the full-scale test article have shown that this occurs within 300 seconds with a helium flow of 60 purge volumes per hour.

The automatic mode of operation is used during tank filling and ground hold operations and during re-entry MLI repressurization. Helium is supplied to the purge gas distribution system upon demand. Purge bag pressure is maintained between 0.5 and 1.5 psid by the valve pressure switches, ensuring that crushing pressure loads will not be imposed on the MLI during re-entry.

The vent mode of operation is used during the ascent portion of the mission. The vent valve is locked open and the supply and bleed valves are locked closed, allowing helium purge gas in the MLI to be vented overboard rapidly as ambient pressure decreases with increasing vehicle altitude. Experiments with full-scale test article show that the Superfloc MLI system will vent down to a pressure of less than 10^{-4} torr in less than 180 sec with the ambient pressure at 10^{-5} torr.

Experimental Evaluation

The reusable cryogenic storage system thermal performance evaluation was conducted by evacuating the MLI to a pressure of less than 2.5×10^{-5} torr. A Shulz-Phelps vacuum pressure transducer embedded in the MLI was used to monitor MLI interstitial pressure. The test tank was allowed to equilibrate for three days. Thermal equilibrium was defined as that time when no MLI layer temperature varied by more than ± 1R during a continuous 10-hr period. Tank pressure was maintained within a 0.0056 psi band during thermal equilibrium testing. The propellant boiloff—and, consequently, equilibrium heat leak—was measured with a hot-film anemometer to be 43 Btu/hr, with the ρk at 6.44×10^{-5} Btu-lb/hr-ft^{4}R.

Leonhard and Hyde[2] have surveyed the available data on thermal performance of flight-type MLI cryogenic storage systems and obtained the ρk product for the five flight-type single-use MLI systems that had actually been fabricated, installed on flight-type tanks, and thermal-performance tested as of their writing. They obtained flight-type tank installed performance data for each system (Fig. 2). The performance of MLI has been improving with time of development. The measured thermal performance for the reusable goldized Kapton Superfloc system (D-G-K Dacron needles) is significantly better than that of the best single-use system (D-A-M Dacron needles) previously tested in 1969 and provides a major improvement in thermal performance capability for installed flight-type MLI systems.

The reusability of the new goldized-Kapton Superfloc MLI system has been demonstrated by repeatedly simulating the environments of the Space Shuttle flight cycle. A typical flight cycle consists of a ground purge of MLI with helium gas, a venting evacuation of the purge gas in the MLI to space vacuum conditions, and a re-entry repressurization and heating simulation following the Shuttle re-entry flight profile. Re-entry heating raises the system surface temperature during each cycle to 810R. Liquid hydrogen is contained in the tank during each simulated flight cycle.

A total of 100 flight simulation cycles has been run with space equilibrium thermal performance tests conducted intermittently during the testing to evaluate the effects of flight environments on the MLI thermal performance. MLI space equilibrium thermal performance is shown in Fig. 3 as a function of the number of flight simulation cycles performed. A degradation of 23% in thermal performance was found from the "as new" condition to the 50-flight-cycle condition. After 52 cycles, testing was halted and a partial visual examination was made of the MLI system in the vicinity of the purge bag door. Several links joining the blanket gores were found to be broken, causing three seams to separate slightly (about 2 by 0.25 in.). After the seams were repaired, but before resumption of testing, a high-temperature (685R)/vacuum soak was performed on the tank and MLI to remove any absorbed moisture.

A new basepoint thermal equilibrium test showed that, after seam repairs and MLI back-out, the MLI returned to nearly its "as new" condition. Another 48 life cycles were performed on the cryogenic storage system and the thermal performance was found to degrade slightly (approximately 9%) from the new, 52-cycle basepoint value.

Complete disassembly and visual examination were performed following completion of all testing. The only system damage noted was failure of one MLI blanket fiberglass support pin, three twin-pin links, and several goldized tape bond joints used as secondary seam closing support. The effect of these minor failures was to allow blanket gore seams to "gap" locally and was undoubtedly the cause of the degradation in the system performance with increasing system service life.

Conclusions

A new, completely reusable flightweight cryogenic storage system has been developed and demonstrated that represents a significant improvement in thermal performance over previously developed single-use flightweight systems. Simulated Space Shuttle life cycle testing produced some degradation in thermal performance due to the MLI blanket gore seam "gapping." The use of overlapping blanket face sheets and positive seam closure (e.g., Velcro fasteners) should eliminate this problem in future designs. The details of the design and performance data for the recently developed reusable cryogenic storage system are presented in Ref. 3.

References

[1] Leonhard, K. E., "Cryogenic Insulation Development, Final Report," Contract NAS 8-26129, Convair Rep. DDB72-004, 28 July 1972, General Dynamics Corp., San Diego, Calif.

[2] Leonhard, K. E. and Hyde, E. H., "Flightworthy, High-Performance Insulation Development," *Cryogenic Technology Magazine*, Jan./Feb. and March/April 1971.

[3] Walburn, A. B., "Development of a Reusable Flightweight Cryogenic Storage System," AIAA Paper 74-726, Boston, Mass., 1974.

Photographic Pyrometry in an Aeroballistic Range

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IN Ref. 1, a novel method using pyrometric techniques to measure surface temperatures on hyperballistic models has been developed for the AEDC ballistics range. Accurate measurements of surface temperature and its downrange variation would be invaluable for deducing quantitative heating rates. However, a major weakness of the method is the inability to differentiate between radiation (in the sensitive bandwidth of the pyrometer) from the hot model surface and extraneous radiation from the shock layer, boundary layer, or chemilumenescence resulting from gas-surface reactions. Chemiluminescent reactions between the hot boundary layer gases and ablating metallic surfaces are particularly serious and may result in anomalously high "surface" temperature measurements.[2]

Received June 2, 1975. Work supported by DNA Contract DNA001-75-C-0048. M. Rubenstein served as technical monitor. Acknowledgements are made to M. Krumins of the NSWC and G.R. Jones of AEDC for their contributions in implementing the purge boxes in their respective ranges.

Index categories: Radiatively Coupled Flows and Heat Transfer; LV/M Aerodynamic Heating; LV/M Simulation.

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To avoid these problems associated with pyrometric measurements, a helium purge box is currently being used in a series of tests designed to deduce hypersonic heat transfer rates on tungsten nosetips in erosive environments.[2,3]

The solution for alleviating some of the aforementioned problems is conceptually quite simple: to minimize shock layer and other gaseous radiation and chemiluminescence effects, the shock strength must be reduced, and a chemically inert gas with high electronic excitation levels as well as high ionization potential must be used. Helium satisfies all of these requirements for the range of conditions which are of interest for typical re-entry problems, (note that the shock strength in helium is considerably less than in air for the same projectile speed since the helium sound speed is three times that of air). However, in order to properly simulate the aerodynamic heating, the model must fly through atmospheric gases. Thus, the pyrometer image is recorded while the model is flying through a small region purged by helium (in the vicinity of the pyrometer focal point). In the tests conducted at the NSWC 1000 foot range,[2] and tests currently underway at AEDC in Range G, [3] the helium purge region is basically a small open ended cylinder which has a manifold with holes fed by helium to purge the interior of the cylinder of possible reactive gasses. The change in surface temperature as the projectile passes through the helium can be shown to be quite small for the short residence times encountered.[3] The mass flow of helium required also has a negligible effect on the primary range gas composition. A major uncertainty is the spectral emissivity of the radiating model surface. However, the temperature error due to this can be calculated given the uncertainty in surface emissivity. The use of pyrometric techniques along with a helium purge box should greatly enhance the capabilities and utility of the ballistics range.

References

[1] Dugger, P. H., Bock, O. H., Enis, C. P., and Gilley, B. W., "Photographic Pyrometry in an Aeroballistic Range," *Proceedings of the SPIE 16th Annual Technical Meeting*, Oct. 1972, San Francisco, Calif.

[2] Shih, W.C.L. and Courtney, J.F., "DNA Ballistic Range Measurements of Aerodynamic Heating in Erosion Environments", Monthly Progress Report, SAI-76-513-LA, 14 March 1975, Science Applications, Inc., El Segundo, Calif.

[3] Shih, W.C.L., Courtney, J.F., "AEDC Ballistics Range G Measurements of Aerodynamic Heating in Erosion Environments," Monthly Progress Report, SAI-76-518-LA, 23 April 1975, Science Applications, Inc., El Segundo, Calif.