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Concept for on orbit liquid hydrogen test bed

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ABSTRACT

There is growing interest in the utilization of cryogenic propellants for future space missions. The utilization of these propellants for long duration in space presents substantial challenges in fluid management in the low g environment. Lockheed Martin (LM) is developing the concept for a space borne system for demonstration of long term storage, various fluid management tests involving control of tank pressure, location and identification of vapor and liquid phases, venting in low g, mass gauging, and extension of life with cryocoolers and location of liquid for transfer. In addition the concept includes autonomous coupling and hydrogen transfer from tank to tank. The concept is based on a flight qualified flight proven hydrogen Dewar design from a previous program The concept for this system is described.

1. Introduction

With the completion of construction on the ISS and the retirement of the Space Shuttle, human space flight is in the position to explore more distant and ambitious destinations. Arguably the most interesting path is following the trajectories of robotic missions to asteroids, the Moon, Mars, and beyond. Cryogenic propulsion provides the necessary performance for Earth departure, and it would facilitate Mars returns and other difficult deep space missions. Presently the use of cryogenic propellants is limited due to high boil-off rates and lack of maturity for low gravity fluid management. Moreover, experience with transfer of cryogenic propellants is limited, impacting the technical feasibility of future propellant depots, for enabling deep space missions.

A Cryogenic Fluid Management (CFM) demonstration system will pave the way for full-scale propellant storage systems, providing utility to diverse organizations including the National Aeronautics and Space Administration (NASA), the Department of Defense, commercial satellite providers, and international partners. NASA, along with its international partners for potential future human and robotic exploration mission collaborations, stands to gain significant mission capabilities from in-space cryogenic storage and transfer.

Lockheed Martin (LM) is developing a test bed for demonstration of CFM technologies. The approach taken is an architecture with a low-risk platform for the cryogenic payload. The cryogenic payload incorporates LM's Dewar thermal protection technology and heritage designs in order to permit a long-term, low-risk test bed in space. This payload represents many of the technologies needed for the very large tanks of the mission scenarios.

2. Relevant technology base at ATC

Cryogenic propellant storage and fluid management technology at LM was active in the 1960s and 1970s, but was largely discontinued until recent renewed interest in space exploration. Long term orbital storage of cryogens at the Advanced Technology Center (ATC) has been demonstrated in the interim on instrument cooling systems, which include cryogens such as hydrogen, methane, ammonia, and helium for orbital missions in excess of 5 years.

Cryogenic propellant systems employed to date have very short storage requirements, typically days. Aspects of both long term instrument cooling and present short term propellant systems must be melded together to achieve an optimum system for long term propellant storage which includes thermal efficiency, cost, weight and reliability.

Lockheed Martin has developed twenty systems for orbital operation, which include hydrogen, methane, ammonia, carbon dioxide, and superfluid helium. These systems circumvent the issue of venting the sub critical fluid without liquid loss, by operating the cryogens in the solid condition so that the gas could be directly vented by sublimation. The only exception was the operation with superfluid helium, which utilized its unique properties by venting through a porous plug. A summary of systems developed for instrument cooling at ATC in space is shown in Fig. 1.

All of these systems utilized conductive shields cooled by vented vapor, composite support tubes, composite plumbing lines and a hard vacuum shell. The insulation systems utilized double aluminized Mylar with silk net spacers. Because of the dominant importance of good multi-layer insulation (MLI) performance, the

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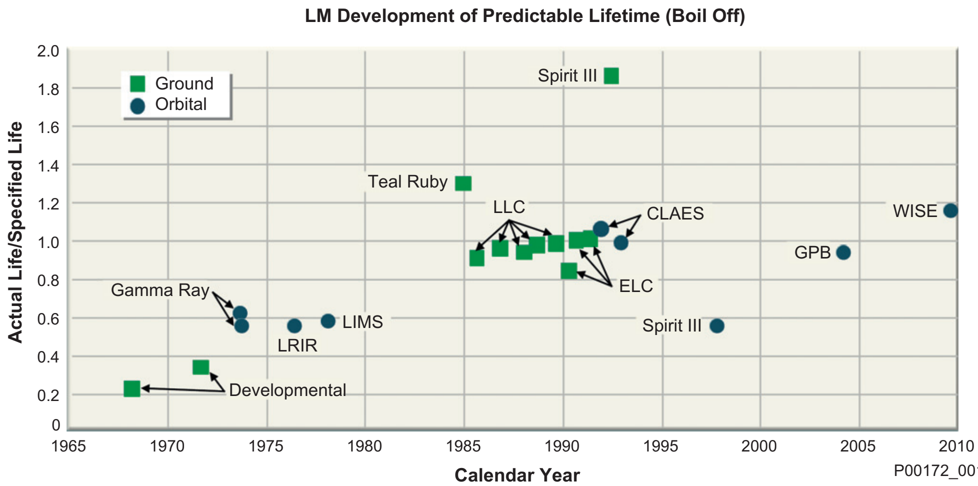

Fig. 1. LM development of predictable lifetime (boil-off). Good performance predictability took two decades to achieve.

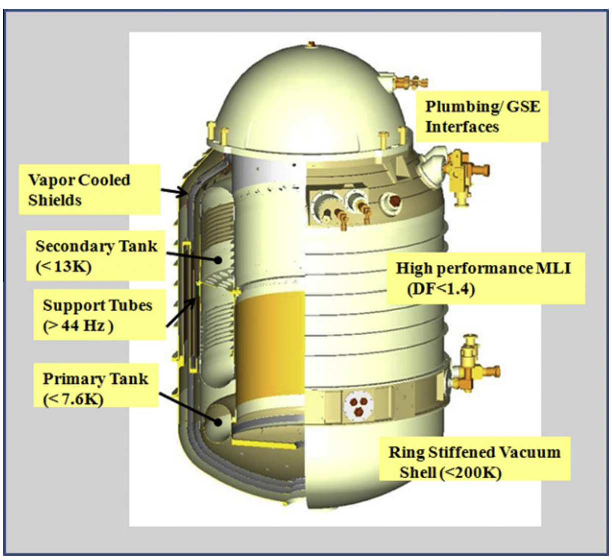

Fig. 2. Characteristics of recent instrument cryostat (WISE) at LM. This technology along with other LM hydrogen Dewars forms the basis for the CFM demonstrator test bed.

layers were applied one at a time with joints taped for the Mylar and sewn for the spacers. This technique consistently resulted in excellent performance approximately 50% above the ideal flat plate performance. The ratio of actual insulation performances to that of ideal flat is referred to as the Degradation Factor (DF). The evolution of the systems to reliable and predictable performance required approximately two decades as shown in Fig. 1 with substantial support from LM independent research. It should be noted that the actual in-flight instrument duty cycle or environments usually turn out different then that used for ground testing, which results in different ground and orbital lifetimes as can be seen by the data in Fig. 1 for Spatial Infrared Imaging Telescope (SPIRIT III). A system recently operated in orbit is the Wide-Field Infrared Survey Explorer (WISE) instrument, which was cooled by a two stage solid hydrogen system developed by LM. Its configuration is shown in Fig. 2 in which the advanced thermal isolation technology is shown.

This system implemented extensive advanced thermal isolation technology and utilized a vacuum shell, which was cooled to 200 K in orbit. The hydrogen was frozen by circulation of LHe through cooling lines on the tanks, which utilized the aluminum tank shell as the extended heat exchanger.

These examples of long-term cryogenic storage prove the capability to extend these technologies to long life cryogenic propellant

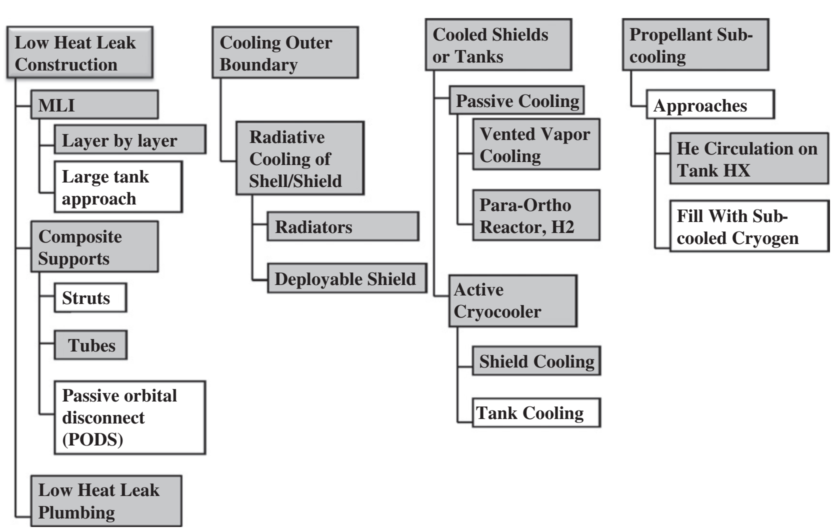

Fig. 3. Required thermal storage technologies for long duration cryogenic propellant storage. Items shaded in gray have been selected for the LM CFM approach.