CRYOGEN INSULATION TECHNOLOGY

REVIEW FOR THE SPACE SHUTTLE

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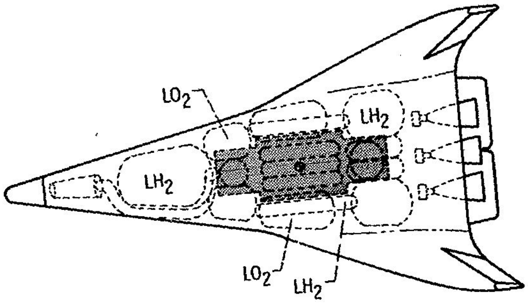
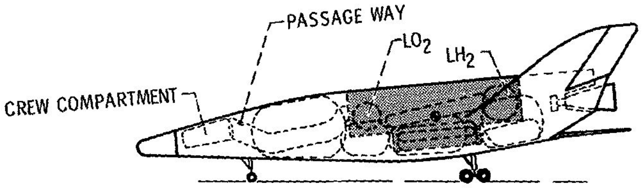
INTRODUCTION

The cryogenic insulation required for a reusable space shuttle vehicle falls into two general categories. These are (1) the insulation required for the ascent LH_2 tanks on both the booster and orbiter and (2) the insulation required for the on-orbit propellant tanks within the orbiter. This figure shows one possible arrangement of propellant tanks in a typical orbiter. The larger LH_2 and LO_2 tanks contain the ascent propellant and the smaller tanks contain the on-orbit propellant. This paper provides a brief description of the technology available for the insulation systems required for the LH_2 ascent tanks and the LH_2 and LO_2 on-orbit tanks. In addition, programs to provide the technology necessary to achieve acceptable insulations for the space shuttle, that are already in progress or planned for the immediate future, are identified.


LO_2
LH_2
LH_2
LO_2
LH_2


PASSAGE WAY
LO_2
LH_2
CREW COMPARTMENT

Environment and Design Considerations

The environment to which the shuttle will be exposed is, in several respects, similar to that of the Saturn vehicle. The ground hold and ascent portions of the flight for both the shuttle booster and shuttle orbiter are similar to those of the Saturn II and Saturn IV-B vehicles. Where the environment for the shuttle differs from that of the Saturn is in the requirements for stay time in orbit and the need to withstand the stresses of re-entry in a reuseable condition. The shuttle environment is summarized in this figure. The 250°F external temperature in orbit is considered to be a maximum temperature and would result from using currently available exterior thermal control coatings. If coatings with lower solar absorptivity to emissivity ratios that can withstand rigors of flight in the earth's atmosphere without degradation become available, this temperature could approach 100°F.

The design considerations that must be included in the selection of a cryogenic insulation are minimum weight, ability to withstand the rigors of 100 flights while maintaining adequate thermal performance and structural reliability, be easily inspected, require minimum repair effort, and assure satisfactory performance on the next flight.

As might be expected, the problem of providing a reuseable insulation system is going to be a primary concern of the technology efforts directed toward developing a cryogenic insulation for the shuttle. It is this phase of the flight profile which to date has had the least effort expended and is therefor the least understood.

CRYOGENIC INSULATION

SHUTTLE ENVIRONMENT

GROUND HOLD - 1 ATM MOIST AIR; ≈70° F EXTERNAL TEMP

ASCENT - RAPIDLY DECAYING EXTERNAL PRESS; >70° F EXTERNAL

ORBIT - VACUUM EXTERNAL; 250° F EXTERNAL; 7-30 DAYS

REENTRY - RAPIDLY INCREASING EXTERNAL PRESS → 1 ATM MOIST AIR ≫ 70° F EXTERNAL

DESIGN CONSIDERATIONS

WEIGHT - BOILOFF WT + TANK WT + INSULATION WT

PERFORMANCE - INFLUENCES WT; FUNCTION OF PROP SUBSYSTEM

REUSE - 100 FLIGHTS (TEMP CYCLES; DAMAGE FROM MOISTURE OR AIR CONDENSATION)

REFURBISHMENT - 2 WEEK TURN-AROUND; REQUIRE EASILY INSPECTED SYSTEM; EASILY CHECKED-OUT (OR PREDICTABLE) SYSTEM

CS-53043

Ascent Tanks - Internal Insulation

A considerable amount of experience has been gained on a reinforced foam insulation system installed internally on the LH_2 tank of the Saturn S-IVB stage. The accompanying figure shows a schematic of that system. Dearing[1] reports that the thermal conductivity increases with time due to the intrusion of hydrogen gas into the pores of the foam. The seal presently being used is adequate for Saturn flights but in order to be suitable for the shuttle, improvements must be made. NASA has recently contracted for work to be done to make this internal foam system available to the shuttle. In addition to improving the seal, the insulation system will be evaluated for effects of varying thickness and increased hot side temperature. Temperature as high as 300°F may be encountered during re-entry and an evaluation of material capabilities to that temperature is required. As long as hydrogen gas permeates the internal seal, the chance for rapid expansion of this gas with attendant damage to the insulation can occur during re-entry. The importance of this factor will be more fully determined. Also to be investigated are (a) adhesives that have adequate strength at both high and low temperature and (b) inspection and repair techniques to be employed between flights.

Another insulation system under consideration for use inside LH_2 tanks is one that is currently under investigation by Lewis Research Center at the Martin Company under Contract NAS3-12425. This program is investigating the principle of the internal gas layer barrier for the methane tanks of the SST. By bonding a series of cells, in this case plastic honeycomb, to the tank wall and covering it with a facing sheet which has one small pore for each cell, a surface tension barrier is set up at each pore and each cell fills with gas. By further filling each cell with a material to reduce convection and radiation, a thermal conductivity equivalent to static gas can be achieved. This system is attractive for the space shuttle LH_2 tanks because high temperature resistant materials are presently available, and venting during reentry should be no problem due to the open pore nature of the system. As with the foam system, work to provide thermal data on varying thicknesses, high temperature effects, effect of many operational cycles, and inspection and repair techniques is required and NASA has recently awarded a contract to start this work.

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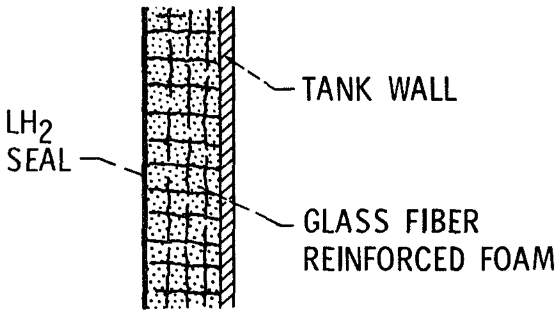
[1] Dearing, D.L. Paper B-8, "Development of the Saturn S-IV and S-IVB Liquid Hydrogen Tank Internal Insulation", Advances in Cryogenic Engineering, Vol. II

INTERNAL INSULATION

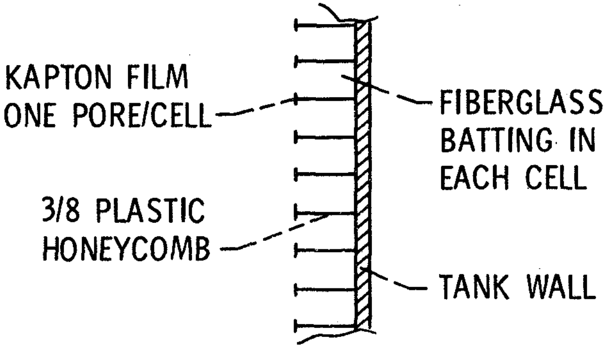
S-IV B SYSTEM



6.0 LB/FT^3

k = 0.025-0.035 BTU/HR-FT-^{0}R
(EXPOSURES <50 HR)

SST METHANE TANK (NAS3-12425)



4.0 LB/FT^3

k = 0.05-0.06 BTU/HR-FT-^{0}R
(GH_2 CONDUCTIVITY)

WORK REQUIRED

1. EFFECTS OF INCREASED THICKNESS
2. DEVELOPMENT OF HIGH TEMP ADHESIVES
3. APPLICATION AND INSPECTION FOR LARGE, COMPLEX TANKS
4. FOAM VENTING DURING REENTRY

CS-53044

Ascent Tanks - External Insulation

In addition to the experience available on the internal foam system used on the S-IVB, there is a significant amount of experience on the external foam system used on the S-II[2]. Although there were several insulations developed for the S-II, this is the most recent one and is currently used on the Apollo launches. In developing this system for the S-II, a great deal of work was done on temperature cycling effects and evaluating the exterior seal for temperature effects during launch. A peak temperature of 525°F is experienced during a Saturn launch and this coupled with exposure to the atmosphere has resulted in erosion of the insulation surface. Since the tanks of the shuttle will be protected by the vehicle structure, erosion is not expected to be a problem, but resistance to high temperature for both launch and re-entry must be evaluated. In addition, work will be needed to determine the effect on performance of many operational cycles, and to develop the necessary inspection and repair techniques. To avoid air and moisture condensation during operation in the atmosphere, a dry gas purge system may be required. The extremely low thermal conductivity and light weight achieved for this system makes it very attractive for the shuttle and NASA presently has plans to contract for this effort during FY '71.

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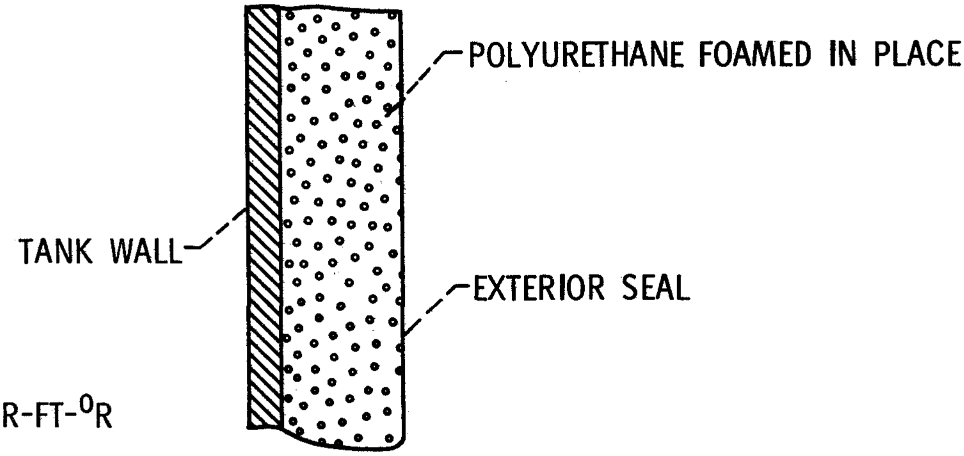
[2] Smith, M.E. and Mack, F.E. "High-Performance Spray Foam Insulation for Application on Saturn S-II Stage", Space Division, North American Rockwell Corporation.

EXTERNAL INSULATION–ASCENT TANKS

S-II FOAM



2.2 LB/FT^3
K = 0.011 BTU/HR-FT-^{0}R

ADVANTAGES - EASILY INSPECTED & REPAIRED

WORK REQUIRED

1. PURGE SYSTEM DEVELOPMENT
2. TEMP CYCLING EFFECTS
3. HIGH TEMP MATERIALS DEVELOPMENT
4. APPLICATION, INSPECTION, & REPAIR ON LARGE COMPLEX TANKS

CS-54831

Multilayer Insulation (MLI)

The on-orbit tanks hold the LH_2 and LO_2 propellants for the Orbital Maneuvering System and the Altitude Control System, and the LH_2 fuel for the Air Breathing Propulsion System. These tanks require an insulation system with a performance level many times better than those previously discussed for the ascent tanks.

Multilayer insulations which consist of alternating radiation shields and low conductivity spacers have been studied by several investigators.[3] [4] [5] Typical results of laboratory data are shown in this figure taken from ref. 5. The radiation shields are aluminized mylar sheets 1/4 mil thick. Doubly aluminized mylar (DAM) is mylar aluminized on both sides and singly aluminized mylar (SAM) is mylar aluminized on one side only. These systems were chosen for comparison because each has 20 reflecting surfaces. As can be seen there is not a significant difference between any of the systems at low compressive loads. However, as the contact pressure between the layers increases causing more direct thermal shorting, each system reacts differently. The goal of most of the investigations to date has been to try to understand the heat transfer process through multilayer insulations and at the same time minimize the effects of variations in performance caused by differing application techniques which result in more or less thermal contact between layers of MLI.

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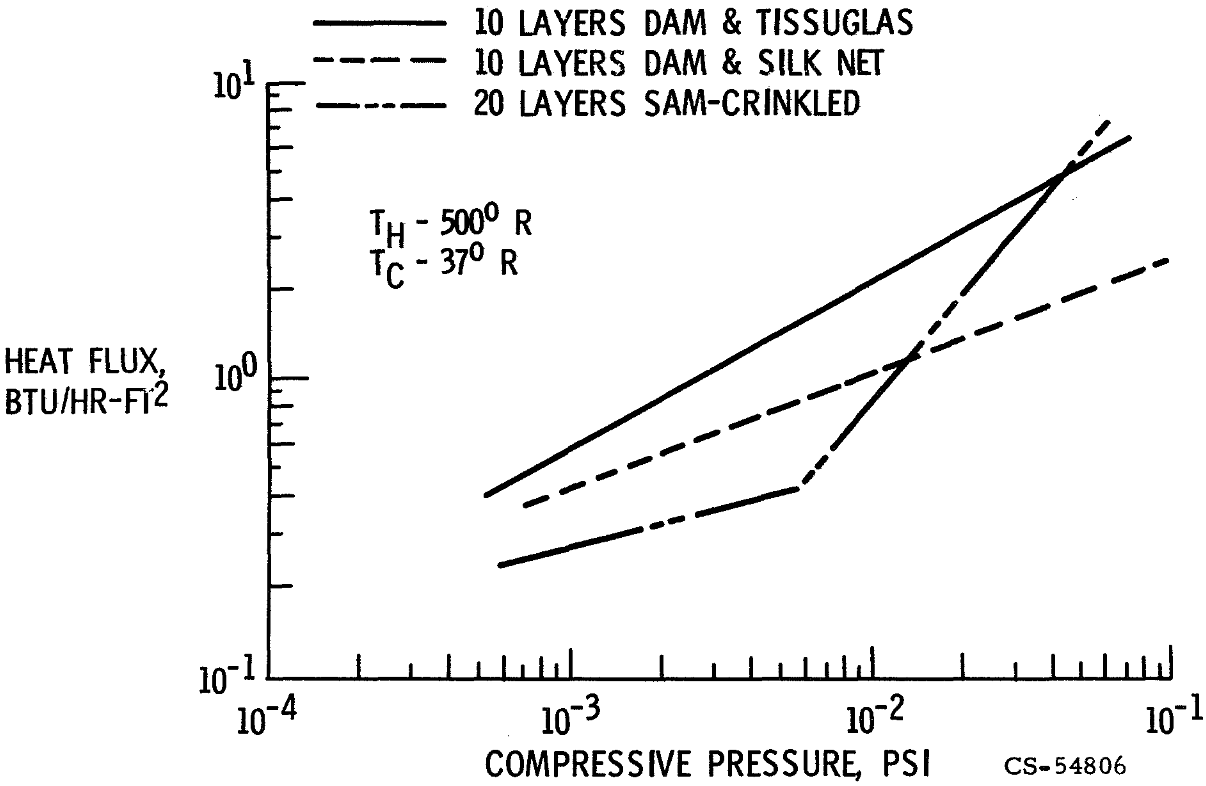
[3] "Advanced Studies on Multi-Layer Insulation Systems", Final Report Contract NAS3-6283, NASA CR-54929, Arthur D. Little, Inc.

[4] "Investigation of High Performance Insulation Application Problems", Fourth Quarterly Report Contract NAS8-21400, MDC G0274, McDonnell Douglas Astronautics Company - Western Division.

[5] Cunnington, G.R., Keller C.W. and Bell, G.A. "Thermal Performance of Multilayer Insulations," Interim Report Contract NAS3-12025, NASA CR 72605, Lockheed Missiles and Space Company.

HEAT FLUX VS COMPRESSIVE LOAD FOR MLI



CS-54806

Heat Flux Vs. Layer Density for MLI

Performance of multilayer insulation expressed as a function of compaction pressure is not particularly useful. An insulation system installed on a tank can not readily be inspected to determine the compressive load between layers. Thus an effort was made[6] to relate compaction pressure of multilayer insulations to layer spacing or density. An example of the results is shown in this figure. Several insulation systems (of which only one example is shown) were tested in a flat place calorimeter. Insulation systems with varying numbers of radiation shields were tested at four different combinations of hot and cold boundary temperatures and at a minimum of four layer densities. The expression shown was obtained by using a least squares fitting technique.

With an expression of this type available for a particular tank mounted insulation and having made a determination of layer density by inspection a better estimate of thermal performance can be made.

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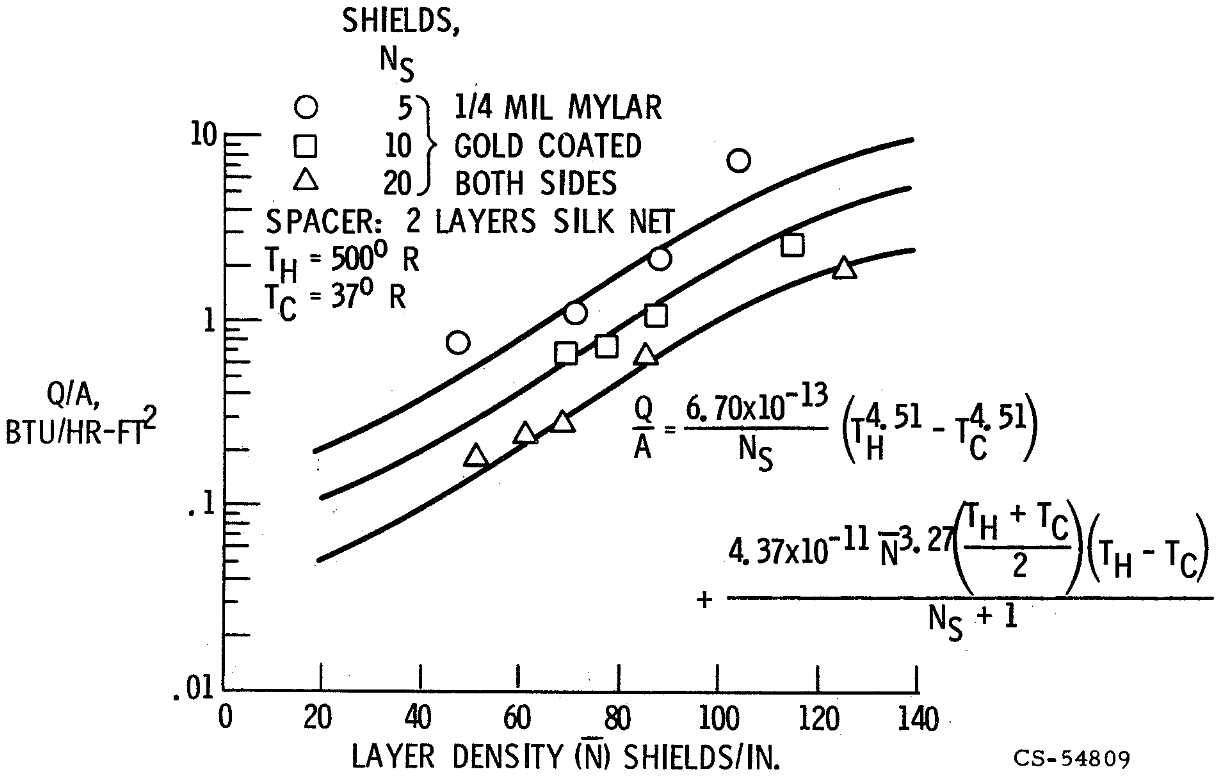
[6] Ibid

HEAT FLUX VS LAYER DENSITY FOR MLI



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Tank Tests vs Flat Plate

The ability to predict tank installed MLI performance from flat plate calorimeter data is illustrated in this figure. A four foot diameter tank was insulated with gold coated mylar radiation shields and silk net spacers [7]. A total of twenty radiation shields were carefully applied such that there was no direct contact between individual shields as determined by electrical resistance measurements. The tank was inspected by X-ray photographs to determine layer density. Following inspection, it was installed in a vacuum chamber. After attainment of minimum chamber pressure, the tank was filled with cryogen. As in the calorimeter tests, two hot boundary temperatures and two cold boundary temperatures were used to obtain four different boundary temperatures. Boiloff tests were performed at each set of boundary temperatures. The vacuum chamber pressure was then returned to one atmosphere completing the test of the 20 layer system. Ten layers of insulation were removed and the X-ray process was repeated. Four boil-off tests were run as in the twenty layer tests. Similarly four boil-off tests were run with five layers of insulation on the tank. As can be seen from the figure, the five layer and twenty layer tests were close to the prediction based on the flat plate Calorimeter results. The ten layer system performed about 50% higher than predicted. In addition it should be noted that there was an apparent change in layer density between tests. This should not be surprising as the insulation system was first exposed to decreasing pressure and then increasing pressure between X-ray measurements. Further, it should be noted that no knowledge could be obtained of the actual layer density during test. Thus, although X-ray measurements were made prior to each test, the insulation system was exposed to a pressure decay after it was measured and before it was tested. Also it was exposed to a pressure increase after test and before it could be measured again. Although neither of these pressure excursions were as severe, either as to rate or temperature of a shuttle flight profile, the concern for an exposed multilayer insulation on the shuttle tanks should be obvious.

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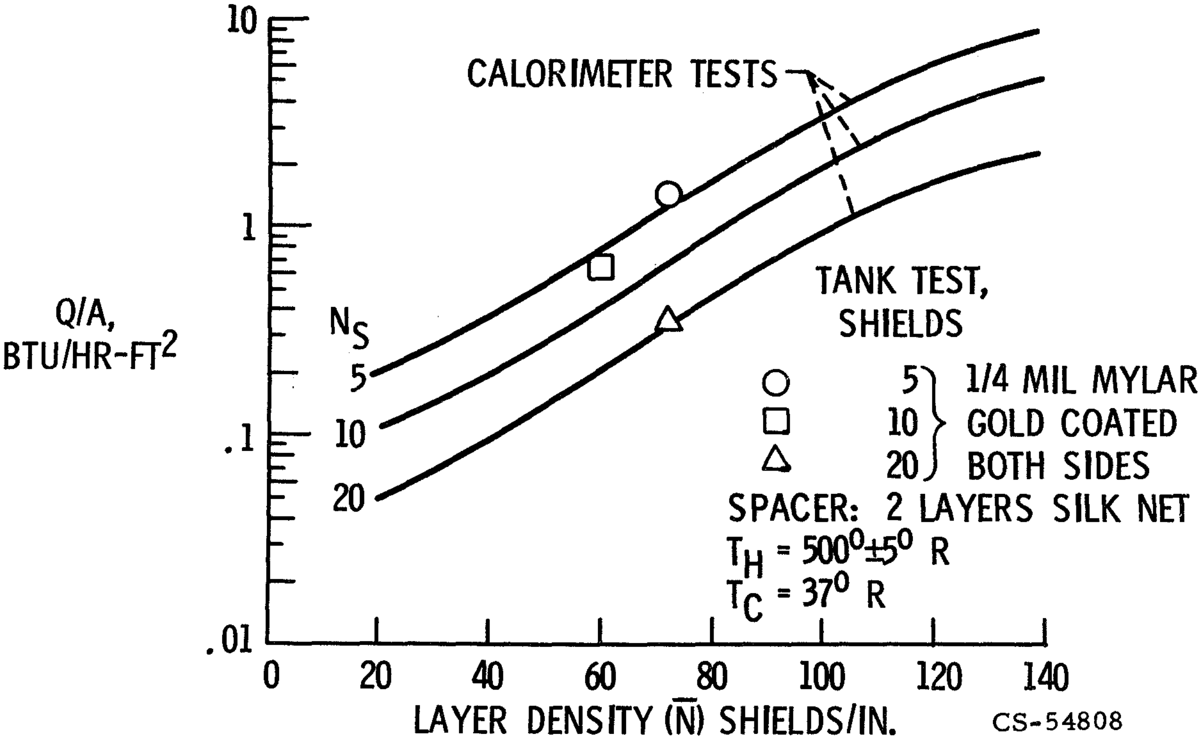
[7] "Thermal Performance of Multilayer Insulation Systems" 20th Monthly Report Contract NAS3-12025 LMSC/695558I Lockheed Missiles and Space Company.

COMPARISON OF TANK TEST WITH FLAT PLATE CALORIMETER TESTS



Environmental Effects on MLI

Multilayer insulation mounted on the exterior of a cryogenic tank will be exposed to a number of environmental contaminates both prior to launch and during re-entry. The effects of these contaminates has not been fully evaluated but an indiction of the effects of high humidity on metallized polyester is shown in this figure.[8] High humidity is potentially present at any time the vehicle is in the launch area. In addition, after the propellants have been loaded, the insulation system could be exposed to formation of frost, purge gases to prevent water vapor from entering the insulation, and leaking propellants. The work being performed under contract NAS3-14342, recently awarded to Lockheed Missiles and Space Co. by Lewis Research Center, will examine the effects of these environments on several materials used for fabrication of multilayer insulation systems. In addition to exposure during ground operations, leaking propellants can be present during space operations, and during re-entry both leaking propellants and high humidity can be expected.

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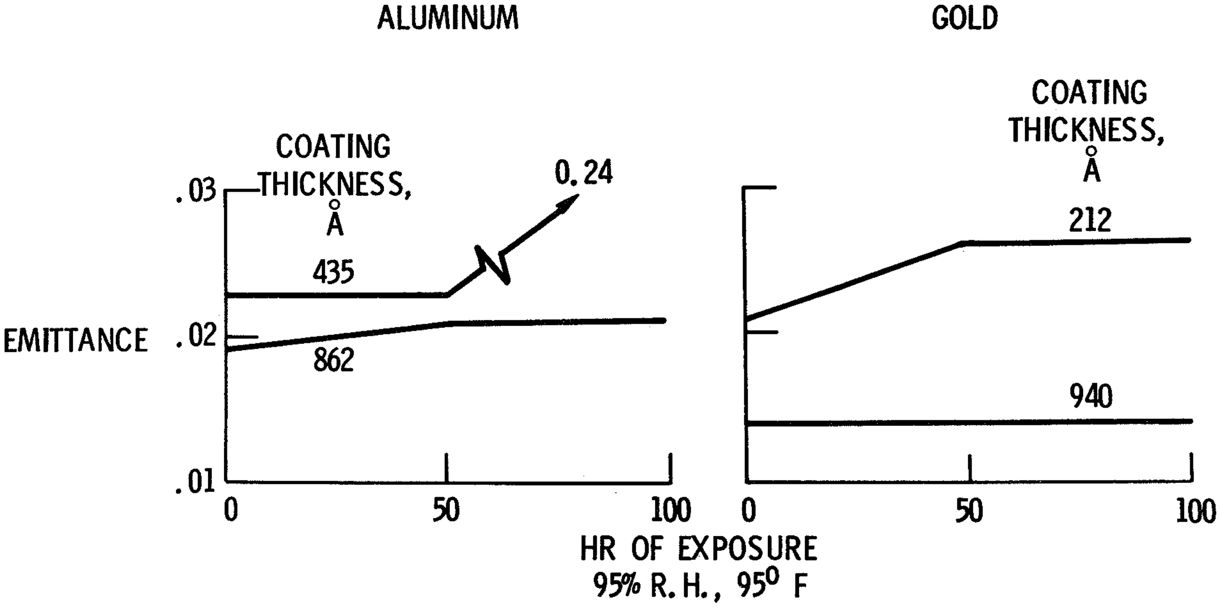
[8] "Advanced Studies on Multi-Layer Insulation Systems," Final Report Contract NAS3-6283, NASA CR54929, Arthur D. Little, Inc.

EFFECT OF HUMIDITY ON METALLIZED POLYESTER



CS-54807

High Performance Cryogenic Insulation-Purged MLI

One candidate insulation system for the on-orbit propellant tanks is shown in this figure. Specifically this system is under consideration for the LH_2 tanks. The system for the LO_2 tanks would be similar but would not require the internal insulation. The internal insulation could be one of those previously considered for use on the ascent tanks. Its purpose in this system is to provide a tank wall temperature, during ground hold, above the liquifaction point of nitrogen or air, and allow the use of gaseous nitrogen as a purge gas during ground hold. The alternative would require gaseous helium and the cost both in dollar amount and loss of critical material (helium gas) would be high. During space flight, the highly efficient MLI on the outside of the tank provides the majority of thermal resistance to heat flow to the propellant. This means that the tank wall temperature approaches that of LH_2. For re-entry the purge system on the LH_2 tank must be helium. Some consideration can be given to use of a nonpurged system during re-entry, providing the condensation of air, freezing of water vapor, and leaking propellants are controlled so as not to constitute a hazard to the vehicle and crew, and acceptable levels of performance can be attained by the insulation system on subsequent flights. An in-flight purge system will be a weight penalty charged to this particular insulation system and will be quite complex in operation. Kline and Mendelsohn[9] suggest a possible purge system for re-entry and offer the opinion that it will be a challenging and expensive task.

In addition to the requirement of a purge system, materials development work is required to provide multilayer insulation systems that can withstand temperatures above 300°F. Also to be evaluated is consistency of performance over many thermal and pressure change cycles and the establishment of post flight inspection and repair techniques.

This work is presently being pursued under a contract recently awarded by NASA.

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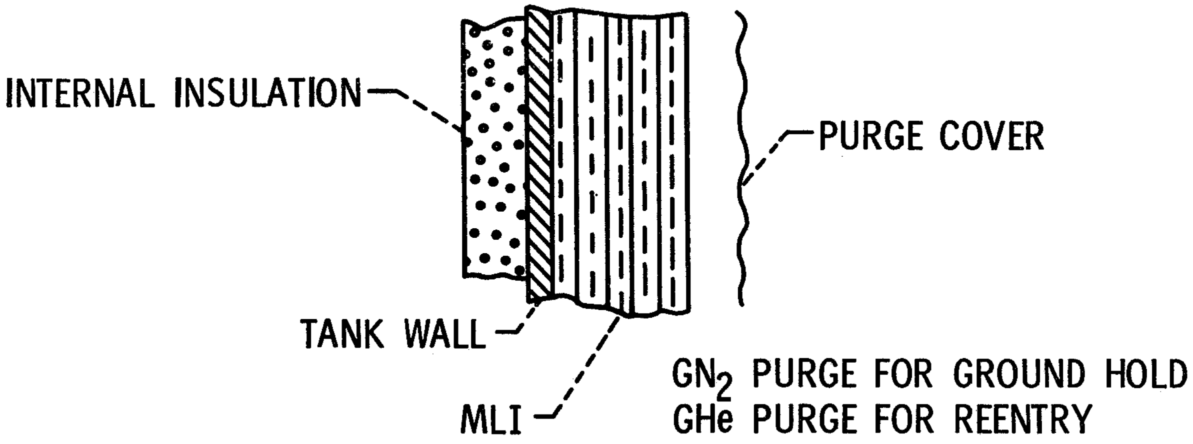
[9] Kline, R.L. and Mendelsohn, A.R. - "Thermal Integration Considerations for the Space Shuttle." Contributed for presentation at The American Society of Mechanical Engineers' Space Technology and Heat Transfer Conference, Los Angeles, California, 21-24 June, 1970. Grumman Aerospace Corporation.

HIGH PERFORMANCE CRYOGENIC INSULATION

PURGED MLI



GN_2 PURGE FOR GROUND HOLD
GHe PURGE FOR REENTRY

WORK REQUIRED:

1. OBTAIN CONSISTENT PERFORMANCE OVER MANY THERMAL & PRESSURE CHANGE CYCLES
2. DEVELOP IN-FLIGHT HELIUM PURGE SYSTEM
3. ESTABLISH INSPECTION & REPAIR TECHNIQUES
4. EVALUATE MATERIALS FOR HIGH TEMP EXPOSURE

CS-54804

High Performance Cryogenic Insulation-Evacuated Multilayers

An alternate to exposing the multilayer insulation to the environment is to encapsulate it. The encapsulation system can be either rigid or flexible. Shown in this figure are examples of each of these concepts.

The Self Evacuating MLI (SEMI) system consists of radiation shields separated by load bearing spacers encapsulated in flexible bags of low permeability. The bags are filled with CO_2. When the tanks are empty the CO_2 gas prevents air and moisture from contaminating the insulation. When the tanks are loaded with cryogen the CO_2 cryopumps to a low pressure and thermal performance during ground hold is very good. When the external atmospheric pressure is reduced simulating launch into space, the contact resistance between layers of insulation is increased and thermal performance improves.[10] [11] In order to evaluate this concept for the shuttle, the effect of many thermal and pressure change cycles must be determined. Also needed are materials that can withstand exposure to high temperature. Since re-entry temperatures will in all probability exceed the temperature at which the CO_2 was loaded, a pressure relief system to prevent pressure build up in the panels may be required. The establishment of inspection and repair techniques is also necessary. This insulation system has the advantages of good ground hold performance, adequate space hold performance, and does not require an in-flight purge system. Its disadvantages are that the flexible bags may be susceptable to leakage which will require recharging the CO_2 during ground operations. Since this system is attractive for use on the space shuttle, NASA presently plans to fund an effort during FY 71 to provide the technology necessary for a more complete evaluation.

By completely enclosing an insulation system in a rigid vacuum jacket all of the disadvantages of changing environments, purge systems, and varying performance are eliminated. Vacuum jackets as presently designed of monocoque construction are heavy. The use of light-weight sandwich construction could be considered and the potential for designing a total system whose weight and performanc approach that of a purged MLI appears possible. The advantages of this system are constant performance in all phases of the flight and no degradation caused by environmental exposure. The problems posed by this system are leakage of propellants into the vacuum annulus and difficulty of fabrication of a leak tight vacuum shell out of thin, light-weight materials. NASA presently plans to fund an effort during FY '71 to provide the technology necessary for a more complete evaluation of this system.

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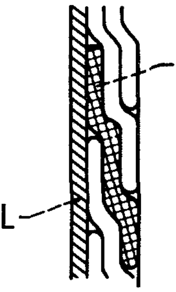
[10] Neindorf, L.R. and Nies, G.E. - "Investigation of a Light Weight Self-Evacuating Prefabricated Multi-Layer Insulation System for Cryogenic Space Propulsion Stages" Final Report Contract NAS3-6289, NASA CR 72017, Linde Division, Union Carbide Corporation.

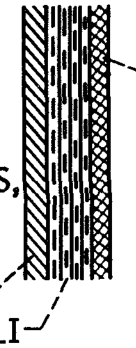
[11] Lindquist, C.R. and Nies, G.E. - "Lightweight Multilayer Insulation System" Final Report Contract NAS3-7953, NASA CR72363, Linde Division, Union Carbide Corporation.

HIGH PERFORMANCE CRYOGENIC INSULATION

SELF EVACUATING MLI



VACUUM JACKET



WORK REQUIRED:

1. DETERMINE EFFECT ON PERFORMANCE OF MANY THERMAL & PRESSURE CHANGE CYCLES
2. DEVELOP PRESSURE RELIEF SYSTEM FOR REENTRY
3. ESTABLISH INSPECTION & REPAIR TECHNIQUES
4. EVALUATE MATERIALS FOR HIGH TEMP EXPOSURE

1. DEVELOP FAB TECHNIQUE FOR LIGHTWEIGHT SHELLS
2. DEVELOP LOW OUTGASSING INSULATION
3. ESTABLISH INSPECTION CRITERIA
4. EVALUATE MATERIALS FOR HIGH TEMP EXPOSURE

CS-54805

Summary

Several insulation systems potentially useful for the space shuttle have been discussed. Supporting research and technology efforts are currently underway for three such systems. These are:

Insulation System	Contractor	Sponsoring Agency
Internal Foam	McDonnell-Douglas	NASA-MSFC NAS8-25973
Internal Gas Barrier	Martin Company	NASA-MSFC NAS8-25974
External MLI	McDonnell-Douglas	NASA-MSFC NAS8-26006

Present plans are to initiate efforts during FY '71 on three additional systems. These are:

External Foam Insulation - NASA-MSFC
Self Evacuating MLI - NASA-LeRC
Light-Weight Vacuum Jacket - NASA-LeRC

ASCENT TANKS

INTERNAL INSULATION - TWO PROGRAMS (FY 70)
EXTERNAL INSULATION - ONE PROGRAM (FY 71)

ON-ORBIT TANKS

PURGED MLI - ONE PROGRAM (FY 70)
SELF-EVACUATING MLI - ONE PROGRAM (FY 71)
LIGHTWEIGHT VACUUM JACKET - ONE PROGRAM (FY 71)

CS-54832