. "The combination of both distance and weight of the liquid nitrogen travellingup the porous media tells us the exact wicking properties of the cryogenic liquids." Using this knowledge, spacecraft designers can build new PMD's for cryogenic fuels. "We now know that the capillarity force will lead cryogenics to wick in porous media, which prevents local dry outs and ensures a gas-free restart", Zhang concludes. "This would allow the engines to safely restart numerous times without the help of an auxiliary propulsion system."