Robotic Refueling Mission-3—an overview

C1Po1B-01

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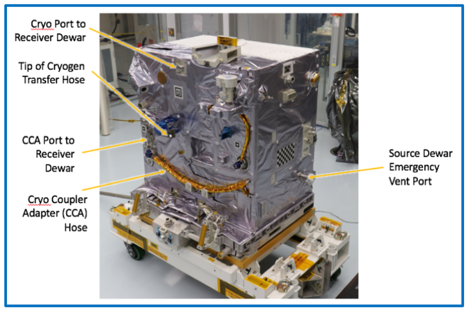
ABSTRACT

Robotic Refueling Mission-3 (RRM3) is an external payload on the International Space Station (ISS) to demonstrate the techniques for storing and transferring a cryogenic fuel—methane—on orbit. RRM3 was designed and built at the National Aeronautics and Space Administration/Goddard Space Flight Center (NASA/GSFC). Initial testing was performed at GSFC using liquid nitrogen and liquid argon. Final testing and flight fill of methane was performed at the NASA Kennedy Space Center (KSC) to take advantage of KSC's facilities and expertise for handling a combustible cryogen.

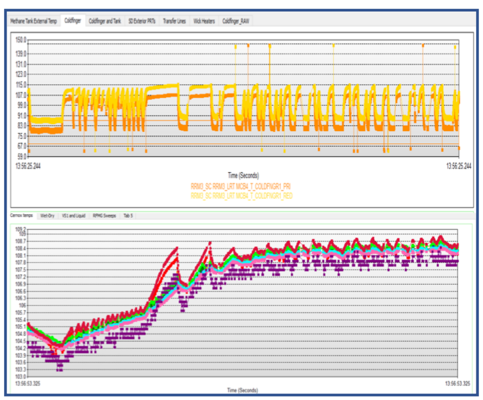
RRM3 Fuel Transfer Module (FTM) on the International Space Station (ISS).

SUMMARY

RRM3 demonstrated the ability to build and launch a hazardous cryogenic payload and operate it safely on the ground and on-orbit. New technologies such as autogenous pressurization, RFMG, and IMLI were successfully demonstrated on-orbit. RRM3 was able to demonstrate a key milestone of long-term cryogen storage in microgravity. However, the cryogenic portion of the mission ended prematurely due to electrical issues. Demonstration of the robotic tool interfaces will continue as the ISS schedule allows.



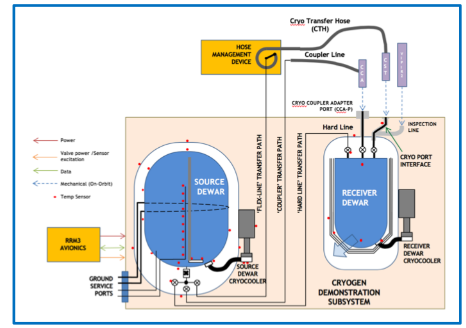
The RRM3 Fuel Transfer Module contains the Cryogenic Demonstration System. Flight plumbing interfaces are on the front panel for robot accessibility.



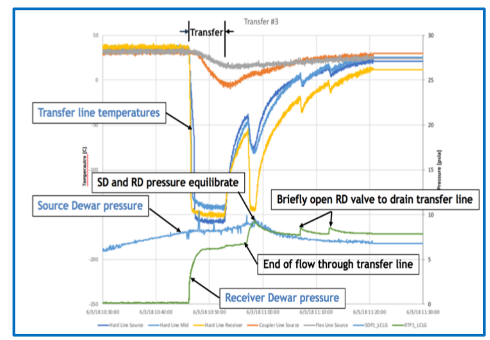
On-orbit temperature variation of the cryocooler cold-finger (top) and bulk methane temperature in the Source Dewar (bottom) over a 24-hour period on-orbit in thermostatic control mode. The bulk methane temperature is measured by an array of sensors located axially along a central post. On-orbit the bulk methane temperature was less strongly coupled to the cold-finger temperature than on the ground.

RRM3 ACCOMPLISHMENTS

- Zero boil-off storage of a cryogen--RRM3 demonstrated zero boil-off of liquid methane for nearly 6 months, including 4 months on-orbit.
- Mass gauging on the ground and in a microgravity environment through use of a Radio Frequency Mass Gauge (RFMG)
- Cryogen flow measurement with a turbine flowmeter was partially successful on the ground. When it registered flow it was accurate, but it did not always indicate flow. It was not used on-orbit.
- Liquid/vapor detectors similar to those used on the Superfluid Helium On-Orbit Transfer (SHOOT) experiment were able to distinguish between liquid and vapor both on the ground and on-orbit during storage. During ground transfers the results were ambiguous due to supersaturation of the fluid.
- Fluid management to orient liquid at the inlet to the transfer line in microgravity was not tested due to the inability to perform a transfer on-orbit.
- Autogenous pressurization using a wick and heater technique developed at GSFC was accomplished both on the ground and on-orbit.
- Integrated Multi-Layer Insulation (IMLI) was shown to be effective on-orbit in allowing the Receiver Dewar cryocooler to lower the tank temperature to <82 K, well below methane triple point of 90.7 K.
- Freezing of a cryogen in microgravity would have been demonstrated at the conclusion of a transfer. Both argon and methane were frozen during ground tests.
- Use of multiple robotic tools to accomplish cryogen transfer for both cooperative and uncooperative cryogenic systems will be demonstrated when the ISS schedule permits, although no cryogen transfer will occur.
- Five no-vent transfers were accomplished during ground testing with methane at KSC.



RRM3 Cryogen Demonstration System block diagram.



Example of a no-vent transfer during ground testing. Transfer line temperature drop indicates flow of liquid methane into the Receiver Dewar. Source Dewar pressure rose steadily for approximately 20 minutes using autogenous pressurization. The Receiver Dewar pressure remained below the Source Dewar pressure throughout the transfer, finally equilibrating at the completion of the transfer as the fluid reached saturation conditions.