Flight servicing of Robotic Refueling Mission 3

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Abstract. The Robotic Refueling Mission 3 (RRM3) payload launched aboard a SpaceX rocket en route to the International Space Station on December 5th, 2018. The Goddard Space Flight Center designed payload carried approximately 50 liters of liquid methane onboard, with a mission to demonstrate long term storage and transfer of the cryogenic fluid in microgravity. Kennedy Space Center (KSC) was tasked to design, fabricate, test, and operate a system equipped to fill an RRM3 dewar with liquid methane prior to launch. Though KSC has a rich history of fueling rockets and payloads, no such operations had previously been accomplished using liquid methane. As such, all of the hardware and processes had to be developed from scratch. The completed ground system design, along with the verification and validation testing will be outlined in this paper. Several challenges that were met and overcome during procurement of the high purity methane are described. In addition, unique and creative processes were developed to maintain payload cleanliness and enable flight servicing to occur in a non-traditional processing facility in order to facilitate cost savings for the project.

1. Introduction

The Robotic Refueling Mission 3 payload was designed at NASA's Goddard Space Flight Center with a mission to demonstrate zero loss storage and transfer of cryogenic methane in orbit. Prior to launch aboard a SpaceX commercial resupply mission to the International Space Station, NASA's Kennedy Space Center (KSC) was tasked to service the payload with approximately 50 liters of liquid methane. Pre-flight ground testing was also required using liquid methane in both an Engineering Demonstration Unit and on the RRM3 payload itself. Both of these ground tests were also accomplished at KSC. Details about the ground testing operations, will be presented at the 2019 Space Cryogenics Workshop by Boyle, et al [1].

2. Ground Support Equipment (GSE)

In order to load the RRM3 payload with 50 liters of liquid methane, ground support equipment had to be designed, built, and certified to interface with the flight hardware. Figure 1 is a block diagram of the complete system layout that was used for testing and ground servicing for flight. All of the ground operations were locally controlled by operators. No automation or software control was utilized for the ground support equipment operation. A 450 liter, Department of Transportation (DOT) approved, liquid methane dewar was used as propellant supply for the transfers. The methane servicing panel, shown in figure 2, was designed and built at KSC to control the flow of liquid methane between the supply dewar and the payload. The servicing panel also controlled the flow of nitrogen purge gas (supplied from the facility nitrogen panel) throughout the entire system and it provided pressure indications from various points in the system. The payload sat atop a high precision scale, which was used to determine methane mass aboard during servicing. A liquid nitrogen dewar was provided to supply the cooling loop heat exchanger that is part of the RRM3 source dewar. A vacuum pump was used to evacuate both the annular spaces of the payload's source and receiver dewars, as well at the liquid volume of the receiver dewar. Further details on the payload design and layout, will be presented at the 2019 Cryogenic Engineer Conference by Breon, et al [2]. A portable pneumatic regulation unit supplied the payload with a gaseous nitrogen purge, supplied from a facility nitrogen panel, in order to maintain an inert environment within the payload compartment. This inert environment enabled power-up of the payload for monitoring while maintaining compliance with the class 1 division 2 requirements of NFPA 497 [3]. A residual gas monitor was connected to an alarm to assure the oxygen content within the payload remained below 1% whenever the payload was powered. A clean air supply, located external to the building was ducted into a custom made enclosure which contained the payload. An oxygen monitor was place inside the clean enclosure to ensure the oxygen content there remained in the normal (20-21%) range, for the safety of those working inside the enclosure. Then entire system was connected with numerous flexhoses. All of the vent exits were plumbed together into a vent manifold system, which also included valves for sampling the percentages of oxygen and methane within the system. The exit of the vent manifold was plumbed and routed to a vent stack located approximately 35 foot away from the work building.

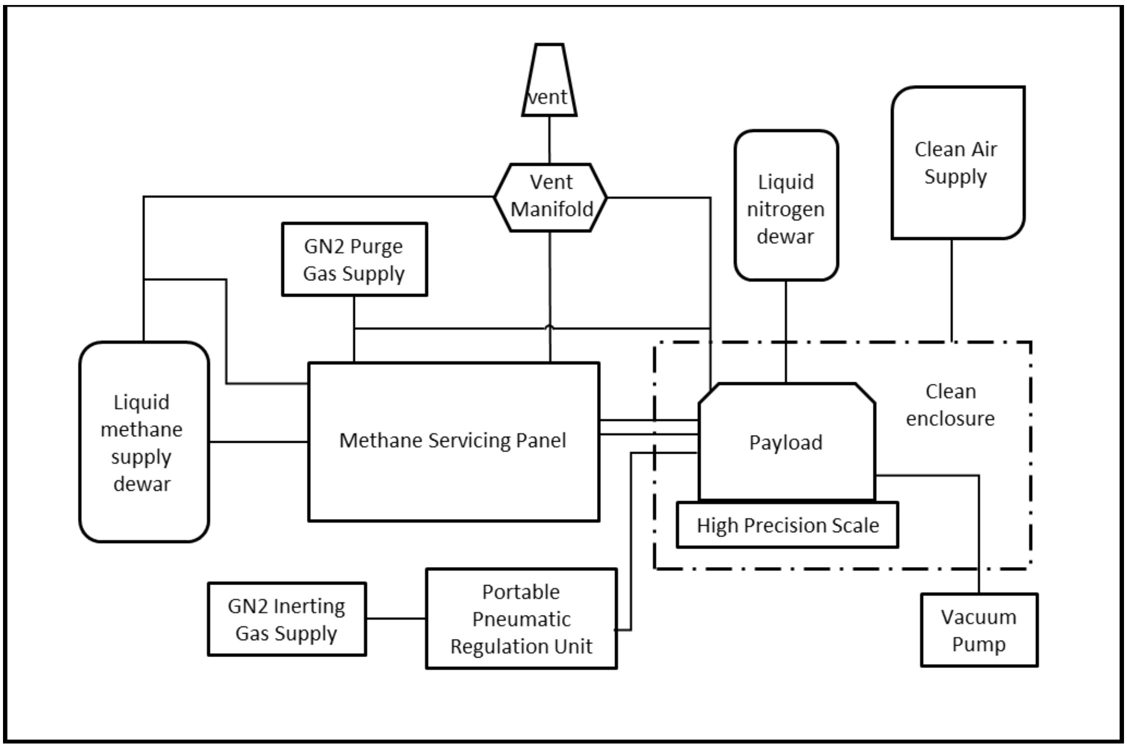

Figure 1. Methane test configuration block diagram

Figure 2. Methane Servicing Panel

3. Hazardous methane testing

In order to reduce costs, KSC was able to set up a testing space outside of the Payload Hazardous Servicing Facility (PHSF). The Fuel Transfer Building (FTB) is a small out building capable of handling the flow of hazardous fuels and is located behind the PHSF. It is, however, lacking in a clean room and other highly desirable features. The team was able to develop creative solutions to make the work space adequate to complete all of the testing and flight servicing activities. Figure 3 represents the layout of the facility with testing controls and equipment set-up identified. Two control areas were established for testing. The larger, 150 foot control was enforced during dynamic testing and cold flow. The smaller, 50 foot control was in effective at all times during testing. The test campaign required methane to reside in the payload for multiple days at a time. During these phases of testing, the 50 foot control limited access to of the test facility to test team members only, while allowing other work within the PHSF Perimeter to proceed unaffected. An ingress/egress log was kept to track personnel within the control area. A perimeter 15 foot around the building was considered to be Class 1 Division 2 zone due to multiple personnel and large roll-up doors, per NFPA 497 [3]. The exhaust of the vent outlet was treated as a Class 1 Division 2 zone, and barriers were established 15 foot around the vent exhaust to prevent personnel access to the area. A portable command trailer was brought in for commanding and monitoring the payload when it was powered. It was set up approximately 18 foot away from the building, as shown in figure 3. The HVAC system, which provided clean, dry air to the payload's clean enclosure was set-up behind the command trailer, and a portable, air conditioned break room was also provided.

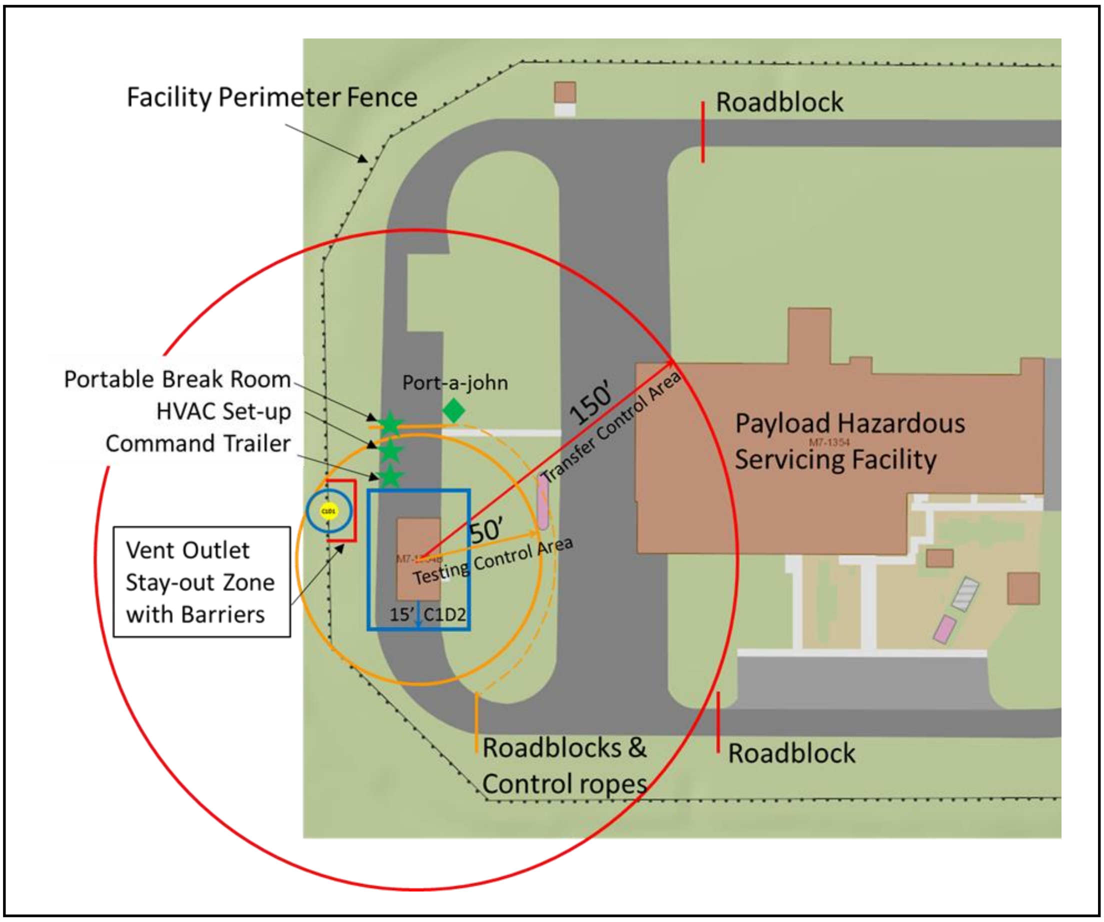

Figure 3. Facility and hazardous control layout for testing

Figure 4 shows the layout of the equipment within and immediately around the Fuel Transfer Building. Due to local control of the hazardous flow of liquid methane, GoPro video recorders were used to record the testing activities. They were place inside explosion proof enclosures to make them suitable for the Class 1 Division 2 environment. The grated area shown in figure 4 represents a depression in the floor of the FTB, intended to provide drainage. Because this area is below grade, it was considered a Class 1 Division 1 environment. Therefore, a tee was established on the clean air supply line and this tee was ducted into an opening in the grating to provide positive flow through the depressed space to prevent any potential collection of methane. All equipment was grounded with grounding straps, and minimal resistances were verified prior to the introduction of methane to the building. Dashed lines along the perimeter of the building, in figure 4, represent access points. There are two personnel ingress/egress access points, and two large roll-up doors. The RRM3 payload was brought into the building while sitting upon a low profile dolly, using a forklift, through one of the large roll-up doors. It was then placed upon the high precision scale and the clean enclosure was subsequently rolled into place. After a clean environment was verified, the protective bagging was removed to allow access to the payload, as required. A pass through panel was designed and built which allowed the vent line, the clean air ducting, instrumentation wiring, and other items to transition outside of the building through the roll-up door access point.

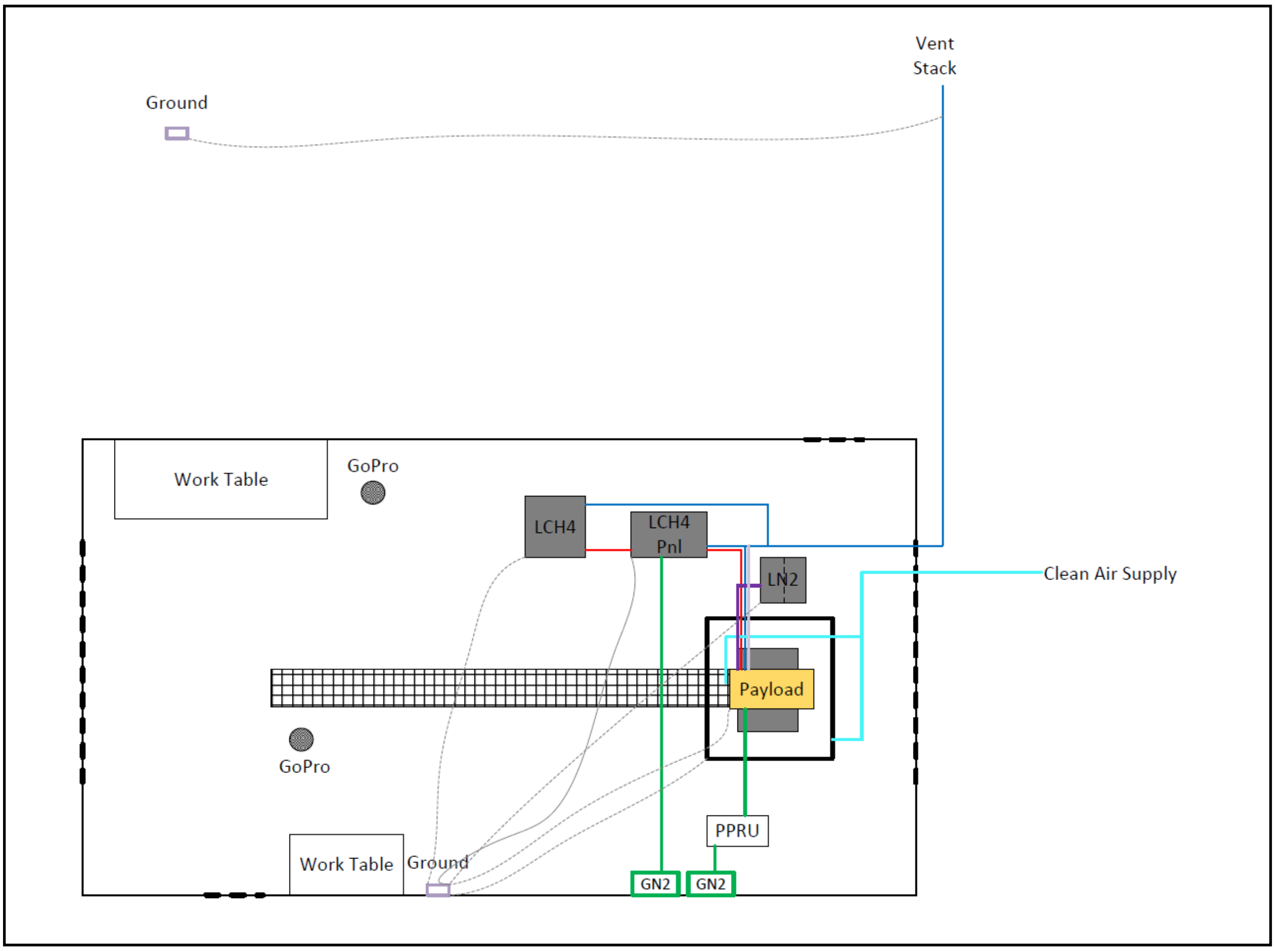

Figure 4. Fuel Transfer Building equipment layout

A photograph of the test set-up within the FTB is shown in figure 5. Grounding straps can be seen taped to floor to prevent trip hazards. Grated platforms covered a mass of flexhoses to provide safe ingress and egress through the personnel access door located nearby. The clean enclosure was transparent to provide visual insight to the payload and those working within the enclosure at all times.

Figure 5. Test set-up photograph inside the Fuel Transfer Building

4. Methane procurement

Liquid methane is typically procured in bulk, by tanker loads. However, for RRM3 testing and flight servicing, only a relatively small amount of methane was required. In order to facilitate liquid methane flow required for RMM3 operations, a Chart LNG Microfueler (450 liter capacity) was procured and is shown in figure 6. This palletized, DOT rated dewar was sent to the methane provider, filled, and then returned to KSC. The RRM3 team at Goddard Space Flight Center requested methane with a purity of 99.9%, consistent with liquid propellant grade B [4]. An extensive national search by KSC's propellant acquisition team found only one company within the United States willing to provide grade B methane. This provider supplied grade B methane for both the Engineering Demonstration Unit testing as well as the initial RRM ground testing at Kennedy Space Center. However, they were unable to provide grade B liquid methane when the time came for flight servicing. With no other grade B liquid options available, the team accepted no-grade methane from an LNG provider. The methane that ultimately flew aboard RRM3 was 98.2% pure.

Figure 6. LNG Microfueler, flowing liquid methane to the RRM3 payload

5. Conclusions

Configuration of the ground support equipment needed to support servicing the RRM3 payload with liquid methane required creative use of existing hardware as well the design and fabrication of unique hardware. Many other distinctive challenges presented during the test set-up and methane procurement phases of testing. All of these challenges were met with innovative solutions which ultimately led to the successful test and servicing of the RRM3 payload.

Acknowledgments

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References

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