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ATTACHMENT METHODS FOR ADVANCED SPACECRAFT THERMAL CONTROL MATERIALS

AN ANNOTATED BIBLIOGRAPHY
PHASE I
SUMMARY REPORT SUPPLEMENT

by

HELEN M. ABBOTT
NORBERT H. KORDSMEIER, JR

CONTRACT NAS-2-4252

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

ABSTRACT

These 210 selected references were compiled by Lockheed Missiles & Space Company as a part of the Task I effort in support of Contract NAS 2-4252, "Study of Attachment Methods for Advanced Spacecraft Thermal Control Materials," performed for the Ames Research Center of the National Aeronautics & Space Administration.

In order to compile a comprehensive list of candidate attachment techniques for a thermal control composite consisting of multiple layer insulation and second-surface mirrors (optical solar reflectors), published literature relating to the aforementioned materials was surveyed. From these sources, as well as LMSC Independent Development Programs, proposal activities, and consultation with industrial suppliers of the thermal control and fastening materials, the list of attachment methods was prepared. The analysis of candidate attachment techniques in relation to their applicability to a specific design, operating in the 200° to 700°K temperature range, are given in the Phase I Summary Report for this contract.

Since this bibliography includes selected abstracts from published papers and reports which relate to thermal design parameters as well as attachment techniques for the two thermal control materials, it is anticipated that this compilation will assist the systems and thermal designer whenever the need for reviewing data on these materials occurs.

So that the bibliography may be readily used as a reference, it is submitted as an independent supplement to the Phase I Summary Report.

The references are arranged in two parts:

Part I – Reports alphabetically by corporate source

Part II – Journal articles, symposia, and books

An Author, Corporate Source, and a Subject Index have been included.

TABLE OF CONTENTS

PART I

GOVERNMENT REPORTS

AEROJET – GENERAL CORPORATION

1. Bradley, W.
INVESTIGATION AND EVALUATION OF MOTOR INSULATION FOR MULTIPLE RESTART APPLICATION. Aerojet-General Corp., Sacramento, Calif. Technical rept., 15 Jan – 1 Apr 1967 on Phase 2. Apr 1967, 64p. (Contract AF 04(611)-1 1609). AFRPL TR-67-104. DDC AD-812 879.

The primary purpose of this program is to investigate the properties and behavior of elastomeric insulation materials during multiple restart conditions and the influence of these properties on materials performance. During the second phase of work, a correlation analysis was conducted to determine which virgin and charred material properties were significantly related to the performance of five representative materials during one, two, and three-pulse motor firings. These properties were then determined on ten additional materials. All 15 materials were reviewed primarily on the basis of these properties and four primary candidates (V-62, V-44, 9790VI-126K, and USR 3800) were selected for further evaluation in pulse motor firings (5, 12 and 21 pulses). A correlation analysis was also conducted to establish the relationship of the fillers, additives, and chemical ingredients to firing performance and significant properties.

2. Chung, J. W.
BOLT AND NUT MATERIAL FOR 1650 + OR 50 F OPERATION. Aerojet-General Corp., Sacramento, Calif., Liquid Rocket Operations. Rept. no. FSC-66-188. 13 Jun 1966, 4p. IDEP 502.55.25.25-A6-01. DDC AD-806 282L.

Distribution: USGO: others to Headquarters, Space Systems Div., Attn: IDEP Office, SSSD. Air Force Unit Post Office, Los Angeles, Calif. 90045.

AIR FORCE MATERIALS LABORATORY

3. Litvak, Sidney
POLYBENZIMIDAZOLE STRUCTURAL ADHESIVES FOR BONDING STAINLESS STEEL, BERYLLIUM AND TITANIUM ALLOYS. Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div. Technical Report, Feb 1962 – May 1965. Mar 1966. (AFML-TR-65-426; AD-645241). N67-21848.

A new high-temperature-resistant adhesive for the binding of stainless steel, beryllium and titanium alloys has been developed. This report reviews the applied research leading to this development, and presents initial information on the mechanical properties of metal-to-metal bonded specimens, lap-shear and sandwich, from room temperature to 1000F for short-time and long-time aging periods at both 600F and 700F.

4. Minges, M. L.
THERMAL INSULATIONS FOR AEROSPACE APPLICATIONS: -423 to 3000F. Aeronautical Systems Div., Air Force Systems Command, Wright-Patterson AFB, Ohio. Sep 1963. ASD TDR 63 699. DDC AD-425 704.

Presented at the ASD 1963 Science and Engineering Symposium on 18 Sep 1963, Wright-Patterson Air Force Base, Ohio.

Very recent advances in Thermal insulation developments for the temperature range from liquid hydrogen (-423 F) to +3000F are reviewed. Some fundamental discussion of convective, conductive, and radiative heat transport mechanisms over this wide temperature range is included in analyzing the observed thermal characteristics of various insulation materials and composites. Variations in overall thermal conductance as a function of such parameters as absolute temperature level, interstitial gas pressure, density, radiation scattering and attenuation, and insulation geometry are discussed for recently developed powders, fibers, foams, and multilayer composites. Recent experimental results of USAF programs on these types of materials are presented and analyzed.

5. Olevitch, Albert
EMERGING AEROSPACE MATERIALS AND FABRICATION TECHNIQUES. Air Force Materials Lab., Wright-Patterson AFB, Ohio. Final revision rept. Rept. no. AFML-TR-67-1. Jan 1967, 190p. (Proj. AF-7381). DDC AD-811 292.

Promising aerospace materials and fabrication techniques resulting from recent research and development programs of the Air Force Materials Laboratory are briefly described. These materials include metals and alloys, seals and sealants, coatings and finishes, fibers and filaments, resins and adhesives, ablation materials, graphites, fluids and lubes and miscellaneous materials. A list of recent handbooks related to these materials is also included.

BATTELLE MEMORIAL INSTITUTE

6. Masubuchi, Koichi and R. E. Keith
FUNDAMENTALS OF SELECTED ASPECTS OF DEFORMATION CHARACTERISTICS OF ADHESIVE-BONDED JOINTS AND METAL-ADHESIVE INTERFACES. Battelle Memorial Inst., Columbus, Ohio, Columbus Labs. Rept. no. RSIC 642. 27 Jan 1967, 105p. (Contract DA-01-021-AMC-14693 (Z). DDC AD-650 149.

The report presents a state-of-the-art survey on selected aspects of fundamentals of deformation characteristics of adhesive-bonded joints and metal-adhesive interfaces.

BOEING COMPANY

7. Crane, C. H.
FABRICATION REQUIREMENTS FOR CRYOGENIC TANKS. Boeing Co., Seattle, Wash. Document no. D2 80535. 1 Nov 1963. (Contract AF33 657 7132). DDC AD-431 052.

Requirements are presented for all pressure vessels as well as to supplement Material and Process specifications where such specifications are not adequate. This document controls the following pressure vessel assemblies and their component parts: hydrogen tank, oxygen tank, and nitrogen tank.

8. Dahlin, L. D.
CORKBOARD DEMONSTRATION TEST PROGRAM NO. 1. Boeing Co., Huntsville, Ala., Launch Systems Branch. Rept. no. D5-13244. 22 Mar 1966. DDC AD-805 913L.

Distribution: USGO: others to Boeing Co., Seattle, Wash. 98124.

Demonstration of use of corkboard as thermal insulation.

9. EVALUATION TESTS OF HIGH STRENGTH STAINLESS STEEL BOLTS FOR ELEVATED TEMPERATURES. Boeing Airplane Co., Seattle, Wash. Rept. no. BOAC T2-9093. 1958.

The tests reported were conducted to determine the tension, shear, and tension fatigue properties of stainless steel fasteners suitable for use in piloted aircraft in areas of severe local heating or general areas of aerodynamic heating caused by supersonic flight. Temperatures considered ranged from room temperature to 1300° F.

Bolts of Type 17-4PH stainless steel were tested in tension, double shear, and tension fatigue to determine those properties at room temperature and 800° F. Lap joints of 17-4PH bolts in 17-7PH sheet were tested to determine the effect of variations in design and test methods at room temperature and 800° F. Type 431 stainless steel bolts were tested in double shear, combined shear and tension, and tension fatigue to determine those properties at various temperatures through 1300° F.

The available applicable results from other sources pertaining to fasteners of the two materials were combined with the results of the tests reported herein. The combined results were analyzed to determine the desired properties of the stainless steel fasteners.

The rated shear and tension strength at 70° F, the reduction of shear strength with increasing temperature and the fatigue properties of bolts of both materials were determined to a degree consistent with the number of specimens tested. The tensile strength at 1300° F with various types of nuts and the limits of combined loading were determined for Type 431 stainless steel bolts.

The differences in specimen design and testing methods were found to have little effect on the strength of 17-4PH bolts in 17-7PH lap joints. The A286 twelve point nuts were found to develop the full strength of Type 431 bolts at 1300° F. In the light weight nut design A286 stainless steel was found to be superior to 17-7PH at 1300° F.

10. Hill, John R.
ADHESIVE BONDING OF SPACE STRUCTURES.
Boeing Co., Seattle, Wash. Rept. no. D2-24154-1.
6 Jun 1966. IDEP 085.45.00.00-C6-03. DDC
AD-809 539L.

Distribution: USGO: others to Headquarters, Space Systems Div., Attn: IDEP Office, SSSD. Air Force Unit Post Office, Los Angeles, Calif. 90045.

The concept of using a mechanical fastener to give the pressure required during the curing of an adhesive was investigated with lap joints bonded with Epon 934, HT-424, and FM-1000. The adherends were 2219-T81 aluminum alloy and a glass cloth reinforced epoxy resin laminate. Tensile-shear tests were made at 75 and 300° F. In general, the shear strengths of the specimens bonded with only bolt pressure were considered to be equivalent to the strengths obtained with specimens bonded without fasteners. No leakage of helium was found through adhesive-bolt joints bonded with Epon 934 and FM-1000.

11. Poe, A. H. and H. E. Shigley
BOEING-WICHITA MATERIALS AND RESEARCH
DEVELOPMENT PROGRAMS 1957 – 1961. Jun
1961. (AF33 616 8141). DDC AD-271 166.

Contents include: light metals and alloys: titanium L-section extrusion (6Al-4V); inorganic nonmetallic solids: high temperature ceramic coatings; elastomers: Q-2-0046 RTV fluorosilicone sealant; one part RTV silicone rubber; plastics: Teflon hose; effect of moisutre and weather on foam; polyurethane foam for fuel cell float valves; liquid and semi-solid high polymers: adhesive, epoxy, Epon 901; adhesive, Eastman 910; adhesive, structural, metalbond 406: triallyloxy pyrimidine; composite materials: honeycomb core, 5052 Al alloy, Al alloy; A-172 silane fabric impregnated with polyester resin; diluents for Epon 828 resin; fluorocarbon elastomer coated fabric.

12. Stratton, W. K., et al.
ADVANCED IN THE MATERIALS TECHNOLOGY RESULTING FROM THE X-20 PROGRAM. Boeing Company, Seattle, Wash. AFML-TR-64-396, Final. Jan – Nov. 1964. Mar 1965, 171p. (Contract AF 33(615)-1624.

Significant advances in the materials state of the art resulting from the X-20 program are reviewed.

Functionally satisfactory refractory alloy fasteners were developed in this program; the recommended fastener materials, specification controls, and installation procedures are outlined. However, further development of a coating system for TZM-base metals is recommended for improved fasteners and lower cost.

High Temperature Insulation. The temperature capability of lightweight efficient fibrous insulations was increased from a 2000 to 2300° F temperature range to a 2900 to 3100° F temperature range. This was accomplished by upgrading and stabilization of a commercial insulation. Complete design, processing, and procurement information was developed for the stabilized material as well as the other insulations used on the X-20. The information developed includes:

(1) The maximum temperature capabilities of 13 commercial fibruous insulation materials were established with respect to entry environments. The dimensional changes occurring when they were exposed to elevated temperatures were determined.

(2) The apparent thermal conductivity of the insulations used on the X-20 was determined as a function of temperature, pressure, and density. The data were reduced to design information which is given in graphs.

(3) Preliminary processes were developed for the fibering of ceramic oxides of aluminum and zirconium, and methods were investigated for processing these fibers into a usable insulation product form.

(4) Resistance of the stabilized insulation to a mechanical and sonic vibration environment of 30-g impact loads and 162-decibel sound levels was demonstrated in the vehicle component development programs.

Cryogenic Insulations. Evacuated multilayer insulation is definitely feasible for use in weight-critical flight applications. At the time of X-20 program cancellation, several cryogenic tanks and transfer tubes were being manufactured on a production-line basis with reasonable cost and flow time. The primary cause of long evacuation times for multilayer-insulated tanks was the presence of adsorbed water vapor on the fiberglass paper. Techniques should be developed for preventing adsorption of water vapor after the glass paper has been degassed (before final evacuation). NRC-2 (aluminized mylar) multilayer insulation is unacceptable for use in small-diameter transfer tubes in high-vibration-level environments because of abrasion of the aluminum coating.

BORDEN CHEMICAL COMPANY

13. Sandler, Stanley R., Florence Berg, and George Kitazawa
DEVELOPMENT OF IMPROVED ADHESIVES FOR USE AT CRYOGENIC TEMPERATURES TO -423° F.
Borden Chemical Co., Philadelphia, Pa. Central Research Lab. Final Summary Report, 11 Jul 1963 – 31 Aug 1965. 15 Sep 1966. (Contract NAS8-11518). (NASA-CR-82602). N67-19101.

Polyurethanes and epoxy resins were evaluated as cryogenic adhesives showing good tensile shear and T-peel properties over the temperature range of -423° F to 400° F. Several other chemical structures were also investigated. Polyethers were found to give the highest tensile shear strength and T-peel on aluminum but had poor properties at 250° F and 400° F. Modification of the polyol, diisocyanate, or amine curing did not alleviate the problem. Copolymerizing epoxy resins with good high temperature tensile shear properties with polyurethanes which lacked these properties gave only a small increase over the latters' results for the homopolymer. The discovery of a new polymer system is reported. Studies of several bisphenol epoxy adhesives indicated that the substituents in the aromatic ring had no effect on adhesive performance but that the epoxy content was the major factor. The use of epoxy esters (polyglycidyl esters of polycarboxylic acid) yielded some adhesives that showed much higher tensile shear strengths than bisphenol A epoxies at 400° F when cured with 4.4-diaminodiphenylmethane at 100° C. Attempts to improve the T-peel strength of the epoxy resins by the addition of some polyether structures led to a decrease in the elevated temperature properties. It is concluded that several adhesives have been made which meet all the temperature requirements but do not have the proper T-peel strength when cured at 73° F.

14. Tsou, K. C., H. E. Hoyt, and B. D. Halpern
HIGH TEMPERATURE RESISTANT ADHESIVES.
Borden Chemical Co., Philadelphia, Pa. Final
rept., 22 Jun 1961 – 22 Jun 1962. (Contract DA
36-034-ORD-3501-RD.)

The objective of this research is the development of a high temperature resistant adhesive for 302 stainless steel which would give a minimum shear strength of 1,000 psi at 1000° F after exposure to 100° F in air for a minimum of one hour. The conditions of cure are to be at temperatures no higher than 500° F and preferably at temperatures near ambient. The impact resistance of the adhesive, when cured, is to be such as to permit a high rate of load as required by missiles in flight or by rough handling.

This report summarizes the results of evaluation of poly-2, 6-dimethyl-1, 4-phenylene oxide, poly-2-methyl-6-allyl-1, 4-phenylene oxide, copolymers of 2, 6-dimethyl-4-bromophenol and 2-methyl-6-allyl-4-bromophenol and epoxy derivatives of the allyl-containing polymers, poly-2-methyl-6-methallyl-1, 4-phenylene oxide, and copolymers of 2-methyl-6-methallyl-4-bromophenol and 2, 6-dimethyl-4-bromophenol as high temperature adhesive base materials.

Phase I of this project involves the synthesis and characterization of these new thermosetting polymers.

Phase II of this project involves evaluation of these new thermosetting polyphenylene oxides as high temperature adhesives. This phase was not complete at the end of this contract period. However, the tensile strength of 1000 – 1400 psi range at 500° F and 600 – 700 psi range were possible at 600° F for several of the polymers. The difficulties in obtaining proper wetting and in arriving at optimal curing conditions are discussed. No attempt to improve performance by compounding was carried out in the course of the work. The stability of these new thermosetting polyphenylene oxides are compared with other conventional high temperature adhesive materials. These polymers show distinct advantage as new base materials for high temperature adhesive system. Further development is therefore needed to perfect this system.

In the course of this work, attempted polymerizations of 2-methyl-4-bromophenol were carried out. Synthesis of bismethylene-2, 2'-dimethyl-4, r° -dibromophenol and attempted polymerizations to ladder type o-cresolnovolac polymer were made. In addition several triazine polymers had been synthesized earlier in this contract period.

BORG-WARNER CORPORATION

15. Thomason, D. P.
ADHESIVE BONDING OF END CLOSURES FOR HIGH STRENGTH AND RELIABILITY IN ROCKET MOTOR CASES. Borg-Warner Corporation, Kalamazoo, Mich., Ingersoll Kalamazoo Div. Quarterly Rept. No. 3, Oct 1962 – Mar 1963. 30 May 1963. (Contract NOrd 15719.)

Seventeen sub-scale bonded joint cases of a 5" nominal diameter and 18" in length were fabricated from cold drawn seamless 4153 steel tubing and hydrotested. Fifteen of these units exceeded the target bonded joint strength of 3750 psi by an average of 40%. The information gained from the sub-scale cases was applied to the fabrication of eight Super Tricent prototype bonded end closure cases of 16" nominal diameter and 41" length. To assure failure of the bonded joint rather than the case wall, desirable for this program to permit direct examination of the bond line, the bonded joint length was decreased from the original 4" length used on the first five cases fabricated. Following the design change, prototype case number eight achieved the 3750 psi target joint strength. The adhesive material used throughout this program was FM-1000.

BURKE RESEARCH COMPANY

16. Burke, O. W. Jr. and B. P. Hunt
NYLON-NEOPRENE LAMINATES. Burke Research Co., Pompano Beach, Fla. Final technical rept., 14 May 1965 – 6 Jul 1966. 13 Jul 1966. (Contract DA-44-009-AMC-1073 (T).) DDC AD-803 265L.

Distribution: USGO: others to Commanding Officer, Army Engineer Research and Development Labs., Fort Belvoir, Va. 22060.

COMPUTING DEVICES OF CANADA, LTD.

17. Gibson, K. F. and G. M. Peace (Bendix Corp.)
DEVELOPMENT AND EVALUATION OF A RIGIDIZED INFLATABLE MICROWAVE REFLECTOR.
Computing Devices of Canada, Ltd., Ottawa (Ontario). In AFSC, Wright-Patterson AFB, Ohio. Aerospace Expandable Struct., Rept. AFAPL-TR-65-108, 1966, pp. 265 – 287. N66-27279.

Techniques were developed for the construction and assembly of an inflated rigidized microwave reflector; and its performance was evaluated. In its simplest form the reflector is made by bonding polyester film to the top and bottom surfaces of flexible support rim. The inner surface of one of films is coated with a metallic reflecting material. Provision is made for feeding a rigidizing agent into the support rim and then into the space between the two membranes which form the front and back surfaces of the reflector. The rigidizer is a low density foaming plastic. Evaluation tests indicate that the surface characteristics, resulting from this method of fabrication and assembly, will permit the reflector to be used satisfactorily at X-band frequencies or lower. It is noted, however, that further refinements in the process, or smaller dish dimensions, might permit the reflector's use for K-band microwaves.

DEVICE DEVELOPMENT CORPORATION

18. Holt, R. B., H. I. Smith, and M. S. Gussenhoven
RESEARCH ON OPTICAL CONTACT BONDING.
Device Development Corp., Waltham, Mass. Final rept., AFCRL 66-649, 15 May 1963 – 30 May 1966. 30 May 1966, 43p. (Contract AF 19(628)-3237 Proj. AF-4600, AF-5635 Task 460003 563503.) DDC AD-643 285.

The adhesion of optically polished surfaces – optical contact – was investigated both under room conditions and ultrahigh vacuum with the twofold objective of determining the adhesion mechanism and its characteristics and extending the technological applications. It is shown that optical contact adhesion occurs readily under ultrahigh vacuum, thus demonstrating that the widely held liquid layer theory is not complete. Adhesion mechanisms are discussed, and it is concluded that London dispersion forces are responsible for the adhesion under ultrahigh vacuum. For optical contacts made under room conditions, surface tension of a liquid probably also contributes.

It is shown that optical contact techniques can be used to obtain extremely efficient transducer-sample bonds for gigacycle ultrasonic work. Reflections as low as 1% of the incident acoustic power were obtained at 3 GC and 9 GC. Techniques for making such bonds are discussed. It is pointed out that the incorporation of evaporated metal films should enhance the properties of optical contact bonds and eliminate some practical difficulties. The design and development of a high vacuum evaporator are described.

ELECTRONIC PROPERTIES INFORMATION CENTER

19. Milek, John T.
POLYIMIDE PLASTICS: A STATE-OF-THE-ART REPORT. Electronic Properties Information Center, Culver City, Calif. Rept. no. S-8. 1 Oct 1965. (Contract AF 33(615)-2460 Proj. AF-7381 Task 738103.) DDC AD-475 505.

This survey report on polyimide plastics has four objectives: (1) to obtain a state-of-the-art picture of this newly-developed family of resins with regard to all available commercial materials, as well as those in their developmental stages: their chemistry, property data, and applications; (2) to report test data on various polyimide materials and compare same with data found in the literature search; (3) to comply with a request to prepare a survey report on this family of plastics; (4) to collectively tie together the properties of the various polyimide forms which, heretofore, have been generally treated individually on a tradename basis rather than a family basis.

ELECTRO-OPTICAL SYSTEMS, INC.

20. Springer, Lee M.
ANALYSIS, FABRICATION AND TEST OF LARGE SOLAR CONCENTRATORS. Electro-Optical Systems, Inc., Pasadena, Calif. Quarterly Progress Report No. 4. (EOS-1860-Q-4.) 10 Mar 1963, 22p. (Contract AF 33(616)-8402.) NASA N63-15971.

The current program is devoted to the design, fabrication, and preliminary testing of an all-metal petal of a 44 1/2-foot-diameter mirror. During this period, plating facilities were completed and checked for leaks with water and plating solution.

The reflective inserts in the front-face master were completed. The polishable plastic surface of the large petal master has been proven experimentally by the model front-face reflective master which showed the practicality of such a system. A front-face skin was plated on the front-face master. It is now in the process of having the backing structure mold attached. A backing structure mold of plastic block foam was fabricated during this contract. The optical testing gear has been designed and is now in the process of assembly. A physical testing fixture has been designed and built.

EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT

21. Bryant, R. W., W. A. Dukes, and J. V. Long
THE SEALING OF THREADED JOINTS. PART 5:
A REVIEW OF COMMERCIAL SEALANTS.
Explosives Research and Development Establishment,
Waltham Abbey (England). (ERDE-10/R/66, Pt. 5:
AD-801794.) 17 Jun 1966, 30p. NASA X67-
13349.

Commercial lutings and thin polytetrafluoroethylene (PTFE) tapes and cord have been assessed as sealants for parallel-threaded joints. One luting is comparable with the Service materials and may find specialized uses. The relative inefficiency of PTFE tapes will often outweigh the advantage of cleanliness, unless resistance to extreme temperatures and to a variety of solvents is required. Many commercial cements, including polysulphides, polyurethanes, epoxides, silicones, surface-catalysed compositions and compounds hardened by atmospheric moisture, have been assessed as thread sealants. Several were superior to the Service material in a stringent thermal-cycling trial. Theoretical analysis of the imposed strain has led to an understanding of the necessary magnitudes of the adhesive and cohesive strength and the flexibility of a sealing cement. These properties can now be specified as a function of the materials and dimensions of the joint and of the temperature range to be withstood.

GENERAL DYNAMICS

22. Clay, J. P., R. C. Getty, T. D. Lange, et al.
SUPERINSULATION RESEARCH PROGRAM.
General Dynamics/Convair, San Diego, Calif.
Progress Report, Apr – Dec 1965. (GD/C-ERR-AN-863.) Dec 1965, 158p. N66-25754.

Insulation problems associated with long term storage of cryogenics in space were identified and evaluated. Solutions to the problems were investigated analytically, and in some cases experimentally, with emphasis on obtaining the best solution or combination of solutions required for an insulation system. Pure research was performed on the phenomena of residual gaseous conduction. A computer program was developed and used to theoretically analyze thermal performance of composite multilayered insulation systems. Self evacuating multilayered insulation panels were developed, fabricated, and tested. The panels performed well and show promise for use in an insulation system. Methods were developed whereby mylar, or mylar-metal laminates, can be fusion welded to form a vacuum tight seal between the laminates from cryogenic to room temperature. Compressed multilayered insulations for use between liquid H_2 and O_2 or liquid H_2 and F temperatures were investigated. "Flocked aluminized mylar" was investigated as a possible, high performance, multilayered insulation. The use of ideally suspended radiation shields for use on cylindrical tank walls was tested on a thirty inch diameter tank. The effect of a suction line penetration into a cryogenic tank on a multilayered insulation was experimentally investigated.

23. Cross, Richard I. and William E. Black
OPTIMIZATION OF INSULATION AND MECHANICAL SUPPORTS FOR HYPERSONIC AND ENTRY VEHICLES. General Dynamics/Convair, San Diego, Calif. Technical rept., Jun 1965 – Dec 1966, rept. no. GDC-DCB66-030. Apr 1967. (Contract AF 33 (615)-1672 AFML TR-66-414.). DDC AD-816 201L.

Distribution: USGO: others to Air Force Materials Lab., Attn: MAAE. Wright-Patterson AFB, Ohio. 45433.

Lightweight thermal protection systems have been investigated for 3,260°R temperature capability by testing potential fibrous insulating materials and their mechanical supports.

24. Getty, R. C.
CRYOGENIC INSULATION DEVELOPMENT.
General Dynamics/Convair, San Diego, Calif.
Quarterly Progress Report, 1 Jul – 30 Sep 1966.
10 Oct 1966, 34p. (Contract NAS8-18021.)
(NASA-CR-80456; Rept. 584-4-3.) X67-10812.

NOTICE (Available to NASA Offices: Centers, and Contractors Only.)

An investigation was made concerning thermal and structural scaling and certain ground rules were formulated. Based on these rules, a scale model test specimen was designed using shingle insulation. At the same time a second insulation system was designed and suggested for the second series of tests. This insulation has very good thermal performance characteristics as a function of weight. A series of four calorimeter tests have been planned to evaluate these two systems. The thermal structural combination test preparation which will follow these initial tests, is on schedule.

25. Ryan, J. M., et al. (General Dynamics/Convair)
LIGHTWEIGHT THERMAL PROTECTION SYSTEM DEVELOPMENT. Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Vol. 1 Composite Design and Test Program Tech. Rept. AFML-TR-65-26, Vol. 1. Jan 1965.

Typical insulation systems have been designed, constructed and thoroughly evaluated to establish the feasibility of using passive fibrous insulation systems on manned, reusable exit and reentry vehicles. Apparatuses have been developed to test insulation systems under simulated flight pressure and temperature environments.

The program identified deficiencies in the most promising insulation materials and candidate systems and established recommended approaches to minimize or correct these deficiencies.

For long term reliability, fibrous insulation systems require adequate provisions for inspection, service and replaceability.

Currently, for long time usage, optimum fibrous insulation materials have a maximum limiting temperature of approximately 2800° F.

26. Ryan, J. M., R. I. Cross, et al.
THE OPTIMIZATION OF THERMAL COMPOSITES.
General Dynamics/Convair, San Diego, Calif.
Technical rept., Jul 1964 – May 1965. Rept. no.
GD/C-DCB-65-027. Dec 1965. (Contract AF 33
(615)-1672 AFML TR-65-244.) DDC AD-479 531L.

Distribution: USGO: others to Air Force Materials Lab., Wright-Patterson AFB, Ohio 45433. Attn: MAAE.

A limited industrial survey to locate new or improved insulation materials and test devices was conducted. Elemental tests and evaluations were made to define the limitations of these materials, and to determine the requirements of helium gas purge systems.

Analytical studies evolved semi-empirical equations for the determination of thermal conductivity and for the effectiveness of radiation attenuation barriers.

Improved mechanical components were delineated to provide integrity and long term reliability.

27. Hertz, J.
INVESTIGATION OF POTENTIAL LOW TEMPERATURE INSULATORS. General Dynamics, Astronautics Rept. No. GD-A-ERR-AN-668. 31 Dec 1964.

A series of reinforced plastic laminates and non-reinforced thermoplastics were evaluated for potential usage as interconnecting structural members, plumbing and attachments in conjunction with "super insulation" systems for cryogenic tankage. Thermal conductivity measurements and tensile properties were evaluated from -423°F to room temperature. Ratios of ρ/F_{tu}, $\rho/.67F_{tu}$, $k/.67F_{tu}$, k/E, and $(k\rho)1/2/.67F_{tu}$ are presented at -423°, -320° and 78°F. Epoxy resin reinforced with high strength S-994 glass or 143 style E glass cloth resulted in the most efficient materials for structural insulators. Kel-F resulted in the lowest K-factors over the temperature range investigated and is the most promising material for non-structural applications.

28. Hertz, J.
CAST FOAM INSULATION EVALUATION.
General Dynamics, Astronautics Rept. No. GD-A-MRG-275, AD 291521, Dec 1962.

An investigation has been conducted on the thermal instability of the insulation on the fuel and oxidizer ducting of the Centaur airborne propellant system. It has been found that molding is hot molds (110 – 120° F) and curing for 2 hours in the mold at 200° F will stabilize the Stafoam AA-402. It had been found that density increases as a result of small cross-sections in the insulation is prohibitive unless all processing is carefully controlled. APCO 1217 polyurethane adhesive utilized for bonding aluminized Mylar around the insulated ducts is adequate over the temperature range of -320° to 160° F. Other adhesives such as Schjelbond GT-100, APCO 1252 can also be used.

29. Hertz, J.
STUDY OF ADHESIVES FOR INSULATION PANELS.
General Dynamics, Astronautics Rept. No. GD-A-MRG-276, AD 405200, May 1963.

Testing of sample insulation panels carefully prepared by the H. I. Thompson Co. indicated that APCO 1219 can be successfully utilized for bonding foam spacers to the inner face of the LH_2 insulation faces. Pi-tension specimens having foam core and epoxy-fiberglass faces indicated that APCO-1219 and APCO 1252 adhesives are acceptable, but NARMCO 3170-7131 is not acceptable. Using of sealants to seal helium leaks between the tank and the insulation panels may result in panels sticking during jettison procedures, and further testing in this area is desirable.

30. Kerlin, E. E. and R. P. Lightfoot
EVALUATION OF CRYOGENIC INSULATION MATERIALS AND COMPOSITES FOR USE IN NCULEAR RADIATION ENVIRONMENTS. General Dynamics/Fort Worth, Tex. Nuclear Aerospace Research Facility. Quarterly Progress Report, 1 Oct – 31 Dec 1966. 15 Jan 1967, 25p. (Contract NAS8-18024) (NASA-CR-83058; FZK-328). X67-12920.

Cryogenic insulation composites are being evaluated for use as cover materials of liquid hydrogen storage tanks. These materials consist of the cryogenic insulations, polyurethane spray foam and cryogenic cork board; the adhesives, polyurethane and epoxy-polyamide; and a vapor-barrier film of polyvinyl fluoride. To simulate the actual service conditions expected, an insulation test system using two types of cryogenic insulation on an aluminum tank with wall panels equivalent to the Nuclear Ground Test Module (NGTM) tank thickness has been designed and fabricated. The initial phase of the test program to investigate the structural and thermal integrity of the cryogenic insulation system has also been formulated.

GENERAL ELECTRIC COMPANY

31. 9.5 FOOT PARABOLOIDAL MASTER AND CONCENTRATOR. General Electric Co., Philadelphia, Pa. Missile and Space Div. Final Report 66SD4391. 30 Jun 1966, 211p. (Contract NAS1-4105) (NASA-CR-66122). N66-35889.

The fabrication of a 9.5 foot mirror master which would be of sufficient quality and durability for the reproduction of lightweight, high quality paraboloidal solar concentrators with the design objective of collector absorber efficiency of 75 percent of a 2000°K black body cavity is reported. An epoxy spin-casting was produced which had an adjusted slope error of less than 35 arc seconds. On this concave surface a 3/8 inch thick nickel master was electroformed which yielded a slope error of approximately 3 minutes. A 9.5 foot nickel solar concentrator was then electroformed against the surface of the master. A nickel torus support ring was bonded to a transition cove ring located on the back of the mirror, after which the entire unit was successfully separated from the master. The various steps in the spincasting and electroforming processes are discussed, as well as investigations into separation of mirror surfaces from masters using vacuum techniques and the improvement of nickel surfaces using Kanigen coatings. These investigations were conducted using a 30 inch nickel master and electroforming an aluminum mirror against the experimental surface.

GEOPHYSICS CORPORATION OF AMERICA

32. Rochon, Ronald and Curtis R. Peterson
AEROSPACE EXPANDABLE STRUCTURES AND MAINTENANCE SUPPORT DEVICES. VOLUME II. EVALUATION OF ADHESIVES SYSTEMS FOR ANCHORING ASTRONAUTS TO A WORK SITE IN SPACE. Geophysics Corp. of America, Minneapolis, Minn., Viron Div. Jul 1965, 21p. (Contract AF33 (615)-1243 Proj. AF-8170 Task 817008.) APL-TR-65-40-Vol. 2. DDC AD-474 088.

Prepared in cooperation with Archer-Daniels-Midland Co., Minneapolis, Minn. See also Volume 1, AD-471333.

The feasibility of utilizing a thermally initiated adhesive as a space maintenance support device was demonstrated under a number of simulated space conditions. As end items of this study, 300 adhesive patches were fabricated and delivered to the Air Force for evaluation. Adhesive coated flexible foam patches adhered to reinforced plastic and aluminum surfaces within the limits of the design specifications. The best adhesive was a combination of Versamide with a "Pyrofuze" energy source. Optimum performance of the adhesive patches was achieved if the separate adhesive formulations on separate patches were used for high and low temperature applications. A one patch system for the entire temperature range with both adhesive formulations combined in concentric areas reduced bond strengths because of the smaller area available to each adhesive. Tensile strengths of bonds to reinforced plastic at 112 F were as high as 44 lb on a 2-inch diameter patch. Tensile strengths of bonds to reinforced plastic at 200 F were 32 lb on 2-inch diameter patches. Tensile strengths of 20.8 psi were recorded when bonding 1-1/2-inch diameter patches to aluminum adherends at 80F.

GOODYEAR AEROSPACE CORPORATION

33. Burkley, R. A. and S. R. Rollins, et al.
DEVELOPMENT OF MATERIALS AND MATERIALS APPLICATION CONCEPTS FOR JOINT USE AS CRYOGENIC INSULATION AND MICROMETEORITE BUMPERS. Goodyear Aerospace Corp., Akron, Ohio. Annual Summary Report. 30 Jun 1966, 142p. (Contract NAS8-11747) (NASA-CR-80778; GER-11676-S/24). X67-11342.

Protecting storage tanks for cryogenic liquid propellants against micrometeoroid damage and extreme temperatures is investigated in terms of developing a new insulation system for a space environment. Considerable improvement in thermal performance was realized through the use of a foam thin spacer in a multilayer composite arrangement with quarter-mil aluminized Mylar as a radiation shield. Filament winding of the tank insulation was investigated; and 23 multilayer specimens were fabricated. Thermal testing facilities, equipment, and procedures are described; and both flat-plate space and ground-hold calorimeter testing are detailed. Results are given for composite systems application and testing on subscale tank, as well as testing related to micrometeoriod protection.

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

34. Donohue, P. J.
MATERIALS ENGINEERING STUDY STUDIES OF ADHESIVE SYSTEMS FOR BONDING OF EVA ANTENNA. Grumman Aircraft Engineering Corp., Bethpage, N. Y. Rept. no. LTC-914-14013. 22 Jun 1966. (Contract NAS9-1100) (IDEP 501.01.00.00-K4-02). DDC AD-810 190L.

Distribution: USGO: others to Army IDEP Office, Attn: AMSMI-RBP, Redstone Arsenal, Ala. 35809.

35. Sanders, H., G. Sheredos, and S. Westerback
LIGHTWEIGHT SANDWICH ADHESIVE SYSTEMS.
Grumman Aircraft Engineering Corp., Bethpage,
N. Y. Rept. no. LMO-853-328. 27 Jan 1966.
IDEP 347.70.00.00-K4-10. DDC AD-806 697L.

Distribution: USGO: others to Army IDEP Office, Attn: AMSMI-RBP, Redstone Arsenal, Ala. 35809.

36. STATIC AND FATIGUE TEST OF ADJUSTO - FIT BOLT. Grumman Aircraft Engineering Corp., Bethpage, N. Y. Rept. no. 123Mt654-F-26. 5 May 1965, 5p. (Contract NOw-64-0289). IDEP 307.10.00.70-K4-01. DDC AD-807 156L.

Distribution: USGO: others to Army IDEP Office, Attn: AMSMI-RBP Redstone Arsenal, Ala. 35809.

HERCULES POWDER COMPANY

37. Greever, W. L.
CASE BONDING AND ADHESIVES. Hercules Powder Co., Cumberland, Md. Allegany Ballistics Lab. In its RMMP Supporting Res. Program (Confidential Report). 30 Jul 1966, pp. 44 – 46. X67-12638.

Studies of the neoprene-triisocyanate coupling layer continued in order to determine the formulating and ingredient variables which affect adhesion and physical properties. Findings confirmed that the type of neoprene solvent system greatly affects the adhesion properties imparted by the triisocyanate component. It was also found that by changing the major solvent from toluene to a mixture of chlorinated and ketone solvent, the quantity of triisocyanate required for adhesion could be reduced to one-fifth of that previously used. Other ingredient experiments indicated that adhesion benefits were obtained by adding phenolic resin, increasing the zinc oxide content, and replacing magnesium oxide with an epoxy acid acceptor. The major effects observed for each ingredient are tabulated. Based on these data, a neoprene-triisocyanate composition was formulated for use as the coupling layer in a double layer Formvar case bond system.

HONEYWELL INCORPORATED

38. Clark, P. R. and Henry Baker
A DIFFUSION BONDING PROGRAM. Honeywell Inc., St. Petersburg, Fla. Final rept., 1 Feb 1966 – 31 Dec 1966. Rept. no. RADC TR-67-62. Apr 1967. (Contract AF 30(602)-4059, Proj. AF-5519, Task 551904). DDC AD-651 545.

An evaluation was made of diffusion bonding processes and techniques. The use of evaporated aluminum patterns on polyimide ("H") film provided the interconnecting metallization. This report summarizes the work, including the development of minimum bonding parameters, the fabrication of significant number of bonds, and the testing of these bonds.

IIT RESEARCH INSTITUTE

39. Kutscha, D.
FEASIBILITY OF JOINING ADVANCED COMPOSITE FLIGHT VEHICLE STRUCTURES. IIT Research Inst., Chicago, Ill. Technology Center. Quarterly progress rept. no. 2, 1 Aug – 31 Oct 1966. Rept. no. IITRI-M6151-6. Oct 1966. (Contract AF 33(615)-3962, Proj. IITRI-M6151). DDC AD 807 774.

The purpose of this study is to establish the feasibility of using rational engineering methods to design bonded and mechanically fastened joints fabricated from composite and composite-metal adherends. Work has continued on the survey of analytical design methods and the use of a finite element technique to analyze some overlap type joints.

40. FEASIBILITY OF JOINING ADVANCED COMPOSITE FLIGHT VEHICLE STRUCTURES. IIT Research Inst., Chicago, Ill. Technology Center. Quarterly progress rept. no. 3, 1 Nov 1966 – 31 Jan 1967. Rept. no. IITRI M6151-9. Feb 1967. (Contract AF 33(615)-3962). DDC AD-809 049.

The purpose of this study is to establish the feasibility of using rational engineering methods to design bonded and mechanically fastened joints fabricated from composite and composite-metal adherends. Work has continued on the survey of analytical design methods for bonded and mech anically fastened joints. Sample calculations have been carried out for a simple lap joint and a scarf joint using a numerical method of shear lag analysis. Two surface cleaning procedures for FRP were investigated and a series of joints bonded with Narmco Metlbond 400 were fabricated and tested to determine the effect of pin layout on joint strength. Adhesive films were fabricated and tested for four different adhesives.

41. Mountvala, A. J. and H. H. Nakamura DEVELOPMENT OF LIGHTWEIGHT THERMAL INSULATION MATERIALS FOR RIGID HEAT SHIELDS. IIT Research Inst., Chicago, Ill. Final summary report, 25 Jun 1964 – 25 Sep 1966. Oct 1966. (Contract NAS8-11333) (NASA-CR-82454; IITRI-G-6002-27). N67-19125.

A program of engineering and scientific research has been carried out to develop lightweight ceramic foams which will provide adequate insulation and survive the mechanical environment associated with launch operations. Castable ceramic foams of zircon, mullite, and calcium aluminate have been prepared and evaluated for use as rigid heat shields in launch vehicles. Chemically bonded, castable type zircon foams of 1/2 in. thickness show good insulative and mechanical characteristics when subjected to a heat flux of 40 Btu/ft^2 sec with simultaneous vibration of 60 cps, 1/2 in. double amplitude displacement and 90 g's acceleration, as well as to a specific sinusoidal sweep-random vibrational test up to 200 cps. Property measurements on an optimized zircon foam disclosed very high optical reflectance in the near-infrared wavelength region and an extremely low thermal conductivity of 2300°F.

JET PROPULSION LABORATORY

42. Riise, H. N.
DEVELOPMENT AND PERFORMANCE OF THE JPL GLASS-LINED METAL REFLECTORS FOR THE SOLAR SYSTEM IN THE 25-FOOT SPACE SIMULATOR. Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena, Calif. In NASA, Washington Proc. of 2d Conf. on Solar Simulation Res. (1964) pp. 103 – 129. N66-37829.

A performance analysis of glass-lined metal reflectors for a solar simulator showed that they can intercept high energy solar radiation without damage to the reflective coating, glass, bond, or substrate metal. The combination should not be used in mirrors requiring a highly accurate figure since the glass and metal have different coefficients of expansion and the combination will change figure with temperature. This deformation can be minimized by making the metal mass larger than the glass and by keeping the temperature as constant as possible by making the substrate metal highly conductive and water cooling the metal to minimize temperature rise. Silicon substituted for the glass could probably survive a higher radiation flux. The epoxy bonding material is unimportant provided the bond thickness is kept below .005 in. Hysol 3X, initially specified for the virtual source mirrors, was too viscous to accomplish the thin bond line required for the larger fly's eye and headlamp mirrors. Furane no. 9633 hardener proved satisfactory. The glass-metal bond must be cured at a temperature above which it will be operated. The glass should be kept thin to minimize warpage and the shear stress which develops at the bond line.

JOINT PUBLICATIONS RESEARCH SERVICE

43. Tarnizhevskiy, B. V., A. D. Razgovorov, and I. G. Savchenko
A STUDY OF OPTICAL AND ENERGY CHARACTERISTICS OF SOLAR RADIATION COLLECTORS FORMED BY INFLATION. Joint Publications Research Service, Washington, D. C. In its Heliotechnology, No. 3, 1965. 26 Apr 1966, pp. 26 – 29. N66-26891.

The inflation of sheet metal by an evenly applied load, followed by stiffening with the application of epoxy resins is suggested as a technique for producing solar collectors of approximately paraboloidal or parabolic shape. In order to determine the possible applications of such collectors, their optical and energy characteristics were investigated. It was experimentally established that the maximum energy density of a paraboloidal collector 540 mm in diameter fluctuates from 4×10^5 to 6×10^5 kcal/sq m per hour. The focal images of the collectors were photographed by the light of a full moon; and it was determined that in addition to the irregular and asymmetric shape of the focal point, the collectors displayed an aureole surrounding the focal point and consisting of radially arranged bands of differing illumination. It was also found, for a parabolocylindrical reflector 2200 mm × 550 mm, that the focal strip varied arbitrarily in its width along the whole length. Based on these and other results, it is recommended that collectors produced by the inflation technique be used in low potential thermal units.

44. Umarov, G. Ya., S. N. Vil'kova, et al.
PREPARING ALUMINUM MIRRORS ON ASBESTOS CEMENT BY THE TRANSFER METHOD. Joint Publications Research Service, Washington, D. C. In its Heliotechnology, No. 3, 1965. 26 Apr 1966, pp. 37 – 43. N66-26893.

Methods and materials are described for constructing vapor deposited or bonded aluminum thin film mirrors for use in solar power plants. The supporting body of the collector was asbestos cement. Since the asbestos could not be directly coated or bonded with the aluminum, it was covered with a layer of epoxy resin, which was mixed with a filler to decrease the absorption coefficient. After several attempts at polymerization and tests of different fillers, a smooth hard surface was obtained with a reflectivity coefficient of approximately 90%. The aluminum was bonded to the resin by the following transfer process. First, the metal was vaporized onto a glass surface; then, this aluminized surface was superimposed on the resin at the beginning of polymerization. During polymerization, the aluminum was transferred to the resin, and upon completion the glass was simply removed. This method, it is pointed out, produced adhesion which was five to six times greater in strength than the adhesion of direct vapor deposition to the epoxy resin surface.

LINDE COMPANY

45. DeWitt, W. D.
A THERMAL INSULATION STUDY. Linde Div., Union Carbide Corp., Ind. Quarterly Progress Report, Oct – Dec 1966. 10 Feb 1967, 56p. (Contract AT(30-1)-3632) (ALO-3632-11). N67-28418.

Small-scale processing tests were conducted on copper flake opacified Refrasil quartz fiber paper and tantalum foil. Offgassing tests were conducted on all of the candidate insulation materials and the data are being reduced. Refrasil quartz fiber paper and copper flake opacified Refrasil quartz fiber paper exhibited higher offgassing rates than the other candidates, and experiments are under way to re-evaluate the processing techniques used. Thermal conductivity tests were completed for the nickel foil – Astroquartz cloth composite and the aluminum foil-glass fiber paper composite. Thermal conductivity data for the experiments were reduced, and an equation defining the temperature dependence of the thermal conductivity is presented. The first vacuum enclosure candidate test specimen, Inconel-600, developed leakage after 300 hours of testing. Metallurgical examination indicated that failure was due to oxidation penetration, accelerated by stress. The desirability of another Inconel-600 specimen test will be evaluated during the next quarter.

46. Lindquist, C. R.
LINDE COMPANY SUPER INSULATION APPLIED TO SPACE VEHICLES. Linde Co., Div., Union Carbide Rept. No. LINDE(1). 1 Dec 1962.

A discussion to describe the various physical properties of Super Insulation to show how a system may be applied to a space vehicle. This data reflects the current state of the art as applied to presently available commercial materials.

47. Niendorf, L. R.
INVESTIGATION OF A LIGHTWEIGHT SELF-EVACUATING PREFABRICATED MULTI-LAYER INSULATION SYSTEM FOR CRYOGENIC SPACE PROPULSION STAGES. Union Carbide Corp., Linde Div., Tonawanda, N. Y.

Monthly Progress Reports (Contract NAS 3-6289)

MPR-1 – 16 Jul 1965	NASA X65-91695
MPR-2 – 17 Aug 1965	NASA X65-92050
MPR-3 – 18 Oct 1965	NASA X66-90295
MPR-4 – 18 Nov 1965	NASA X66-90731
MPR-7 – 18 Apr 1966	NASA X66-92942
MPR-9 – 17 Jun 1966	NASA X66-93747

48. Niendorf, L. R. and G. E. Nies
INVESTIGATION OF A LIGHTWEIGHT SELF-EVACUATING PREFABRICATED MULTI-LAYER INSULATION SYSTEM FOR CRYOGENIC SPACE PROPULSION STAGES. Union Carbide Corp., Tonawanda, N. Y. Linde Div. Final Report, 3 Jun 1965 – 31 Jul 1966. 15 Jul 1966, 293p. (Contract NAS3-6289) (NASA-CR-72012). N66-38500.

The fabrication and assembly of multilayer insulation specimens of various insulation materials to determine pressure deflection characteristics and thermal performance are described. The use of carbon dioxide as the cryopumpable gas in the self-evacuating insulation panel system was investigated, and details are given on the gas conductance experiments and substrate development work. Based on a properties data survey on permeability, an aluminized Mylar laminate was selected for the vacuum casing material; a mathematical thermal analysis was also conducted to determine that the insulation panel heat leak would be less than 1 Btu/hr-ft^2 with the insulation system in the uncompressed space condition. Double aluminized Mylar radiation shields, separated by thin sliced (.02 inch) sheets of open-cell polyurethane foam, were selected for the lightweight multilayer insulation. Full scale insulation panel tests were conducted to determine cryopumping capability and thermal performance. Data are also included on a thermal analysis of a calorimeter insulation system, and on the use of open-cell cell foam and aluminzed Mylar for insulating a 30-inch calorimeter tank.

49. Perkins, P. J., R. P. Dengler, L. R. Niendorf, and G. E. Nies (Union Carbide Corp., Tonawanda, N. Y.)
SELF-EVACUATED MULTILAYER INSULATION OF LIGHTWEIGHT PREFABRICATED PANELS FOR CRYOGENIC SPACE PROPULSION VEHICLES.
National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.
Washington, NASA, 1967, 18p. To be presented at the 8th Struct. Structural Dyn. and Mater. Conf., Palm Springs, Calif., 29 – 31 Mar 1967; sponsored by AIAA. (NASA-TM-X-52266). N67-16046.

A concept for simplifying the application of radiation shield insulation to propellant tanks was developed and tested for both ground and space performance. Vacuum-tight flexible casing material of laminated aluminized Mylar encloses the multilayers forming panels that are bonded to tank walls in an overlapping shingle arrangement. The panels with CO_2 gas which cryopumps to provide required vacuum when the tank is filled with a cryogen. Thermal performance of insulation was determined in flat plate and cylindrical calorimeters. During ground-hold tests, insulation panels as large as 3- by 6-ft mounted on a cylindrical calorimeter of liquid hydrogen, cryopumped down to at least 5×10^{-3} torr and resulted in a heat flux of 23 Btu/(hr)(sp ft) for an external temperature of 70° F. In simulated space tests, panels evacuated by outside vacuum resulted in a heat flux of 0.86 Btu/(hr)(sq ft) with outside surfaces at 70° F.

LING-TEMCO-VOUGHT

50. Mulcahy, E. L.
ATTACHMENT TECHNIQUES FOR THE "C" SECTION TESTS IN THE SPACE ENVIRONMENT SIMULATOR. Ling-Temco-Vought, Dallas, Tex.
Rept. no. 3 52130 0210. 21 Nov 1963, 12p. IDEP 428 74 50 60D4 01. DDC AD-439 157.

This report culminates a study of the accuracy of the various thermocouple attachment techniques which have been used or have been proposed for use in testing of the Scout C Section in the Space Environmental Simulator. Thermocouples were attached to metal and fiberglas surfaces in several different ways and subjected to varying vacuum and thermal conditions similar to those encountered in the SES. The relative accuracy of the various attachment methods are established and data are provided from which correction factors can be obtained for purpose of data analysis.

LITTLE (ARTHUR D.), INCORPORATED

51. ADVANCED STUDIES ON MULTI-LAYER INSULATION SYSTEMS. Little, Arthur D., Inc., Cambridge, Mass. First quarterly progress report, 2 Mar – 31 May 1965. Report no. ADL-67180-00-01. Jun 1965, 68p. (NAS3-6283). NASA-CR-63839. X65-17758.

On March 2, 1965, Arthur D. Little, Inc. initiated work on Contract No. NAS3-6283 with the Lewis Research Center of the National Aeronautics and Space Administration. This effort is devoted to "Advanced Studies on Multi-Layer Insulation Systems" and is, in part, a continuation of previous work on Contract Nos. NAS5-664, NASw-615, and NAS3-4181.

The present contract includes three principal tasks:

Thermal Conductivity Apparatus, Emissometer Experiments and Insulated Tank Calorimeter. Efforts will be made to establish ways of preparing and fastening "prefab" insulation systems representative of what might be expected in a shop-type operation to the tanks.

52. THERMAL CONDUCTIVITY STUDIES OF POLYSTYRENE AND POLYESTER FILMS FOR USE IN HIGH PERFORMANCE INSULATION SYSTEMS. Little, Arthur D., Inc., Cambridge, Mass. Monthly progress report, 1 – 31 Mar 1965, NASA-CR-62622. 15 Apr 1965, 14p. (NAS3-6283). X66-91876.

53. THERMAL CONDUCTIVITY APPARATUS, INSULATED TANK PROGRAM, AND EMISSOMETER PROGRAM. Little, Arthur D., Inc., Cambridge, Mass. Monthly progress report no. 2, 1 – 30 Apr 1965. Report no. -67180. 15 May 1965, 14p. (NAS3-6283) NASA-CR-63604. X66-92862.

54. Little, Arthur D., Inc., Cambridge, Mass. Monthly progress report, 1 – 31 May 1965. Report no. MPR-3. 15 Jun 1965, 11p. (NAS3-6283). X65-91581.

55. THERMAL CONDUCTIVITY MEASUREMENTS ON THREE SAMPLES OF MULTI-LAYER INSULATION. Little, Arthur D., Inc., Cambridge, Mass. Monthly progress report no. 4, 1 – 30 Jun 1965. NASA-CR-64167. 15 Jul 1965, 24p. (NAS3-6283). X66-92898.

56. Little (Arthur D.), Inc., Cambridge, Mass. MONTHLY PROGRESS REPORTS (Contract NAS 3-6283).

MPR-5	– 1 Jul – 31 Jul 1965	NASA X65-92009
MPR-6	– 1 Aug – 31 Aug 1965	NASA X66-90099
MPR-7	– 1 Sep – 30 Sep 1965	NASA X66-90678
MPR-8	– 1 Oct – 31 Oct 1965	NASA X66-90558
MPR-11	– 1 Jan – 31 Jan 1966	NASA X66-92666

57. ADVANCED STUDIES ON MULTI-LAYER INSULATION SYSTEMS. Little (Arthur D.), Inc., Cambridge, Mass. Final Report. 1 Jun 1966, 390p. (Contract NAS3-6283) (NASA-CR-54929; ADL-67180-00-04). N67-13190.

Analytical and experimental studies were reported on the performance of multilayer insulation systems to reduce the heat leak rate into stored cryogenic propellants carried in space vehicles under varying environments. Emphasis was placed on: (1) use of an emissometer to evaluate new radiation shield materials; (2) operation of a flat plate thermal conductivity apparatus to evaluate spacer material for improved insulation efficiency; and (3) on a series of insulated calorimeter tank experiments. Experimental results showed that multilayer insulations with spacers of two or more materials are most effective because each component can be selected to perform a specific function. Emittance stability of silver and copper coatings was highest under exposure to high humidity, carbon dioxide, and salt environments. Commercial sources of good quality, low emittance shields consisted of polyester film, vacuum metallized on both sides with aluminum, silver and gold; they showed the best emittance values with .025, .011, and .017, respectively.

58. Black, Igor A., et al.
BASIC INVESTIGATION OF MULTI-LAYER INSULATION SYSTEMS. Little (Arthur D.), Inc., Cambridge, Mass. Final Report. 30 Oct 1964, 298p. (Contract NAS3-4181) (NASA-CR-54191; ADL-65958-00-04). N65-23738.

Work carried out on the experimental measurements of thermal protection systems for liquid hydrogen tanks is summarized. The purpose of the experimental program was to increase knowledge of the thermal behavior of multilayer insulations and to obtain data on the effects of variables on their performance. Major emphasis was placed on problems of installation and techniques from ground-hold to space conditions. Less emphasis was placed on the theoretical aspects of the behavior of insulation systems. Also, tests to determine the heat leak through various insulation materials installed on calorimeter tanks; and the design, construction, and operation of an emissometer to determine the total hemispheric emittance of materials for multilayer insulations are covered.

59. Bonneville, J. M.
DESIGN AND OPTIMIZATION OF SPACE THERMAL PROTECTION FOR CRYOGENS-ANALYTICAL TECHNIQUES AND RESULTS. A. D. Little, Inc., Cambridge, Mass. NASA CR-54190, ADL-65958-02-01. (Contract NAS 3-4181). N65-19847.

The object of this report is to assemble the significant results of all the analytical work performed to date on the subject of multilayer insulation.

In the introduction, the basis for the organization of the report is laid down in terms of (i) the role played by various insulation schemes and (ii) the steps involved in solving the thermal problem. The scope of the report is then made clear: to present the analytical aspects of the work involved in choosing, designing and optimizing a thermal protection system, with emphasis on MLI.

The environment of space is first treated, by way of an outline of the analytical procedure required to account for that environment. Previous work on the subject is referred to. The environment external to a tank is next discussed; this will differ from the space environment in the case of a shrouded tank. A shroud appears to be mandatory, in view of the requirements of ascent aerodynamic heating and space micrometeoroid protection; it would be most useful during groundhold also.

Section IV, which is divided into six parts, treats in detail multi-layer insulation. Part A is a general, though quantitative, discussion of the thermal behavior of real multilayer insulation necessary for an understanding of MLI. Part B justifies and discusses the treatment of MLI as a continuous blanket over the tank. This approach is valid because penetrations will affect the heat flow through the MLI blanket only slightly, whereas the converse is not true (the MLI blanket affects the heat flow through penetrations.)

In Part C, the thermal effect of penetrations and discontinuities in MLI is discussed in detail. First, concepts are developed for an understanding of the basic effect. Following this, various types of thermal shorts are graded according as they permit simple analysis or not. Methods for designing shorts for minimum heat leak are introduced. The very important matter of decoupling penetrations from the edges of foil is treated in detail. Some cases appear where decoupling is useless, or worse.

Parts D and E deal with analytical methods and relationships. Part D treats of scaling laws that can be applied to the MLI blanket, and to the penetrations. Part E summarizes the methods of computation recommended in determining the temperature field within MLI.

Part F discusses those parts of the experimental work done at Arthur D. Little, Inc., to investigate the validity of the analytical approach.

60. THE DEVELOPMENT OF HIGH PERFORMANCE INSULATION SYSTEMS. A. D. Little, Inc. Prepared for AF Ballistic Systems Div., AF Systems Command Progress Rept. No. 14, 1 Jan – 31 Mar 1963. Rept. no. ADL C-62458. Apr 1963. (Contract AF04(647)464.) DDC AD-410 053.

In 1958, Arthur D. Little, Inc., began a study (under Contract No. AF 33-(616)-5641) of the available insulation systems as well as of the feasibility of developing new insulation systems. The object was to find the most satisfactory means of achieving highly efficient insulation under severe weight and space limitations.

In the course of the study, the basic configuration of a high-efficiency, multilayer insulation was developed from a theoretical analysis. Insulation samples were prepared and their performance evaluated by laboratory tests. These tests indicated that this new insulation would perform as predicted and a program for its development was undertaken under Contracts AF 04-(645)-34 and AF 04-(647)-464. This report discusses the selection of insulating materials, the methods of constructing samples of insulation systems, and the tests that were conducted for evaluating their effectiveness.

61. DESIGN OF THERMAL PROTECTION SYSTEMS FOR LIQUID HYDROGEN TANKS. A. D. Little, Inc. Rept. no. ADL 65008-03-01. Apr 1963, Prepared for NASA Contract NASw-615.

The objectives of this study were the following: (1) To provide data to guide the design of efficient thermal protection systems for cryogenic fuel tanks for use in extended space missions with primary emphasis placed on multilayer insulations for liquid hydrogen tanks. (2) Establish design parameters adequate to meet production requirements, preflight check-out, and mission objectives to assure highest insulating effectiveness. (3) To measure the thermal performance of typical multilayer insulations consistent with materials within the present state-of-the-art.

Some environments (e.g., meteoroid interaction) affecting thermal protection systems are discussed briefly. The selection of materials is analyzed, such as the use of powders and foams.

Multilayer insulation is discussed in greater detail. Typical materials are described. A description is given of a thermal conductivity apparatus which permits experimental measurement of the influence of certain variables on insulation performance. At present, three double-guarded cold-plate apparatus are in use for the measurement of the thermal conductivity of various thermal insulators at liquid hydrogen and liquid nitrogen temperatures.

It can be concluded from available data that multilayer insulations of quite reasonable thickness will be adequate to reduce the boil-off losses in hydrogen tanks to reasonable proportions. However, multi-layer insulations have been successfully applied only to ground-based, double-walled storage vessels, and no large insulated cryogenic tanks have yet undergone the stresses of space flight.

Further information is presented on typical design parameters influencing selection of insulations. Launch environmental influences and leak detection techniques are also discussed.

62. INSULATED TANK PROGRAM. Little (Arthur D.), Inc., Cambridge, Mass. Monthly progress report no. 9, 1 – 31 Jul 1964. 12 Aug 1964, 21p. (Contract NAS3-4181) (NASA-CR-58747). X65-20285.

An aluminized foam insulation with 10% chopped glass fiber content, and a multilayer insulation consisting of 5 radiation shields of aluminized foam and 6 spacers of 0.020 inch thick vinyl coated glass fibers were tested by tank calorimeter for thermal conductivity. Test results showed that the heat flux through the composite system was approximately 40 times larger than the heat flux through the multilayer insulation. Heat flux measurements of samples containing eleven spacers and ten radiation shields arranged so as to provide 11%, or 100% support area were performed under mechanical loading. The 11% supported area samples produced a heat flux about 2.5 times less than the sample with a 100% support area.

63. LIQUID PROPELLANT LOSSES DURING SPACE FLIGHT. Arthur D. Little, Inc., Cambridge, Mass. Quarterly progress rept. no. 1, Sep – Dec 1962. Jan 1963, 44p. NASA X63-14200.

Programs continued during this report period were: (1) experimental studies of thermal protection systems; (2) the development of a sound analytical model for the action of a meteoroid bumper protection system.

1. The objectives of the insulated tank experimental program were to obtain values for heat leakage into a tank of realistic geometry, to gain experience in applying the insulation on a tank, and to test the validity of the assumption underlying the analysis of heat leaks through discontinuities and penetrations. Experimental investigation of multi-layer insulation were continued in the three thermal conductivity instruments. The effects of mechanical loading or the thermal conductivity of these insulations and preliminary results of the effects of discontinuities are presented. (1) Under

compressive mechanical loading of up to 15 psi the thermal conductivity of the six samples tested, is proportional to the two-thirds power of the applied mechanical load. (2) The effects of mechanical loads, on thermal conductivity up to several atmospheres can be predicted with reasonable confidence for these six insulations. (3) Insulation samples of crinkled aluminized polyester film radiation shields and soft aluminum foils with fiberglass spacers exhibit an improved thermal conductivity as the result of having been subjected to mechanical loading, while tempered aluminum foils with fiberglass spacers yields the opposite result. (4) There appears to be very little difference in the thermal conductivity of insulations containing fiberous spacing materials at loads exceeding 3 psi.

2. Construction of a small-scale prototype meteoroid penetration sensor was undertaken to demonstrate the feasibility of the logic circuitry for a sensor consisting of a matrix of electrical wires. Work was continued on a report on the design of meteor bumpers.

64. LIQUID PROPELLANT LOSSES DURING SPACE FLIGHT. Arthur D. Little, Inc., Cambridge, Mass. Second Quarterly Progress Rept., Jan – Mar 1963. Rept. no. 65008-00-02. Apr 1963, 111p. (Contract NASw-615.)

Principal aspects of the present program are the following:

1. Analytical Studies of Thermal Protection Systems. The radiative-conductive effect of heat transfer in a pipe connected to an insulated liquid hydrogen tank was analyzed to provide a guide in the thermal design of a system. Thermal radiation emitted at the warm end of such a line is partly absorbed by the pipe walls at locations near the cold end. Some of this energy is conducted and some re-radiated toward the cold end. The resultant radiation and increased wall gradients can result in heat leaks greater than the heat flows through the blanket of thermal insulation applied over the entire tank.

The multifoil insulation systems contemplated for use on cryogenic storage containers may be immersed in a non-condensable gas at atmospheric pressure at launch. As the vehicle ascends, the interstitial gas vents to a constantly and rapidly reducing pressure. A pressure gradient exists within the foils, therefore, and a question arises as to the ability of the insulation system to withstand this gradient without damage. Accordingly, an analysis is presented to shed some light on this problem and to provide some guidance to the design of experiments which should be made to prove the adequacy of the insulation system to withstand ascent decompression.

2. Experimental Studies of Thermal Protection Systems. A program that provides for the insulation of a tank and the measurement of the performance of this insulation system was initiated. The program is intended to develop techniques for applying multifoil insulations to compound curved surfaces, correlate heat transfer results

with those obtained in the thermal conductivity apparatus and analytical studies, and initiate the development of a practical insulation system to meet the various requirements under consideration.

Investigations of multilayer insulations were continued. The effects of mechanical loading on multifoil insulations and discontinuities in the insulation blanket were included in the study. Also the effects of warm and cold boundary temperature variations and of residual gas pressure within the insulation layers were initiated to determine the resultant apparent thermal conductivity of the insulations.

3. Evaluation of Meteor Bumper Protection Systems. An experiment was begun to study the effects of meteoroid-bumper debris on multilayer insulations. It is hoped to determine the minimum standoff distance for a bumper and/or the minimum weight system that will result in no damage to the multilayer insulation from meteoroid impact on the vehicle.

Data and information on meteoroid hazards was collected. A considerable portion of the program to develop and test a theory for the penetration of thin targets (bumpers) by hypervelocity projectiles is being conducted at McGill University. Effort was devoted to improving the facility and its instrumentation, and to preliminary investigations of bumper performance. Preliminary data and range capability are reported, together with spectrometric observations.

65. LIQUID PROPELLANT LOSSES DURING SPACE FLIGHT. Little (Arthur D.), Inc., Cambridge, Mass. Final Report, 1 Sep 1960 – 30 Sep 1963. Rept. no. -65008-00-04. Oct 1964, 307p. (Contract NASw-615) (NASA-CR-53336). N65-10372.

Full reports are included on the performance of multilayer insulations for liquid-hydrogen tanks, the application of multilayer insulations to small tanks, the effect of meteoroid-bumper debris on multilayer insulation, and the mechanical-test program for a load-bearing multilayer insulation system (of alternate layers of NRC-2 crinkled, aluminized-mylar radiation shields, and silicone-impregnated fiberglas spacers). Also given are abstracts of earlier reports on the space environment and on the evaluation of meteoroid-bumper protection systems.

LOCKHEED AIRCRAFT CORPORATION

66. Titus, R. K.
THERMAL INSULATION FOR PROTECTION OF MISSILE INTERIORS. Lockheed Aircraft Corp., Van Nuys, Calif. Rept. no. LMSD-1633. 19 Mar 1956, 6p. (Contract AF 04(645)-7.) DDC AD-802 317.

The overall objective of this investigation is to determine the relative values of various insulation materials; this initial report is issued to illustrate the heat sink effect of missile structures and components on their temperature rise, as a function of the time of exposure to a heat source. Specifically, only the case of the temperature rise of the skin with no insulation is included.

67. Titus, R. K., R. Stabler, and M. Allison
INSULATING VALUE AND SHEAR STRENGTH OF GLASS FABRIC AND 91-LD RESIN LAMINATE EXTERNALLY MOUNTED WITH THIKOL PR-1421 ADHESIVE ON THE X-17 VEHICLE. Lockheed Aircraft Corp., Van Nuys, Calif. Missile Systems Div. Rept. no. LMSD-1801; AD-802204. 26 Jun 1966, 40p. (Contract AF 04(645)-7). X67-13923.

This investigation was initiated to determine the insulating value of .040 inch 91-LD fiberglass bonded to a stainless steel sheet. The shear strengths of PR-1421 adhesive which was employed to bond the laminate to the steel became a critical factor in the study. Test coupons were prepared and subjected to high temperature flames directed against bare steel coupons and against the laminate protected samples. The ability of the laminate to remain intact and protect the steel skin was measured. The effect of the high temperatures upon the adhesive was also measured. The temperature rise was followed by thermocouples and recording millivoltmeters. It was found that the initial rate of rise of temperature of the bare steel was about ten times as fast as the steel protected with laminate. A large number of photographs, tables and graphs present the information visually. The shear strength of the adhesive was measured at the temperatures from ambient to that which were found to exist during the flame heating.

LOCKHEED-GEORGIA COMPANY

68. Aseff, G. V.
TEST PROCEDURES DOCUMENT FOR NO. 2 FOUR FOOT DIAMETER TANK FOLLOW-ON RIFT INSULATION DEVELOPMENT PROGRAM. Lockheed-Georgia Co., Marietta, Ga. Rept. no. LAC ER 6272. 14 Jun 1963. (Contract NAS-8-5600.)

This procedure establishes the methods to be used and measurements to satisfy the requirements as outlined in Test Assignment Document, TA NP-10032 No. 2, Four-Foot Diameter Tank Follow-On Test, RIFT Insulation Development Program, dated 26 April 1963.

An insulation system (classified System A) as installed by personnel from the LGC Chemical and Metallurgical Research Laboratory in a large-radius spherical lid to the four-foot diameter tank will be re-tested under simulated operating conditions. The results of the test will be used as the basis for selection of insulation systems to be used in the nine-foot tank tests, radiation/liquid hydrogen combined environment tests, and acoustic panel tests.

Development of test methods and instrumentation techniques will be conducted as required to ensure compliance with test requirements and the investigation of the behavior of the permanent insulation in the tank dome will be continued.

LOCKHEED MISSILES & SPACE COMPANY

69. Baxter, J. W.
DEVELOPMENT OF THERMAL PROTECTION SYSTEM FOR A CRYOGENIC SPACECRAFT MODULE. Lockheed Missiles & Space Co., Sunnyvale, Calif. Second Quarterly Progress Report, 1 Oct – 31 Dec 1964. 15 Jan 1965, 140p. (Contract NAS3-4199) (NASA-CR-57280; LMSC-A729936.) X66-21518.

Design and manufacturing analysis of the selected semi-monocoque conical titanium support system are reported. This design will be employed in the half-scale test apparatus and integrated into the thermal protection system. Laboratory tests of components and the subscale tank model were conducted, and detailed results are given. The insulation system that was selected consists of alternate Mylar layers, aluminized on both sides, with spacers and button retainers. This multilayer insulation will be installed over a fiberglass mat sublayer which will be ground purged with helium gas. Procedures and results of the purge test are given in detail. Initiation of manufacturing assembly and detail drawings to suspend the 82.6-inch diameter test tank within the load-carrying shell by the continuous support system is presented. A summary is given of quality assurance measures taken during the design and production stages.

70. Coston, R. M., J. J. Brogan, and J. H. Guill
STUDY ON HIGH-PERFORMANCE INSULATION THERMAL DESIGN CRITERIA. Lockheed Missiles & Space Co., Sunnyvale, Calif. Second Quarterly Progress Report. 15 Oct 1966, 60p. (Contract NAS8-20353) (NASA-CR-79881; LMSC-A837978). X67-10444.

Progress is reported from a study devised to provide practical thermal design data and criteria that can be applied in designing thermal protection systems for long-duration space storage of cryogenic propellants. A mathematical model is being used to demonstrate the ability to take laboratory generated data on multilayer insulations and predict the thermal behavior of a flight type system exposed to flight thermal and pressure environmental conditions. Experimental data are discussed in the specific areas of computer program correlations, refinements, and applications, thermal design handbooks, and gas flow studies.

71. Cunnington, G. R., et al.
PERFORMANCE OF MULTILAYER INSULATION SYSTEMS FOR TEMPERATURES TO 700°K. Lockheed Missiles & Space Co., Palo Alto, Calif. Final rept. Rept. no. LMSC-4-05-67-17. May 1967. NAS2-2441.

Multilayer insulations which will operate in the 300° to 700°K temperature range are being considered for use as portions of the thermal control systems on advanced spacecraft for near-solar missions. The high operating temperatures necessitated the evaluation of new materials and composites. Also, as this type of insulation has highly anisotropic thermal properties, the multidimensional heat transfer properties of the materials must be characterized.

An analytical treatment is derived for evaluating the one-dimensional heat transfer through multilayer insulations. Experimental verification of the influence of the significant properties of the components of the system on overall thermal conductivity is reported. Data on the thermal conductivity of a number of multilayer insulations over the temperature range of 300° to 700°K are presented. Analytical models are developed for study of the effects of exposed edges, joints, and penetrations on the heat transfer in this type of insulation and comparison is made with experimental data for a cylindrical system.

72. Greenberg, S. A. and D. Vance
LOW SOLAR ABSORPTANCE AND EMITTANCE SURFACES UTILIZING VACUUM DEPOSITED TECHNIQUES. Lockheed Missiles & Space Co., Palo Alto, Calif. Final rept. 29 Jun – 28 Sep 1966. Report no. LMSC-4-06-66-13. Oct 1966. NASA Contract NAS2-3063. NASA CR-73039.

An investigation was made of the techniques and materials for finishing spacecraft structural surfaces with stable, reproducible, thermal control materials. Various coating systems, prepared by vacuum physical vapor deposition, were evaluated in terms of optical characteristics. Coating systems were selected to satisfy practical engineering requirements.

73. Marshall, K. and R. Olsen
OPTICAL SOLAR REFLECTOR THERMAL CONTROL SURFACE. Lockheed Missiles & Space Co., Palo Alto, Calif. Report no. LMSC-3-56-65-2. 2 Feb 1965. (Contract AF04(647)787).

A program to evaluate and establish a stable, low α_S/ϵ thermal control surface for use on Program 461 vehicles has been completed. The surface has been termed the Optical Solar Reflector (OSR).

The program consisted of (1) determining the thermal radiative properties of the OSR, (2) subjecting candidate OSR materials to environmental tests, (3) selecting an appropriate adhesive system, and (4) establishing application methods and procedures for applying the OSR to flat panels. The environmental tests included near-ultraviolet radiation exposure, high-energy electron exposure, low-energy proton bombardment, combined high-energy electron and near-ultraviolet exposure, thermal cycling, thermal shock, sinusoidal and random vibrations, mechanical shock, and weathering.

The complete OSR program and results obtained are presented herein. The results of the high-energy electron, low-energy proton, and combined high-energy electron plus near-ultraviolet tests were originally presented in References 1, 2, and 3, respectively.

74. Parmley, R. T.
HANDBOOK OF THERMAL DESIGN DATA FOR MULTI-LAYER INSULATION SYSTEMS. Lockheed Missiles & Space Co., Sunnyvale, Calif. Report no. LMSC-A742593, Vol. VI – Design of High-Performance Insulation Systems. 11 Aug 1965. (NAS-8-11347).

The Handbook of Thermal Design Data for Multilayer Insulation Systems was prepared under Contract NAS 8-11347 for Marshall Space Flight Center (MSFC). This volume is the sixth in a series of seven that constitute the final report on work conducted under the MSFC contract. The prime intent in assembling the data presented in this volume is to provide a sourcebook of consistent data about thermal and physical properties, so that the data can be applied in the mathematical thermal models of cryogenic propellant tankage, associated structure and plumbing, and multilayer insulation systems developed under Contract NAS 8-11347 and described in Volumes II through V of this report.

The body of thermal and physical design data on multilayer-insulation systems is not always consistent. Furthermore, the available data of good quality can be found only by recourse to many different technical reports. The rapid advances made recently in the practical techniques of design, fabrication, and application for this type of insulation warrant one sourcebook of consistent data for application to refined insulation-system thermal analyses now available with use of the mathematical models.

The second intent of this report is to provide readily available design data for general usage by designers and thermal analysts of cryogenic space vehicles who will not necessarily employ the mathematical models. A variety of design data is presented, including thermal conductivity, specific heat, density, linear thermal expansion, weight per unit area, and maximum material operating temperatures.

Only the most promising materials under investigation were included in this compilation. If data on a specific material were not available, a similar material was chosen to represent the properties in that material class.

The data presented in this report are divided into four major categories, as follows:

1. GASES
2. METALS
3. FIBERGLASS LAMINATES
4. MULTILAYER INSULATIONS
    4.1 Substrates
    4.2 Multilayer-Insulation-System Materials
    4.3 Multilayer Composites
    4.4 Attachment Methods

75. Smith, D. D.
ANALYSIS OF INSULATION OPTIMIZATION.
Lockheed Missiles & Space Co. Rept. no. LMSC-A742593, Vol. VII – Design of High Performance Insulation Systems. 11 Aug 1965. (NAS-8-11347).

The derivations and resulting expressions that define the optimum thickness of insulation for cryogenic propellant tankage were prepared under Contract NAS 8-11347 for Marshall Space Flight Center. This volume is the seventh in a series of seven that constitute the final report on work conducted under the MSFC contract.

The thickness of insulation used on cryogenic propellant tankage for space applications can markedly affect the stage inert weight because it influences many component inert weights on the stage, e.g., the amounts of propellant vented in flight and the tank operating pressure, which governs tank weight. Since the tank insulation affects stage weight, its influence is also felt on the attainment of the velocity increment, ΔV, required to achieve a particular mission. As a result, the criteria considered for optimizing the insulation thickness include the maximization of payload upon achieving a design ΔV, and maximization of ΔV with a fixed payload. One special optimization case was also studied. This consisted of optimizing the insulation thickness for a vehicle assembled and tanked in orbit. The optimization criterion applied was to ensure a minimum stage weight in orbit.

The vehicle design missions considered include short, medium, and long ones. Any phase within a mission can be considered, such as ascent, earth orbit, lunar transfer, lunar orbit, interplanetary coast, and park orbit.

The following three general categories of tank pressurization modes were considered:

- Vented tanks
- Nonvented tanks without refrigeration
- Nonvented tanks with refrigeration

76. Stabler, R. and S. Greenberg
INSULATION (THERMOFLEX) EVALUATION OF SURFACE BINDER. Lockheed Missiles & Space Co., Sunnyvale, Calif. Rept. no. LMSD-1541. 19 Jan 1956. Contract AF 04(645)-7. DDC AD 802 790.

The purpose of this investigation was to evaluate commercial coating materials as surface binders for Thermoflex insulation and recommend a satisfactory material for application to insulation which has been cemented into place in instrument areas of X-17 vehicles.

77. Sterbentz, W. H.
DEVELOPMENT OF THERMAL PROTECTION SYSTEM FOR A CRYOGENIC SPACECRAFT MODULE. Lockheed Missiles & Space Co. First quarterly progress rept., 30 Jun – 30 Sep 1964. Report no. LMSC-A703794. (NAS-3-4199).

The major objective of this program is to develop an optimum thermal protection system based upon the use of multilayer insulation materials for the liquid hydrogen tank of the cryogenic spacecraft propulsion module. The program is both analytical and experimental in scope, culminating in a performance test of a 7-foot diameter (half-scale) insulated tank simulating insofar as possible those conditions expected during an 8-day lunar-mission as specified by the NASA Lewis Research Center. Details of this program covering proposed activities, facilities, test specimens, and schedule are given in the Project Plan and Schedule, LMSC-A664284, dated 30 July 1964.

The cryogenic propulsion module is conceived as a spacecraft propulsion module for the spacecraft of the Saturn V Apollo/LEM vehicle. The total height of the Saturn V vehicle with the cryogenic propulsion module would be about 143 inches higher than the current vehicle.

Estimated mission performance advantages show that, for example, the LEM vehicle lunar orbit weight may be increased from the current value of about 27,000 pounds to over 40,000 pounds. Such marked performance gains however are highly dependent upon the effectiveness of a thermal protection system for the liquid hydrogen tank of the propulsion module to retain the propellant with very low boiloff over the 8-day mission duration and to survive the flight loads to which it will be subjected.

Significant developments toward demonstrating the practicability of a thermal protection system based upon the use of multilayer insulation materials for the liquid hydrogen for this vehicle and mission have been made during the first quarter of this program.

78. Sterbentz, W. H. and J. W. Baxter
THERMAL PROTECTION SYSTEM FOR A CRYOGENIC SPACECRAFT PROPULSION MODULE.
Lockheed Missiles & Space Co., for NASA NAS 3-4199. Rept. no. LMSC A794993, Vol. 1; NASA CR 54879. 15 Nov 1966.

A primary objective in the development of a thermal protection system for a cryogenic spacecraft propulsion module conducted by the Lockheed Missiles & Space Company for the National Aeronautics and Space Administration, was the development of a lightweight insulation that would limit liquid hydrogen boiloff to less than 5 percent of the initial propellant load during an 8-day lunar mission. This program, which was both analytical and experimental in scope, answered the following additional questions posed by the NASA Lewis Research Center: (1) How can the insulation be applied to survive boost loads? (2) How can it be augmented to provide ground-hold and boost-phase insulation? (3) What is an optimum support system for the tank? In addition, the Lockheed program was aimed at developing a design based upon the practicalities of cryogenic stage manufacturing and the quality control requirements of simplicity, producibility, repeated assembly and reassembly, low cost, and controllable quality. All of these objectives were successfully achieved.

79. Sterbentz, W. H. and J. W. Baxter
THERMAL PROTECTION SYSTEM FOR A CRYOGENIC SPACECRAFT PROPULSION MODULE.
Lockheed Missiles & Space Co., for NASA NAS 3-4199. Rept. no. LMSC A794993, Vol. 2; NASA CR 54879. 15 Nov 1966.

The development of a thermal protection system for a cryogenic spacecraft propulsion module is reported in two volumes. The first volume summarizes the program, evaluating the salient results in light of the program objectives. In this second volume, all the details of the technical effort, including graphs, curves, tables of data, drawings, analyses, and evaluations, are discussed.

80. A STUDY ON HIGH-PERFORMANCE INSULATION THERMAL DESIGN CRITERIA. Lockheed Missiles & Space Co., for Marshall Space Flight Center, Ala. Third quarterly progress report. Rept. no. LMSC A852904. (NAS8-20353). 15 Jan 1967.

Experimental data obtained in the continuing investigation of heat transport occurring in and around multilayer insulation penetrations. Further data are presented on the insulation performance without penetration.

81. A STUDY ON HIGH-PERFORMANCE INSULATION THERMAL-DESIGN CRITERIA. Lockheed Missiles & Space Co., prepared for George C. Marshall Space Flight Center, Huntsville, Ala. Final rept. Report no. LMSC-A847882. Jun 1967. (Contract NAS 8-20353).

The study described in this report was conducted by Lockheed Missiles & Space Company under contract NAS 8-20353. The results of this study are presented in three volumes. The first volume describes the complete details of the technical effort. The second volume consists of an updated and revised version of the "Handbook of Thermal Design Data for Multilayer Insulation Systems," which was originally compiled under NAS 8-11347. Volume III is a "Handbook of Optical Properties for Thermal Control Surfaces." The basic objective of this program was to provide practical thermal design data and criteria which can be applied in designing thermal protection systems for long-duration space storage of cryogenic liquids.

Volume I – STUDY ON HIGH PERFORMANCE INSULATION THERMAL DESIGN CRITERIA

Volume II – HANDBOOK OF THERMAL DESIGN DATA FOR MULTILAYER INSULATION SYSTEMS

Volume III – HANDBOOK OF OPTICAL PROPERTIES FOR THERMAL CONTROL SURFACES

MARINE ENGINEERING LABORATORY

82. Braden, John R. and Richard E. Heise, Jr.
MECHANICAL SHOCK RESISTANCE OF THREADED FASTENERS. Marine Engineering Lab., Annapolis, Md. Rept. no. (MEL-412/66; AD-639953). Oct 1966, 36p. N67-14678.

An investigation was made of the mechanical shock resistance of K-Monel full-body studs set in HY-80 steel under various conditions. Strain gages mounted on the stud shanks were used to measure dynamic loading. Elastic nylon-insert monel stop nuts were used throughout the test. The data indicated that for the conditions of the test Locktite-coated 3A-3B threads are equal in shock resistance to uncoated 5A-5B threads, and that the elastic stop nuts are reusable after repeated shock.

MARTIN COMPANY

83. Crawford, R. F. and R. G. Hannah
CRYOGENIC INSULATION RESEARCH. Martin Co., Baltimore, Md. Structure Dept. Final report. 23 Jan 1967, 183p. (Contract NAS8-11397) (NASA-CR-61162). X67-11981.

A program to determine through experimental evaluation the suitability of a variety of insulation systems for protecting cryogens from the thermal environments of ground hold, rocket boost, and extended space storage is described. Systems tested are discussed giving geneses of the various concepts and the general characteristics of each system, and the test plan is summarized including detailed objectives, factors leading to the selection of the specimens and their test tank, and the sequence, specifications and apparatus used in the screening test. A comprehensive discussion of results is given including an assessment of the fabrication and installation characteristics of each system, and problem areas likely to affect the system's reliability are pointed out. Detailed information on the design and performance analyses for each insulation system is presented, and four studies considered ancillary to the system studies are described. They are: (1) error analysis for space thermal tests, (2) evacuation study for helium purged NRC-2, (3) effects of perforating multilayer insulation systems, and (4) redesign of Marshield support pins.

84. DESIGN TECHNIQUES FOR STRUCTURES CRYOGENIC INSULATION INVESTIGATIONS. Martin Co., Baltimore, Md. Rept. MAR ER 13502. Oct 1964. (Contract NAS 8-5268). NASA X65-10298.

The objective of this program was to develop design techniques and solutions for integrating highly efficient thermal insulations with cryogenic tankage for space vehicles. Emphasis was placed upon developing insulation systems and their attachments having high structural and thermal reliability consistent with maintaining efficient mission performance and manufacturing practicability.

A uniform basis for the development, evaluation and comparison of the design solutions was provided by prescribing a typical but idealized set of conceptual design criteria for use in developing all insulation systems. Of the existing insulation materials only National Research Corporation's "NRC-2" and Linde Division of Union Carbide's "Super Insulation" were found to be efficient enough for feasibility of the prescribed mission. Three different methods of augmenting each to satisfy insulation requirements in the atmosphere were considered; passive with subinsulation, purged and ground evacuated. Another type of insulation named Marshield was designed that consists typically of a fewer number of thicker, more widely and positively spaced radiation barriers than either NRC-2 or Linde SI. Its estimated thermal performance is lower than NRC 2 and Linde SI.

85. Rieckmann, R. E., RESEARCH STUDY TO PROVIDE CONCEPTS OF PANEL ATTACHMENT MECHANISMS SUITABLE FOR REFURBISHABLE PANEL APPLICATION. Martin Co., Baltimore, Md. Nov 1966, 86p. (Contract NAS1-5253) (NASA-CR-640). N67-11950.

A study has been made to select the best attachment mechanism concept for use in the refurbishable heat shield system. The selected system was an ablator bonded to a phenolic/glass honeycomb substrate panel which was supported off the primary vehicle by phenolic/glass tapered cylindrical cups. The actual refurbishable panel tie is accomplished by the use of lock nuts which are put on aluminum stud fittings located on the primary vehicle shell insulation mats are installed between the vehicle and substrate panel. After selecting the attachment concept to be used, a detail structural analysis was made for three representative areas on an HL-10 manned lifting entry vehicle. The three areas were a leading edge section, a bottom section, and a crown section of the vehicle. Critical thermostructural conditions were determined and a digital analysis performed to determine aerodynamic and thermal substrate panel and standoff member stresses and deflections. All of the structural problem areas encountered can be minimized utilizing conventional engineering approaches.

MCDONNELL AIRCRAFT CORPORATION

86. Robertson, J. E.
EFFECT OF LAUNCH HEATING ON STRENGTH OF VELCRO. McDonnell Aircraft Corp., St Louis, Mo. Final report. Report no. MAC-052-015.44. 28 Jan 1966. IDEP 307.40.60.00-F4-01. DDC AD-806 375L.

Distribution: USGO: others to Headquarters, Space Systems Div., Attn: IDEP Office, SSSD. Air Force Unit Pose Office, Los Angeles, Calif. 90045.

Environmental tests on Velcro fastenings.

MIDWEST RESEARCH INSTITUTE

87. Loser, J. B., C. E. Moeller, and M. B. Thompson
THERMOPHYSICAL PROPERTIES OF THERMAL INSULATING MATERIALS. Midwest Research Inst., Kansas City, Mo. Report for 1 Feb 1961 – 19 Jan 1962, 15 Jan – 15 Dec 1963. Apr 1964. Contract AF33 657 10478, Proj. 7381, Task 738103. ML TDR64 5, ASD TDR62 215 rev. NASA N64-22689. DDC AD-601 535.

This handbook is a compilation of thermophysical property data of insulating materials, which can be used in both cryogenic and high-temperature applications. Thermal conductivity, linear thermal expansion, specific heat, total normal emittance, thermal diffusivity, and compressive strengths are plotted with respect to temperature. Density, melting point, continuous service temperature, typical available form, and modulus of elasticity are given in tabular form in a General Properties Table. The data listing is arranged on the basis of two principles; first, alphabetically, and then by form (powders, foams, multiple layers, etc.). Various experimental methods for determining thermal properties are described and their accuracies are indicated. The other sections also included in the handbook are: Glossary of Synonyms and Trade Names, Conversion Factors, References, and Author Index.

MITRON RESEARCH & DEVELOPMENT CORPORATION

88. Goldman, E. J., W. E. Lee, and R. A. Rosenberg DEVELOPMENT OF FLUOROCARBON BONDED CLOSURES. Mitron Research & Development Corp., Waltham, Mass. Final rept. Jul 1964 – Jun 1965. Jun 1965, 67p. Contract DA-18-035-AMC-268 (A), Proj. DA-1C533601D103. DDC AD-811 576L.

Distribution: USGO: others to Commanding Officer, Army Edgewood Arsenal, Attn: SMUEA-TSTI-T, Edgewood Arsenal, Md. 21010.

MONSANTO RESEARCH CORPORATION

89. Fincke, John K., Glenn R. Wilson, et al. SYNTHESIS OF NEW AND IMPROVED THERMALLY STABLE POLYIMIDE LAMINATING RESINS AND ADHESIVES. Monsanto Research Corp., Dayton, Ohio. Dayton Lab. Summary technical rept. May 1966, 114p. Contract AF 33(615)-2759, Proj. AF-7340 Task 734003. AFML TR-66-188. DDC AD-804 267L.

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

90. Gray, V. H. et al.
BONDED AND SEALED EXTERNAL INSULATIONS FOR LIQUID-HYDROGEN-FUELED ROCKET TANKS DURING ATMOSPHERIC FLIGHT. APPENDIX B: STRENGTH OF INSULATIONS AND BOND TO ALUMINUM AT CRYOGENIC TEMPERATURES. APPENDIX C: STEP METHOD OF APPROXIMATE NUMERICAL CALCULATION OF ONE-DIMENSIONAL TRANSIENT HEAT CONDUCTION WITH VARIABLE THERMAL PROPERTIES. National Aeronautics and Space Administration. Oct 1960. (NASA Technical Note D-476).

Several currently available nonmetallic insulation materials that may be bonded onto liquid-hydrogen tanks and sealed against air penetration into the insulation have been investigated for application to rockets and spacecraft. Experimental data were obtained on the thermal conductivities of various materials in the cryogenic temperature range, as well as on the structural integrity and ablation characteristics of these materials at high temperatures occasioned by aerodynamic heating during atmospheric escape. Of the materials tested, commercial corkboard has the best overall properties for the specific requirements involved.

91. Kennedy, Bobby W.
HIGH TEMPERATURE POLIMIDES FOR ELECTRICAL EQUIPMENT. National Aeronautics & Space Administration, Marshall Space Flight Center, Huntsville, Ala. 24 Feb 1967, 51p. (NASA-TM-X-53523). N67-24630.

Polyimide materials, such as H-film (pyromellitic dianhydride), molding compounds, and adhesives, that can be used in electronic equipment and withstand space and lunar environments, have been studied. The H-film, a polyimide with the ability to maintain its physical, electrical, and mechanical properties over a wide temperature range, is expected to withstand the high vacuum on the moon. It has a chain of rings in its skeleton instead of a single chain. The carbon ring absorbs energy without degradation; under the same conditions, a single chain would rupture. The adhesive systems used in laminating H-film will have approximately the same properties as H-film. An example is benzophenoneteracarboxylic dianhydride (BTDA) reacted with oxydianiline (ODA) in which the thermal stability appears to be similar to that of H-film. This adhesive system decomposes within 20 hours at 400°C. It shows relatively small weight losses at 300°C during the same period.

92. Levinsohn, M.
VACUUM UV COATINGS, MICROCIRCUITRY WELDING, METAL POLISHING STUDY, ABSOLUTE SPECTRAL RESPONSE SYSTEM, PARABOLIC REFLECTORS, SOLDERING TO ELECTRODEPOSITED METALS. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. Quarterly progress report, 1 Jan – 31 Mar 1966. (1966), 24p. (NASA-TM-X-57614). N66-27757.

This report describes progress on a series of experimental fabrication and engineering projects. This period's activities include an investigation of a procedure for depositing uniform vacuum ultraviolet reflecting coatings on large surfaces; installation and testing of a device to measure electrode tip movement during a microcircuitry welding cycle; results of a metal polishing study to determine the suitability of nickel, beryllium, Haynes 25, Lurium 5, and aluminum 2024 and 6061 as reflective optical elements; testing of a high intensity light source optical system; further development of an explosive forming technique for fabricating parabolic reflectors; and tests to determine the suitability of electroplated gold as a base for soldering.

93. SEALED-FOAM, CONSTRICTIVE-WRAPPED, EXTERNAL INSULATION SYSTEM FOR LIQUID HYDROGEN TANKS OF BOOST VEHICLES. National Aeronautics and Space Administration, Washington, D. C. Mar 1965, 157p. NASA TN D-2685.

An investigation was conducted to determine a light-weight hydrogen tank insulation system that would provide adequate thermal insulation during ground hold conditions, and would be able to withstand the aerodynamic forces and heating encountered during the launch trajectory. The experimental investigation included tests of impact sensitivity of the insulation components in the presence of liquid oxygen, aerodynamic tests in which the heating and dynamic pressure conditions were more severe than during a typical launch trajectory, and measurements of the effective thermal conductivity of the insulation by means of (1) small samples, (2) heat-transfer measurements on subscale tanks filled with liquid hydrogen, and (3) heat-transfer measurements on a full-scale insulated Centaur tank filled with liquid hydrogen. The insulation system as finally developed consisted of 0.4-inch thick, 2-pound-per-cubic-foot-density polyurethane foam panels hermetically sealed within a covering of a foil laminate of Mylar and aluminum. A thin layer of fiber-glass cloth over the insulation provided protection from aerodynamic erosion during launch. The insulation was bonded to the tank wall using adhesive a grid pattern, primarily to keep air from cryopumping behind the panels. The principal means of holding the insulation on the tank was a prestressed constrictive wrap of fiber-glass roving. This wrap was completely effective in holding the insulation in place under all aerodynamic test conditions including heating in a jet engine exhaust and a wind tunnel test at Mach numbers up to 2.0.

The results of the investigation indicated that the hazard resulting from impacting insulation panels that may contain liquid oxygen from cryopumped air was negligible, the thermal effectiveness of the insulation was as good as predicted based on evacuated foam tests, and the insulation, which weighed only 0.16 pound per square foot installed, could well withstand the environmental conditions expected during ground hold and launch.

94. SELECTED MACHINING AND METAL FABRICATING TECHNOLOGY. National Aeronautics and Space Administration. 1967. NASA-SP-5065.

CHAPTER on

- Fastening devices
- Threadless fastener
- Latch-ejector unit
- Torque-indicating washer
- Captive nut
- Safety locking screw and washer

NATIONAL CASH REGISTER COMPANY

95. Peters, G., J. Whitaker, and J. Hanny
EXTRAVEHICULAR SPACE ADHESIVE SYSTEM.
National Cash Register Co., Dayton, Ohio.
Final technical rept., Apr 1965 – Mar 1966. Aug 1966. (Contract AF 33(615)-2693, Proj. AF-8170 Task 817008). AFAPL TR-66-59. DDC AD-646 659.

The purpose of this program was to demonstrate the feasibility of developing and incorporating capsular adhesives formulations into an extravehicular astronaut attachment device for stabilization of the astronaut during EVA maintenance or repair missions. Program investigations involved the screening and evaluation of numerous rapid-curing adhesive formulations, encapsulation of adhesive components, testing of capsular adhesive systems, and the design and fabrication of adhesive pads and dispensers. Two potential adhesive systems were selected during the screening studies. These were the Eastman "910" (methyl 2-cyanoacrylate) catalyzed with dimethyl p-toluidine, and epoxy resins catalyzed with BF3 complexes. All of the selected adhesive components were encapsulated and formulated into functional capsular adhesive systems. Because of certain inherent mixing problems which were related to the epoxy resins and the selected cure-inducing catalysts, the majority of work was directed toward the "Eastman 910" adhesive formulation. Test data obtained in regard to the capsular "Eastman 910" adhesive formulation indicated the system satisfied the majority of program design goals.

NATIONAL RESEARCH CORPORATION

96. Reed, Malcolm E.
DEVELOPMENT OF TECHNIQUES AND HARDWARE FOR INSULATION WRAPPINGS OF CRYOGENIC CONTAINERS. National Research Corp., Cambridge, Mass. Eighth quarterly progress report, Aug – Oct 1965. Dec 1965, 13p. (Contract NAS8-11042) (NASA-CR-69538). N66-15726.

During this report period most of the work was directed towards completing drawings for the fabrication and assembly of the superinsulation system. A design for the purge bag was conceived. The calculations for determining the optimum number of layers resulted in a value of 54 layers to yield the minimum ratio of non-useful to useful weight.

PART II

JOURNAL ARTICLES, SYMPOSIA AND BOOKS

97. Reed, Malcolm E.
DEVELOPMENT OF TECHNIQUES FOR INSULATION WRAPPINGS OF CRYOGENIC CONTAINERS.
National Research Corp., Cambridge, Mass.
Feb 1967, 69p. (Contract NAS8-11042) (NASA-CR-82763). X67-12604.

A design study was initiated of the use of a superinsulation both with and without a vapor sealed inner layer of insulating material. The study involved an insulation system consisting of an outer releasable bag for helium purge gas, multilayer insulation and no vapor sealed underinsulation. Included are manufacturing drawings for the superinsulation assembly designed for a NASA 105 in diameter liquid hydrogen vessel, recommendations for methods of purge gas bag construction and a release device for the bag as well as recommendations for methods of making temperature and pressure measurements within the multilayers.

NAVAL AIR ENGINEERING CENTER

98. Dever, Joseph H.
EVALUATION OF SELF-LOCKING DEVICE INCORPORATED IN COUPLING NUTS. Naval Air Engineering Center, Philadelphia, Pa. Aeronautical Materials Lab. Final report. Rept. no. NAEC-AML-2564. 3 Feb 1967, 27p. Task A34-530-004/200-1/F01207-02. DDC AD-811 608L.

Distribution: DoD only: others to Naval Air Engineering Center, Attn: Aeronautical Materials Lab., Philadelphia, Pa. 19112.

99. Snyder, H.
QUALIFICATION OF "SCOTCH-WELD" BRAND STRUCTURAL ADHESIVE SYSTEM, AF-20125-2 "SCOTCH-WELD" PRIMER EC-2320 WITH "SCOTCH-WELD" FILM ADHESIVE AF-126-2, TYPE I, CLASS 1 AND 2, MIL-A-25463 (ASG) SUBMITTED BY MINNESOTA MINING AND MANUFACTURING COMPANY. Naval Air Engineering Center, Philadelphia, Pa. Aeronautical Materials Lab. Report for 16 Aug – 12 Oct 1966. Report no. NAEC-AML-78503-67. 14 Oct 1966. DDC AD-802 452L.

Distribution: USGO: others to Naval Air Engineering Center, Philadelphia, Pa. 19112. Attn: Aeronautical Materials Lab.

NORTH AMERICAN AVIATION, INC.

100. ADHESIVE PROPERTIES, -300° to 700°F.
North American Aviation, Inc. Report no. NAA-Al-2590. Sep 1957. DDC AD-151 529.

Results obtained in tests on specially selected adhesive systems indicate that adhesive bonding may be considered as a structural joining method for service temperatures from -300 to 700°F. The limitations and advantages are pointed out.

101. ALTERNATE CURE CYCLE FOR MA0106-040 THERMALLY CONDUCTIVE ADHESIVE. North American Aviation Inc., Downey, Calif. Space and Information Systems Div. 28 May 1964, 13p. IDEP 501.01.00.00-F1-02. DDC AD-810 411L.

Distribution: USGO: others to Headquarters, Space Systems Div., Attn: IDEP Office, SSSD. Air Force Unit Post Office, Los Angeles, Calif. 90045.

102. Mahoney, J. W.
OPTIMIZATION AND EVALUATION OF HIGH-TEMPERATURE STRUCTURAL ADHESIVES.
North American Aviation, Inc., Los Angeles, Calif. Sep 1966, 79p. (Contract AF 33(615)-2848) (NA-66-581; AFML-TR-66-198; AD-489499).
X67-10913.

Subsequent to a literature and experimental survey of potentially serviceable high temperature structural adhesives, two polyimide types were chosen for further studies. Process optimization studies for these adhesives on INCO-718, PH14-8Mo, and 8-1-1 titanium are reported. Engineering data for the first two adherends, including both lap bonds and honeycomb constructions are presented. These data cover the temperature range to 423°F – 700°F. Studies to improve adhesion to 8-1-1 titanium after thermal aging are reported.

103. S II INSULATION EVALUATION. (U)
North American Aviation, Inc., Downey, Calif.
Report no. SID 61-212-5. 122p.
CONFIDENTIAL REPORT

Insulation has been found to be required for airborne liquid hydrogen vessels. The types of insulation avialable for use and how to fabricate them is discussed in this report. In addition the advantages and disadvantages of the three major types of insulation (internal, external and integral structure insulation) which appear to be desirable for the Saturn II booster are discussed.

NORTHROP CORPORATION

104. Bischoff, G. H., H. V. Willey, and K. W. Kuster
BONDING OF HEAT SHIELD MATERIALS.
Northrop Corp., Hawthorne, Calif. Norair Div.
Technical report 30 Jun 1965 – 30 Apr 1966.
Jun 1966, 72p. (Contract AF 33(615)-2745) (NOR-66-213; AFML-TR-66-189: AD-802090L). X67-13906.

NOTICE: Available To U.S. Government Agencies Only.

Synthesis, formulation, and processing research were conducted on high performance polymeric materials for bonding ablative heat shield materials to metallic and non-metallic substructure materials which are intended for use on advanced ballistic and lifting reentry vehicles. Initial and selective screening studies were performed to assess the ability of various bonding materials to meet predetermined functional and processing requirements. An epoxy and a modified epoxy novolac, two commercially available adhesive systems currently being used to bond ablative heat shield materials to the substructure of ballistic and lifting reentry vehicles, were used as a base line reference bonding system. Twelve selected adhesive systems, which were satisfactorily cured at 300° F for 8 hours under 50 psi pressure, were further evaluated under a variety of conditions which were intended to simulate environmental conditions that can be encountered by advanced reentry vehicles. Under these selected exposure conditions, which ranged from cryogenic soak (-300° F) to very high temperature (1200° F) and based on lap-shear tensile properties, polymide and polybenzimidazole adhesives and formulated mixtures performed as well as or better than the baseline modified epoxy phenolic, excepted room temperature. Initial studies on specially prepared polyphenyl ether adhesive formulations, which had from 2.56% to 5.17% reactive sites, indicated that the formulation with 3.43% reactive sites cured most readily.

105. Hugill, Douglas B. and Bernerd Gaiennie´
SOLID STATE DIFFUSION BONDED TANTALUM HONEYCOMB PANELS. Northrop Corp., Hawthorne, Calif.
Interim Engineering Progress Report No. 5, 1 Jun – 31 Aug 1966. 31 Aug 1966, 41p. (Contract AT 33 (615)-2777) (NOR-66-283; IR-8-214(V); AD-489062). X67-10965.

A program is described for the development of solid state diffusion bonding technology for production of tantalum alloy honeycomb panels suitable for either hot structural or heat shield applications in aerospace environments. The techniques employed in the bonding and packaging of five 6 × 6 inch test panels are discussed. These techniques include initial attempts in utilizing core in which the titanium intermediate is applied by vapor deposition rather than the more conventional method of employing titanium foil. Results obtained through destructive tests performed on several of the panels are also presented. A method for vapor depositing the titanium intermediate material on the tantalum honeycomb core edges is described with the presentation and discussion of the results obtained. Limited investigations of laser welding as a possible joining method for tantalum have been made with the results being presented as a comparison with those obtained by TIG welding. A presentation of several of the more promising oxidation preventative coatings is made with a discussion of the relative merits of each being included.

OAK RIDGE NATIONAL LABORATORY

106. Matlock, O. D.
A NEW, VERSATILE, VACUUM QUICK-SEAL AND VACUUM LOCK. Oak Ridge National Lab., Tenn. In Calif. Univ. Proc. of the 1965 Symp. on Eng. Probl. of Controlled Thermonuclear Res. (1965), pp. 18 – 19. N66-27150.

A convenient quick-seal and vacuum lock has been developed for rapid and inexpensive installation of probes, leads, lines, or shafts in existing equipment or future equipment where welding, soldering or drilling, and tapping is a problem. The quick-seal is installed by simply drilling a hole 1/8 in. larger than the size of probes or lines; no tools are required other than an Allen wrench for assembly. Systems have been developed for probe sizes from 1/4-in. through 3/4-in. diameter. The valve assembly is a compact integral valve, air lock, and pump-out system which was designed to be compatible with the quick-seal. It has the unique feature that the gland seal at the front may be tightened after pump-out and insertion of probes, etc., in order to isolate the volume behind, thus avoiding possible virtual leaks from this part of the assembly.

PHILCO CORPORATION

107. Briggs, Donald C.
EXPERIMENTAL STUDY OF COATINGS FOR TEMPERATURE CONTROL OF SOLAR CELLS. Philco Corp., Palo Alto, Calif. WDL Div. 6 Jun 1966, 172p. (Contract NAS7-409) (NASA-CR-73030; WDL-TR-2949). N66-35946.

An analytical and experimental program was undertaken to study the use of selective interference filters and highly reflective coatings for temperature control of solar cells. Optical characteristics of reduced bandpass filters and metallic reflective coatings as a function of angle of incidence and temperature were measured and presented. Experimental efforts included the measurement of filter-adhesive-cell composite performance under equilibrium temperature conditions at insolation levels approximately equal to those encountered at 1.0, 0.6, and 0.4 AU. These tests were performed on a model simulating a spinning spacecraft. In addition, analytical studies were performed to determine the optimum assembly using filters and/or reflective metallic coatings and to predict solar cell temperature and performance at 1.0, 0.6, and 0.4 AU. The analysis was also conducted for the case of spinning spacecraft with solar cells bonded to, but thermally insulated from, the spacecraft.

PICATINNY ARSENAL – PLASTEC

108. Hall, Richard L. and David W. Levi
POLYBENZIMIDAZOLES: A REVIEW. Picatinny Arsenal, Dover, N. J. Plastics and Packaging Lab. State of the art report. Report no. PLASTEC-28. Jul 1966. DDC AD-637 569.

A review of the polvbenzimidazoles is given, based on 47 references. Included is the preparation, some properties and a few applications of these polymers.

109. Landrock, Arthur H.
PROPERTIES OF PLASTICS AND RELATED MATERIALS AT CRYOGENIC TEMPERATURES. Plastics Technical Evaluation Center (PLASTEC), Picatinny Arsenal, Dover, New Jersey. PLASTEC report 20. Jul 1965, 251p. Including bibliography and indexes.

This report reviews the effects of cryogenic temperatures on plastics and such related materials as elastomers and adhesives. It presents an annotated bibliography of 319 references from open literature, government project and contract reports, and conference papers. A detailed subject index and a number of supplemental indexes are included. Topics covered are: Molded Polymeric Materials (Plastics); Cryogenic Insulation; Structural Plastic Laminates; Elastomers, Seals and Sealants; Adhesives; Plastic Films, Film Laminations and Vapor Barriers; Fibers; Electrical Applications; Wear and Friction; Liquid Oxygen (LOX) Compatibility; Radiation and Combined Effects; and Miscellaneous Applications. Test Methods are not treated in a separate section in the discussion, but the subject index refers to many references with information on test procedures and apparatus.

110. Wegman, Raymond F.
A SURVEY OF ADHESIVE BONDING TECHNOLOGY FOR MATERIALS FOR AIRCRAFT FABRICATION. Picatinny Arsenal, Dover, N. J. Plastics and Packaging Lab. Technical rept. Report no. PA TR-3418. Feb 1967, 63p. DDC AD-808 791L.

Distribution: DoD only: others to Picatinny Arsenal, Attn: Scientific and Technical Information Branch, Dover, N. J. 07801.

ROHR CORPORATION

111. Reed, C. H.
RESEARCH AND DEVELOPMENT PROGRAM FOR A BONDED CYLINDRICAL STRUCTURE UTILIZING BONDED LONGITUDINAL METAL STIFFENERS, PHASES I AND II. Rohr Corp., Chula Vista, Calif. Test Report. Jul 1966, 84p. (Contract NAS8-11955) (NASA-CR-82629; Rept. -24-7001). X67-12494.

This report covers Phases I and II of a program designed to demonstrate the degree of increased structural efficiency achievable with adhesive bonding. Phase I entailed the analysis of the existing structure of the Saturn V, S-1C forward skirt and the creation of drawings defining test specimens which would substantiate the analysis. Phase II consisted of the fabrication and destructive testing of the specimens designed in Phase I. Two specimen (straight and contoured) configurations were designed, fabricated and tested. After true static loading conditions were achieved, the straight specimens produced failure loads at room and elevated temperature of approximately 2% greater than required. The contoured specimens produced failure loads approximately 4% greater than required. The structure designed in Phase I and fabricated and tested to failure in Phase II was approximately 12% lighter than the existing S-1C forward skirt while the failure loads were greater than 100%. The feasibility of substituting adhesive bonding for mechanical fasteners for this structure was verified to the extent that the limiting factor was not the adhesive system but the aluminum alloy of the structure.

ROYAL AIRCRAFT ESTABLISHMENT

112. Althof, W.
THE STRENGTH OF BONDED SINGLE-LAP METAL JOINTS AT LOW AND HIGH TEMPERATURES AND AFTER TEMPERATURE CYCLING (DIE FESTIGKEIT VON UBERLAPPTEN METALLKLEBUNGEN BEI TIEFEN UND HOHEN TEMPERATUREN UND NACH TEMPERATURWECHSELN). Royal Aircraft Establishment, Farnborough (England). Rept. no. Library Trans-1189. Nov 1966, 46p. DDC AD-808 845.

Bonded single-lap joints have been tested at temperatures from -195C to +300C for short-time and long-time loading and after temperature cycles between -25C and +90C or +150C. The test results are useful for the selection of adhesives acting in selected temperature ranges. Correlations between the shear strength and the joint factor have been established.

SOUTHERN RESEARCH INSTITUTE

113. Perkins, R. B. and S. N. Glarum
ADHESIVES, SEALANTS, AND GASKETS – A SURVEY. Southern Research Inst., Birmingham, Ala. 1967, 63p. (NASA-SP-5066). N67-16060.

As part of a technology utilization program to accelerate the dissemination of technical information developed for space missions, a survey is presented on adhesives, sealants, and gaskets developed to operate in the extreme environments encountered in space work. Emphasis is on reliability of materials that can be used in a liquid oxygen environment. Considered to be of special potential interest for industrial use, the following are described: polymeric fillers in adhesives, elastomeric films in glue lines, epoxy ester adhesives, sealants for low-temperature service, gasket design, and measurement of stress in gaskets.

STANDARD PRESSED STEEL COMPANY

114. Glackin, J. J. and E. F. Gowen, Jr.
EVALUATION OF FASTENERS AND FASTENER MATERIALS FOR SPACE VEHICLES. Prepared by Standard Pressed Steel Co., for NASA Marshall Space Flight Center. Report no. NASA CR 357. 1964. (NAS 8-11125).

This document is the annual report for the year 1964 of Contract NAS 8-11125 for the "Evaluation of Fasteners and Fastener Materials for Space Vehicles." The objectives were to characterize those fasteners and materials most suitable at temperatures from -423° F (-253° C) to 1600° F (871° C). The effort was accomplished in the following four phases:

Phase I – Survey
Phase II – Fastener Evaluation
Phase III – Standard Fastener Tests
Phase IV – Potential High Strength Fastener Materials.

Phase I determined the space vehicle industry's present and future fastener requirements. The information obtained in the survey included present and future fastener materials, configurations, application and design criteria, testing and test methods, and fastener information and specifications.

As a result of the survey, twenty-one different classes of fasteners were selected for evaluation in Phase II. The fasteners consisted of variations in tension and shear bolts, blind bolts, structural rivets, and companion fasteners fabricated from within the specified base alloys of iron, nickel, titanium, and aluminum. The fasteners were tested to determine the following properties or exposure effects: tensile, shear, stress rupture, stress relaxation, nut reusability, nut vibration, corrosion resistance, effect of thermal cycling, and the effects of relaxation on mechanical properties.

Phase III is continuing to determine the unique tests required to characterize fasteners specifically for space vehicle applications.

Five alloys of iron, nickel, and titanium base were evaluated in Phase IV. The alloys were selected from the results of the survey on the basis of potential for high strength fastener applications, and expectant future usage. The alloys selected were Ti 1Al-8V-5Fe, 18 per cent nickel maraging steel (Vasco Max 300), U 212, Inconel 718, and 25 per cent cold reduced Waspaloy.

115. Glackin, J. J. and E. F. Gowen, Jr.
EVALUATION OF FASTENERS AND FASTENER MATERIALS FOR SPACE VEHICLES. Standard Pressed Steel Co., Jenkintown, Pa. Final report, Nov 1963 – Dec 1965. 31 Dec 1965, 486p. (Contract NAS8-11125) (NASA-CR-78442). N66-38104.

Different classes of commercially available fasteners and potential high strength fastener materials were evaluated and a summary of the results is included in this report. The results show that fasteners fabricated from iron-base corrosion resistance alloys, nickel base alloys, and aluminum base alloys would be suitable for space vehicle applications from -423° F to their respective maximum utilization temperature. In addition, a detailed discussion is presented on unique fastener tests to insure the reliability of fasteners for space vehicle applications. Noteworthy were the angle block tensile tests and tension impact tests to determine the effect of localized stresses and cryogenic temperatures on bolt properties. The results from the entire test program show that no one test is sufficient for determining a fastener's capability for space vehicle application; the fastener itself must be tested.

116. Roach, Thomas A. Jr.
DISPERSION STRENGTHENED MATERIALS EVALUATION PROGRAM. FEASIBILITY FOR STRUCTURAL MECHANICAL FASTENERS 1400° – 2200° F. Standard Pressed Steel Co., Jenkintown, Pa. Interim Technical Report, May – Jul 1966. Jul 1966, 9p. (Contract AF 33(615)-3820) (ITR-1; AD-487614). X67-11232.

A mail survey of potential dispersion strengthened material suppliers was conducted. Orders were placed for four nickel base dispersion strengthened alloys and three cobalt base dispersion strengthened alloys. Minor modifications were begun on the dynamic oxidation test apparatus for 1400 – 2200° F operation on specimens.

117. Roach, Thomas A. Jr.
DISPERSION STRENGTHENED MATERIAL EVALUATION PROGRAM FEASIBILITY FOR STRUCTURAL MECHANICAL FASTENERS 1400 – 2200° F. Standard Pressed Steel Co., Jenkintown, Pa. Interim technical rept. no. 3, Nov 1966 – Jan 1967. 10 Feb 1967, 14p. (Contract AF 33(615)-3820). DDC AD-807 566.

WHITTAKER CORPORATION (NARMCO)

118. Hergenrother, Paul M. and Harold H. Levine
HIGH-TEMPERATURE STRUCTURAL RESINS.
Whittaker Corp., San Diego, Calif. Narmco
Research and Development Div. Final report,
18 Oct 1965 – 17 Jul 1966. Jul 1966, 44p.
(Contract NOw-660144-c) (AD-642043). N67-19819.

The report summarizes an investigation directed toward the synthesis and evaluation of thermally stable polymers for potential use in fabricating rocket and missile components, and devices requiring deep submergence for long periods of time. Research was concentrated on three aromatic polyheterocyclics, the polyquinoxalines, the polybenzothiazoles, and a novel hybrid polymer, the phenyl-substituted polyquinoxalines. Major emphasis was placed on fabrication of laminates as large as 9 in. × 12 in. × 14 plies, and adhesive bonds from prepreg and tape prepared from stable m-cresol solutions of the polyquinoxalines. Excellent test results were obtained. Polybenzothiazole research also centered on fabrication work which provided 14-ply laminates having high individual flexural strengths and moduli. The successful preparation of an A-B monomer, 3-amino-4-mercaptobenzamide, was accomplised; this was subsequently polymerized to yield poly (2.5-benzothiazole) having polymer decomposition temperatures in air and in helium of 600C and 675C respectively. Novel phenyl-substituted polyquinoxalines were prepared via melt and solution polymerization to yield polymers which exhibited outstanding oxidative stability. A phenyl-substituted diether polyquinoxaline exhibited only a 7% weight loss under isothermal aging at 371C in air after 100 hours and clear, tough, yellow films exhibiting good flexibility were cast from m-cresol solutions.

119. Jones, Rodney A. and Glenn H. Sievert
EXOTHERMIC SPACE BONDING SYSTEM.
Whittaker Corp., San Diego, Calif. Narmco
Research and Development Div. Final technical
report, 1 Jun 1965 – 28 Feb 1966. Aug 1966, 65p.
(Contract AF 33(615)-2814, Proj. AF-8170, Task
817008.) AFAPL TR-66-63. DDC AD-646 670.

The report covers the development of a system, including materials, design, and techniques, for attaching adhesive pads to the exterior surface of spacecraft. The purpose of these pads is to provide attachment points for astronauts and their equipment while carrying out maintenance and repair functions in space. The pads consist of aluminum disks of 1-1/4 in. diameter and 0.050-in. thickness with a fastening stud on one surface and a layer of thermoplastic adhesive on the other surface. A thermal pulse to soften the adhesive and produce bonding under light pressure is obtained from the reaction of a small exotherm charge, which is enclosed in an insulative housing on the back or stud-side of the pad. Vacuum bonding experiments at approximately 0.000001 Torr plus the results of bond strength tests over the range from -100F to 250F are described. Adhesive bond strengths of nearly 900 psi at room temperature were obtained on aluminum skin specimens. Design strength objectives of more than 100 psi were achieved over the entire temperature range. Also described is the development and test of an exotherm heating unit for preheating spacecraft structure skins before pad bonding to improve adhesion and operational flexibility. Vacuum exposure tests on organic adhesive bonded specimens indicate suitability for extended use without degradation of adhesive strength.

120. Levine, Harold H.
POLYBENZIMIDAZOLES AND OTHER AROMATIC HETEROCYCLIC POLYMERS FOR HIGH TEMPERATURE RESISTANT STRUCTURAL LAMINATES AND ADHESIVES. VOLUME I. POLYBENZIMIDAZOLES. Whittaker Corp., San Diego, Calif. Narmco Research and Development Div. Report for 1 Nov 1963 – 31 Oct 1964. Report no. NRD-MJO-328-Vol. 1. Nov 1964, 355p. (Contract AF33 657 8047, Proj. 7340, Tasks 734002; 734003.) ML TR-64-365, Pt. 1-Vol. 1. DDC AD-463 863.

The synthesis of AF-R-151 polymer and processable prepolymer was the most significant development of the past year's research. This resin can be synthesized to a condensation volatiles content of only 5% while maintaining solubility and fusibility; in contrast, AF-R-100 had to be processed with a condensation volatiles content of 28%. Further efforts to improve heat aging performance of AF-R-100 laminates have been discontinued in favor of AF-R-151. However, excellent performance was demonstrated in creep, electrical properties up to 200 hours at 600 F or 30 minutes at 1200 F, and heat aging to 200 hours at 600 F in air. Highly satisfactory adhesive data using AF-A-121-1,2 have been obtained for bonding titanium by modification of the curing schedule, surface preparation, and from a priming study.

121. Levine, Harold H., Norman P. Loire, and Chadwick B. Delano
POLYBENZIMIDAZOLES AND OTHER AROMATIC HETEROCYCLIC POLYMERS FOR HIGH-TEMPERATURE RESISTANT STRUCTURAL LAMINATES AND ADHESIVES. Whittaker Corp., San Diego, Calif. Narmco Research and Development Div. Summary technical rept., 1 Nov 1965 – 30 Nov 1966. Report no. NRD-MJO-368. Jan 1967, 120p. (Contract AF33 (615)-2283, Proj. AF-7340, Task 734002.) AFML TR-67-23. DDC AD-814 192L.

Distribution: DoD only: others to Air Force Materials Lab., Attn: MANC, Wright-Patterson AFB, Ohio 45433.

122. Levine, Harold H. and Richard D. Stacy
POLYBENZIMIDAZOLES AND OTHER AROMATIC HETEROCYCLIC POLYMERS FOR HIGH TEMPERATURE RESISTANT STRUCTURAL LAMINATES AND ADHESIVES. Whittaker Corp., San Diego, Calif. Narmco Research and Development Div. Technical rept., 1 Nov 1964 – 31 Oct 1965. Report no. NRD-MJO-368. Jan 1966, 269p. (Contract AF 33(615)-2283, Proj. AF-7340, Task 734002, 734003.) AFML TR-65-350. DDC AD-479 852L.

Distribution: DoD only: others to Air Force Materials Lab., Wright-Patterson AFB, Ohio 45433. Attn: Plastics and Composites Branch (MANC).

123. Litvak, Sidney
POLYBENZIMIDAZOLE STRUCTURAL ADHESIVES FOR BONDING STAINLESS STEEL, BERYLLIUM, AND TITANIUM ALLOYS. Whittaker Corp., San Diego, Calif. Narmco Research and Development Div. Summary technical rept., Feb 1962 – May 1965. Feb 1966, 43p. (Contract AF 33(657)-8047, Proj. AF-7340, Task 734002. AFML TR-65-426. DDC AD-645 241.

A new high-temperature-resistant adhesive for the binding of stainless steel, beryllium, and titanium alloys has been developed. This report reviews the applied research leading to this development and presents initial information on the mechanical properties of metal-to-metal bonded specimens, lap-shear and sandwich, from room temperature to 1000F for short-time and long-time aging periods at both 600F and 700F.

124. Noton, Bryan R.
A SURVEY OF COMPOSITE MATERIALS AND STRUCTURES. Whittaker Corp., Los Angeles, Calif. Presented at the 1965 Aerospace Develop. Briefings and Related Equipment Displays of the Air Force Assoc., Washington, D. C., 15 – 17 Sep 1965. Sep 1965, 21p. N66-22401.

Design concepts using alumina-tile segments for large ceramic structures and alumina "Imidite" radomes with superior rain-erosion resistance, are covered. Selferecting, self-supporting, expandable aerospace structures for airlocks, interconnecting tunnels, etc. are included because of possible MOL applications. Efforts are pursued to reduce the cost of materials and structures. A method to automatically reproduce high-quality, reinforced plastic structures, a 250° F curing high-strength adhesive, and a low-temperature curing, dual-purpose, laminate requiring no adhesive, have thereby been developed. Cyrogenic and heat-resistant adhesives and applications are further discussed. A variety of tailored thermal-insulating materials and applications is then covered. Future developments will concern multiperformance composites providing the structure, armor protection, and passive antiradar. Among the precision structures manufactured, are the "Telstar" horn and "Tetrac" parabolic antennas, and the communications antenna on "Mariner IV." Numerous other components are mentioned. Using a "multi-shell" concept, highly-reliable pneumatic pressure vessels are in production. Weight comparisons and cyclic fatigue values support the paper. A further specialty is the bonding of LEM and supersonic air-vehicle windows. The composite approach was necessary for cryogenic gasket problems.

125. Smith, M. B. and S. E. Susman
DEVELOPMENT OF ADHESIVES FOR VERY LOW TEMPERATURE APPLICATION. Whittaker Corp., Narmco Research and Development, San Diego, Calif. Quarterly summary report. Oct 1961, 27p. (Contract NAS 8-1565.)

Experimental invesigations are being conducted to obtain a structural adhesive system applicable over the temperature range of +260° F to -423° F. It is desired that the adhesive meet the following requirements; simple applications to vertical, horizontal or overhead surfaces, ambient cure conditions, resistance to environmental exposure, high thermal conductivity, low shrinkage, thermal expansion matched to that of the adherend, modulus equal to or lower than the adherend, high strength, low specific gravity, long shelf life, short cure time, tape form, sufficient flow to fill voids, thermosetting, high impact and peel resistance, good aging resistance, and good mechanical shock and vibration resistance.

During this report period it was found that prior to bonding anodizing is the best surface treatment for aluminum and hydrogen peroxide or sandblasting is the best for stainless steel. Strong consideration has been given to the use of various nylon (polyamide) epoxy resin adhesive systems. Powdered nylon fiber with epoxy-polyamine adhesive offers a very promsing low temperature system.

126. Smith, M. B. and S. E. Susman
DEVELOPMENT OF ADHESIVES FOR VERY LOW TEMPERATURE APPLICATION. Whittaker Corp., Narmco Research and Development, San Diego, Calif. Quarterly summary report. 15 Jan 1962, 33p. (Contract NAS 8-1565.)

A room temperature cured epoxy resin-polyamide adhesive system was found to be a far superior reinforcing agent for nylon based structural adhesives at very low temperatures, i.e., compared to phenolics, acrylics, polyesters and polyurethanes.

Composite structural adhesives consisting of elastomer substrates in resin matrices have demonstrated excellent tee peel strengths and tensile shear strengths at -320° F. These systems appear very promising for application at very low temperature because of their strength and because of moderate and simplified bonding requirements.

127. Smith, M. B. and S. E. Susman
DEVELOPMENT OF ADHESIVES FOR VERY LOW TEMPERATURE APPLICATION. Whittaker Corp., Narmco Research and Development, San Diego, Calif. Quarterly summary report. 15 Jul 1962, 37p. (Contract NAS 8-1565.)

Three adhesive systems developed by Narmco were evaluated for use at room and cryogenic temperatures. These systems were denoted as Adhesvies A (epoxy-polyamide), B (composite system of Teflon FEP films in an epoxy polyamide) and C (a three-part room-temperature contact-pressure curing polyurethane elastomer adhesive system). The addition of nylon fibrous filler to the adhesive systems offered no particular advantage of using powdered nylon fiber. The use of a polyamine salt accelerator in curing an epoxy-polyamide adhesive at room temperature was found to be no advantage.

Butt tensile strength data for Adhesives A, B, and C were excellent at -423° F, causing failure in adherends at stress levels up to 9200 psi. Stress levels fell to about 1000 psi at +180° F. Compression loads up to 60,000 psi caused no failures or distortion in Adhesive A, B, and C bonded assemblies when tested at -320° F and RT. Twenty cycles from -320° F to RT did not impair the RT tensile shear strength of Adhesives A, B, and C. A 200° F postcure tended to significantly upgrade the -320° F tensile shear and tee peel strengths of Adhesives A and B cured at ambient temperature and contact pressure. Only the peel strength of Adhesive C was improved. The RT strength of all adhesives was noticeably improved.

128. Smith, M. B. and S. E. Susman
DEVELOPMENT OF ADHESIVES FOR VERY LOW TEMPERATURE APPLICATION. Whittaker Corp., Narmco Research and Development, San Diego, Calif. Quarterly summary report. 15 Oct 1962, 49p. (Contract NAS 8-1565.)

Considerable work has been done with adherend surface preparations for optimizing adhesive strength and toughness at very low temperature, with emphasis on chemical etches for field application. LOX compatibility and mechanical shock data at -423° F are reported. Three new adhesive systems have been selected and partially evaluated which demonstrate faster cure at RT, and superior peel strength at very low temperature than adhesive systems A, B, and C. In addition these adhesive systems were LOX compatible, whereas the previous group was not.

129. APPLYING FASTENERS EFFECTIVELY.
Electronic Products, 8(10):36 – 38, 40 – 43, 110, 112, 114, 116, 118, 120, 122 – 123, Mar 1966.

Properties of plastic and metal fasteners and their selection, and application to electronic equipment; properties discussed include wear resistance, heat resistance, heat and electrical conductivity, weight, magnetic permeability, and corrosion; corrosion resistance of fastener finishes and coatings; application criteria includes head style, type of drive, clearance, tooling, assembly method, and joint accessibility; fastener materials include steel, aluminum, copper, and brass.

130. Ardell, R. D.
SEALANT RIDES IN FASTENER SLOT. Iron Age, 197(6):64 – 65, 10 Feb 1966.

Author's improvements resulted in lock-bolt that is not only leak-tight but one which offers increases in fastening strength on order of 30 to 40%; axial groove is provided along outer surface of pin member; modified malleable collar is then swaged onto pin; annular grooves of pin are treated beforehand with sealant; new design was incorporated by Huck Mfg. Co., Detroit, in three shear type Huckbolt fasteners, primarily intended for aircraft and missile applications; extensive tests of grooved lockbolt fasteners are reported.

131. Baumgartner, Thomas C.
FASTENER PERFORMANCE AT ELEVATED TEMPERATURES. (Standard Pressed Steel Co., Precision Fastener Div., Jenkintown, Pa.).
American Society of Mechanical Engineers, Design Engineering Conference and Show, New York, N. Y., 15 – 18 May 1967, Paper 67-DE-18.

Discussion of the need for better understanding of the factors affecting fastener selection caused by the advent of increasing operating temperatures in commercial and aerospace applications. Since time at temperature can reduce the clamping force through relaxation of the fastener, selection must be based on the needed conditions at some finite time in the future. From this the initial fastener preload at the first exposure to temperature can be established. Since it is necessary to assemble a joint at room temperature, consideration must be given to the thermal expansion of the components. In addition, since the modulus of elasticity changes with the temperature, it is also necessary to incorporate this element into the room-temperature design parameters. The method for determining this with each of these factors is described. Other characteristics as stress alloying and oxidation resistance are briefly discussed, and the characteristics of some common materials at elevated temperatures are reviewed.

132. Beasley, R. M. and R. B. Clapper
THERMAL-STRUCTURAL COMPOSITES FOR AEROSPACE APPLICATIONS. ASTM-Special Tech. Publ. No. 379, pp. 91 – 106, 1965.

Lockheed Missiles & Space Company has developed materials concept and processes for composites specifically for aerospace application; concept is based on inorganic bonding of refractory component and control of construction of composite to achieve as nearly as possible during fabrication disposition of materials desired during use; inorganic binders have been developed for glass, carbon, graphite, asbestos, potassium titanate, and other refractory fibers; examples are given for transition cone and re-entry radome.

133. Black, I. A. and P. E. Glaser
EFFECTS OF COMPRESSIVE LOADS ON THE HEAT FLUX THROUGH MULTILAYER INSULATIONS. (Arthur D. Little, Inc., Cambridge, Massachusetts.) Advances in Cryogenic Eng., Vol. 11:26 – 34, 1965.

Compressive loads – either caused by atmospheric pressure or developed during the application of multilayer insulations – are already known to reduce the overall effectiveness of insulation. Figure 1 shows the effect of compression on the heat flux through 15 multilayer insulations. The increase in heat flux after a compressive load of 2 psi has been reached is of comparable magnitude for all insulations tested. When compressive loads up to 2 psi are applied, the majority of the insulations show a heat flux about 100 times greater than the no-load condition.

This marked deterioration of the effectiveness of multilayer insulations limits their usefulness in several aerospace applications. Therefore, measurement of the effects of the compressive loads below 2 psi is essential not only to provide data on the magnitude of these effects for specific insulations, but also to guide the design and selection of new and improved material combinations. Even if the compression of the lower layers caused by the weight of the upper layers is excluded, external forces – such as tension applied during the wrapping of a multilayer insulation around a cylindrical tank, thermal expansion or contraction of the insulation components with respect to a tank, and localized loads in the vicinity of tank supports – can compress the insulation.

These compressive loads can be reduced, but a finite load which may be in the range from 0.01 – 1 psi will probably remain. Thermal conductivity measurements, therefore, must be made with an apparatus capable of applying small compressive loads.

This paper presents experimental results showing the effects of low compressive loads on heat flux and indicates the applicability of correlating heat flux with applied pressure.

134. Bodnar, M. J. (Edit.)
STRUCTURAL ADHESIVE BONDING: SYMPOSIUM, STEVENS INSTITUTE OF TECHNOLOGY. Hoboken, N. J. 14 – 16 Sep 1965. Applied Polymer Symposia No. 3, Interscience Publ., N. Y. 1966, 495p.

This contains several papers presented at a symposium on Structural Adhesive Bonding sponsored by the U.S. Army, Picatinny Arsenal, Dover, N. J. An author and a subject index were included.

135. Burgman, H. A.
TREND IN STRUCTURAL ADHESIVES. Machine Design, 35(27):192 – 8, 21 Nov 1963.

Summary of characteristic properties and applications of structural adhesives; among newer applications, nylon-epoxy film is used for bonding metal skins to honeycomb core; polymethanes provide strong adhesives for various plastics and for bonding plastics to metal; silicon-rubber and teflon-silicon tapes provide high-temperature resistant electric insulation; ceramic metal oxides are used for very high temperature structural applications.

136. Carson, R. W.
WHERE TO GET HELP IN SPECIFYING STRUCTURAL ADHESIVES. Product Eng., 36(11):65 – 72, 24 May 1965.

Types of adhesives available are reviewed; tables of epoxy and modified-epoxy structural adhesives, phenolic and high-temperature metal-bonding adhesives; properties, costs, curing times and temperatures.

137. Cornely, K. W.
DEVELOPING SPECIAL CEMENTS TO RESIST TEMPERATURES OVER 4000°F. Adhesives Age, 26 – 27, Sep 1961.

Discussion of American Thermocatalytic Corporation high temperature refractory cement called Astroceram.

138. Coston, R. M.
EXPERIMENTAL EVALUATION OF THE EQUATIONS AND PARAMETERS GOVERNING FLOW THROUGH MULTILAYER INSULATIONS DURING EVACUATION. (Lockheed Missiles & Space Company, Palo Alto, California. Advances in Cryogenic Eng., Vol. 11: 56 – 64, 1965.

The majority of the cryogenic propellant storage schemes associated with long-term storage aboard space vehicles incorporate multilayer insulation systems. In order to predict propellant losses during vehicle ascent and to determine the proper vent path spacing which will allow rapid depressurization of the insulation while maintaining the physical integrity of the insulation system, it is necessary to have a complete description of the flow phenomena within the insulation.

Multilayer insulation systems provide very effective thermal resistance to energy transmission by solid conduction and radiation. However, if the insulation interstitial gas pressure is sufficiently high to induce a measurable energy transport by gaseous conduction, then the effectiveness of the composite as an insulation is lost. It has been experimentally determined ([1,2]) that interstitial pressures less than 10^{-4} torr must be maintained to achieve optimum thermal performance of multilayer insulations. On a space vehicle it will therefore be necessary either to provide for complete evacuation of the multilayer insulation prior to filling of the cryogenic vessel and vehicle boost or to provide for purging of the insulation with a noncondensible gas at atmospheric pressure and subsequently to allow the low-pressure vehicle boost environment to effect the evacuation. The rapid depressurization of the ambient surroundings of the insulation during vehicle boost will result in a positive pressure buildup within the insulation which can physically destroy the insulation if proper vent paths are not available.

A literature survey indicated a paucity of information which would allow an adequate description of the flow processes involved. As a result a program was initiated to investigate the flow phenomena associated with multilayer insulations during their evacuation. The ultimate purpose of the program was to describe mathematically the flow phenomena such that a computer solution could be effected which would allow an estimation of the transient behavior of the propellant boiloff during simulated ascent of a cryogenic space vehicle, as well as predicting the pressure buildup within the insulation. It was also recognized from previous work that the expected mathematical description of the flow phenomena would contain various flow properties of the insulation system which could only be obtained experimentally.

139. Coxe, E. F., R. O. Lowrey, R. T. Hunt, and S. M. Freeman
AN INVESTIGATION OF THE USE OF INTERNAL INSULATION FOR LIQUID-HYDROGEN-FUELED MISSILES. (Lockheed-Georgia Company, Marietta, Georgia.) Advances in Cryogenic Eng., Vol. 8: 404 – 410, 1962.

An analytical and experimental study was conducted to determine the suitability of several commercial plastic foams for insulating liquid-hydrogen-fueled missiles. The laboratory values of thermal conductivity of many of the low-density plastic foams indicate that they would be satisfactory for mission times approaching several hours duration. In actual practice, however, these values often prove difficult to obtain for any sustained length of time and with a reasonable degree of confidence.

It is the purpose of this discussion to point out some of the major problems involved in the use of plastic foams and areas where additional attention must be given if a high measure of reliability with this type of insulation is to be achieved. In this study emphasis was placed on the internal insulation concept. The higher skin temperature that would occur on the externally insulated tank of launch vehicles during aerodynamic heating would render unsatisfactory many of the otherwise acceptable foams.

The insulation system considered was a plastic foam bonded to the inside of the propellant tank wall and covered by a vapor barrier bonded to the foam. The vapor barrier was considered to be highly impermeable and to effectively seal the foam from the hydrogen propellant. When the tank was filled with liquid hydrogen, the residual gases in the foams, which are normally CO_2 or Freon, were assumed to freeze out, resulting in a very low pressure in the foam, i.e., of the order of 1 μ Hg. The insulation system would then exhibit the thermal conductivity of an evacuated foam.

140. Dastin, S. J.
BONDED BERYLLIUM STRUCTURES. Adhesives Age, 9:24 – 27, May 1966.

Adhesive bonding of beryllium for the production of aircraft structures is superior to riveting and brazing.

141. Dearing, D. L.
DEVELOPMENT OF THE SATURN S-IV AND S-IVB LIQUID HYDROGEN TANK INTERNAL INSULATION. (Douglas Aircraft, Inc., Huntington Beach, California.) Advances in Cryogenic Eng., Vol. 11:89 – 97, 1965.

This paper describes the development of the insulation for the second and uppermost stage for the Saturn I space booster. In this program it was necessary to develop an insulation for this stage (the S-IV stage) that was capable of withstanding the thermal shock associated with loading of liquid hydrogen, could provide adequate insulative properties to limit the flow of heat into the liquid hydrogen, and still be of minimum weight.

This development has necessitated new testing techniques and apparatuses to provide representative test conditions. Since virtually no analytical techniques were available, materials had to be tested on a "see if it works" basis. In order to check out the propulsion system the insulation had to be developed before the flight stage, so that it could be installed in a heavy-walled, static ground test vehicle. All objectives of the development program were successfully met, and on January 29, 1964, the first S-IV Stage was orbited.

A program aimed at further improving the insulation was well under way by that time. This improvement program was for the S-IVB Stage, a new stage which was to have a requirement for orbiting about the earth for up to 4.5 hr with sufficient hydrogen and oxygen remaining for a second burn to achieve escape velocity. One of the basic philosophies of the S-IVB program was to use as much of the S-IV technology as possible. This meant that the hydrogen tank insulation that had been designed strictly for a boost mission of 10 min total now had to function throughout the 4.5-hr orbit. Analysis showed that the hydrogen tank could be sized to carry the expected boiloff losses, so that a new insulation development was not required.

When this development program was first initiated, it was more conventional to consider insulations external to a hydrogen tank. However, it was decided to develop an insulation to be bonded internally for the following reasons:

1. The difficulties in maintaining an adequate bond of the insulation external to a surface at -423° F were much greater than for an insulation bonded internally to a surface which is above -100° F.
2. Cryopumping of air with attendant liquefaction and increased heat transfer is avoided.
3. Unavaoidable damage due to handling or shipping is minimized.
4. There is no exposure to salt spray, fungus, sand, rain, etc.
5. LH_2 boiloff during loading and tank contraction due to chilling is minimized.

142. DeLollis, N. J.
HIGH-TEMPERATURE TESTING OF REENTRY BONDS. ASME – Paper 66-MD-38 for meeting 9 – 12 May 1966, 4p.

Problem of representative testing of materials for use in bonding of ablative shields and heat insulators to structural metal shell is presented; performance data of some adhesive types based in epoxies, silicones, and fusible glass are included; test equipment described consists of focused beam of IR energy on bonded specimen which is preloaded in shear.

143. Elonka, S.
THERMAL INSULATION. Power, 108(3): S1 – S24, Mar 1964.

Special report on developments in thermal insulation and insulation materials on broad range of temperatures; factors in selecting insulation; insulation systems designed for cryogenic and space applications; installation methods as dependent on materials and surfaces; soil conditions to be considered when insulating underground piping.

144. EPOXY TAPE SUPPLIES STRENGTH TO STRUCTURAL HONEYCOMB. Iron Age, 197(18):76 – 7, 5 May 1966.

Product discussed is pair of large aluminum honeycomb pallets that are bolted together and used to hold F-1 Saturn rocket engine for airborne transportation; honeycomb sections are bonded into single structural unit solely by epoxy tape which is suitable for high strength metal-to-metal bonding and for honeycomb bonding: two-part design and production operations described.

145. FASTENING AND JOINING. Product Eng., 38(12):50 – 52, 54, 56, 5 Jun 1967.

Discussion of types of fasteners and joining methods that were represented at the Design Show.

146. Freeston, W. D.
METAL FABRIC FOR AEROSPACE STRUCTURES.
SAMPE Journal, 3(2):31 – 32, 37 – 39, Feb – Mar 1967.

Many aerospace structures under current development require utilization of flexible, textile-like fabrics having high strength at high temperatures. To minimize form-drag during launch, these aerospace structures must have a small pre-development volume. Thus, the fabric must be capable of being folded, packaged, and subsequently deployed without suffering damage.

In a project sponsored by the Fibrous Materials Branch of the Air Force Materials Laboratory, the feasibility of weaving fabric from multifilament yarns, composed of metal filaments as fine as 0.0005 inch in diameter, on modified, power textile equipment has been demonstrated.

The properties of the fabrics are compared to those of a typical, equally strong, commercial fabric woven from single wires. The superior flexibility, crease recovery, fold endurance and tear strength of multifilament metallic-yarn fabrics are shown.

The tensile properties, tear strength, creep and fold endurance of a superalloy multifilament-yarn fabric in air at temperatures to 2000°F are given.

The joining of panels of metal fabric by conventional sewing with threads composed of a large number of fine metal filaments is discussed.

147. Freeston, W. D. and J. W. Gardella
METAL FABRICS FOR DECELERATION OF RE-ENTRY VEHICLES. Am. Dyestuff Reporter, 53(10):34 – 9, 11 May 1964.

Designs of various space vehicles and structures incorporate flexible, low porosity or impermeable (coated), thermally durable fabrics; some of missions anticipate exposure to temperatures in 1500 – 2500°F range and strengths of 20 to 200 lb/in. for short intervals; feasibility of weaving fabric from multifilament yarns composed of metal filaments as fine as 0.0005 in. diam. on standard power textile equipment is demonstrated; evaluation of fabrics woven is also reported.

148. Getty, R. C., J. P. Clay, E. J. Kremzier, and K. E. Leonhard
EXPERIMENTAL EVALUATION OF SOME SELECTED LIGHTWEIGHT SUPERINSULATION FOR SPACE VEHICLES. (General Dynamics/Convair, San Diego, C lifornia.) Advances in Cryogenic Eng., Vol. 11:35 – 48, 1965.

The use of high-energy cryogenic fuels has imposed demands for effective design and application of superinsulation for advanced tank designs. The high effectiveness of multilayer superinsulations is achieved by a series of radiation shields of low emissivity. The shields may be separated by insulating spacers under a pressure below 10^{-5} mm Hg absolute. During ground hold and boost, the insulation is exposed to the atmosphere unless it is sufficiently shrouded. This paper will not discuss these transient conditions, but rather will be concerned only with the subsequent space performance.

While a considerable amount of basic data are available on highly developed insulating materials, only limited work has been done in performance versus weight comparison of superinsulation systems. The main purpose of the present experimentation was to screen effectively all available insulation systems for space thermal performance, system weight, and ease of application. The basic thermal measurements were made on a small, precision, guarded calorimeter. Some of the new insulation systems devised are very promising in regard to strength and thermal performance. In combination with the thermal tests, a gaseous conduction test was also conducted to aid in predicting performance at less than the optimum vacuum conditions.

149. Glaser, P. E. (A. D. Little, Inc.)
CRYOGENIC INSULATIONS. Machine Design, 39(19):146 – 152, 17 Aug 1967.

Thermal insulation systems for use with cryogenic fluids (those colder than -250°F) are of two general types: those that are gas-filled, and those that are evacuated. Evacuated systems are more efficient; gas-filled systems are used in containers that cannot be conveniently evacuated and kept evacuated.

150. Gowen, E. F. Jr. and J. J. Glackin
FASTENERS FOR CRYOGENIC APPLICATIONS. Metal Progress, 90(1):76 – 8, Jul 1966.

Out of 18 iron, nickel, cobalt, titanium, and aluminum alloys examined at Standard Pressed Steel Co., Jenkintown, Pa., one nickel-base alloy (Inconel 718) and two iron-base alloys (A286 and Unitemp 212) have required mechanical properties down to -423° F and experienced no brittle failure; two points brought out by investigation, which may apply to all cryogenic fasteners and fastener materials, are that fasteners must be tested in their finished form, and that no satisfactory single indicator of overall cryogenic performance exists; thermal cycling was found to have little effect on tensile properties of bolts of three alloys.

151. Gowen, E. F. Jr., and T. A. Roach, Jr.
FASTENERS FOR 2000° F AND UP. Assembly
Eng. 8(6):24 – 7, Jun 1965.

Fasteners of refractory metals such as tantalum, columbium, molybdenum and tungsten for temperatures in range of 2000 to 3000° F; columbium is best metal for manufacture of fasteners; fabrication, coatings and design practice; installation and tightening procedure; environmental effects on fastener design and performance.

152. Hall, G. N. and Oliver Breward (Unbrako, Ltd., Coventry, England).
FACTORS IN FASTENER RELIABILITY. Aircraft
Engineering, 39:35 – 37, Mar 1967.

Review of significant factors affecting the reliability of aerospace fasteners. It is pointed out that the mechanical testing, whether tensile, fatigue, stress, rupture, shear, sustained load or torque tension properties, as required, is carried out on every lot of fasteners shipped under an advanced design label and constitutes a fundamental part of the assurance of the performance reliability that aerospace contractors have come to expect.

153. Hertz, J.
AN EVALUATION OF SEVERAL STRUCTURAL ADHESIVES IN CRYOGENIC APPLICATIONS.
Adhesives Age, pp. 30 – 37, Aug 1961.

A general evaluation of adhesives for anticipated use in future space vehicles. Advanced missiles and space vehicles will have many applications for metal-to-metal, metal-to-plastic, and plastic-to-plastic bonding materials that can withstand extreme low temperature conditions. Some of the problem areas include: contractable plastic film fuel bags; bonding of brackets, clips, spacers, etc. directly to or within cryogenic tanks; joining of tank sections; bonding of dissimilar metals in an effort to prevent corrosion, etc.

154. Hertz, J.
EPOXY-NYLON ADHESIVES FOR LOW-TEMPERATURE APPLICATIONS. (General Dynamics/Astronautics, San Diego, California.) Advances in Cryogenic Eng., 7:336 – 342, 1961.

Because of the extensive use of liquid oxygen and liquid hydrogen in both present and future spaces vehicles it has become necessary to obtain adhesives which will retain structural strengths at temperatures as low as -423° F. The Centaur vehicle is now utilizing adhesives for bonding plastic foam insulation to a stainless steel tank, for bonding plastic honeycomb sandwich panels, and for bonding Mylar to stainless steel tanks. These adhesive bonds must withstand operating temperatures of -423° F. Future vehicles will have many more cryogenic applications which will require adhesive bonding. These applications may vary from the bonding of small clips to cryogen tanks to the problem of manufacturing full-scale, adhesive-bonded metal tanks.

155. Hauck, J. E.
NEW HIGH TEMPERATURE ADHESIVES: EASIER TO APPLY, STAND MORE HEAT. Materials Eng., 65(4):84 – 86, Apr 1967.

Discussion of structural adhesives for extended use at 350° F and up. They come in easy to handle tape and film forms and in liquids that need no mixing. Many can be cured at moderate temperatures and pressures in standard equipment and ovens.

156. Hill, J. R.
PROCESS DEVELOPMENT OF POLYBENZIMIDAZOLE ADHESIVES. Adhesives Age, 9(8):32 – 6, Aug 1966.

Adhesives based on polybenzimidazoles, which offer great potential for making structural bonds to withstand elevated temperature for relatively long period of time, have been investigated by testing of standard lapshear specimens of steel, titanium and beryllium; good bonds have been obtained with steel under pressure as low as 10 psi; good results have also been obtained with beryllium; titanium presented problem in getting good adhesion; shear strength of titanium bonds at 700° F was improved by postcuring; all strength was lost in 50 hr at 700° F regardless of metal substrate.

157. Ishaghoff, I. and J. M. Canty
QUILTED SUPERINSULATION. (Linde Company, Division of Union Carbide Corporation, Tonawanda, New York.) Advances in Cryogenic Eng., 9: 46 – 51, 1963.

Large vessels for the storage of cryogenic fluids are field-erected, rather than assembled in a factory, because it is difficult to ship parts much larger than 12 ft in diameter. It is impractical to insulate these field-erected tanks with high-efficiency multilayer insulations by conventional methods, so a new technique has been devised to apply superinsulations to vessels which cannot be moved or rotated.

This paper describes the method used to insulate a 105,000-gal liquid-hydrogen tank for Aerojet General at Nimbus Station, California. Extension of this technique to large barges and space simulator cryopanels is also described.

In recent years there have been many new developments in sophisticated vacuum-insulation systems. These new developments have revolutionized the small-container field, where cryogenic fluids, down to and including helium, are now economically stored in small quantities. In addition, the superior thermal performance of these materials has made it possible to build trailers, trucks, and railroad tank cars with a much larger capacity than would be possible with evacuated powder systems. Multilayer insulations have been readily applied to factory-fabricated vessels utilizing conventional methods, such as spiral wrapping.

Large field-erected vessels comprise one type of cryogenic vessel construction that has been singularly omitted in the application of high-performance insulations. The reasons for this omission are twofold. For many applications, such as storage of liquefied atmospheric gases (oxygen and nitrogen), it is not always economically justifiable to use high-performance insulation. In fact, many vessels have been, and will continue to be, insulated with nonvacuum powder insulation, especially large vessels for the storage of millions of cubic feet of liquid oxygen or liquid nitrogen. Secondly, because of the nature of these insulating materials, the techniques used to apply multilayer superinsulations required a closed space, where the wind would not whip the insulation and where the method of application could be very carefully controlled.

There are several features of these superinsulations that are attractive for modern applications. One of these features is, obviously, reduced thermal conductivity. This permits storing or transporting larger quantities of product within the same size envelope, which could be very important in the barge shipment of liquid hydrogen. Another feature is that these insulations are easily evacuated and do not release foreign material or contaminants into the vacuum space. This property is important to space chambers, where it is desirable to insulate the cryopanels to reduce the refrigeration load.

158. Jones, D. P.
EPOXIES FOR THE TIROS SATELLITE.
Adhesives Age, pp. 28 – 29, May 1961.

Components, power supply and circuitry in Tiros satellites are protected against hazards of space flight by epoxy resin formulations serving as adhesives, coatings, sealants and encapsulations.

159. Kausen, R. C.
HIGH- AND LOW-TEMPERATURE ADHESIVES – WHERE DO WE STAND? SAMPE – 7th Materials Symp., Adhesives & Elastomers for Environmental Extremes, May 1964, Sect. I.

Various classes of structural adhesives for high and low temperature service and their respective typical properties for use in space technology; effect of temperature on shear strength; coefficient of thermal expansion of adhesive system of epoxy resins can be reduced from 5×10^{-5} in./in./C to 3×10^{-5} by using aluminum oxide as fillers; list of trade names of commercial adhesives and their manufacturers are given.

160. Kausen, R. C.
ADHESIVES FOR HIGH AND LOW TEMPERATURES.
Matls. in Design Eng., 60(2):94 – 8, Aug 1964; 60(3):108 – 12, Sep 1964.

Review of advantages and limitations of different types of structural adhesives for use at high temperatures and cryogenic temperatures (down to -400° F; although only ceramic-based adhesives are usable above 1000° F, many of adhesives listed in article are available for use in 350 to 1000° F range, particularly those in polyaromatics group; among low-temperature adhesives, optimum properties are shown by polyurethanes and epoxy-nylons.

161. Kuno, J. K.
COMPARISON OF ADHESIVE CLASSES FOR STRUCTURAL BONDING AT ULTRAHIGH AND CRYOGENIC TEMPERATURE EXTREMES.
SAMPE – 7th Materials Symp., Adhesives & Elastomers for Environmental Extremes, May 1964, Sect. 11.

Classifications of various structural adhesives according to their chemical types and properties from cryogenic to elevated temperatures; advantages, design considerations, fabrication techniques, selection adhesives and typical applications are summarized; effects of temperature, aging time, shock loading, impact resistance, environmental exposure and bonding different substrates with wide degree of thermal expansion on classification.

162. Laughner, V. H. and A. D. Hargan
HANDBOOK OF FASTENING AND JOINING OF METAL PARTS. McGraw-Hill Book Co., First Edition 1956.

The aim of this book is to provide the design engineer with both a reference and an idea source covering all known methods of joining metal parts. The first section covers fundamentals of various fasteners and fastening techniques. The second section is in sketch and caption form.

163. Licari, J. J.
GUIDE TO HIGH TEMPERATURE ADHESIVES.
Product Eng., 35(25):102 – 6, 7 Dec 1964.

Specifications and characteristics of adhesives at temperatures above 250°f are discussed in relation to composition requirements, surface preparation and application techniques; tables of tensile shear strength are given; types of adhesive and suppliers are cataloged.

164. Light, J. S.
RECENT TECHNIQUES FOR INSULATION IN SPACE ENVIRONMENT. IN Application of Advanced and Nuclear Physics to Testing Materials, ASTM Special Technical Publ. No. 373, 1965 1965, pp. 127 – 134.

Weight and performance needs of space programs have given impetus to the use of new thermal isolation techniques. Uses are currently ranging from the control of thermal environment in spacecraft with internal energy releases and limiting temperature changes in static storable fuels to insulating cryogens in bulk for long term employment in space. Aspects of such applications are discussed in this paper.

165. Litvak, Sidney (USAF, Systems Command, Research and Technology Div., Materials Laboratory, Wright-Patterson AFB, Ohio).
RESEARCH ON POLYBENZIMIDAZOLE STRUCTURAL ADHESIVES FOR BONDING STAINLESS STEEL, BERYLLIUM, AND TITANIUM ALLOYS. IN Structural Adhesives Bonding; Symposium, Stevens Institute of Technology, Hoboken, N. J., 14 – 16 Sep 1965. (Edited by M. J. Bodnar.) New York, Interscience Publishers, Division of John Wiley and Sons, Inc., (Applied Polymer Symposia No. 3), 1966, pp. 279 – 298.

Polybenzimidazole (PBI) resins have been successfully formulated as structural adhesives for bonding stainless steel, beryllium, and titanium alloys. Tensile-shear specimens made with stainless steel adherends have been evaluated from -424 to 1000°F. Test results at -424°F were in excess of 5800 psi and shear strengths in excess of 1000 psi were obtained at 1000°F after 1/2 hr aging in air. PBI adhesives have also been investigated for bonding stainless steel skins to stainless steel core. Evaluation results of the honeycomb sandwich specimens fabricated from the above materials, demonstrated that PBI structural adhesives are, up to 1000°F, far superior to the best commercial adhesives now being utilized.

166. Markley, F. W.

SELECTING STRUCTURAL ADHESIVE.

Assembly Eng. 8(8):31 – 5, Aug 1965.

Some important aspects in matching adhesives to job; categories of structural or thermosetting adhesives are epoxy, silicon, aldehyde, isocyanate, polyester adhesives, and mixtures; some points for selection of adhesives such as mechanical, thermal, electric characteristics of fastening material, bonding of optical components, chemical environment that adhesives will be exposed to, and effect of radiation and ultraviolet rays; average properties of thermosetting adhesives and mixtures.

167. Matsch, L. C.

ADVANCES IN MULTILAYER INSULATIONS.

(Linde Company, Division of Union Carbide Corporation, Tonawanda, New York.) Advances in Cryogenic Eng., Vol. 7:413 – 418, 1961.

It is generally accepted that there are two outstanding types of modern high-quality cryogenic insulations. The first group consists of opacified powders and the second is the so-called superinsulations which are of multilayer construction. Table 1 compares the outstanding characteristics of the two types of insulation. The advantages of powders are:

1. The vacuum requirement is much less stringent for achieving full performance. Usually a pressure of several μ Hg is quite acceptable, while superinsulations require a pressure not higher than 0.1 μ Hg.
2. They are relatively easy to apply, even to complicated shapes of the insulation space, while multilayer insulations require special techniques to achieve economical installation.

The advantages of the multilayer insulation, on the other hand, are:

1. The achievable thermal conductivities are more than an order of magnitude lower.
2. The weight of the insulation per unit volume is lower and consequently, based on equal heat leaks, the total insulation weight is lower by one to two orders of magnitude.
3. They are free of the problem of settling which frequently plagues powder insulations, usually necessitating in the latter system a compromise between reliability and performance. At the same time, the support of the multilayer insulations admittedly presents a severe problem as will be discussed later.
4. Although the cost per unit volume is usually higher for the multilayer insulations, the cost for equal performance is lower because considerably less material is required.

168. McClure, Alex

METAL FASTENERS IN ULTRA-HIGH TEMPERATURES. Machinery Lloyd, 39(4):26 – 29, 18 Feb 1967.

Refractory metal fasteners (Ta, Cb, Mo and W) used at temperatures from 2000° F up are discussed, based on recent research information. Ta appears to be the most promising in applications calling for temperatures of 2000 and 3600° F. W is apparently the only satisfactory material for fastener applications beyond 3600° F. However, W is handicapped by severe oxidation when uncoated. Mo will probably yield to Cb at the low end of the 2000 to 3000° F range and will probably be replaced by Ta at the high end. This results from the extremely rapid oxidation of Mo when unprotected. Cb may prove to be the best fastener material for the 2000 to 2800° F range. The two most promising Cb alloys, Cb 752 and C 129Y, have been fabricated and coated and for the past year have been undergoing extensive testing for mechanical properties. Dispersion strengthened alloys, such as TD Ni, may be used up to 2400° F for short times, but are not suitable as fastener materials because of low performance at room temperatures. The best antioxidation refractory metal coatings are various silicides. The best coatings for Mo are modified disilicides. The best for Cb is the Cr-Ti-Si system. Electrophoresis appears to be the best method for coating of fasteners. Pack cementation is also used.

169. McGrew, J. L.

A COMPARATIVE STUDY OF AIRBORNE LIQUID-HYDROGEN TANK INSULATION. (Martin-Marietta Corporation, Denver, Colorado.) Advances in Cryogenic Eng., Vol. 8, pp. 387 – 392, 1962.

At the present time an important cryogenic problem with missiles utilizing liquid hydrogen as a propellant is that of propellant system insulation. These propellant systems must be insulated with a very effective thermal insulation in order to reduce propellant evaporation to an acceptable limit during prelaunch, boost, and space flight periods. The extremely low temperature and low volumetric heat of vaporization of liquid hydrogen impose severe requirements on the physical, mechanical, and thermal behavior of the insulation. Further, insulation remaining on the vehicle during flight must be kep to a minimum weight because of the infleunce of weight on vehicle performance.

170. Merrill, H. K. and D. W. Murphy
EXTERNAL INSULATION TECHNIQUES FOR LIQUID-HYDROGEN TANKS. (Martin-Marietta Corporation, Denver, Colorado.) Advances in Cryogenic Eng., Vol. 8, pp. 393 – 397, 1962.

Many of the liquid-hydrogen-fueled vehicles now envisioned require the ability to operate in space. For satisfactory long-term performance in this environment these vehicles must be insulated. The work presented here was directed at developing an external insulation, utilizing existing materials and processes, that would provide adequate performance on the ground and at the same time be effective in space.

An experimental program to evaluate two external insulation design concepts that might meet long-term space requirements was undertaken. Figure 1 shows a cross section of these two types and the results of the experimental evaluation.

The first concept, Type I, consisted of eight layers of fiberglass and aluminum foil. These layers were then covered with an aluminum shroud and purged with helium gas to prevent air condensation in the insulation. Type II was corkboard bonded to the tank and then covered with fiberglass matting to simulate multilayer insulation. The purpose of the corkboard was to increase the temperature in the multilayer sufficiently to prevent air condensation and thereby eliminate the necessity of purging the insulation. In addition to providing good thermal protection, these concepts, with the aluminum shroud and soft insulation underneath, may be very effective in providing micrometeorite protection in space.

171. Middleton, R. L., J. M. Stuckey, J. T. Schell, et al.
DEVELOPMENT OF A LIGHTWEIGHT EXTERNAL INSULATION SYSTEM FOR LIQUID-HYDROGEN STAGES OF THE SATURN V VEHICLE. (NASA George C. Marshall Space Flight Center, Huntsville, Alabama.) Advances in Cryogenic Eng., Vol. 10, pp. 153 – 160, 1964.

The success of the nation's space program depends on the availability of suitable insulation systems for cryogenic tankage. It is imperative that these insulation systems have high reliability, be light in weight, and low in conductance. In many areas of such insulation systems, demands have exceeded today's technology. Many research and development programs are currently in progress throughout the country and in time will provide much of the information desperately required. The ultimate goals of such studies include insulation systems for practical vehicle configurations for both short-duration flights, such as launch vehicles, as well as for long-duration flights or missions such as lunar exploration.

Marshall Space Flight Center has conducted development on insulation systems for hydrogen tanks typical of those utilized in the SATURN V Program as well as tankage configurations envisioned as requirements for long-duration missions. The program reported herein was initiated for purposes of weight control and reliability in support of this space program. Upon program initiation, the lightest-weight insulation system proposed was the system shown in Fig. 1, weighing 0.82 lb/ft^2 and having a conductance of 0.45 Btu/hr-ft^2-°R.

The relatively poor thermal performance of this insulation concept is attributed to a required helium purge of the insulation, establishing a conductivity of the system approximately that of the helium gas. The helium purge is required on this insulation to prevent air cryopumping into the insulation (in the event of a damaged outer seal) and creating any LOX compatibility problems or additional weight penalty.

This paper discusses results on the development of a new insulation concept originating from this program having a weight of approximately 0.50 lb/ft^2 and a conductance of 0.33 Btu/hr-ft^2-°R.

172. Moeller, C. E.
SPACECRAFT DEMANDS BRING NEW THERMAL INSULATIONS. Product Eng., 37(4):91 – 5, 14 Feb 1966.

Fibrous metal blankets, ceramic fibers, mats and foams, powders, bubbles, composites, multilayers and ablatives are reviewed by type and application, mostly to aerospace use; temperature limits, thermal conductivity, resistance to thermal shock and relative cost are tabulated.

173. Nast, T. C.
EFFECTIVE PURGING OF HIGH-PERFORMANCE MULTILAYER INSULATION SYSTEMS. (Lockheed Missiles & Space Co., Sunnyvale, California.) Advances in Cryogenic Eng., Vol. 11: pp. 49 – 55, 1965.

The majority of insulation systems considered for long-term storage of cryogenics in space are multilayer types. These types consist of multiple radiation shields which often utilize low-conductivity spacer materials to maintain shield separation. High-thermal-performance multilayer systems require operation in a vacuum in order to eliminate gaseous conduction within the insulation. During ground-hold operation the condensible gases within the individual layers must be removed prior to cryogen loading. This is necessary to prevent the formation of solids, which can be detrimental to the insulation. Two methods for removing the condensible gases are commonly considered by industry. The first employs a vacuum bag around the insulation. The gases within the insulation are then pumped from the bag. The second method uses a purge bag around the insulation; however, in this method a noncondensible gas is circulated within the bag and insulation until a negligible quantity of condensible gases remains.

The present paper deals with the consideration of an effective purge system. The results of six tests in which air was purged from within three multilayer insulation types with helium are presented and discussed. A simple method of scaling the results to other size tanks is presented.

174. Nast, T. C. and W. S. Williams
THE EFFECTS OF PROPELLANT LEAKAGE ON THE HEAT TRANSFER TO A CRYOGENIC PROPELLANT TANK UTILIZING HIGH-PERFORMANCE MULTILAYER INSULATIONS. (Lockheed Missiles & Space Co., Sunnyvale, California.) Advances in Cryogenic Eng., Vol. 12: pp. 229 – 238, 1966.

Long-term storage of cryogenic propellants in space requires an insulation system utilizing multiple radiation shields (multilayer insulations). The heat flow through this type of insulation is critically dependent upon the gas pressure within the insulation. Laboratory investigations indicate that gas pressures exceeding 10^{-5} torr can significantly increase the heat transfer through these insulations. Propellant leakage from a tank, if present in sufficient quantities, can increase the heat transfer through the insulation many times.

Results of the tests showed that leakage rates below approximately 10^{-3} cc/sec (stp) can be tolerated without excessive thermal degradation of the insulation. Since sensitivity of current leak detectors is orders of magnitude greater than this level, harmful leakage rates from tanks can be detected easily and repaired before application of insulation. These leakage rates are orders of magnitude higher than normally accepted values for well-built tanks.

175. NATIONAL CONFERENCE ON SPACE MAINTENANCE AND EXTRA-VEHICULAR ACTIVITIES, 1ST, Orlando, Fla., MARCH 1 – 3, 1966, PROCEEDINGS. Conference sponsored by the U.S. Air Force Aero Propulsion Laboratory and the Martin Marietta Corp., Baltimore, Md., National Conference on Space Maintenance and Extra-Vehicular Activities, 1966, 495p.

176. Owen, H. P.
DEVELOPMENT OF HIGH TEMPERATURE AEROSPACE STRUCTURAL ADHESIVE.
SAMPE – 7th Materials Symp., Adhesives & Elastomers for Environmental Extremes, May 1964, Sect. 10.

Research and development of phenyl silanes and epoxy novolacs as high temperature structural adhesive for aerospace industry undertaken by General Dynamics; effect of fillers, antioxidants, plasticizers and catalysts on adhesive formulations; epoxy novolac does not have good strength at 1000°F but has better oxidation resistance and strength retention in temperature range from 500 to 600°F.

177. Parmley, R. T., D. R. Elgin, and R. M. Coston
SHINGLE MULTILAYER INSULATION FOR SPACE VEHICLES USING CRYOGENIC FLUIDS. (Lockheed Missiles & Space Company, Sunnyvale, California.)
Advances in Cryogenic Eng., Vol. 11: pp. 16 – 25, 1965.

An efficient multilayer thermal protection system design is necessary for the successful development of spacecraft using cryogenic propellants for mission durations of more than a day. This design must satisfy the requirements peculiar to the mission and perform satisfactorily when subjected to the often contradictory demands of ground hold, ascent, and space environments.

From these requirements, thermal protection systems can be developed and evaluated. A convenient method for evaluating these systems is to break them into three component parts: (1) multilayer materials, (2) methods for attaching the multilayers to the propellant tank, and (3) techniques to provide ground hold and ascent insulation. (It is assumed that the tank insulation is protected from aerodynamic loads by the use of an outer structural shell.)

Each component part can be evaluated separately and then combined into flight-type multilayer system designs. Typical of the various radiation shield and spacer material combinations in use are: (1) Mylar, aluminized on two sides, with fiberglass paper spacers, and (2) aluminum foil with fiberglass paper spacers. Another technique uses crinkled Mylar, aluminized on one side, to provide point contact between the radiation shields.

The attachment method must be tailored to the structural properties of the materials (Fig. 1); for example, a button system was devised to support the fragile fiberglass paper spacers with either aluminized Mylar or aluminum foil radiation shields. On the other hand, the shingle and tape methods shown require adequate tensile strength in the multilayers, i.e., crinkled aluminized Mylar, to allow attachment along one edge. In addition, the system design must provide adequate ground-hold insulation and prevent gas liquefaction or frost buildup in the multilayers. For liquid oxygen tanks, a dry nitrogen purge in the interstage region is sufficient. However, for liquid hydrogen tanks, more elaborate techniques must be used to prevent gas liquefaction. These techniques can be classified into passive (cryopumped), purged, and evacuated systems. The many facets of multilayer insulation system design for flight tanks are not discussed here; instead, we will concentrate on the shingle attachment method.

178. Pascuzzi, B. and J. R. Hill
STRUCTURAL ADHESIVES FOR CRYOGENIC APPLICATIONS. Adhesives Age, 8(3):19 – 26, Mar 1965.

Development of simple adhesive bonding process for 2219 aluminum in which bonds possess suitable stability under dynamic and cryogenic environments; evaluation of four adhesives – to epoxy resins, one epoxy-polyamide resin mixture, and one polyurethane resins using tensile-shear and vibration-fatigue screening tests, followed by comprehensive mechanical and environmental tests; with proper design, polyurethane resin adhesive tested is considered suitable for cryogenic applications.

179. Perkins, P. J., M. A. Colaluca, and L. S. Smith
PRELIMINARY TEST RESULTS ON A COMPRESSED MULTILAYER INSULATION SYSTEM FOR A LIQUID-HYDROGEN-FUELED ROCKET. (NASA Lewis Research Center, Cleveland, Ohio.) (Linde Company, Division of Union Carbide, Tonawanda, New York.) Advances in Cryogenic Eng., Vol. 9, pp. 38 – 45, 1963.

The development of economical travel to the moon in this decade and of interplanetary exploration in the next will depend in part on the successful storage of cryogens in space. In the vacuum of space, heat transfer to the cryogens from external heat sources is primarily by radiation; thus, radiation-type insulations are required. Presently available multilayer insulation materials are adequate for moderate-duration space storage when used in a vacuum. The vacuum of space is ideal for multilayer insulation, but some means must be provided to maintain a vacuum in the insulation during ground-hold and boost through the atmosphere. Present multilayer insulation systems for gound storage use a heavy-walled vacuum jacket, which is impractical for flight use because of its large mass. Replacement of this outer wall with a light-weight and impermeable jacket lessens the weight penalty but introduces other problems. Evacuation of the flexible jacket with external pressure compresses the multilayer insulation. This compression increases the apparent thermal conductivity. Small-scale tests have shown that the insulation nearly recovers its original thickness when the compressive load is removed. Protection of this flexible jacket against aerodynamic loads during boost through the atmosphere may require a shrouded tank stru structure.

This paper deals with the design, fabrication, and testing of a jacketed multilayer insulation system (SI-62) employs superinsulation, sealed within a lightweight evacuated flexible jacket. The system was applied to a 150-gal cylindrical cryogenic tank and tested under compression due to atmospheric pressure on the flexible jacket with vacuum within the insulation. This simulated the ground-hold condition on the insulation. Further tests were conducted lessening the compressive load on the insulation by reducing the external pressure on the jacket, approaching pressures outside the earth's atmosphere. The purposes of the tests were to determine the feasibility of the super-insulation concept and the thermal performance of the insulation under ground-hold and reduced-pressure conditions, and to provide data for design of future systems. Some earlier work with this concept is reported in the literature.

180. Poe, L. R.
PLASTIC FASTENERS AND THEIR APPLICATIONS.
Indus. Fastening & Assembly Conference – Report
17 – 20 Feb 1964 paper A2, 13p.

Plastic fasteners have following inherent benefits – inert to corrosive environments, electrical and thermal insulation, vibration resistance, combining of complicated forms to perform multiple functions, rapid assembly without damage to painted or plated surfaces, color matching, and self locking; synthetic fasteners are used in securing nameplates, for metal-to-plastic joining and hinge fastening; rivets are molded in one piece from thermoplastic compositions of nylong, acetate, polystyrene or polyethylene; acetal, or nylon, trim clips are used in automotive industry to solve metal corrosion problems, and seal against water seepage.

181. Price, J. W. and T. G. Lee
ANALYSIS, DESIGN, AND TESTING OF HEAT-SHORT-ISOLATION COMPONENTS FOR HIGH-PERFORMANCE INSULATION SYSTEMS. (Douglas Aircraft Company, Inc., Santa Monica, Calif.)
Advances in Cryogenic Eng., Vol. 12: pp. 265 – 273, 1966.

Heat that enters a propellant tank has two principal routes. One is the tank-wall insulation through which the heat is radiated, and the other is the tank supports and plumbing which conduct heat into the tank. The latter is called a heat short and is the subject of this paper. The objectives of the development program described in this paper were as follows:

1. To formulate criteria and analyses for the prediction of heat flux through full-scale tank supports and plumbing.
2. To conduct experiments to verify the validity of these analyses.
3. To develop heat-isolation components and optimum piping configurations for use in flight tankage.
4. To compare the relative thermal efficiency of point tank supports as opposed to continuous-band supports.

182. Reinhart, T. J. Jr. (USAF, Systems Command, Research and Technology Div., Materials Laboratory, Wright-Patterson AFB, Ohio) and R. Hidde (Whittaker Corp., Narmco Research and Development Div., San Diego, Calif.).
MECHANICAL PROPERTIES OF IMIDITE ADHESIVES. IN: Structural Adhesives Bonding; Symposium, Stevens Institute of Technology, Hoboken, N. J., 14 – 16 Sep 1965. (Edited by M. J. Bodnar.) New York, Interscience Publishers, Division of John Wiley and Sons, Inc. (Applied Polymer Symposia No. 3), 1966, pp. 299 – 318.

The mechanical properties presented show that the polybenzimidazole resin system has promise for solving many critical design problems in the area of adhesive bonding. The properties developed show remarkable thermal stability for short periods of time at temperatures as high as 900°F (maximum test temperature), and for 1000 hr at 500°F. Excellent strengths were also exhibited at cryogenic temperatures and after exposure to various environments such as salt spray, 100% humidity, aromatic fuel immersion, and hydraulic oil immersion. A study of bond geometry indicates that the perimeter of the bond may effect bond performance as much as the classical length-to-thickness ratio or the shear modulus.

183. Robbins, R. F., D. H. Weitzel, and R. N. Herring
THE APPLICATION AND BEHAVIOR OF ELASTOMERS AT CRYOGENIC TEMPERATURES. (CEL National Bureau of Standards, Boulder, Colorado.)
Advances in Cryogenic Eng., Vol. 7: pp. 343 – 352, 1961.

Elastomers offer the cryogenic engineer a dramatic demonstration of how the properties of some materials change radically when cooled to cryogenic temperatures. These materials have room-temperature properties of high extensibility and forcible quick retraction but, without exception, become hard and glass-like when sufficiently cooled, and thereafter behave like crystalline solids. Around this so-called glass-transition temperature, the modulus of elasticity may increase by a factor of 400 to 1000, and the coefficient of expansion may decrease by a factor of three or more [1]. Because of these changes, elastomers are not commonly used at cryogenic temperatures to solve problems for which they would be used at room temperature. Where an elastomer O ring would perform the function of a static seal at room temperature, countless designs are now being used to seal cryogen transfer lines, fuel and oxidizer missile components, experimental apparatus, and so on. However, none of these alternatives has met with universal approval, and all exhibit at least one of the disadvantages of high cost, poor performance, or complexity.

To augment the efforts of industry in this area, NBS is investigating low-temperature seals, with emphasis on use and behavior of elastomers. Early work was reported at least year's Cryogenic Engineering Conference and elsewhere [2,3]. In brief, it was found that elastomeric O rings, molded from several compounds, could be used for high-vacuum seals at cryogenic temperatures with system pressures up to 1000 psig. The present paper describes modifications of the earlier designs which result in substantial reduction in required sealing force, greater simplicity, and no apparent loss of reliability. An apparatus designed to measure the contraction of compressed elastomers in the temperature range 300° to 76°K will be discussed, together with some test results.

184. Roseland, L. M.
MATERIALS FOR CRYOGENIC USAGE. SPI-21st Annual Tech. Conference – Proc., Feb 1966 paper 4-C, 6p.

Methods for improving mechanical properties of structural adhesives and composite materials at cryogenic temperatures; use of polyurethane and nylon-epoxy films, addition of adhesion promoting silanes and utilization of fibrous materials.

185. Roseland, L. M.
EVALUATION OF STRUCTURAL ADHESIVES FOR POTENTIAL CRYOGENIC USAGE. SAMPE-7th Materials Symp., Adhesives & Elastomers for Environmental Extremes, May 1964, Sect. 7.

Investigation on mechanical properties of various commercial structural adhesives films and pastes at cryogenic temperatures for potential use in aerospace industry; test methods and equipment using liquid nitrogen and hydrogen as coolants are discussed; polyurethane adhesives showed highest tensile and peel strength at cryogenic temperatures.

186. Roseland, L. M.
DEVELOPING STRUCTURAL ADHESIVES USED FOR SPACE APPLICATIONS. Adhesives Age, 9(4):32 – 5, Apr 1966.

Review of history of adhesives; epoxy-phenolic structural adhesive containing glass cloth carrier used for bonding honeycomb core to aluminum skins, forming bulkhead of Saturn space vehicles; urethane polymers are likely to be used for on-site joining and sealing of bulkheads which have been segmented for shipping purposes.

187. Ruccia, F. E., R. B. Hinckley, and R. C. Reid
THERMAL PERFORMANCE OF TANK APPLIED MULTILAYER INSULATIONS. (A. D. Little, Inc. Cambridge, Massachusetts.) (Massachusetts Institute of Technology, Cambridge, Massachusetts.) Advances in Cryogenic Eng., Vol. 12: pp. 218 – 228, 1966.

Multilayer insulations show considerable promise in reducing heat flow to stored cryogenic propellants from a space environment. The investigation reported in this paper was conducted to develop combinations of shields and spacers that produce the lowest heat flux for the lowest system weight as well as to develop the techniques of applying the system to tanks. In addition, a number of tests were performed with a calibrated helium gas leak on the underside of the insulation to simulate propellant-tank leaks in space.

188. SEVENTH NATIONAL SAMPE SYMPOSIUM – ADHESIVES AND ELASTOMERS FOR ENVIRONMENTAL EXTREMES. Soc. of Aerospace Materials & Process Engrs. May 1964, Los Angeles, Calif.

Several papers on adhesive bonding at temperature extremes.

189. Sharpe, L. H.
MATERIALS, PROCESSES, AND DESIGN METHODS FOR ASSEMBLING WITH ADHESIVES. Machine Design, 38(19):177 – 200, 18 Aug 1966.

Design guide is presented concerning "how" and "why" of adhesive bonding from designing joint to specifying complete processing method; functions of adhesives; materials to be joined; adhesive joints; types of adhesives; joining process; quality control by means of destructive or nondestructive tests; influence of adhesives on surroundings.

190. Siegel, Martin J. (Southern California, University, Dept. of Mechanical Engineering, Los Angeles, Calif.).
HIGH-TEMPERATURE SPRINGS. Machine Design, 39:113 – 116, 30 Mar 1967.

Study of the effects of high temperatures on springs fabricated of such materials as music wire, 18-8 stainless steel, 17-7 PH, and Inconel-X. It is found that loss of load, length, and a change in the modulus of rigidity are the most significant effects of high temperatures in compression springs. Relaxation or creep reduces preset loads or changes the location of supported components, and a change in the modulus of rigidity alters the spring rate.

191. Skeist, Irving
HANDBOOK OF ADHESIVES. Reinhold Publishing Corp., N. Y., 1962.

An adhesive is a substance capable of holding materials together by surface attachment. Adhesives are essential to shoes and space ships and scaling wax as well as cars, cabinets, countertops, corrugated cartons, and curtain wall construction. Sections given on fundamentals, adhesive materials, adherend and bonding technology.

192. Smith, M. B. and S. E. Susman
DEVELOPMENT OF ADHESIVES FOR VERY LOW-TEMPERATURE APPLICATION. (Narmco Research and Development, Division of Telecomputing Corporation, San Diego, California.) Advances in Cryogenic Eng., Vol. 8: pp. 300 – 305, 1962.

The purpose of this program was to provide an adhesive, or family of adhesives for bonding clips, brackets, etc., to skin portions of cryogenic fuel and oxidizer containers and other related components of launch vehicles for space craft. The adhesives were to be applicable when completely submerged in various cryogens. It was desired that the techniques of surface preparation and bonding be simple and readily adaptable to field use by technicians with little or no experience in plastics technology. It was further desired that the adhesives be suitable for application to vertical, horizontal, or overhead surfaces. Bonding and curing were to be accomplished under ambient conditions with an absolute minimum of bonding pressure – less than 1 psi.

193. Soled, Julius
FASTENERS HANDBOOK. Reinhold Publishing Corp., N. Y. 1957.

This handbook contains information useful to those engaged in the design of production of fasteners. Each fastener is discussed on a separate page which also includes an illustration.

194. SPACEMAN TO BOND SELF TO VEHICLE WITH ADHESIVE CAPSULES. Adhesives Age, 10(1):35, Jan 1967.

Space researchers are literally seaking a means to glue an astronaut to the outside of his space vehicle. A cyanocacrylate monomer which in 10 seconds forms a rigid and structurally sound bond is undergoing tests.

195. SPECIFICATION FOR PRESSURE-SENSITIVE ADHESIVE TAPES FOR ELECTRICAL PURPOSES. Brit Standards Instn – Brit Standard 3924, 1965, 37p.

Standard specified requirements for tapes suitable for use where electrical and corrosion-resistant properties of tape are important; tapes are classifed by base (or backing) material (woven cloth, paper, film, composite), maximum working temperature, and type of adhesive (thermoplastic, thermosetting, silicone).

196. Stiles, W. S.
ADHESIVES GO TO WORK ON APOLLO. Iron Age, 197(20):78 – 9, 19 May 1966.

Command module for Apollo spacecraft is designed around bonded aluminum honeycomb sandwich concept; adhesive bonding is used to attach more than 700 miscellaneous details, ranging from simple angles to complex machined fittings, to external and internal surfaces of module; how this challenging bonding program is met successfully by Space and Information Systems Div., North American Aviation; three adhesive systems, designed for temperatures ranging from minus 250°F to plus 250°F, are used for bonding operations.

197. Strauss, E. L.
STRENGTH OF BOLTED AND BONDED ATTACHMENTS OF GLASS – REINFORCED POLYBENZIMIDAZOLE AND PHENOLIC LAMINATES TO METAL. SPI-21st Annual Tech. Conference – Proc., Feb 1966 paper 4-F.

Stress concentration effects and strength of simple bonded and bolted butt joints were investigated for glass fabric-reinforced polybenzimidazole laminate at room temperature and at 700°F, and for glass fabric-reinforced phenolic laminate at room temperature and at 500°F; room temperature tensile strength of polybenzimidazole laminates was higher than that of phenolic laminate; both laminates exhibited high room temperature tensile strengths and little degradation of that strength occurred at elevated temperature.

198. Streed, E. R. and J. C. Arvesen
A REVIEW OF THE STATUS OF SPACECRAFT THERMAL CONTROL MATERIALS. SAMPE J., 3(4):17 – 24, Jun – Jul 1967.

The need for reproducible and space stable thermal control materials has been indicated from past and present experience. These materials will enable the design of minimum weight, reliable passive thermal control systems for long duration missions or for severe environments. Although certain inorganic coatings exhibit good stability in near earth orbits, the influence of temperature and particulate radiation, and application or handling difficulties remain as serious coating-material problems. Additional research is required to determine fundamental degradation mechanisms.

With knowledge of the structural and purity requirements, routine quality control techniques must be established to insure reproducibility. Recent studies have demonstrated the need and the complexity of apparatus to provide adequate simulation of the complete space environment effects can cause either positive or negative synergistic effects on material optical properties. When simulation capabilities approach duplication of the space environment, then the extraterrestrial spectral distribution and flux of both particular and electromagnetic radiation must be known more accurately. Because of the uncertainties in knowledge of the space environment, the inability to duplicate the environment, and the impractical aspects of long exposure simulation, flight experiments will continue to provide the ultimate verification of environmental performance. It is also evident that, although some compromises in weight, simplicity, and cost may be required, materials and techniques are now available for the design of thermal control systems for presently planned missions.

199. Streed, E. R., C. R. Cunnington, and C. A. Zierman
PERFORMANCE OF MULTILAYER INSULATION SYSTEMS FOR THE 300° TO 800°K TEMPERATURE RANGE. Prog. in Astronautics & Aeronautics, Vol. 18, pp. 735 – 71, 1966, Academic Press, N. Y.

The need for the development of materials and design data for multilayer insulation systems for use on spacecraft in the temperature range of 300° to 800°K is shown. An analytical treatment is developed for one-dimensional heat transfer through multilayer insulation. Experimental verification of the influence of parameters such as thermal conductivity of spacer materials, emittance of shields, absorption and scattering coefficients of spacer materials; compression, and boundary temperatures on over-all thermal conductivity is reported. The results of single-plate, guarded calorimeter apparatus measurements of composite insulation systems over the temperature range of 300° to 800°K for several shield and spacer material combinations are presented.

200. Strouhal, G., D. M. Curry, and J. M. Janney (NASA, Manned Spacecraft Center, Thermal Protection Systems Section, Houston, Tex.). THERMAL PROTECTION SYSTEM PERFORMANCE OF THE APOLLO COMMAND MODULE. IN: American Institute of Aeronautics and Astronautics, and American Society of Mechanical Engineers, Structures and Materials Conference, 7th, Cocoa Beach, Fla., 18 – 20 Apr 1966. Technical Papers. New York, American Institute of Aeronautics and Astronautics, 1966, pp. 184 – 200.

Description of the thermal behavior of the Apollo Command Module thermal protection system for lunar return speed entries. The protection consists of a low-density (phenolic-epoxy novolac) charring ablation material gunned into a nonmetallic, open-face, honeycomb reinforcing matrix which is bonded to a brazed stainless steel honeycomb structure. The system configuration is discussed in conjunction with design entry trajectories and structural thermal requirements used to determine ablator thickness for operational missions. A description of the charring ablation routine used by the Manned Spacecraft Center in predicting thermal performance is presented. Methods of analyzing the ground test results in the establishing and verifying of the mathematical model are given. The results of the combined analytical and experimental study are then utilized to demonstrate quantitatively the method for predicting the thermal performance of the system for typical maximum heating rate and heat load trajectories.

201. Swalley, F. E. and C. D. Nevins PRACTICAL PROBLEMS IN DESIGN OF HIGH-PERFORMANCE MULTILAYER INSULATION SYSTEM FOR CRYOGENIC STAGES. (NASA George C. Marshall Space Flight Center, Huntsville, Alabama.) Advances in Cryogenic Eng., Vol. 10: pp. 208 – 215, 1964.

In order to store cryogenic propellants in orbit for any length of time, a high-performance insulation system is required. In this paper an insulation system will be defined as the insulating material, the means of attaching it, and the method to provide the vacuum within the insulation. The insulating material which offers the highest thermal performance is the multilayer type (frequently referred to as super-insulation). Several different kinds of multilayer insulation are available and have been applied to ground dewars. However, the application to space vehicles introduces new problems and requires additional development work. Many insulating schemes using multilayer insulation have been proposed for cryogenic spacecraft. Knoll and Oglebay have evaluated the insulating schemes in terms of their thermal efficiencies and discussed some of their inherent faults. Of the schemes proposed, the evacuated flexible-jacket scheme using a spacer-type multilayer insulation was considered to be in the most advanced state of development. Basic calorimeter data on the thermal properties of the spacer-type insulation material were available and a system employing the flexible-jacket scheme had been applied to experimental tankage. The next logical step was the incorporation of this scheme into a workable insulation system for operational, flight-type tankage; therefore, an extensive program was begun to design such a system for a lunar mission stage. The emphasis was placed on solving the practical problems associated with producing a complete insulation system. To solve these problems, a series of flight-type tanks, and supporting experiments were planned. At present, two tanks have been designed and fabricated. The first tank has been insulated and tested. The results of that work will be discussed in this paper.

202. Tariel, H. M., J. C. Boissin, and M. P. Segel
THERMAL INSULATION FOR LIQUID HYDROGEN SPACE TANKAGE. (Société l' Air Liquide, Centre d'Etudes Cryogeniques, Sassenage, Isére, France) Advances in Cryogenic Eng., Vol. 12: pp. 274 – 285, 1966.

The thermal insulation for a cryogenic stage is closely related to the intended mission of the space vehicle. For a low-orbit, short-duration flight (less than 1 hr), the thermal insulation is used primarily to restrict the heat flux into propellants induced by kinetic heating while passing through the earth's atmosphere. When dealing with a final stage, the weight of the non-jettisonable insulation is fully chargeable against the stage payload capability. A drastic optimization must then be carried out, taking into account boil-off losses and cavitation losses at the turbopumps, on the one hand, and insulation weight, on the other hand.

It is clear that such requirements can be satisfied only by using a lightweight material having low thermal conductivity and the mechanical properties necessary to withstand the aerodynamic, thermal, and mechanical stresses occurring during the stage life. This material must then be bonded to the tank walls and protected by an adequate coating (having ablative or high heat-capacity properties), if kinetic heating is too large.

To our knowledge, U.S. aerospace companies make use of both expanded polyurethane and honeycomb plastics. . Both possess the same shortcomings – they are not air-tight (external insulation) or hydrogen-tight (internal insulation). Moreover, the mechanical properties of expanded polyurethane are relatively low, and thermal stresses induce crack which necessitate use of a fiberglass constrictive wrap to maintain the insulation integrity.

This paper presents the results of research carried out on Klegecell G 300. This insulation material is a rigid plastic foam comprised of polyvinyl chloride (PVC) chains cross-linked by an isocyanate bridge. These isocyanates are bonded on the PVC chains by a vinylidenic and maleic anhydride copolymer. This tridimensional structure tends to increase the mechanical properties and dimensional stability of the material at moderately high temperatures. It can be obtained in a density range varying from 30 to 100 kg/m^3. The gas in the plastic cells is a mixture of CO_2, air, and Freon 11 under a pressure of about 3 bars.

203. Thomas, M. and W. Weitzman (Douglas Aircraft Co., Inc., Santa Monica, Calif.).
A COMPARISON OF SHROUD-MOUNTED WITH TANK-MOUNTED HIGH-PERFORMANCE INSULATION. Advances in Cryogenic Eng., Vol. 12: pp. 239 – 249, 1966.

Discussion of the advantages and disadvantages of the shroud-mounted and tank-mounted high-performance insulation systems. "Tank-mounted insulation" is a system in which the high-performance insulation is primarily supported by the propellant tanks, feed and vent lines, and tank supports. "Shroud-mounted insulation" refers to a high-performance insulation system supported on the inside of some structure with simple curvature that encloses the propellant tanks, feed and vent lines, and tank supports. The results of the thermal optimization of the study vehicle for a variety of conditions are tabulated. The insulation systems used were Dimplar, NRC-2, and Mylar-paper-spacer system (MPSS). In terms of usable propellant weight, Dimplar and NRC-2 are comparable and are both significantly superior to the MPSS. In terms of usable propellant weight, shroud- and tank-mounted systems are comparable, with the shroud-mounted system having a slight advantage with Dimplar, and the tank-mounted system having a slight advantage with NRC-2.

204. Twiss, S. B.
STRUCTURAL ADHESIVE BONDING. Adhesives Age, 7(12):26 – 21, Dec 1964, Part I – Adhesive Characteristics; 8(1):30 – 4, Part II – Adhesive Classification.

Examples of structural adhesives; review and summary of adhesive characteristics and properties; consideration of synthetic resins and rubbers and their combinations in blended formulations, as guide to adhesive selection for particular application. Pt. 2. Adhesive grouping by chemical types helps identify product characteristics, reduces testing, production problems, failure in service; classification simplifies structural adhesive selection and thereby reduces costs; materials include thermosetting and thermoplastic resins, and vulcanizable elastomers used in adhesives;

adhesive alloys, such as epoxies, epoxy-phenolics, -polyamides, -polysulfides, silicones, phenolic-neoprenes, -nitriles, -vinyls, and polyurethanes are described with their mechanical properties and applications.

205. Vaughan, W. L.
ELASTOMERIC ADHESIVES FOR AEROSPACE APPLICATIONS. SAMPE-7th Materials Symp., Adhesives & Elastomers for Environmental Extremes, May 1964, Sect. 9.

Cold chamber tests and results of testing of shear and tension of various elastomeric adhesives at temperatures ranging from -100 to 600° F; method of calculating tensile stress in heat shield due to temperature drop with relief of flexible adhesive is considered; silicone rubber system proved to be must optimum for conditions of -100 to 600° F.

206. Vicars, E. C.
POLYIMIDE AND POLYBENZIMIDAZOLE HONEYCOMB FOR ELEVATED TEMPERATURE APPLICATION. (Hexcel Products Incorporated, Berkeley, California.) AIAA/ASME Seventh Structures & Materials Conf., Apr 1960, pp. 267 – 273.

Increasing interest in glass reinforced materials for high temperatures structural applications can be clearly identified with the development of polyimide and polybenzimidazole resins. These materials allow a significant advance to be made in the employment of resins in those applications where strength with service at temperatures of about 550° to 600° F are important. In an Air Force supported program, a heat resistant honeycomb consisting of AF-R-100* polybenzimidazole resin and glass fabric reinforcement was fabricated to a nominal 6 lb per cu ft density. Stabilized flatwise compressive strength and modulus were determined in air at room temperature, at 500° F, 600° F, 700° F, 900° F, and at 1000° F after 1/3 hour and 1 hour at temperatures. Flatwise compressive strength and modulus were also measured on the material at 600° F after heat aging for 1, 10, 50, 100, 150, and 200 hours at 100° F in air. In addition, flatwise tensile strength was evaluated at room temperature on specimens heat aged 1, 10, 100, and 192 hours at 500° F, 550° F, and 600° F, respectively. The outstanding heat resistanceof this honeycomb was evident when compared with a commercially available, heat resistant, phenolic honeycomb tested under similar conditions. A program to assess the performance of polyimide honeycomb for periods of exposure of 0.5, 100, and 1000 hours is under way. Temperatures included in the study are room temperature, 400° F, 500° F, and 550° F. Property measurements include shear strength, shear modulus, compressive strength and compressive modulus.

207. Weikel, R. C.
STRUCTURAL ANALYSIS AND DESIGN OF A LARGE AREA SOLAR ARRAY. SAE Conf. Proc., Aerospace Systems Conference, Los Angeles, Calif., Jun 1967, pp. 184 – 196.

The problem of establishing the configuration and sizing of the primary structure of a large area solar array yielding 20 watts-per-pound is analyzed. The factors affecting the structural design and examined in this paper include:

1. Effects of launch environment,
2. Deploying and deployed phases of a typical mission,
3. The impact of ground support and test equipment upon the design, and
4. Fabrication problems affecting the structural design.

The analyses consider:

1. The dynamic and internal loads,
2. Temperature distributon and thermal control,
3. Selection of materials,
4. Weight distribution, and
5. Interface of the structural and electrical technologies.

It is found that the feasibility of design of a 20-watts-per-pound large area solar array is within the present state-of-the-art only if beryllium is used to transmit primary loads.

208. Yeager, Robert E. (LTV Aerospace Corp., Dallas, Tex.).
DEVELOPMENT OF ADHESIVE SYSTEMS FOR EXTREME ENVIRONMENTS. IN: Structural Adhesives Bonding; Symposium, Stevens Institute of Technology, Hoboken, N. J., 14 – 16 Sep 1965, Papers. [A67-22499 09-18]. Symposium sponsored by the U.S. Army. Edited by M. J Bodnar. New York, Interscience Publishers, Division of John Wiley and Sons, Inc. (Applied Polymer Symposia No. 3), 1966, pp. 369 – 395.

Commercial adhesive systems were examined for attachment utility in joining components designed to operate through extremely variable environments. Systems were conditioned by simulated reentry heating, lunar orbiting and heated space vacuum.

Strength evaluations were then conducted from -320 to 3000°F. Systems were evaluated for substructure bonding to solid ablators and to honeycomb. Adhesive attachment of ejectable nose caps was examined by experimental modifications of adhesives and processes to obtain thermal release characteristics of the bond. Structural adhesive attachments for front face caps of reentry vehicles were evaluated. Experiments involving formulations and processing variables were conducted to influence pyrolyzed char properties and structures derived from resin systems. Polymers, thus converted to pyrolyzed adhesives produced room temperature joint strengths exceeding the strength of the substrates after cycling to 2300°F.

209. Young, A. W.
ADHESIVES RISE TO NEW PLATEAU WITH BETTER MATERIALS, TEST. Iron Age, 196(14):102 – 5, 30 Sep 1965.

Developments in structural adhesives include easy-to-use polymers, technique for curing epoxy adhesives in place, and high heat resistant polybenzimidazole; design and surface preparation of joints with studs, variable-adhesive, and magnesium joints; testing strength of bonded components using pulse-echo reflection, pulsed-through transmission, and ultrasonic-resonance techniques.

210. Zelman, I. M.
DEVELOPMENT OF ORGANIC SEALANTS FOR APPLICATIONS AT CRYOGENIC TEMPERATURES. (Hughes Aircraft Company, Culver City, California.) Advances in Cryogenic Eng., Vol. 9: pp. 153 – 160, 1963.

The problem of sealing pressurized containers in cryogenic applications has been quite significant in the development of launch vehicles for space applications. Two basic concepts of sealing are involved: (1) seals, such as O-rings, lip seals, flat gaskets, etc., used in sealing joints of cryogenic storage containers and transfer systems, and (2) sealants applied by brush, spatula, or caulking gun, and cured in place for sealing skin portions of such containers as instrument and payload compartments, cryogenic tanks, and other related components of launch vehicles that will be exposed to cryogenic environments.

Work done here for the past two years has involved a program to develop such sealants for launch-vehicle use by NASA, Huntsville, Alabama. These sealants are required for use in manufacturing operations and in making field repairs that would otherwise be very expensive and time-consuming. Ideally, the sealants and seal-materials must retain a measure of flexibility or toughness at temperatures down to 20°K. However, materials of considerable utility will be developed if adhesion to metal substrates and resistance to bend loading and shock and vibration can be achieved at 76° K.

It is realized that even at this higher temperature, organic materials of this nature are below their glass transition temperature and their utility is dependent upon a lack of brittleness and high impact resistance below this transition. The problem, therefore, is to find a curable elastomer that will resist, as much as possible, bend stresses and shock and vibration loading without exhibiting brittle failure.

It is necessary, also, to make every effort to keep the loads imposed on the sealant to aminimum by:

1. Reducing large volume changes by having a sealant with no tendency for crystallization in the temperature range.
2. Matching the sealant's coefficient of contraction, within the temperature range, with that of the substrate.
3. roviding a method of load transfer in the compounded sealant through the use of reinforcing fillers.

Many types of elastomers were screened to determine their relative abilities to resist bending loads at 76°K. This screening consisted of bending a nominal 1/16-in.-thick coating of the sealant, on a strip of 0.032-in.-thick aluminum, around a 4-in.-diameter mandrel at 76° K. The aluminum surface was cleaned by etching in a crhomic acid solution, and the sealants were applied and cured. In some instances, a primer was used to promote adhesion.

A low-temperature flexibility apparatus, described in MIL-S-8516 and modified by the addition of insulated walls, was used to bend the coated aluminum strips around the 4-in.-diameter mandre. This is schematically shown in Fig. 1. The entire apparatus was cooled first with dry ice and then with liquid nitrogen. The specimens were then inserted and liquid nitrogen was allowed to flow over them for approximately one minute before testing.

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These 210 selected references were compiled by Lockheed Missiles & Space Company as a part of the Task I effort in support of contract NAS 2-4252, "Study of Attachment Methods for Advanced Spacecraft Thermal Control Materials." This bibliography includes abstracts from published papers and reports which relate to thermal design parameters as well as attachment techniques for the two thermal control materials. It is anticipated that this compilation will be of some assistance to the systems and thermal designers. The analysis of candidate attachment techniques in relation to their applicability to a specific design, operating in the 200° to 700°K temperature range, are given in the Phase I Summary Report for this contract.

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