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DESIGN STUDIES AND PROTOTYPE FABRICATION

OF

LUNAR SAMPLE CONTAINERS

December, 1965

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Prepared under Contract NAS 9-4338

by

RALPH STONE AND COMPANY, INC.
ENGINEERS
Los Angeles, California

FOREWORD

The work reported herein was performed for the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas, under Contract NAS 9-4338. The contract authorized a six-month study commencing May 22, 1965, for continuing work in lunar geologic and biologic sample acquisition, packaging and return. The study was conducted under the cognizance of the Lunar Sample Receiving Laboratory with Donald A. Flory serving as the NASA Technical Representative.

Acknowledgement is extended to members of the Early Apollo Sciences Teams who contributed time and advice, including Drs. Clifford Frondel, James R. Arnold, P. R. Bell, A. J. Tousimis, and Klaus Bieman.

All work on the contract was performed under the overall cognizance of Ralph Stone, President. Directly assisting the contractor's staff on the details of the study were Drs. Gregory Jann, (bacteriology), John C. Simons, Jr., (vacuum technology), and Lewis D. Felton, (structures and dynamics). Members of the contractor's staff assigned to the work were E. T. Conrad, D. A. Link, and H. J. Steinberg. J. A. Borges, Jr., M. S. Israel, H. F. Newman, and A. W. Dickinson, Jr., Senior Staff Engineers, were also assigned to perform specialized phases of the study. E. A. Webster directed the program and served as Project Manager.

Subcontractors included Ardel, Inc., Glendale, California, and Rohr Corporation, Chula Vista, California.

RALPH STONE AND COMPANY, INC.
ENGINEERS

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OF
LUNAR SAMPLE CONTAINERS

RALPH STONE AND COMPANY, INC.
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SUMMARY

The prior study contract, reported in NASA document CR65000, established basic objectives and constraints for the sample return container program. Particular emphasis was placed during the study phase on scientific mission requirements, working within applicable mission-oriented definitions of physical and climatic environments supplied by NASA, including astronaut limitations and spacecraft interfaces.

The current work emphasized design optimization of the sample box. Detailed evaluations were completed on such phases as structural and fabrication techniques, cover and latching systems, handle configurations and seal designs, as well as a review and design study of the sample protection system, inner containers and a bag dispensing system.

The study also encompassed fabrication of four mockups of the sample return box and internal canister arrangement, showing progressive design improvements as the program matured. In addition, two prototype boxes were fabricated to permit tests and evaluations by NASA of the various design concepts finalized during the current phase of work.

The sample box designs now call for a stainless steel honeycomb parallelepiped, approximately 7 1/4 by 11 by 18 3/4 in., having a full-opening 11 x 18 3/4 in. lid. Access to the vacuum-sealed box on the lunar surface will be accomplished by pulling a cable through the ductile nickel membrane seal. The return or transearth seal is a unique indium-solder design permitting zero leakage and requiring little effort on the part of the astronaut.

The outside of the box is coated with white zinc-oxide for passive thermal control, while the inside is selectively fluorocarbon-coated to prevent metal to metal contact. The inside of the box is filled with open-topped canisters approximately 2 1/2 in. square which can be removed as required to accommodate any desired sample configuration. With the canisters in place, optimum protection is provided for individual samples.

Rock samples will first be packaged in flexible laminated metal foil bags, which are packed into the canisters by the astronaut. A bag dispensing device is proposed for opening, closing, and sealing without intermediate handling by the astronaut. The device consists essentially of a clean bag storage cylinder, guide rails and seal crush-rollers mounted with a pistol grip configuration. Being battery-operated all functions except filling occur automatically on a single trigger squeeze.

The proposed inner container intended for gas sampling is a polished stainless steel cylinder utilizing an indium crush gasket. Access for the analyzer sensing probe is through a port sealed by a foil rupture diaphragm.

The proposed protobiological sampling device is a double-barreled pointed probe designed to obtain samples from 6 to 18 in. beneath the lunar surface. Sample material is acquired in a specially designed telescoping cartridge which is capped and returned to a storage container without exposure to astronaut- or surface-originated contaminants.

Throughout the design and fabrication phases coordination was maintained with leading members of the Early Apollo Sciences Teams, as well as experts at NASA-MSC and various manufacturers of special materials and equipment.

INTRODUCTION

The sample return program encompasses various packaging techniques and equipment required to preserve lunar surface material until ready for processing in the Lunar Sample Receiving Laboratory. Guidelines for a protection system were evolved in mid 1964, when packaging of geologic samples in flexible bags, preservation of special purpose specimens in small, rigid inner containers, and storage of all sample-containing units within a rigid, drawer-like sample box aboard the LEM were proposed.

The first study contract on lunar sampling and sample return methods was completed in March 1965. The study described more specifically certain design recommendations for maintaining minimum container weight, controlling contamination sources, optimizing sample protection, and minimizing demands on the astronaut throughout the acquisition and packaging activities. The current contract extended the prior activities to include detailed engineering and prototype fabrication of certain specific items of container hardware. Details of the work performed under the present phase of the contract are presented in six technical sections, the contents of which are as follows:

PART I: PROGRAM OBJECTIVES. - This section describes the scope of the current program and includes a tabulation of specific design criteria and constraints applicable to the sample box and inner container hardware.

PART II: SAMPLE BOX DESIGN STUDIES. - Overall design features of the sample box are summarized, including size and shape, cover and fastener design, mounting provisions, pin retraction and handle mechanisms, temperature, pressure and weight instrumentation, and receiving station interface considerations.

PART III: STRUCTURAL DESIGN STUDIES. - A synopsis is presented of the design approach for materials selection, wall and framing structural design, and weight optimization. Dynamic and static considerations are also reviewed with respect to box mounting provisions.

PART IV: SEAL SELECTION. - Various candidate seals are analyzed, ranging from elastomers and crush gaskets to the indium-solder concept. A comparison is presented between the seal concepts and the mission design goals, together with a description of problem areas to be evaluated during prototype tests.

PART V: PACKAGING STUDIES AND SPECIAL PURPOSE INNER CONTAINERS. - The basic packaging and special container studies are reviewed, including the canister concept for sample protection, the flexible inner bags for packaging rock samples, metal cylinders proposed for samples to be used for gas analysis, and the protobiological sampling system. The section also summarizes the problems of maintaining sufficient packaging flexibility to accommodate a wide range of possible sample types, and methods are proposed for minimizing dependence upon the astronaut's limited time and dexterity for dispensing sample bags and obtaining aseptic subsurface samples.

PART VI: PROTOTYPE HARDWARE FABRICATION. - Fabrication methods and techniques for the two prototype boxes are discussed including details on wall and framing configurations, joining techniques, and seal hardware.

Appendices include structural calculations, a summary of the comments of the scientific community relative to box and packaging requirements, test results and a bibliography. A Drawing Supplement is provided under separate cover containing reduced scale reproductions of pertinent prototype hardware designs, as well as a List of Materials.

RECOMMENDATIONS

Test Program

Comprehensive test procedures should be defined to evaluate the prototype hardware fabricated during the current work. The intent of the initial series of tests should be to determine the suitability of the proposed hardware in terms of mission requirements. Subsequent review and coordination with the scientific community are recommended to verify design judgment in areas of specific experimental interest.

While not a formal qualification series, the evaluations should be designed to uncover physical deficiencies quickly and efficiently by concentrating on those areas of traditional weakness or greatest susceptibility to failure. A summary of the recommended test program follows.

Seal, return. - The seal test program should define the criteria and test instrumentation for evaluating leakage throughout the functional environments expected during the mission.

Specifically, the studies to be completed in a 10^{-5} torr or lower vacuum environment should include susceptibility of the seal to contamination and the effectiveness of the protective fluorocarbon shields, the melting temperature, the time required for heating and cooling the indium, the heater wattage required, the effectiveness of the indicator light to determine the indium melting point, the suitable time lag established before shutting off the power source. Since penetrations are not provided on the as-delivered prototypes, suitable instrumentation must be specified and adapted to the test unit. The possibility of using radioactive gas as a means of leak detection should also be evaluated.

Seal, outbound. - Similar instrumentation and techniques devised for the return seal study program should be adapted to test the leakage characteristics during the outbound mission profile. In addition, further tests are needed to determine the susceptibility of the cover to cold welding during long storage periods, the ease of removal of the outbound tear-away seal under high vacuum, and the probability of seal rupture and failure due to accidental rough handling.

Structural tests. - Uniform 14. 7 psi atmospheric loading will provide 3/4 of design load for static structural evaluations. Structural design verification tests include determinations of wall and cover deflections in a hyper-baric chamber at 20 psi differential pressure.

Dynamic tests should be performed if possible with the boxes mounted in the same frame configuration as will be used in the LEM and Command Module. Tests to specification dynamic environments should be performed on the empty and loaded box in both the outbound and inbound seal configurations. Such evaluations should include individual samples packaged in flexible bags to study wear and abrasion characteristics.

<u>LEM interface.</u> - Tests in thermal vacuum equipment at the time the LEM prototype is evaluated would be useful in determining ease of installation and handling characteristics on the loaded and unloaded box.

<u>Human factors.</u> - An evaluation of the outbound box configuration should be accomplished to study the effectiveness of the tear-away seal and the outbound cover spacer. In addition, the handle and pin retraction system should be tested by space suit technicians, together with cover handling and latching characteristics.

Additional Designs and Fabrication

<u>Weight-optimized prototype.</u> - Current calculations indicate up to eight pounds of additional samples can be returned by utilizing advanced concepts evolved as a result of this study. Final designs and selection of materials for such a weight-optimized prototype should be commenced immediately. Design improvements, if any, evolved during structural tests of the current prototypes should be included on this unit for study prior to releasing proof hardware for fabrication.

<u>Manufacturing specifications.</u> - Following design verification tests on the current and weight-optimized prototypes, manufacturing specifications delineating materials, dimensions, assembly and cleaning techniques should be prepared for the fabrication of proof hardware.

<u>Protobiological sample container and dispenser.</u> - Designs should be completed for a protobiological sampling system to obtain asceptic samples from between 6 and 18 in. below the lunar surface. Mockups would be helpful in obtaining early design evaluation and approval by MSC and advisers in the Early Apollo Sciences Teams. Prototype hardware should be fabricated illustrating design characteristics and permitting full evaluation of the physical and aseptic characteristics of the sampling dispenser and containers.

<u>Gas sampling container.</u> - Current recommendations for the container to be used for gas analysis should be analyzed and mockups prepared for MSC evaluation. Prototypes should be fabricated at an early date to permit detailed evaluations by scientific advisers.

Drive tube. - A simple device for obtaining surface samples, consisting of a cartridge-like cylinder driven by foot into the lunar surface, should be studied and design recommendations evolved for consideration by MSC.

Packaging tools. - Current design analyses should be completed and a mockup of a packaging tool for use with flexible bags prepared. The device should be designed to minimize the astronaut's activity by semi-automatically (1) dispensing open sample bags, (2) positioning the bags for easy filling, and (3) sealing after filling.

Flexible bags. - Flexible bags compatible with the packaging tool equipment should be designed and prototypes fabricated in 1, 3, and 7 in. diameter sizes.

PART I

PROGRAM OBJECTIVES

INTRODUCTION

The purpose of the Lunar Sample Container Program is to integrate the needs of the scientific community with Apollo mission objectives and constraints to produce optimum designs for the return of lunar samples.

In general, the consensus of scientific requirements centered on the return of the maximum possible payload, packaged in such a manner as to minimize physical damage and contamination. Fabrication of the boxes from materials of known and suitable chemical composition was considered essential to ensure accurate differentiation between samples and packaging trace contamination during post-mission analysis and study programs.

Mission-oriented design requirements included: (1) configuration, weight, and mounting interface constraints; (2) pre-launch, Command Module, LEM, and lunar climatic environments; (3) functional environments such as vibration and shock; (4) astronaut mobility, dexterity and time limitations; and (5) pre- and post-mission isolation and sterilization precautions.

Work under this phase of the program followed the completion of basic feasibility studies and was broadened to include special purpose container designs, studies of problems in seal and structural optimization, and manufacturing techniques, tentatively identified in the initial investigations.

PRIOR WORK

The initial study contract produced the basic criteria for sample container design, including the outer container, flexible inner bags for geologic samples, and special purpose inner containers intended for scientific experiments such as gas analysis and biological investigations.

The study also analyzed the practical impact of the extremely low contamination levels demanded by scientific constraints and the extent of these limitations on the choice of container materials and as-manufactured cleanliness. The problems of protecting against contamination of the sample and packaging systems due to external sources such as descent engine effluent, astronaut outgassing and the transearth environments of the LEM and Command Module were reviewed. The results of that study were published in April, 1965, under the title "Investigations of Lunar Sampling and Sample Return Methods," NASA Document CR65000.

CURRENT WORK

To minimize confusion in the report due to terminology, the technical presentation will refer to the large outer sample return containers as "boxes," the inner packaging modules described in Part V as "canisters," the flexible containers as "bags," and the special purpose gas and protobiological sample containers as "inner containers."

Work Performed

The principal objectives of the current study were to optimize seal and structural designs for the overall sample return system and to fabricate two prototypes of the large, vacuum-sealed sample boxes. Concurrent with this work was further study to define designs for (1) weight, temperature, and pressure monitors, (2) bag dispensing techniques, (3) a gas sampling inner container, and (4) a protobiological sample inner container.

Additionally, overall design support was provided in the area of manufacturing technology, as well as interface coordination with scientific experimenters and Early Apollo Sciences Team members.

Design Goals

Guidelines for the design and selection of prototype hardware were derived from applicable NASA specifications and scientific requirements. The objectives, grouped and tabulated according to major study areas, are defined in Table I.

TABLE I

Item	Design Objectives
1. Maximum Unloaded Container Weight	11.5 pounds, as defined in Grumman ICD LTS-360-22102.
2. Maximum Loaded Container Weight	50 pounds, per above reference.
3. Maximum Container Size	As defined by LEM, C/M interface drawings, Grumman LID 360-22802, NAA MH01-12001-116.
4. Apollo Engineering Materials Constraints	Materials to be compatible with Grumman ICD LIS-360-22101 or approved exception.
5. Structural Integrity	Samples to be retained but vacuum may fail under 78 g impact. Hold vacuum under random vibration.
6. Sample Packaging Materials	To be compatible in all respects with scientific requirements, as well as Grumman ICD LIS-360-22101 or approved exceptions.
7. Miscellaneous Environmental Specification Compliance	Per NASA General Working Paper No. 10,030, "Environmental Specifications for Apollo Scientific Equipment," dated August 11, 1964.
8. Environmental Compatibility	All parts and materials to retain their essential functions and properties in the lunar environment.
9. Thermal Range	$-64^{\circ}F$ to $+187^{\circ}F$.
10. Passive Thermal Control	$150^{\circ}F$ maximum.
11. Lunar Vacuum	10^{-10} torr.
12. Passive Vacuum Retention	10^{-5} torr.
13. Seal Redundancy	Secondary seal to prevent gross contamination and retain vacuum integrity to 10^{-2} torr.

TABLE I - Concluded

Item	Design Objectives
14. Pre-Mission Vacuum Preparation	Following solvent wash and normal vacuum vessel cleaning, box internal materials to be baked 96 hours, 250°F under 10^{-9} torr vacuum to minimize further outgassing. Follow with electron brushing.
15. Pre- and Post-Mission Sterilization	Materials and configurations to be compatible with methods of sterilization selected for post-mission handling. In general, pre- and post-mission high temperature bake to be limited to 250°F.
16. Crew Requirements	Handles, latches, seal caps, packaging, and stowage equipment to be readily operable by gloved astronauts as designated by MSC Crew Systems personnel.
17. Packaging Flexibility	Design to be fully adaptable size, configuration and degree of protection to range of materials likely to be found on lunar surface.
18. Sample Damage Protection	To be designed for 78 g impact, plus random vibration per Apollo mission requirements.
19. Lunar Materials Effects	Seals, mating and sliding surfaces to be protected from or insensitive to lunar dust or debris.
20. Contamination	Box and packaging of lunar samples to provide control of contamination from foreign compounds or organisms, whether of lunar or non-lunar origin.

PART II

SAMPLE BOX DESIGN STUDIES

INTRODUCTION

The configuration and maximum size of the envelope in which the sample boxes are transported within the spacecraft were defined to the Contractor by Command Module and LEM interface drawings, together with the general method of attachment and the location of the box-to-structure mounting points. The objective of the configuration study was to place an optimum payload within these envelope constraints consistent with the scientific and mission objectives described in Part I.

Descriptions of overall design features only are included in Part II. Specialized structural implications of various alternate configurations are described in Part III, "Structural Design," while the development of final designs for the vacuum seal are described in Part IV, "Seal Selection." The design of special purpose inner containers and the management of internal box space for sample protection are included in Part V, "Packaging Studies and Special Purpose Inner Containers."

SIZE AND SHAPE

Table II summarizes clearances, overall dimensions, and volume utilization. It will be noted that additional clearance allowances over the minimum specified on the interface drawings have been provided. One reason for this is to permit shock mounts to be evaluated on the prototypes, if comprehensive dynamic testing proves them to be needed. Full utilization of the allowable envelope for box structure would have precluded this degree of testing flexibility, and should the shock mounts prove not to be required, the volume may be added to the proof hardware boxes without jeopardizing the usefulness of present test hardware.

The second reason for retaining the extra clearance was to allow more flexibility in the choice of certain peripheral hardware such as electrical or instrumentation connectors, the vacuum probe penetration, outbound welded

TABLE II

DIMENSIONAL SUMMARY

No.	Item	Box Dimension Requirements, Inches A Ship's Structure (C/M)	B Permissible Box Envelope	C Current Box Dimensions	D Shock Mount Clearances
1.	Width	19.160	19.00	18.91	0.250 (1)
2.	Height	8.160	8.00	7.41	0.750 (2)
3.	Depth	11.600	11.50	11.45	0.150 (3)

(1) Clearance divided equally on both sides, 0.125 per side.
(2) Height clearance divided 0.250 above, 0.500 below box.
(3) Depth clearance divided 0.130 to the rear of the box, 0.020 front clearance behind flush edge of structure.

		External and Internal Volumes, Cubic Inches	Current Prototype	Weight-Optimized Prototype	Weight-Optimized Prototype with Min. Clearance
4.	(E)	Total volume, ship's storage compartment, (dimensions from column A, above)........	1814	1814	1814
5.	(F)	External volume of maximum permissible box (dimensions from column B, above)........	1748	1748	1748
6.	(G)	External volume of box as designed	1604	1604	1748 (4)
7.	(H)	Gross internal volume of box as fabricated ...	1299	1349	1482
8.	(I)	Useful internal volume of canisters	1243	1293	1426

(4) Assuming shock mounts not required.

TABLE II - Concluded

DIMENSIONAL SUMMARY

No.	Item	Volume Utilization, Cubic Inches	Current Prototype	Weight-Optimized Prototype	Weight-Optimized Prototype with Min. Clearance
9.		Specification clearances, (E-F)	66	66	66
10.		Additional clearances for possible future shock mount deflections and external hardware, (F-G)	144	144	-
11.		Volume of box walls, (G-H)	275	225	236
12.		Handle and latch protrusions	30	30	30
13.		Volume lost in canister walls and clearances	56	56	56
14.		Useful volume	1243	1293	1426
15.		TOTAL VOLUME, $in.^3$	1814	1814	1814

exterior seals, tethers, or other protrusions. In addition, the 0.5 in. bottom clearance provides a potentially useful storage space for a collapsible sunshade, weighing stand, or other hardware currently under consideration but not yet defined. The inclusion of these parts within the box would in part defeat cleanliness objectives by requiring the outbound seal to be broken early in the mission and might necessitate a revision in the internal sample protection canister scheme to make room for non-modular items.

GUIDES AND SELF-CENTERING PINS

Fluorocarbon guide rails 0.420 in. high are provided to bring the mounting pins to within normal self-centering distance of the holes. Should it be desired to use flexible shock isolation in place of the current mounts, other suitable guide members will be provided. Alternatively , if the space is not required for deflection clearance or hardware storage, the final box dimension will be enlarged and thin (0.010 in.) fluorocarbon strip runners will replace the 0.420 in. rails.

Centering rails are not required for the 0.125 in. side clearances, since the end taper on the mounting pins is sufficient to accommodate the maximum sideways positioning dimension.

COVER

Configuration

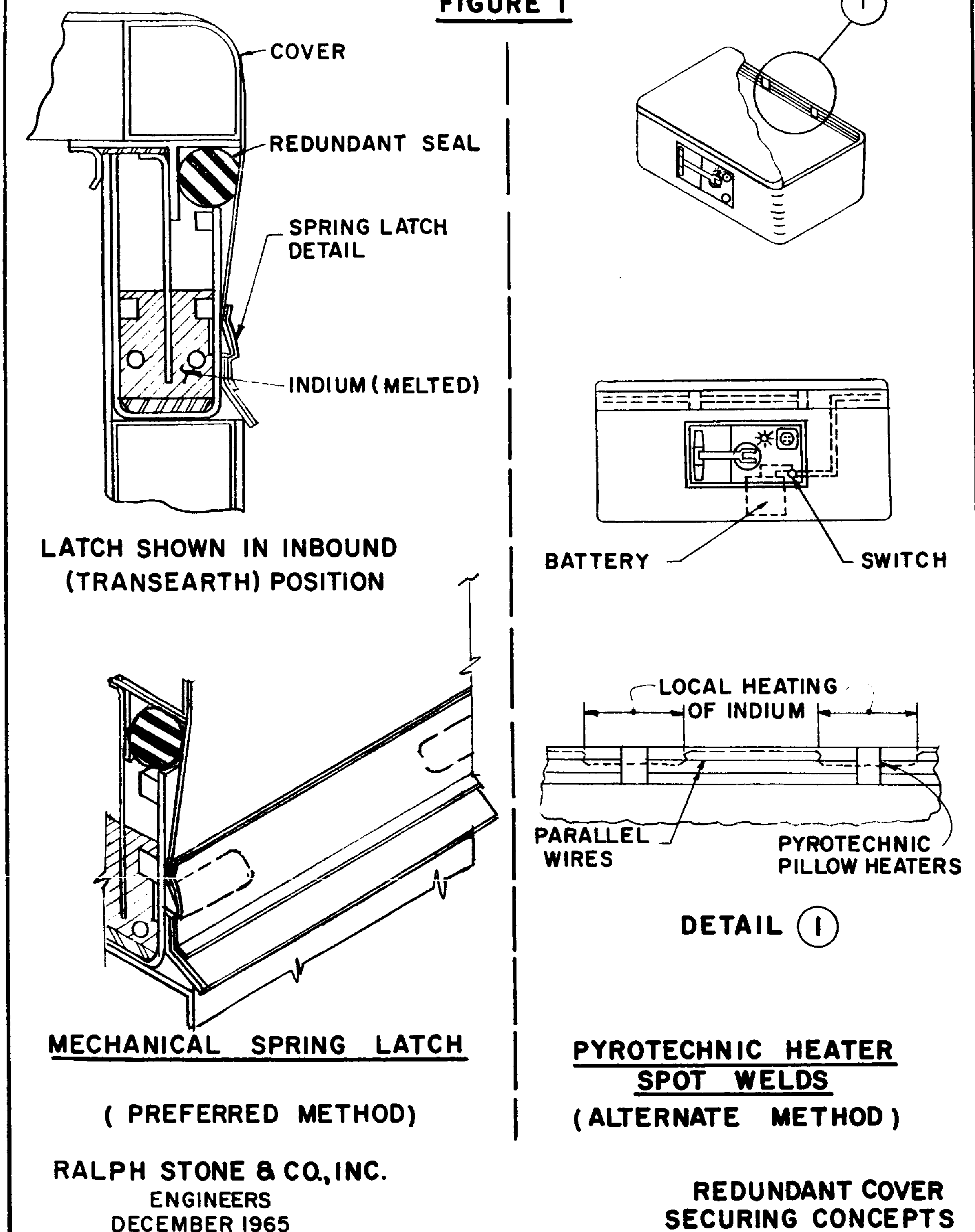
Recommendations from the previous study for a circular or oval-shaped lid were based on anticipated difficulties in providing a reliable seal, particularly if high unit loading crush-gaskets were to be used. The indium-solder seal concept described in Part IV made it possible to reconsider the cover design, resulting in a full-opening plate concept. The seal design, being self-centering and relatively uncritical dimensionally, eliminated the requirement for a hinge or articulated cover swing mechanism. During the first mockup design review, preference was shown by NASA-MSC for an unhinged lid, possibly using a tether between cover and body.

Redundant Fasteners

Nearly 700 lb force is exerted on the top of the box lid by the gas pressure in the Command Module.

However, in the event the two heater elements fail to melt the indium, redundant latches (see Fig. 1) are provided to hold the lid in place and to

FIGURE 1



REDUNDANT COVER SECURING CONCEPTS

allow the secondary elastomeric seal to function while the box is returned to the LEM and later transferred to the Command Module.

The redundant fasteners also provide additional structural protection to the indium seal, preventing the edges of the lid from rotating due to static loads. By preventing edge rotation, lid deflection is also minimized.

An alternate system which was considered but later rejected for structural reasons consisted of a series of pyrotechnic "pillows." These units were intended to spot-weld the indium at six locations around the seal perimeter in the event the heaters failed to function (see Fig. 1). The pillows would be fabricated of welded stainless steel hollow wafers, approximately 0.2 in. by 0.2 in. to retain all products of the exothermal reaction. The pyrotechnics would be activated simultaneously by closing the initiating circuit with a panel-mounted switch connected to a small, separate battery stored in the limited-use space beneath the handle well in the front of the box.

Box Level Indication

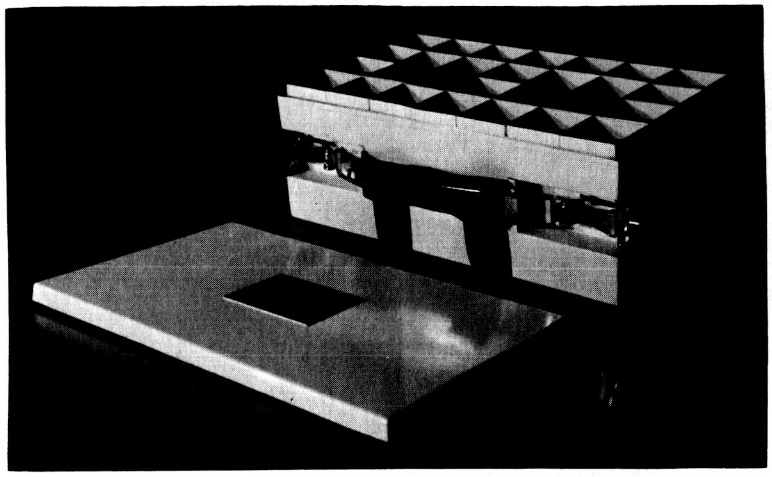
To seal the cover to the box, the indium in the seal gland must be heated to slightly above its melting point and allowed to freeze. To make certain that the indium height remains reasonably constant over the length of the seal gland, it will be necessary to level the box. This can be done by placing one of the astronaut's hand tools, equipped with a level, on the flat provided for that purpose in the center of the cover and adjusting the container orientation as required.

PIN RETRACTION AND HANDLE MECHANISMS

Preliminary Designs

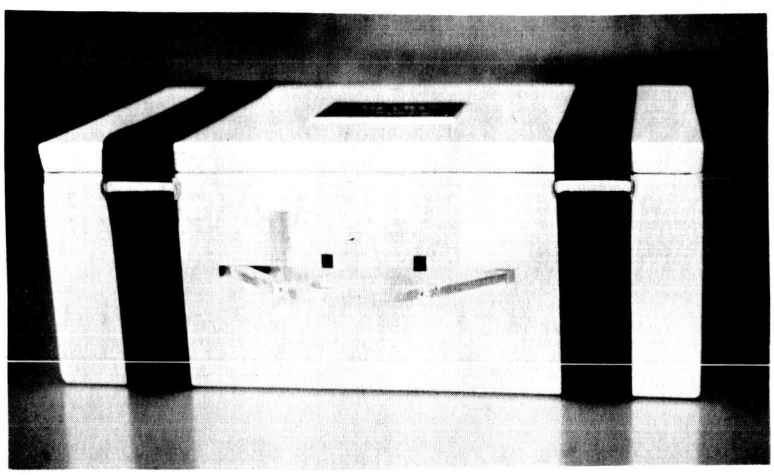
The principal constraints on handle designs were that it be (1) stowed flush with the surface of the box and (2) readily accessible and correctly sized for the heavily glove astronaut. The first designs submitted for mockup review utilized soft fabric for the handle and separate latches on either side of the box to retract the front mounting pins (see Fig. 2). While the strap was of minimal weight and volume, its flexibility detracted from the astronaut's ability to manipulate and steer the box. The latches, while efficient and easy to actuate, required two large wells for finger access and made it necessary for the astronaut to shift his hand from one side to the other when removing or storing the box.

FIGURE 2



INITIAL MOCK-UP

FIGURE 3



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DECEMBER 1965

MOCK-UP OF STRAIGHT-PULL HANDLE AND PIN RETRACTION SYSTEM

The second unit (see Fig. 3) submitted for evaluation was a straight-pull handle which retracted the two front mounting pins when extended from the "stowed" to the "carry" position. While being an improvement of the two-latch concept in terms of volume use and astronaut handling, locking characteristics were considered deficient.

Final Design

The combination 90° rotation handle and pin retraction assembly shown in Fig. 4 was efficient from a volume and weight standpoint, had positive latching characteristics, provided more positive feel for carrying and steering, and had better handle access than either of the previous designs.

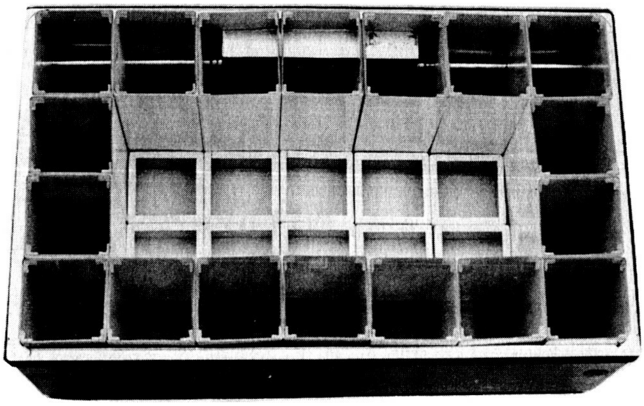
To ensure positive latching, each of the handle positions is fully detented, requiring the handle to be depressed against a positive spring load before rotating from the "latch" to the "carry" position. In the "carry" position the weight of the box aids the spring load in holding the handle in detent, preventing inadvertent rotation while maneuvering. Construction and manufacturing details of the latch assembly are presented in the Drawing Supplement.

THERMAL CONTROL

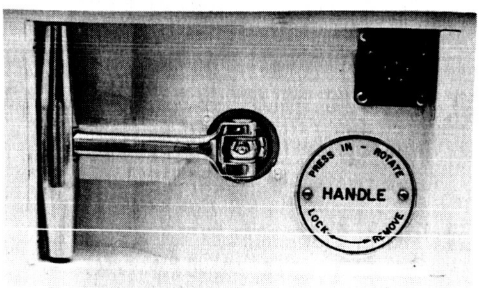
The optimum thermal control is a passive coating which would be used to maintain the box at an equilibrium temperature of 120-150°F when exposed to sunlight. However, even with reflectivity factors of .9 and higher, the box temperature is expected to exceed 150°F over a period of several hours. Additional polishing to improve the thermal balance was considered, but the resultant glare would make the box difficult to use while handling and packaging samples. In addition, the thermal coating efficiency may be expected to degrade noticeably due to deposition of layers of lunar dust, making its effectiveness doubtful.

An alternate solution which could be used in addition to coating is to provide a collapsible or inflatable sunshade. Either concept might be combined with a stand containing a weighing device.

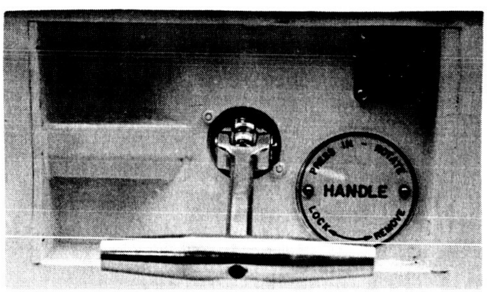
FIGURE 4



INTERIOR VIEW SHOWING CENTER CANISTERS REMOVED



HANDLE IN STORED POSITION



CARRYING POSITION
(MOUNTING PINS RETRACTED)

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FINAL MOCK - UP

INSTRUMENTATION

Seal Melt Indicator

A simple means of determining when the indium-solder seal has melted (reference Part IV, "Seal Designs") is to use the melted indium to complete an electrical circuit. The schematic of this system consists of a 250 milliampere light on the front handle well, wired in series to a suitable battery and with two open junctions five inches apart in the indium seal well. The ends of the open junction wires are inserted in small cavities within the indium and protected from shorting by insulated spacers, until submerged by the melted indium. No other switch or circuit component is required, the light remaining on until the battery burns out.

Temperature Indicator

The primary design objective for temperature indication was to provide a readout instrument on the surface of the box to show the average temperature of the payload space. Various mechanical schemes such as bi-metallic elements proved impractical because of lack of sensitivity and because they were difficult to position in areas indicating sample payload temperature, rather than that of the conducting walls near the element. Various self-contained thermocouple devices were evaluated but were rejected primarily because the readout indicators were too large and heavy. In addition, the sophistication of the equipment greatly exceeded the requirement for an average, gross indication of the equilibrium temperature of the payload.

Several alternate solutions were considered. One, thermal indicating paint, could be applied at various points to the outside of the boxes to indicate gross maximum temperature at such locations. A second alternative was to install several permanent thermocouple junctions within the payload space, connected through a penetration to a plug in the front of the box. Meaningful data could then be obtained by the use of recording instruments, either during the mission or upon return to earth. Finally, sample temperature could be determined on the lunar surface by the astronaut with a portable sensor, indexing samples to specific bag numbers by voice recording.

Pressure Indicator

At the present time there is no requirement to instrument the boxes for hard vacuum pressure indication. However, it would be useful to have a means of determining if gas pressure were increasing, whether from seal failure or sublimation of samples. A most promising design for gross pressure indication employs a metallic bellows which flexes with pressure changes and extends a direct-connected red-tipped probe 1/8 in. from the face of the recessed handle well. In the event the internal pressure should exceed by 1 psi the external pressure on the box, a pointed extension on the bellows would rupture a thin metal diaphragm.

Weight Measurement

The maximum weight permitted in either box by LEM and Command Module interface specifications is 50 lb, while the maximum for both boxes together is 70 lb. Thus, a simple go, no-go weight indicator is insufficient, and a reasonably accurate (± 2%) scale must be provided.

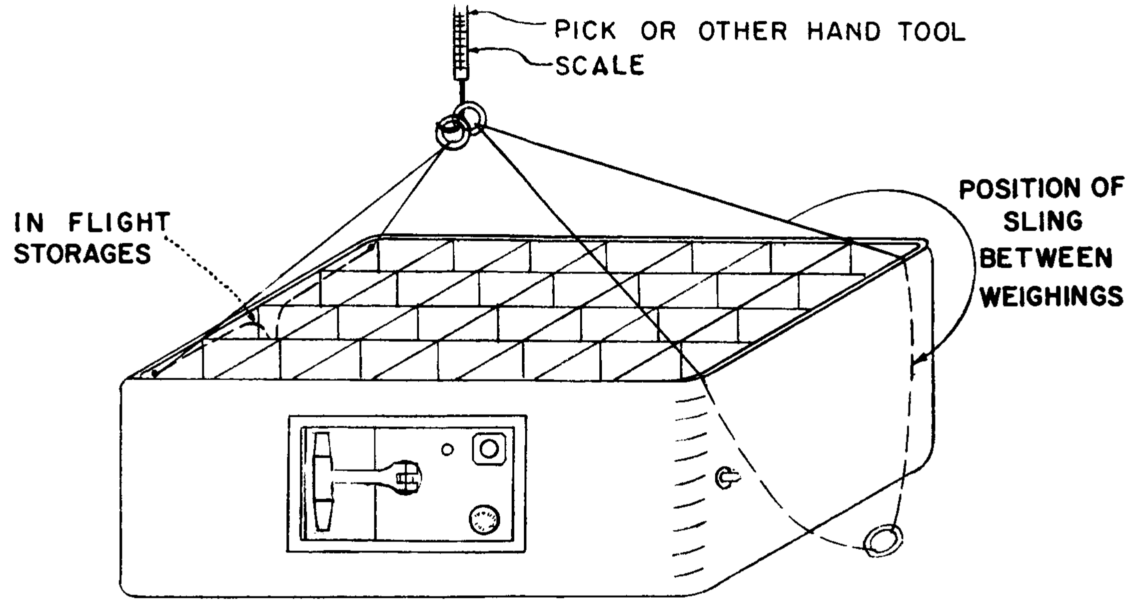
Building the weight indicator into the box handle is feasible from a design standpoint, and would require very little added weight. However, because the samples would have to be secured from falling out as suggested by the alternative shown in Fig. 5, other techniques are being explored. For instance, a separate NASA contract to develop hand tools includes investigating means of weighing individual samples. The same device might be adaptable to weighing the entire sample container in its loading orientation by use of the sling concept illustrated in Fig. 5.

RECEIVING STATION INTERFACE CONSIDERATIONS

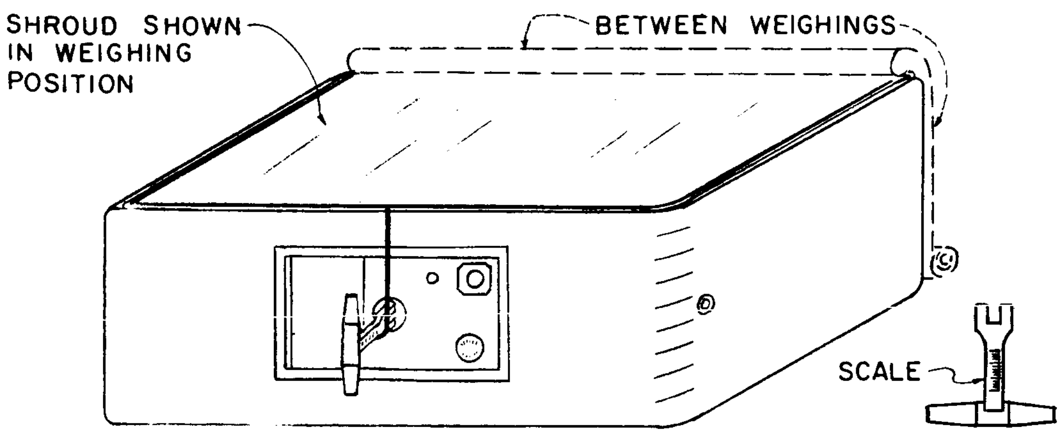
Final Pre-mission Cleaning and Outgassing

An intermediate sized vacuum chamber five to six feet in diameter should be equipped with an infrared array designed to apply even, controlled heat to the inner surfaces of the box, the seal cavity, and the individual canisters. The handling assembly should be designed so that the aluminum canisters can be baked at approximately 450°F, while the box itself should be maintained below 200°F so as not to induce permanent changes in the shape of various fluorocarbon bearing assemblies. It is recommended that, if possible, pressures lower than 1×10^{-9} torr be maintained during this period. When gas load sensing instrumentation has indicated that sufficient pumping has been done to have cleaned the surfaces (estimated to be ten to fourteen days), the canisters should be placed within the box and the lid positioned for welding of the outbound seal without removing any of the parts from the vacuum.

FIGURE 5



WEIGHING SLING
USING HAND-HELD SCALE



HANDLE SCALE

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ALTERNATE WEIGHING CONCEPTS

Outbound Seal Installation

As described in Part IV, the indium-solder seal will be used only for the return flight. The outbound seal will be a thin strip of metal between the body and lid which will be sheared on the moon with the aid of a thin cable and ring (see Fig. 6). The metallic shear strip must be electron-beam welded in a special holding fixture in the aforementioned vacuum chamber. Since this procedure will produce the final closure of the container, the degree of vacuum and cleanliness achieved will largely be determined by the quality of the vacuum equipment and chamber in which the seal welding is accomplished. The protective elastomeric cover assembly used to prevent sharp edges from being exposed can be installed at any time prior to launch.

Sterilization

Many concepts for solving the complicated sterilization problems have been investigated. One step toward pre-sterilizing the interior of the assembly will have been accomplished in the hard vacuum bake-out procedure described in the paragraph on pre-mission cleaning. Following the handling and check-out of the box after welding, final pre-mission sterilization will be accomplished with a combination of procedures to be determined by NASA. To aid in reaching internal cavities in the pin retract mechanism and mounting holes, a system of small diameter tubes manifolded to a single fitting in the front of the box is recommended to permit liquid or gaseous disinfectants to be utilized. Following the use of such procedures, boil-off of residual disinfectants should be accomplished under protracted mild heat and vacuum (8 hours, 150°F, 10^{-6} torr). Similar problems exist in handling the boxes at the completion of the mission, except that biological contamination will be minimized by the use of remote manipulators. The complete sterilization process, including connection to the suggested manifold fitting, must be accomplished by remote means. (Reference Fig. 7)

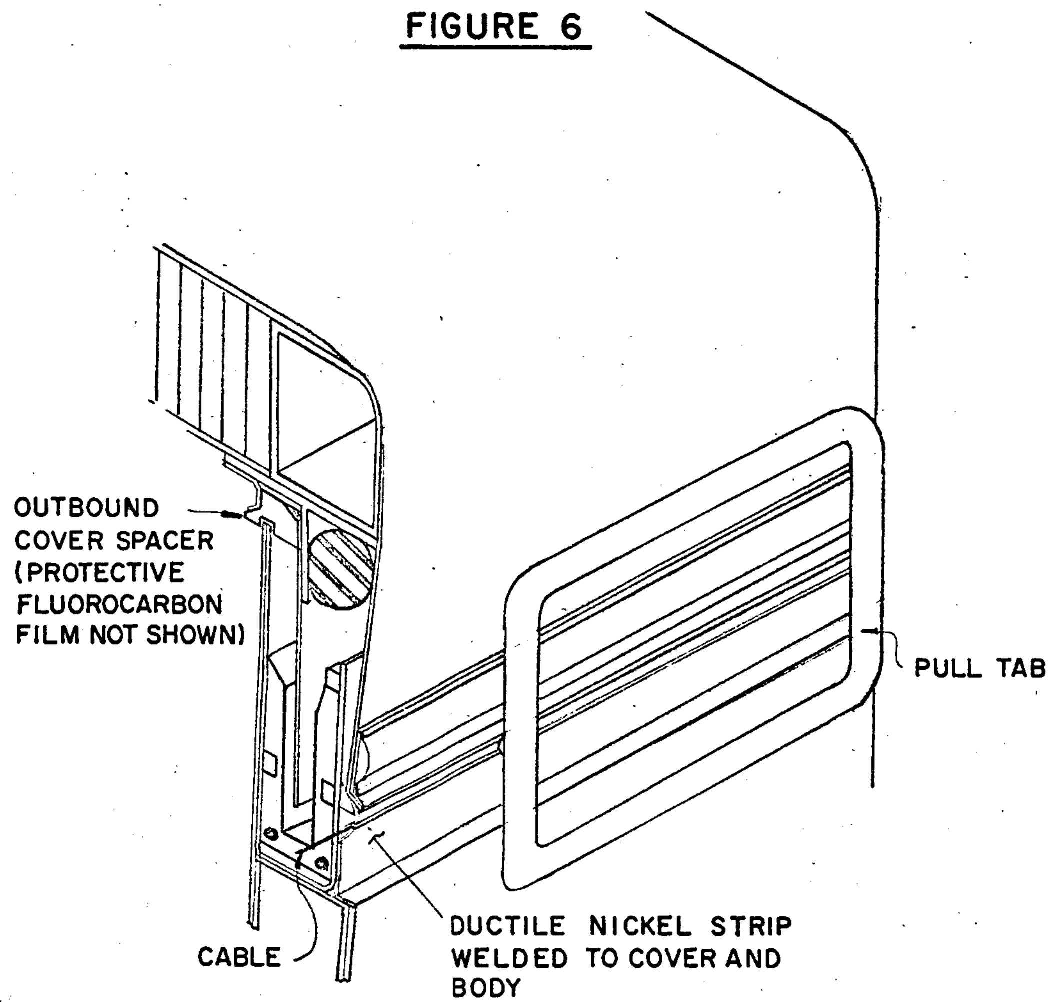
Gas Sampling

A gas sampling port will, when defined by NASA, be provided in the front of the box. A pointed probe will be inserted into the port to rupture a thin metal diaphragm prior to opening the box lid at the receiving station laboratory.

Unsealing

The indium-solder seal simplifies the problem of lid removal, since the same electrical connection used for sealing on the lunar surface can be utilized to reheat the indium. Should this circuit fail, a secondary heater

FIGURE 6



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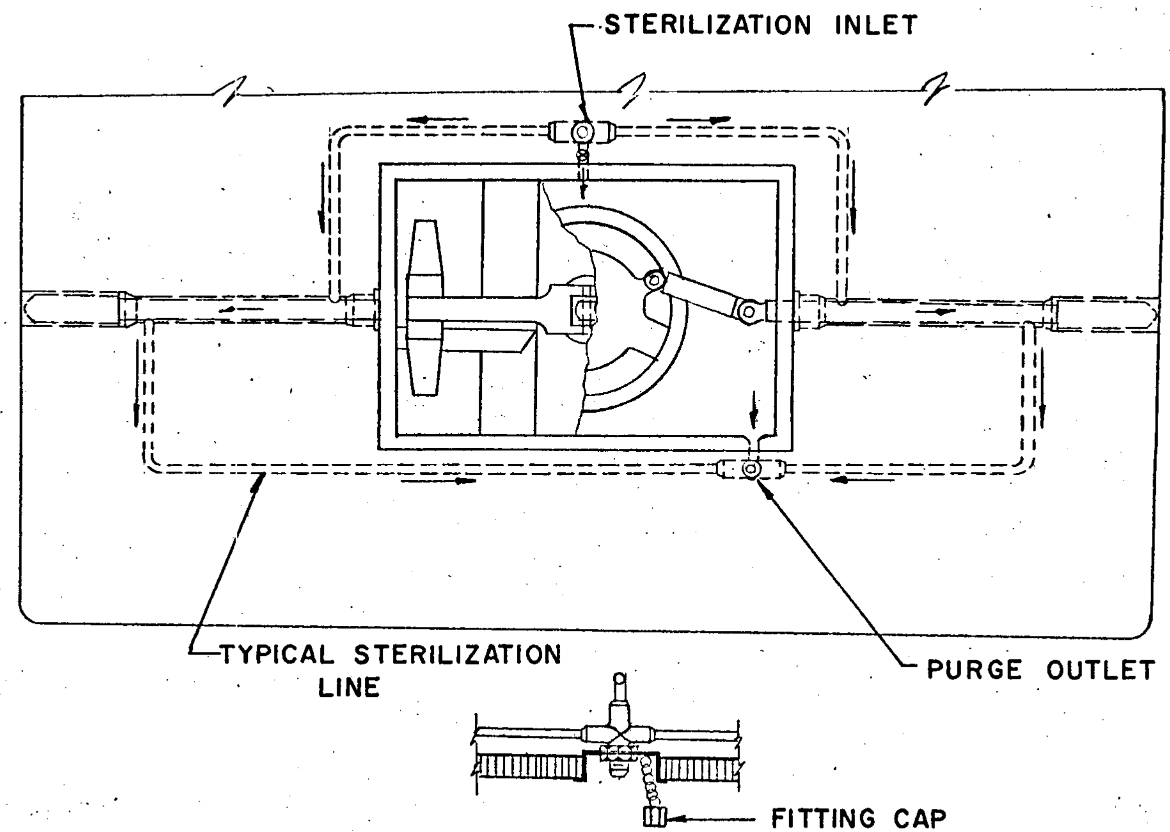
OUTBOUND (TRANSLUNAR) SEAL CONFIGURATION

FIGURE 7



NOTE

ROTATE HANDLE DURING PURGE.

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STERILIZATION MANIFOLD SYSTEM

can be readily applied in the form of a band around the outside of the lid. Should both means fail, the shear strength of the indium is sufficiently low that a force of 15 lb per lineal inch will remove the lid. If the redundant hook-detent fasteners are used as recommended, a means of cutting or prying these from the box perimeter must be provided. In all cases, either the lid should be removed within a vacuum, or the container vacuum must first be broken by admission of inert, purified gas through the gas sampling port.

Lid Removal

Interface coordination between the box designers and the Receiving Laboratory will establish the configuration, size and location of the lid removal attach points. Since the structural backup for these fittings can be supplied between the sandwich layers without penetrating the inner liner, it may be possible to retrofit the attach points upon receipt of detailed interface requirements. The boxes have been designed to limit stresses on the indium seal and thereby avoid vacuum failure. Maintaining the integrity of the seal at the receiving station depends in part upon avoiding excessive or concentrated tension loads on the cover.

Canister and Special Purpose Container Removal

The design of the remote manipulators should take into account the presence of the removable canisters and special purpose inner containers. The canisters have been designed with 0.25 in. diameter holes on all four walls, 0.25 in. from the top, to accept hooks. Threaded connectors or other attachment aids will be provided on special purpose inner containers when these requirements have been defined.

PART III

STRUCTURAL DESIGN STUDIES

INTRODUCTION

The objective of this phase of the program was to select the most promising structural concept for prototype fabrication of the large sample return boxes. Work performed during the prior study contract served to identify the nature and extent of volume and weight trade-offs for various basic structural shapes and systems. The earlier decision to use a rectangular parallelepiped configuration, making maximum use of the volume available, was retained throughout the current work. The structural system design problem was then to provide the largest possible box consistent with the physical demands and scientific constraints of the mission and containing maximum storage volume.

Physically, the boxes must be capable of functioning satisfactorily in a design load environment consisting primarily of a net external pressure of 20 psi, a shock and vibration spectrum, and a maximum anticipated shock load of 78 G. The performance goal under these conditions was complete box integrity except under 78 G impulse. For this latter condition the possibility of vacuum degradation was accepted, provided there were no catastrophic failures leading to loss of contents.

The remaining basic structural constraints were the overall envelope dimensions, a rectangular parallelepiped 8 by 11.5 by 19 in., and the four-pin suspension system located on a horizontal plane at the geometric center of the mounting space. Minimum clearances, as well as mounting pin hole sizes and shapes, were also specified as a part of the spacecraft fabricator's interface control documentation.

BASIC MATERIAL SELECTION

The preliminary studies which established the rectangular geometry also recognized that at the relatively low normal load intensity of 20 psi good structural efficiencies could be obtained from sandwich construction. This type of material allows the use of thin gauge inner and outer walls while providing a structure with a high overall stiffness to weight ratio. Factors influencing the selection of basic sandwich materials and the structural design of the prototype containers are discussed in the following sections. More detailed methodology and synopsis of structural calculations may be found in Appendix A.

Materials

The two aluminum alloys which were considered were 6061-T4 and 6061-T6. While attractive from a density standpoint, problems in effecting an adequate vacuum-tight joint by welding the inner liner panels, seal glands, penetrations, and attach points were critical. In addition, the initial optimum heat treatment was adversely affected by the welding process, and dimensional distortions following post-assembly heat treatment procedures could not be tolerated. Assembly of an aluminum box by brazing was not practical because of the necessity for using very low secondary temperatures.

Titanium offered the most attractive strength to weight ratio for this application of all the materials considered. An evaluation of the current status of titanium honeycomb manufacturing as well as a study of the difficulties in fabricating and joining peripheral hardware, such as seal glands and box penetrations, left the decision to bypass titanium for the initial prototype boxes and proceed with more readily obtainable materials which offered fewer engineering and manufacturing problems. A titanium prototype has been proposed which will reduce the weight of the boxes by an estimated 40%. With construction phased to parallel the laboratory evaluations of the existing prototypes, design changes found to be advantageous during the forthcoming comprehensive human factors and environmental test programs could be included without sacrificing the critical time schedule set for the overall sample return project.

Another promising concept was studied, applicable to the weight-optimized version, for utilizing a gas-tight inner liner to which the required core material, structural stiffeners, penetrations, and outer skins would be brazed or bonded. Weight reduction by this technique was anticipated by elimination and simplification of structural frame members as well as by the use of titanium.

Inconel 718 was attractive because of its relatively low notch sensitivity. Two factors which influenced the decision not to proceed with this material were (1) relatively few suppliers were found who were skilled in its use, and (2) the thin gauge material required for honeycomb manufacture was not readily available and would have delayed fabrication an additional eight weeks. In other respects, the Inconel appeared to be competitive with stainless steel in terms of weight advantage and structural integrity.

The stainless steel selected for honeycomb fabrication was PH15-7MO. Factors favorable to this selection were its compatibility with the scientific mission requirements, its availability and relative ease of manufacture, and its favorable physical properties, particularly with respect to heat treatment and secondary brazing characteristics.

Structural Characteristics

The specific honeycomb and framing system construction selected for the prototypes was designed to be compatible with static and dynamic loading conditions described in NASA environmental specifications and mission requirements.

Each panel was considered as being loaded by a uniform pressure of 20 psi, as well as by the edge support provided for contiguous panels. Depending upon the degree of fixity between panels and frame members at various intersections, the edge conditions for each panel varied between simply supported and built-in. The total static load on each panel was obtained from the sum of direct loads resulting from in-plane reactions of adjacent panels and bending moments (primary moments due to normal loads and secondary due to in-plane loads).

The lid was assumed to have edge constraints most closely approaching simple supports and therefore was assumed to have the greatest static bending moment due to external pressure. The magnitude of the bending moment (see Appendix A), coupled with in-plane loads, resulted in a required sandwich panel consisting basically of 0.006 in. face sheets brazed to a 0.3 in. honeycomb core, having 0.25 in. square cell size. Core ribbons were 0.002 in. foil. To simplify fabrication of the prototypes, all panels were identically designed even though loading conditions varied from panel to panel. To further simplify fabrication as well as enhance the structural integrity of the assembly all honeycomb was fabricated initially of 0.020 in. face sheets and selectively etched to 0.006 in., leaving 0.020 in. reinforcing in required areas by masking (Reference Part VI and "Drawing Supplement" for details).

The stiffness of each panel was such that the possibility of the box collapsing under external pressure was virtually eliminated. As will be seen from Appendix A, the local behavior of the sandwich (core shear properties, face wrinkling due to biaxial load, shear crimping, and face dimpling) was evaluated to ensure that none would cause failure.

Construction Techniques

Welded, brazed, and bonded honeycomb construction was studied. While of considerable structural promise, the welded honeycomb was rejected for this application, because of the tendency for pin holing with thin gauge face sheet material. Also characteristic of the welded honeycomb were discontinuities between cell walls due to the spot welding technique, eliminating the possibility of intracellular vacuum redundancy, such as would be available with continuous brazing. Organic adhesives were rejected partially on the basis of physical properties but primarily because of the desire on the part of the scientific community to eliminate all organic materials from the sample box.

Brazed honeycomb for the stainless steel construction was found to offer the best combination of advantages. A silver-lithium brazing alloy having a melting point of in excess of 1800°F was selected, allowing an ample temperature margin above the 1450°F secondary brazing temperature for overall box assembly.

The brazed honeycomb not only offered the advantage of added vacuum protection due to independently sealed cells but was a comparatively stiff, light-weight structure with a high natural vibration frequency. The inclusion of 0.8 in. diameter stainless steel disks in place of the honeycomb between the face sheets at the mounting pin locations provided additional structural reinforcing.

STRUCTURAL SYSTEM DESIGN SELECTION

Framing System

The six flat honeycomb panels were brazed to a system of light-weight, rectangular cross-section, rigid tubular frames to which T-sections were attached to accommodate the inner skin of the honeycomb panels. This was done in preference to integral edge members fabricated with the honeycomb panels to facilitate dimensional control of the box during final assembly.

Partitioning Systems

The internal canisters described in Part V are not considered a part of the structural stiffening for the boxes, since they may be removed by the astronaut at his option as a part of the packaging program. Various bulkhead configurations were proposed and analyzed as possible means for supplying structural support. However, these designs placed unacceptable limitations on the maximum sample size which could be accommodated as well as astronaut handling, sample protection, and packaging techniques.

Lid Design

The success of the indium seal described in Part IV depends largely upon the degree of structural isolation or protection from stress which can be afforded the seal combination. The full opening lid, being simply supported at its edges, may be expected to rotate several degrees about its support unless additional attachment means were provided to stiffen the lid at its edges. The irreversible latching system designed for the transearth phase.

places the outer edges of the lid in tension, decreasing to approximately 20% the calculated nominal lid deflection and minimizing tension stresses on the male seal member which might produce structural failures in the indium.

MOUNTING SYSTEMS

Dynamic Environment and Analysis

The most severe dynamic load, which the box must be designed to withstand, was defined by Apollo environmental specifications and interface structural documents as an 11 millisecond impulse of 78 G peak amplitude (see Figs. 8 and 9) applied to the box support frame. The interfaces between the ship's structure and the box frame have been established at four specifically designated points in the mid plane of the box envelope.

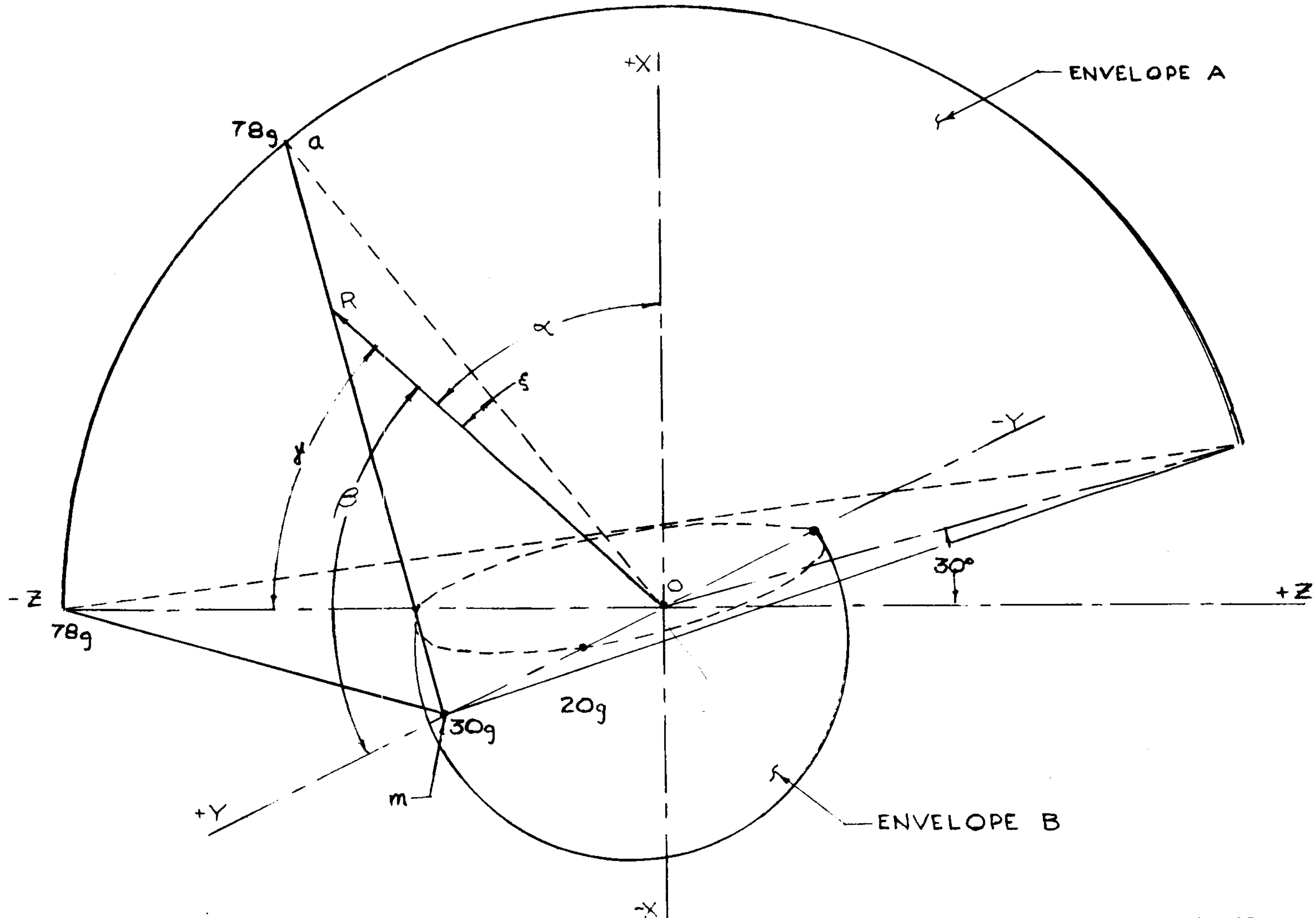
Actual interfaces were defined by Command Module and LEM interface documents to consist of 0.375 in. diameter pins and pin receptacles compatible with the frame configuration.

The dynamic response of the box was therefore directly dependent upon the structural characteristics of the mounting system and upon the mass of the box and its contents. The maximum weight of a single container including its contents was defined by interface documents to be 50 lb.

An initial study of flexible shock mounting systems was conducted to determine whether container acceleration could be reduced below the 78 G peak acceleration. Two different conceptual models of the dynamic system were considered: (a) the container and contents as an elastically supported single mass system; (b) the container and contents as an elastically supported multiple mass system.

The term "elastic supports" in this context includes both linear and nonlinear springs. In addition, the effect of viscous damping was considered in case (a). Significant features of this analysis are outlined on the following page. Fig. 10 shows the model for the single mass system, consisting of a rigid mass, m, representing container and contents, connected by an elastic spring to a base, s, representing the support frame. The possible inclusion of a viscous damping system in parallel with the spring is also illustrated. The base is subjected to the 78 G impulse shown in Figs. 8 and 9.

FIGURE 8



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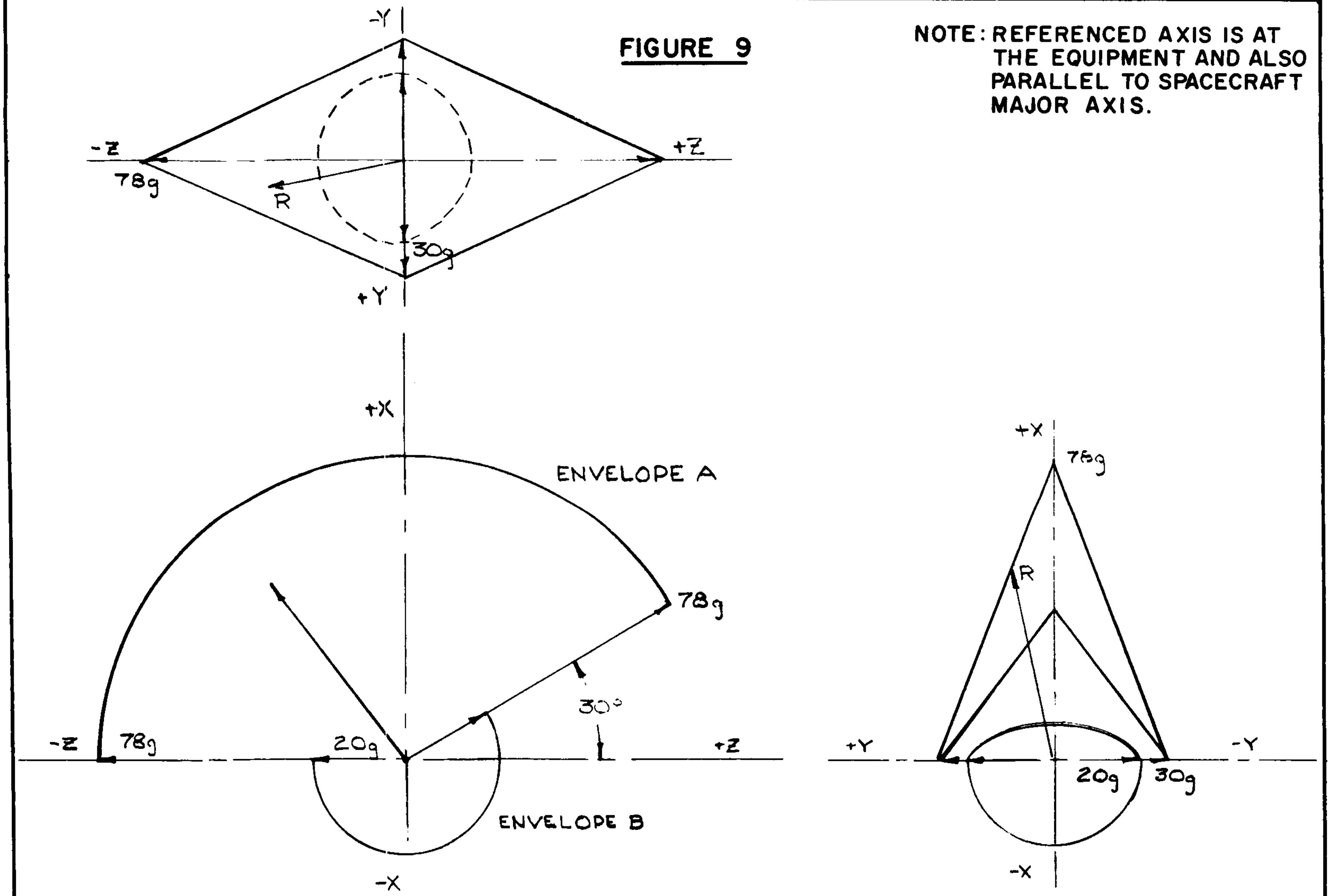
INTERNAL EQUIPMENT
ULTIMATE DESIGN ACCELERATIONS

FIGURE 9

NOTE: REFERENCED AXIS IS AT THE EQUIPMENT AND ALSO PARALLEL TO SPACECRAFT MAJOR AXIS.



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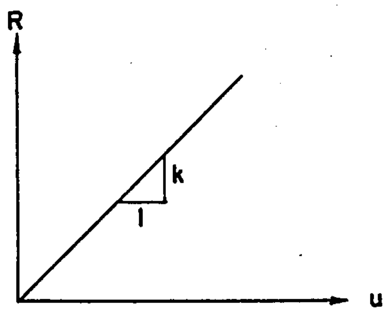
INTERNAL EQUIPMENT
ULTIMATE DESIGN ACCELERATIONS



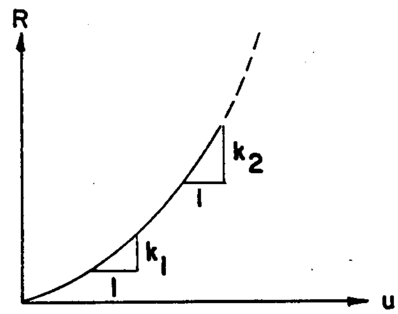


Figure 10. Force-Deflection Characteristics of Mounting System (k = spring constant)

The impulse considered was a half sine wave of $2t_d$ equal to 0.022 sec. The quantities y and y_s represent mass deflection and base deflection, respectively, from the equilibrium position.

The differential equation describing the dynamic resposes of such a system was represented as:

$$\ddot{u} + \frac{R}{M} + \frac{c}{M}\,\dot{u} + \ddot{y}_{s_o}\, f_a(t) \;=\; 0$$

where

u	=	$y - y_s$
r	=	spring force at any value of u
c	=	damping coefficient
y_s	=	measure of impulse amplitude
$f_a(t)$	=	impulse as a function of time

Note that this is sin (286t) for $0 \leq t \leq t_d$, and 0 for $t \geq t_d$.

Spring force was considered to be either linear or non-linear, as shown in Fig. 11.

It is recognized, however, that the foregoing analysis is largely theoretical, while actual shock mount design is essentially an empirical art dependent upon comprehensive dynamic tests. For this reason, the prototype box is designed to accommodate tests of flexible mounting devices if required to establish final proof and flight hardware design criteria.

PART IV

SEAL SELECTION

INTRODUCTION

Applications for high vacuum seals in configurations approximating those of the sample boxes may be found in existing laboratory apparatus and hermetically sealed flight-weight hardware. The latter designs are characterized by small, closely-spaced bolts on a clamping flange around the seal perimeter. This provides uniform, high compression unit loadings, but with a slight attendant weight penalty.

The seals for conventional laboratory high-vacuum apparatus are critical, since seal leakage detracts from the capacity of a pump to scavenge gas molecules from the test part or materials. Because of this, laboratory equipment usually employs wide, heavy flanges with multiple tie-down bolts to apply high unit loading uniformly over the length of the seal. Under these circumstances it is possible to establish an efficient mechanical bond utilizing malleable metal gaskets having very low outgassing rates.

The lunar sample box is a passive or unpumped vacuum chamber in which seal leakage or gas diffusion would result in vacuum degradation and serve as a potential source of sample contamination. The fact that the box is a flight-weight container in which tare weight detracts from the quantity of returned lunar material further differentiates the problem from conventional laboratory practice, where the weight of the gland and its clamping devices are of little consequence.

The seal under discussion in the paragraphs to follow is the trans-earth or return seal. The selection of materials for this seal was made somewhat easier by the fact that the tear-away outbound seal will be applied while the box is at high vacuum, preventing oxygen or other potentially deteriorating substances from being able to contact the return seal material or gland walls prior to opening on the lunar surface.

CANDIDATE SEALS

Vacuum technologists have at their disposal a wide variety of proven concepts ranging from ceramic and epoxy potting techniques for permanent joints to metallic and elastomeric crush gaskets for removable ports and penetrations. The philosophy of the seal selection program was that existing designs would be examined first to determine their suitability to the objectives of the box design.

As previously indicated, certain seals commonly used in pumped systems were unsuitable for passive vacuum use because of relatively high outgassing and gas transmissibility characteristics. The following paragraphs deal only with the more promising candidates on which detailed studies were accomplished.

Metallic Gaskets

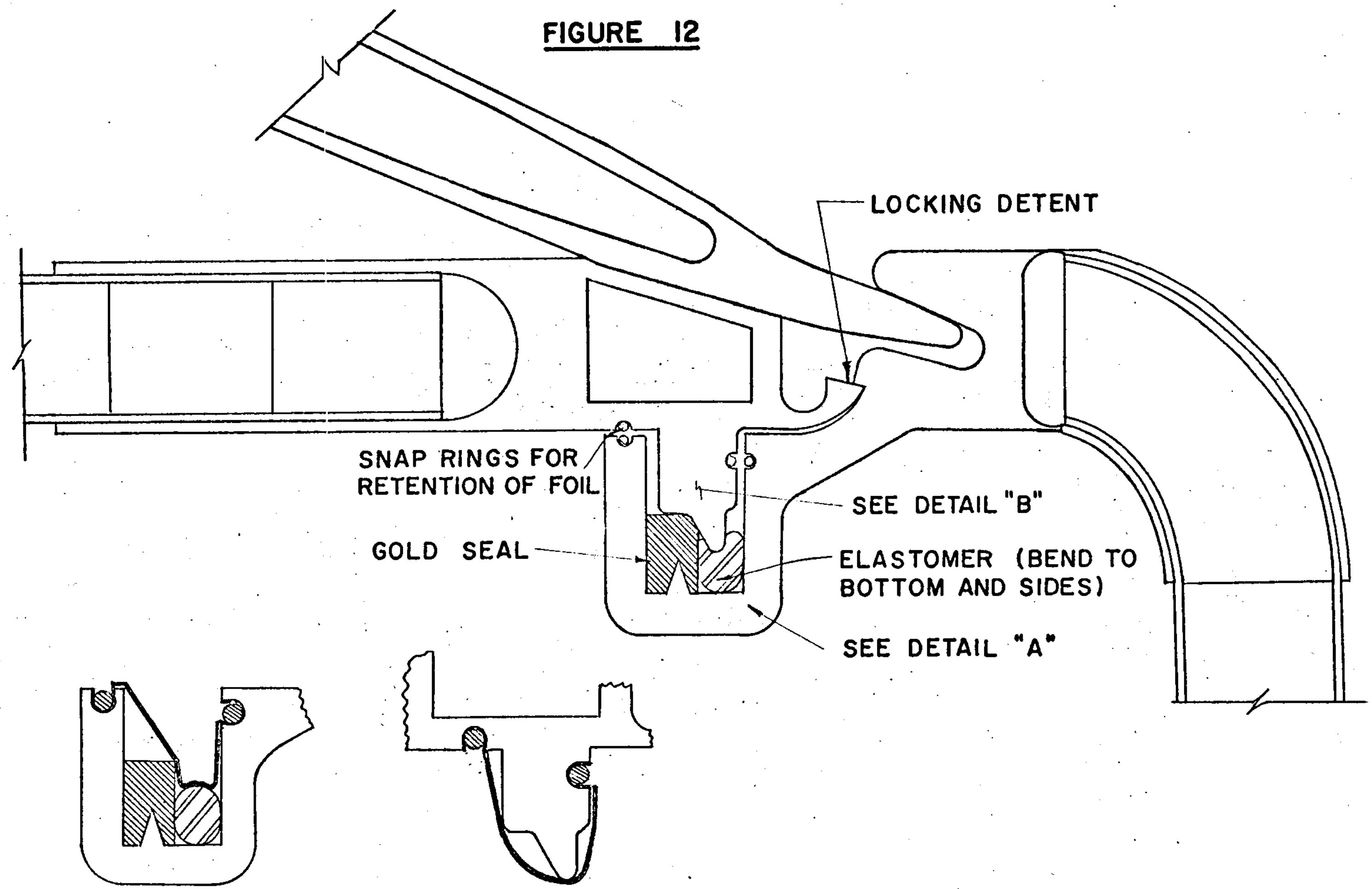
Crush gaskets of copper, aluminum, and gold are often employed in laboratory test apparatus to produce vacuum seals. The most effective are capable of applying one to two thousand pounds squeeze per lineal inch, crushing the malleable seal material into the interstices of the mating surfaces.

At first rejected because of the weight penalty implied by supplying uniform high unit loading, the concept was re-examined using the wedging action of an inclined gland wall to provide the necessary crush loading for a gold gasket. To avoid the added weight and complexity of internal hardware to apply sufficient lid loading, a pry-bar was considered. A rim around the edge of the box provided the force reaction point and served to detent the lid in place once sufficient crush action had been attained (see Fig. 12). Seal integrity depended largely on the evenness of loading, which is difficult to control. Also the pry-bar lid attach system implied added demands upon the astronaut's time and physical resources.

While the wedge crush design avoided some of the characteristic weight and complexity disadvantages attributed to standard laboratory configurations, the high unit loading necessary to deform the gold was transferred to the opposite gland wall, making the design potentially susceptible to cold welding. Numerous research programs are currently active to determine the conditions under which cold welding occurs in a vacuum. The diversified nature of these programs suggests the magnitude of uncertainties still associated with the problem, and the prospect of prematurely welding the lid at random locations prior to effecting a vacuum seal became a major design concern with the crush gasket approach. In addition, the susceptibility of the design to leakage by excessive contamination or accidental surface damage was considered a major deficiency.

For the high unit load seal approach various schemes were investigated to relieve the astronaut of excessive manipulation of tools or hardware. Among these were rotating cams and inflatable balloons or bellows actuated by a small compressed gas cylinder. While the designs had merit, each added an element of uncertainty to the question of overall seal reliability, often contributing potential mechanical problems such as cold welding or differential thermal expansion which appeared to outweigh their advantages.

FIGURE 12



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GOLD CRUSH GASKET
SEAL CONFIGURATION

Foil Seals

A second attractive seal design evolved from studies of various methods of sealing the inner foil bags (see Part V, "Packaging Studies and Special Purpose Inner Containers"). It became apparent that the characteristic of cold welding in vacuum, which was detrimental in the case of the crush gasket, might be made to work advantageously in various forms to seal layers of foil. The application of this principle to the primary vacuum seal was first proposed as a redundant backup, using the wedging action of the previously designed gasket seal (see Fig. 12, lower inserts) to effect a crush bond between layers of foil.

A common laboratory technique for vacuum sealing of copper tubing is to cut it with a blunt-edged shear. Several experiments were successfully performed demonstrating this technique on a much smaller scale using .001 in. copper and aluminum foil. While encouraging, the results showed the vulnerability of the approach to any type of physical stress, the bond between the foil layers being fragile. In addition, the surfaces, though not required to be free of oxides or chemically clean in the case of the shearing seal, nevertheless had to be free of dust or other gross physical impurities.

It was concluded that, while the approach would be pursued in the case of the inner foil bags, its susceptibility to failure due to contamination and vulnerability to accidental damage made it impractical to consider further as a backup seal for the boxes.

Elastomeric Seals

By far the easiest approach to the sealing problem would have been to select one of the conventional elastomers now in use for pumped vacuum systems and attempt to protect the interior of the box from seal outgassing and gas diffusion.

The more attractive features of the elastomeric seal include relatively low susceptibility to imperfections, low unit loading requirements, and a wide choice of available standard sizes and materials. The possibility of using elastomers received considerable design attention during the period when a foil backup appeared to be a practical means of eliminating outgassing products from the box interior (see preceeding section).

In this connection, the use of two O-rings, while providing redundant protection against catastrophic seal failure, was considered relatively ineffective as means of improving vacuum. The double seal has often been used where either the guard vacuum between the seals is large, or where a separate pumping system can be utilized to draw off leakage and outgassing products from the guard vacuum space. Since neither of these features could be incorporated in the sample container, the sealing effectiveness of parallel elastomers was considered to approximate that of a single O-ring.

Though discarded for the primary vacuum seal, the elastomer was reconsidered for the secondary or redundant backup seal. Referring to the previously described design goal (10^{-2} torr) for seal redundancy, which eliminated the hard vacuum requirement, the elastomeric seal appeared to be an optimum choice as a barrier against gross contamination. In this regard, fluorocarbon is relatively non-compliant, requiring high unit loading and considerable design finesse to achieve an effective seal throughout its length.

FINAL SELECTION (INDIUM-SOLDER PRIMARY SEAL)

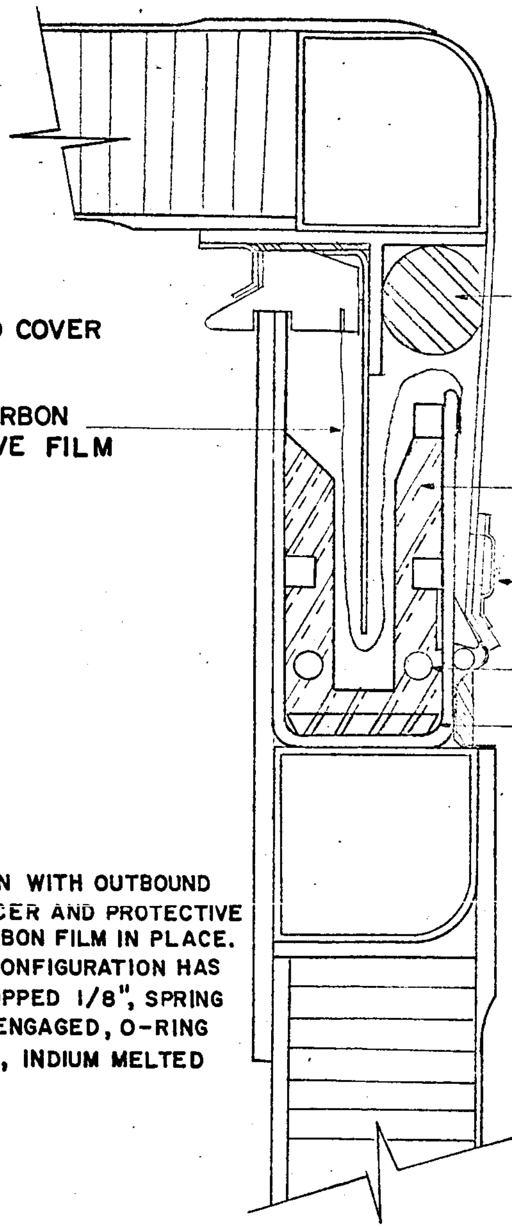
Examinations of the types of seals commonly used in vacuum practice revealed continued reference to indium as a practical gasket material. Being considerably more malleable than gold, it flows easily into interstices and surface imperfections. This feature was at first considered to be its most attractive attribute, and it was studied for adaptation to the then existing crush gasket design. It later developed that its low (330°F) melting temperature might be utilized to advantage for producing a seal requiring little effort on the part of the astronaut.

An examination of the seal revealed certain design uncertainties in its application, yet the prospect of achieving near-zero leakage made the risks appear minimal.

Design Configuration (Reference Fig. 13)

The indium will be molded in place in the female (lower) gland to form a cavity. At the bottom of the indium space are two 1/16 in. diameter electrical heater units connected to a receptacle in the front of the box. The male, which is connected to the lid of the container, is designed to accommodate the redundant elastomeric seal, yet to remain flexible so as not to transmit lid deflection forces to the indium. Both male and female seal members are protected by a film of fluorocarbon to help protect them from accidental damage and assure against unwanted sticking during the period of vacuum storage before use. The protective fluorocarbon film will also reduce the exposure of the seal to contamination by rock particles and lunar dust and will protect the metallic surface until the last possible moment before replacing the box lid.

FIGURE 13



NOTE:

SEAL SHOWN WITH OUTBOUND COVER SPACER AND PROTECTIVE FLUOROCARBON FILM IN PLACE. INBOUND CONFIGURATION HAS COVER DROPPED 1/8", SPRING LATCHES ENGAGED, O-RING IN CONTACT, INDIUM MELTED

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SEAL CONFIGURATION

To apply the seal a power source must be connected to the electrical receptacle on the front of the box and held for approximately one minute. A signal light will then indicate the seal has melted at two separate locations and is ready for cooling. It is estimated that five minutes will be required for the seal to solidify in sunlight and two minutes in shade.

Comparison With Design Goals

The following sections compare the optimized indium seal to the project design goals outlined in Part I. In some cases, an accurate appraisal of the compliance of the seal to these criteria will be not possible until after the prototypes are evaluated under simulated lunar environmental conditions.

Leakage. - A properly seated indium seal is expected to approach zero gas transmissibility. Surface outgassing should approach that of the adjacent stainless steel surfaces. Preliminary tests completed for this contract demonstrated that such leakage goals were realized in the laboratory.

Ease of application. - As in any seal configuration, the astronaut must first tear away the protective fluorocarbon shields. He must then (1) replace the lid, (2) level the box, (3) plug in the electrical connection, and (4) press the switch in the connecting cable. When the signal on the front of the box lights, power should be disconnected and the seal allowed to cool.

Mission compatibility. - The acceptance of indium as a primary seal material has not aroused serious concern to date in the scientific community except to the extent it might contain impurities such as lead. Experiments with 99.99% pure indium were performed in which the material was heated for several days at 500°F without depositing detectable contaminants on the surface of a glass-liquid nitrogen trap. However, on being raised to 700°F at 2×10^{-8} torr, a faint deposit was picked up after 12 hours.

Protection against this possibility takes several forms: (1) the flight hardware will contain the purest form of indium attainable, monitored from its point of origin and specially packaged to preserve purity; (2) the indium and seal gland will be subject to the same thorough precleaning under heat and vacuum as the rest of the container, prior to electron-beam welding the outbound seal strip in place; (3) the total heat cycle is not expected to be more than 7 minutes including cooling time; (4) the top of the gland is gasketed so as to provide a trap for containing and condensing vapors; (5) the vapor pressure of indium is approximately 10^{-10} torr at 700°F, a 400°F safety margin over that temperature necessary to melt and form the seal.

Should evaluations of the prototype hardware reveal these features to be inadequate, a special thin-film protective shroud of laminated aluminum foil will cover the tops of all storage canisters. This shroud will provide a large area for heat dissipation and condensation of indium vapors.

Contamination. - Assuming problems having to do with seal surface wettability are overcome during manufacturing and subsequent processing, the contamination source of greatest concern will be that introduced on the lunar surface. As described in the "Design Configuration" section, a protective fluorocarbon film will be installed over the seal glands at the time of box manufacture and retained until just prior to resealing on the lunar surface. Even with this provision, there is a strong possibility that lunar dust, if it is present, will be attracted electrostatically to the box. Because of the high specific gravity (7.3) of indium, most of the dust will float quickly to the surface. The probability that sufficient contamination will occur during the short time between removal of the fluorocarbon caps and activation of the seal to interfere with the wetting characteristic of the melted indium is considered slight. In laboratory experiments, the tendency was for contamination to form a surface layer of slag, leaving the pure indium-solder material beneath. With the 0.2 in. depth of penetration designed for the male member, careful astronaut closure training should minimize the lunar dust problem.

Weight. - The weight of the indium is an unattractive feature, approximately 0.85 lb being required to fill the gland. However, because the indium seal does not require large compression forces, weight was saved in both the male and female gland assemblies, making the overall design weight competitive with other concepts.

Complexity. - The female member of the seal assembly is a simple U-shape. It does not require high surface finish or close tolerance for proper operation, and is probably the least susceptible to malfunction by damage of any of the configurations studied. The male, on the other hand, is designed to be flexible, minimizing forces transmitted from the lid into the indium. It is therefore more susceptible to damage, and a protective skirt has been provided around the perimeter of the cover, extending below the seal tip. Again, the fluorocarbon cap covering both seal members will also be useful for protection against accidental damage.

Disadvantages

Preliminary laboratory tests and discussions with various indium users have revealed certain shortcomings of the material as a seal. In evaluating these, design judgment was required to determine whether these adverse characteristics would pose problems in the one-shot application under study, since most experience involved designs intended for continuous or repetitive seal use.

One difficulty with indium is in preparing gland surfaces to ensure proper wetting. Various users report problems ranging from amalgamation with gold or silver coatings to a need for elaborate surface preparation procedures such as hydrogen firing to ensure wettability. Most report that with a hyper-clean surface, that is one cleaned mechanically of all dirt, oil, oxides, or other impurities, little wetting difficulty was experienced with indium. Since such precautions will be a normal consequence of eliminating contamination from the box regardless of what seal configuration or material is used, the problem may not be of practical significance in this application.

A second disadvantage is the tendency of the material to form surface oxides. As a precaution against this, it is expected that all of the box manufacturing operations subsequent to final cleaning will be done either in an inert atmosphere or under vacuum, including the molding of the indium in the female gland. Immediately following these steps, the tear-away outbound seal strip will be welded in place in the vacuum chamber, not to be removed until on the lunar surface. The seal will thus be protected from oxygen or other outside contaminants.

A third disadvantage lies in the extremely weak physical properties of indium. Tensile strength in the order of 380 psi and compression of 300 psi make the material structurally unattractive. For that reason the lid has been designed as if it were a hinged plate, resting on top of the inner wall of the seal cavity with the seal carrying no moment. The male seal gland is a straight, flexible section of 0.010 in. stainless steel. Stresses at the edges due to atmospheric loading on the lid are carried by the latching system, preventing edge rotation and attendant seal stress.

The box will be sealed while still exposed to the lunar vacuum and subsequently exposed to external pressure only. However, as described in Part II, a pressure-relieving port will be provided to protect the structure against possible build-up of internal pressure from sample outgassing or sublimation.

Another problem is the low thermal coefficient of expansion of indium. To help ensure against separation as the indium cools, gland walls were designed to be flexible by using 0.020 in. stainless steel. Laboratory tests with similar configurations were successful.

A final problem is that the indium seal we have proposed represents an advanced application that has not been commonly employed in high vacuum systems. However, current test experience and data indicate the aforementioned negative factors can be surmounted in the prototype box design concepts.

PART V

PACKAGING STUDIES AND SPECIAL PURPOSE INNER CONTAINERS

CANISTER CONCEPT

Sample and Container Advantages

A single, uninterrupted volume within the sample box, while providing the most flexible overall use of available space, places the entire burden of sample protection on the flexible packaging bags. The prior study considered employing a series of truncated baffles lining the sides and bottom of the box to protect the smaller samples. The larger rocks were to be supported by the baffle edges in the open center cavity. One difficulty with this design was that the center cavity had to be sized to accommodate the largest anticipated sample, requiring that additional packaging material be placed around rocks of lesser dimensions to prevent excessive movement. In addition, the large center cavity afforded little intrasample protection.

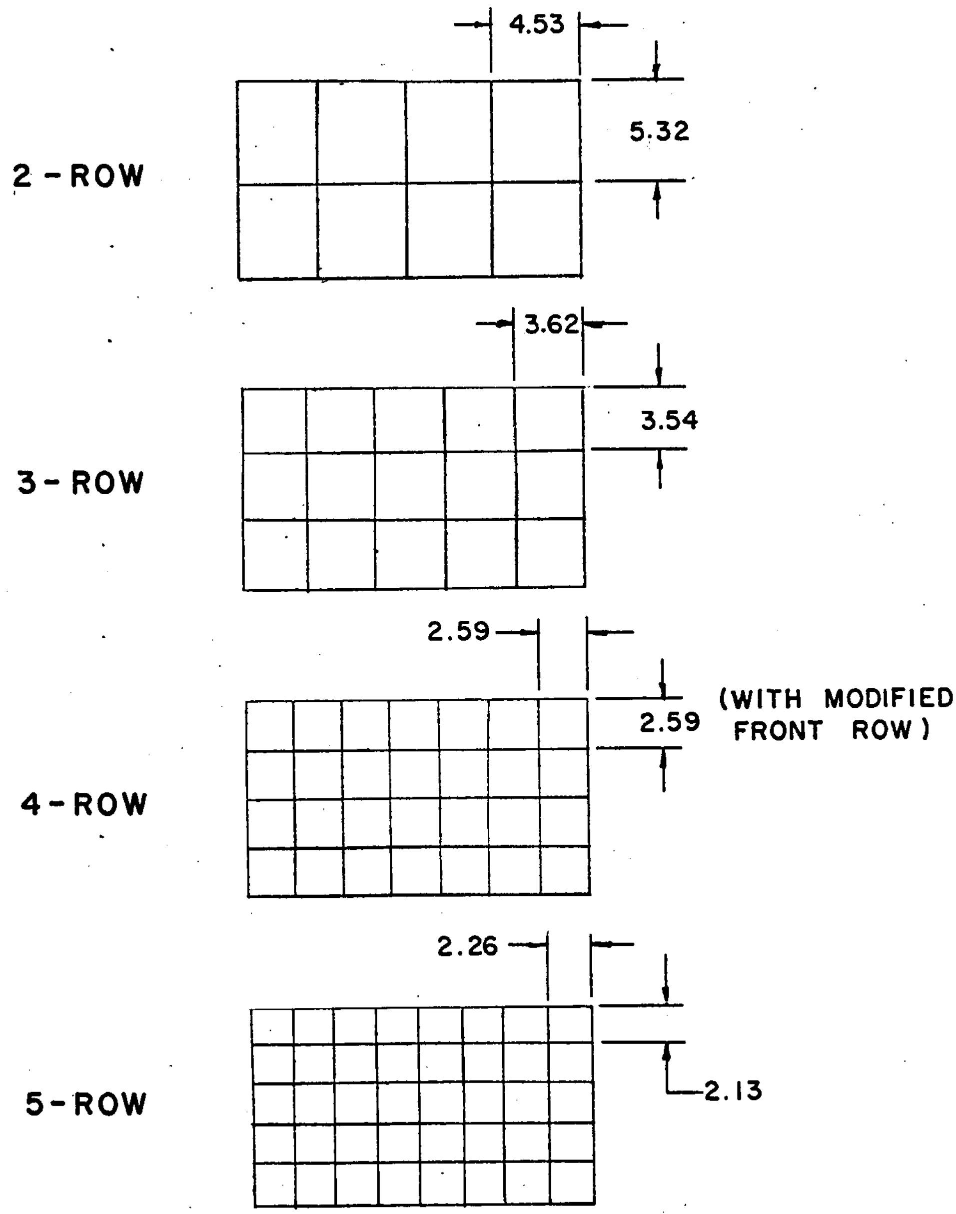
The removable canister concept evolved during the present study avoids these difficulties. First, it affords maximum physical protection to individual samples and protects the inner walls of the vacuum box from puncture by sharp rock projections during periods of impact or vibration. Second, storage space for larger specimens may be arranged and altered as required by the astronaut by removing various canisters.

Sizing and Configuration

Tha basic canister sizing criterion was to provide suitable protection for small geologic hand specimens. Secondary criteria were (1) the canisters should be modular for interchangeability; (2) rocks too large to be placed within a single canister should be accommodated by removing two or more canisters to provide a larger cavity; and (3) large rocks should be separated from the box walls by at least one row of canisters.

Considering the plan view of the box (reference Fig. 14), two rows of canisters would not meet the latter design criteria. Three rows provide the desired outer wall protection, but samples larger than 1/3 the width of the box (3½ in.) would require removal of one or more canisters from the outer rows, exposing the vacuum jacket to potential hazard. The four row configuration allows two inner rows, or slightly over 5 in., to be removed if required for larger rocks. With five rows, the modular canister size drops to approximately 2 in., which was considered too small for practical sample storage.

FIGURE 14



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CANISTER SIZING ALTERNATIVES

The four row configuration thus is optimum. Allowing 0.010 in. clearance between canisters, the row at the box front is 2.93 in. wide and the other three rows are each 2.59 in. wide.

To provide bottom protection against penetration by larger rock specimens, the ten center canisters occupying the aforementioned large sample storage position have each been divided into separate upper and lower canisters, the upper being 5.01 in., or 3/4 of the total available storage height, and the lower 1.67 in., or 1/4 of the height. The lower canisters have a 0.30 in. flange around their opening to form a ledge for the large rock samples to rest upon, minimizing cutting and abrasion problems.

Loading Sequence

Fig. 15 illustrates the preferred loading arrangement for various payloads. In general, it is considered more desirable to have a few filled canisters than many which are half empty, so that vertical movement of the cargo will be minimized. The cargo should be distributed so that the corner canisters nearest the mounting pins are loaded first, followed in turn by the end and side canisters. The center rows should be reserved for final loading and/or large specimens.

FLEXIBLE BAGS

Materials

The previous design study recommended multiple laminations of thin, flexible material to reduce the possibility of gas diffusion or contamination transmittal through the bag walls. A successful material consisted of four 0.0005 in. laminations of aluminum/polyester film/polyester film/aluminum, making a 0.002 in. sandwich. The Manned Space Science Lunar Working Group at Falmouth, Massachusetts, recommended in July, 1965, that polyester film be eliminated from the sample bag and TFE fluorocarbon substituted in its place. Although the manufacture of prototype inner bags was not included with the current work, investigations of manufacturing problems showed that a two layer lamination, using an inner liner of aluminum foil and an outer layer of fluorocarbon film, is a practical combination. The aluminum liner provides an optimum material for direct contact with the sample, while the outer fluorocarbon layer is expected to prevent the bags from sticking together in vacuum. As recommended in the prior study, each bag should be serially numbered to enable the astronaut to record surface conditions and other acquisition information pertinent to each sample.

Configuration

Packaging studies performed under the previous study contract indicated that the minimum practical bag size for astronaut handling was 3 in. in diameter at the opening by 5 in. in length for small samples. Bags 7 in. in diameter by 9 in. in length for larger rocks were recommended. Further recent packaging studies with these configurations showed that excessive bag tare weight would result unless each bag were filled to near capacity. Thus, sample mixing within the same bag would be required for specimens under 2½ in. in diameter which is undesirable for certain post-mission scientific evaluations.

An alternate solution would be to provide small bags in the 1 to 2 in. size for pebble or marble-sized samples. In the previous study this was avoided because the astronaut could not efficiently handle bags of this size and because several hundred would have to be filled to make efficient use of the available storage volume. Under the current contract, a semi-automatic means of efficiently accomplishing this type of packaging has been studied, as described below under "Bag Dispensing Systems".

Seal Concepts

The flexible inner containers are adaptable to two basic sealing approaches. Since the recommended material has an aluminum foil inner liner, a cold welding or fusion bonding seal can be considered. Also, using a dispensing tool with resealing capabilities, a crimp-over or canning technique might be employed to produce more positive seals.

The laminated fluorocarbon and aluminum material also lends itself to various plastic seal configurations. Among the most promising to date has been a conventional interlocking zipper, which is convenient to apply and relatively tight up to 100 torr differential pressure. Considering the bag seal as a molecular migration barrier between differential vacuums of 10^{-5} to 10^{-9} torr, the zipper configuration should be effective. On the other hand, if the design criterion is to protect the samples with an effective redundant seal in the event the primary box vacuum fails, a more positive seal would be required.

Bag Dispensing Systems

The design of the flexible containers and the choice of sealing methods are both dependent upon the time and dexterity constraints of the astronaut. Without a semi-automatic bagging mechanism the larger, less efficient bags recommended in the previous study appear to be optimum.

Fig. 16 shows a design for automatically opening and resealing small (2 in.) flexible bags. Each squeeze of the handle trigger advances a newly opened bag to the filling hopper position, where sample material is dropped in by the astronaut. The next trigger pull advances an empty bag to the hopper position and seals the filled bag between two crimp-seal rollers.

A 1 in. continuous strip along the top opening of the bags serves as a guide for the sample material when under the hopper and protects the critical sealing interface from dust and debris. The strip is torn away from the bag mouth along a perforation just before entering the crimp-seal roller closure.

GAS SAMPLING CONTAINER

Materials

Highly polished 410 stainless steel is a recommended material for bake-out and vacuum degassing to minimize residual molecular gas traces from the interior of the container intended for transporting samples to be used later for gas analysis. Among the available candidate seal materials, indium is attractive from the standpoint of being (1) consistent with the existing box seal and (2) readily deformable as a crush gasket.

Configuration

A configuration design is shown in Fig. 17. The overall assembly is 2.5 in. in diameter by 6.0 in. long. For outbound transportation, the lid and body are loosely packaged in foil until ready for use. After stripping away the foil, the two halves are brought together and twisted to exert the necessary crushing force on the gasket. The ball at the end of the cover assembly transmits axial force from the screw without causing rotation against the gasket surface.

The gas sampling port in the recessed hole in the base of the container is designed to accept a sampling probe from the mass spectrometer. A foil diaphragm, ruptured by the insertion of the analyzer probe, is used to ensure positive sealing of the container.

FIGURE 16-A

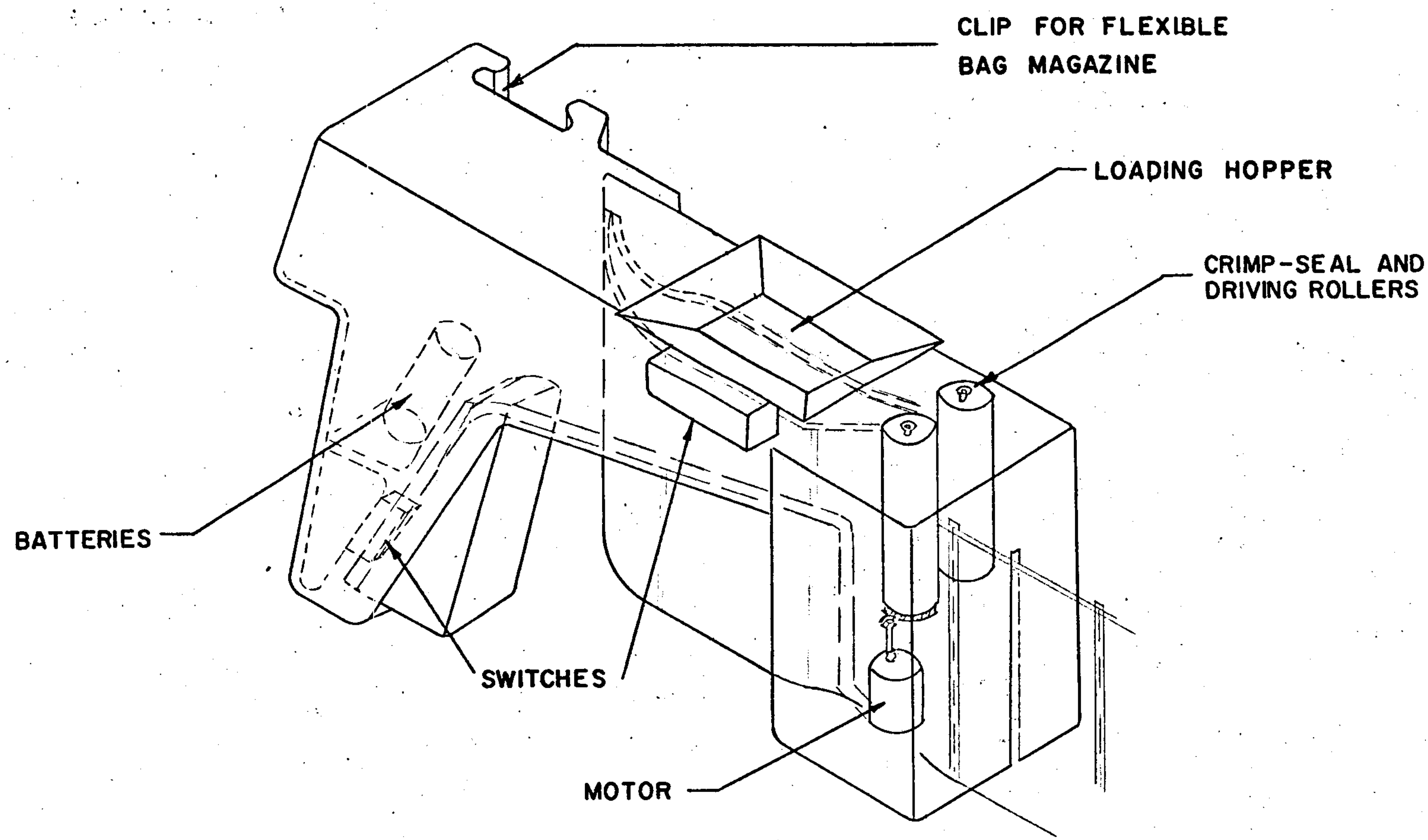

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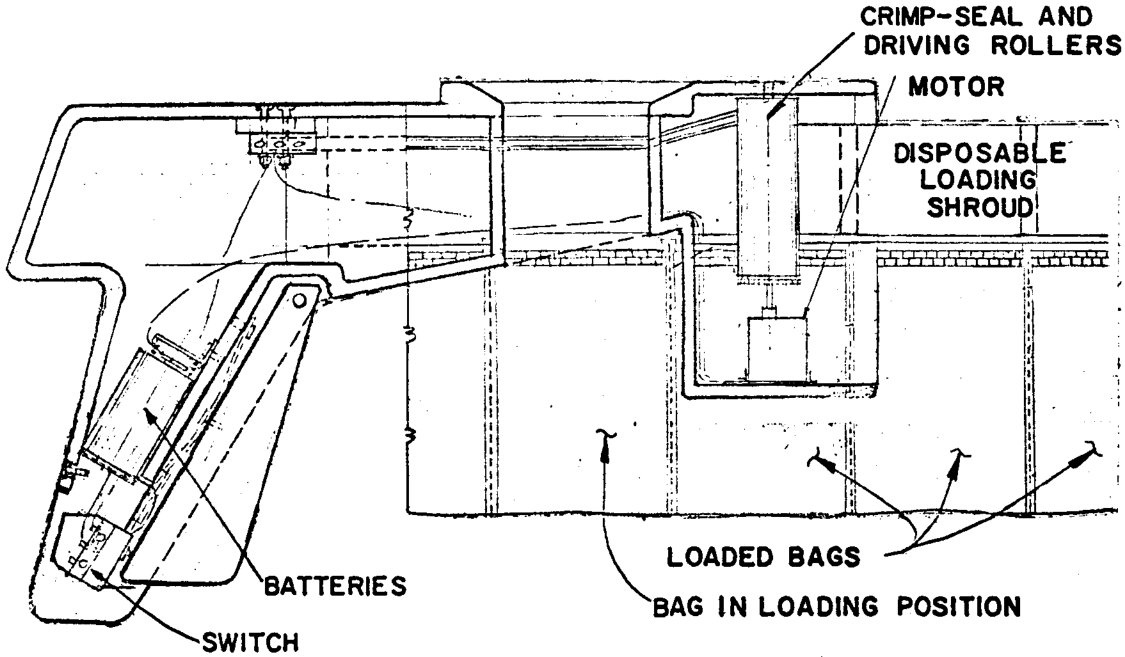
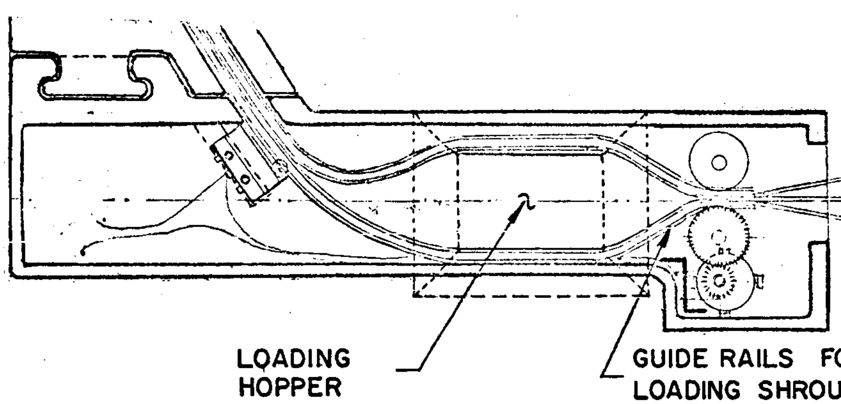
FIGURE 16-B





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BAG DISPENSING AND
RESEALING DEVICE

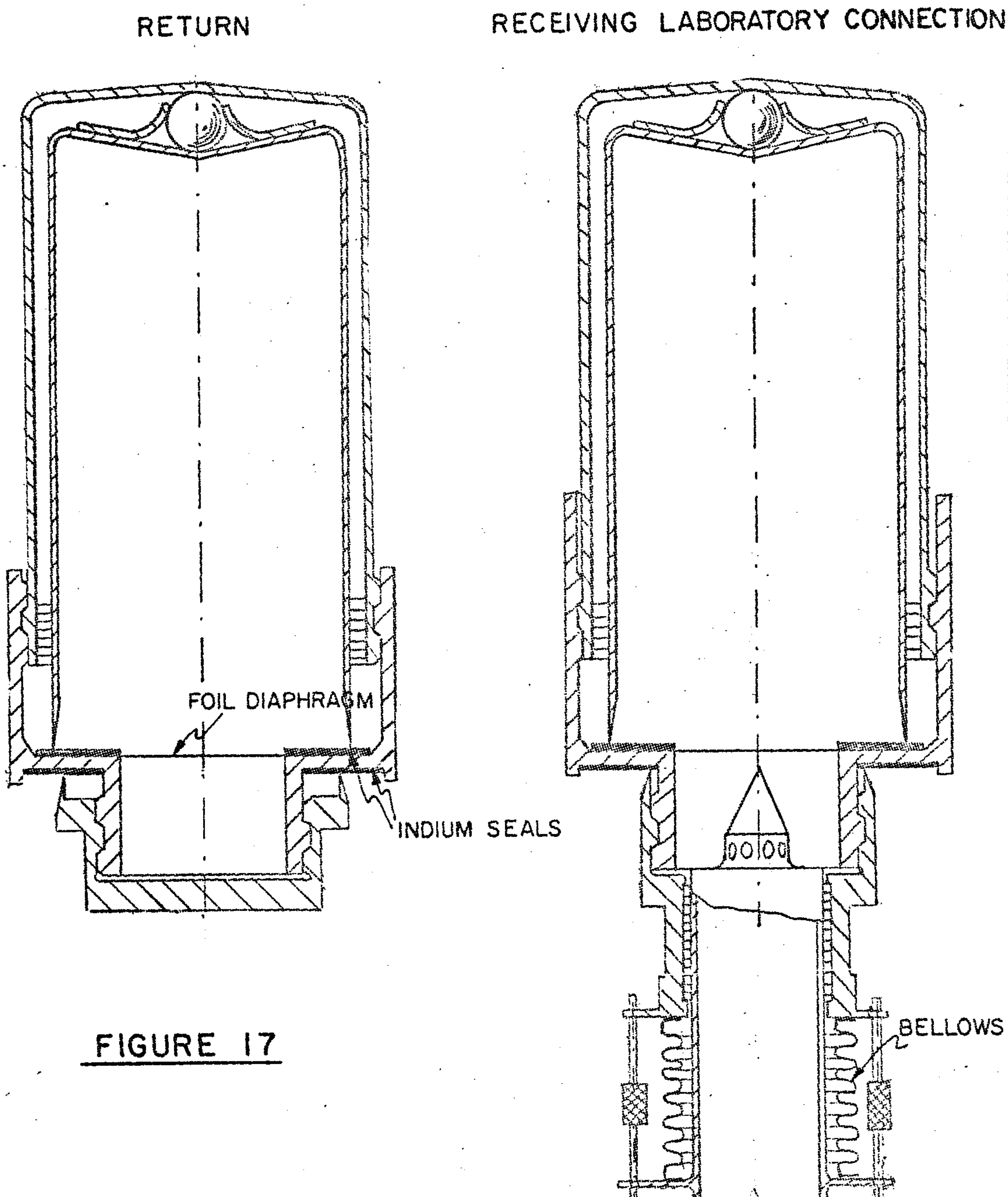

FIGURE 17

GAS SAMPLING
INNER CONTAINER

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PROTOBIOLOGICAL SAMPLING CONTAINER

Requirements

The protobiological sampling container must be adaptable to a system of obtaining material from 6 to 18 in. beneath the contaminated lunar surface. Every precaution must be taken to ensure aseptic handling of the container before, during, and after the sampling operation. Thirty to fifty samples, each 1 to 5 grams in weight, are desired. The seal must provide an effective barrier against transmission of contaminants from within or without and must be protected against pollution by the astronaut's suit, gloves, or LEM wastes.

Dispensing Tools

Because of the necessity for isolating the sampling operation, the design of the sampling container cannot be effectively isolated from the dispensing tool. A concept for such a combination is shown on Fig. 18, depicting a double-barreled probing tool in which the right-hand barrel dispenses empty, clean sample cartridges, while the left-hand barrel returns filled and capped units. The pointed end of the probe remains closed until the desired depth has been reached, at which time a trigger mechanism retracts the probe cover and permits the empty cartridge to be pushed forward for filling. This action also scrapes aside any surface contaminants left on the probe tip, exposing only the virgin lunar material.

The design of the cartridge assembly must be predicated almost entirely upon the probing, retract, and capping action occurring at the probe tip. A single-walled cartridge would not be acceptable, because it could be contaminated during the retract cycle by debris from previous probings. The double-walled cartridge, enclosed by a foil diaphragm, avoids this by keeping the inner sampling unit covered until the last possible moment, when the probe cap is retracted (see Fig. 19).

Having been thrust through the foil diaphragm into the lunar material, the sampling unit is then withdrawn into the outer cartridge and held in an inverted position until capped. In this way the inner sample container does not contact at any time the contaminated elements within the probe tip, seeing only the inside of the outer cartridge.

The sample container cartridges are designed with an internal flap or iris which serves as a check-valve against loss of material during the retraction and capping operations. An indexing lug on the side of the container

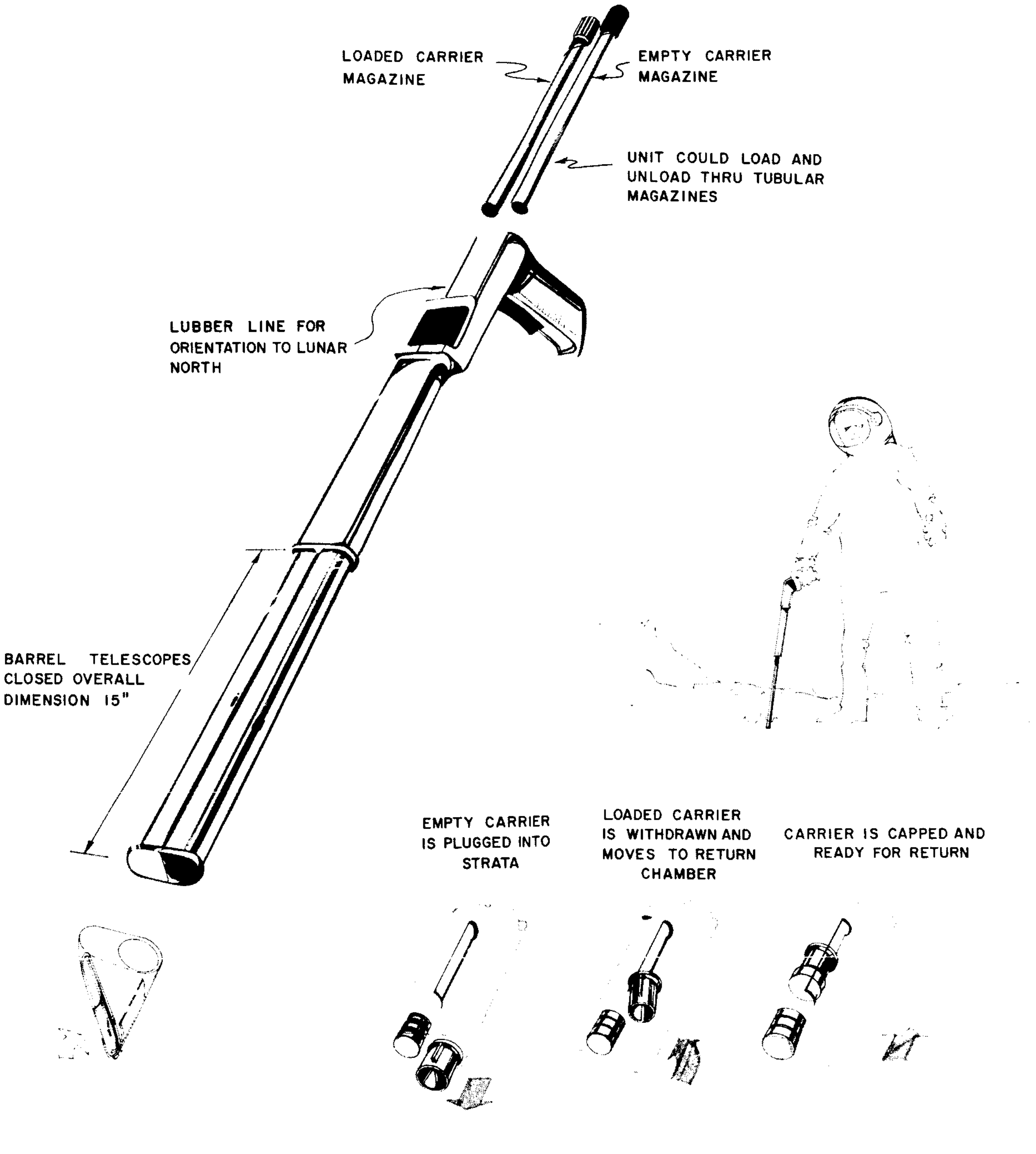

FIGURE 18

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SCHEMATIC
BIOLOGICAL SAMPLE CONTAINER DISPENSER

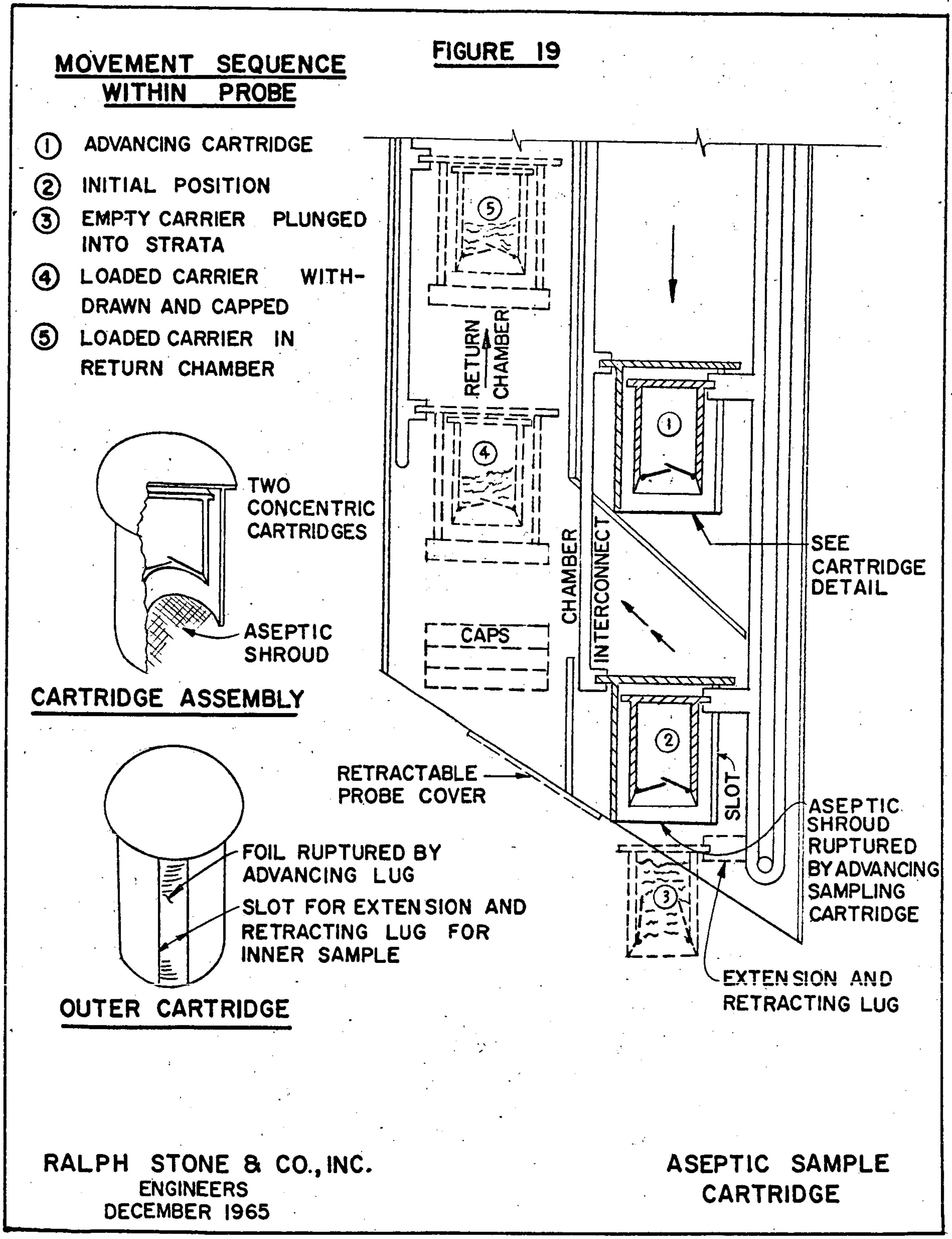
FIGURE 19
MOVEMENT SEQUENCE WITHIN PROBE
① ADVANCING CARTRIDGE
② INITIAL POSITION
③ EMPTY CARRIER PLUNGED INTO STRATA
④ LOADED CARRIER WITHDRAWN AND CAPPED
⑤ LOADED CARRIER IN RETURN CHAMBER
RETURN CHAMBER
CHAMBER
INTERCONNECT
CAPS
SLOT
TWO CONCENTRIC CARTRIDGES
ASEPTIC SHROUD
CARTRIDGE ASSEMBLY
SEE CARTRIDGE DETAIL
RETRACTABLE PROBE COVER
ASEPTIC SHROUD RUPTURED BY ADVANCING SAMPLING CARTRIDGE
FOIL RUPTURED BY ADVANCING LUG
SLOT FOR EXTENSION AND RETRACTING LUG FOR INNER SAMPLE
OUTER CARTRIDGE
EXTENSION AND RETRACTING LUG
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ASEPTIC SAMPLE CARTRIDGE

allows the operation to be oriented to lunar north or any other desired reference direction.

Upon further retraction of the probe the cartridge unit is then ejected into the left-hand return barrel in a manner similar to the action of an expended rifle cartridge. At the same time, the pointed cap over the open sampling port is again closed. The next triggering operation, during which a new sample cartridge is thrust forward, also presses the filled unit into its capping mechanism. When the probe is retracted, the capped container moves up the left-hand barrel just ahead of the incoming uncapped, newly-filled cartridge.

While external power is not a design necessity, a low-amplitude vibrator working from a battery in the handle would help keep the device free from the effects of accumulated debris in the probe tip and would be of modest assistance in penetrating surface materials other than hard rock which could not be bored with this configuration.

STORAGE PROVISIONS

The canister concept is readily adaptable to the storage requirements of the various special-purpose inner containers discussed in this section. For instance, the smaller flexible bags are intended to be inserted directly into the canisters. For larger samples, selective removal of canisters serves as a means of sizing the storage cavity.

The former storage plan for gas sampling containers involved clips on the side walls of the box. This concept was not consistent with the modular canister packaging system, and the alternative was to treat the small gas sample inner containers as if they were rock specimens, packaging them within flexible bags and storing them in the modular canisters. The inner containers will thus receive maximum physical protection as well as redundant vacuum sealing, while not requiring special clips or storage provisions. Similarly, the small protobiological cartridges can be stored within flexible bags and placed in one of the modular canisters.

PART VI

PROTOTYPE HARDWARE FABRICATION

INTRODUCTION

Two prototypes of the sample container and internal canisters were fabricated to permit subsequent tests and evaluations of critical design features. Investigations leading to theconstruction of the prototypes covered all facets of configurational, structural, seal, handle and latch, sample protection, and special purpose appendages described in Parts II, III, IV, and V. Special purpose inner containers, while included in the design studies, were not a part of the prototype fabrication program.

Inasmuch as minimum design development and release time was estimated to be 3½ months and manufacturing 2½ months, particular emphasis at the beginning of the current 6-month phase was placed on those materials and processes already developed. For example, when it was determined that honeycomb construction would be an optimum structural choice, various alternate materials, core depths, cell sizes, and skin thicknesses were evaluated in terms of meeting technical as well as schedule commitments. The choice of stainless steel honeycomb was strongly influenced by the latter consideration, yet other attractive alternatives were noted and parallel efforts made to determine the best manufacturing system and the minimum time needed for development. One such investigation resulted in recommendations to NASA for an optimized unit possibly weighing 40% less than the initial prototypes described in the following sections. Evaluations of these alternatives are expected to continue and be completed prior to the release of manufacturing specifications for proof and flight hardware.

The following sections discuss the general design philosophy and manufacturing techniques used for producing the prototype hardware. Drawings and a list of materials are available under separate cover, "Lunar Sample Container Prototype - Drawing Supplement," containing specific engineering designs.

WALL CONFIGURATION

Honeycomb Configuration

The basic wall structural material was honeycomb fabricated of PH15-7MO stainless steel, initially fabricated of 0.020 in. face sheets (see chemical milling description in the following paragraph). Core thickness was 0.300 in., fabricated of 0.002 in. PH15-7MO stainless steel foil in 1/4 in. cells. Brazing was accomplished at 1800°F with 0.001 in. silver-lithium (99.8% silver, 0.2% lithium) alloy. The heat treatment condition was 170,000 psi yield, 200,000 psi ultimate.

Chemical Milling

Stress calculations for the stainless steel honeycomb walls showed that 0.005 in. wall thickness was adequate, but manufacturing and handling difficulties with honeycomb of such thin face sheet gauge were considerable. Therefore, it was decided to use heavier gauge material (0.020 in.) initially and rely upon subsequent chemical milling for weight reduction.

A secondary advantage of the chemical milling process was that areas near penetrations and points of load concentration were masked to retain the original 0.020 in. thickness which provided better local stress distribution without the necessity of doublers or secondary structural members. In general, 0.5 in. borders were left around all attach points, utilizing a tapered edging process to minimize notch effects.

Nominal thickness following chemical milling was specified on the drawings as $0.006^{+0.002}_{-0.001}$ in. depth.

FRAMING CONFIGURATION

The honeycomb panels were manufactured without edge members with the outer face sheet extending 1/4 in. in all directions beyond the edge of the inner sheet and core. The framing system was designed of square cross-section tubes to which T-sections were tack-welded. All frame members and seal glands were then jigged to proper configuration, tack-welded, and vacuum furnace brazed at 1800°F. Honeycomb panels were then inserted from the outside, resting both the inside and outside skins against surfaces at least 0.200 in. wide to which they were vacuum furnace brazed at 1450°F. Interior corner caps were used for additional vacuum integrity at each 3-wall intersection.

Framing details and dimensions may be found in the Drawing Supplement.

JOINING TECHNIQUES

The high temperature (1800°F) silver-lithium brazing alloy was selected for the honeycomb panel manufacture as well as the basic framing system to permit the use of a secondary, 1450°F brazing technique in joining the panels, penetrations, and attachments to the box during a single final joining operation. A heat treat and aging (stress relief) cycle established by the honeycomb manufacturer was used subsequent to brazing to provide the 160,000 psi yield and 190,000 psi ultimate strengths described in the design calculations. Vacuum weld repair subsequent to brazing was done with heli-arc welding following helium leak detection techniques.

PENETRATIONS

Mounting point stress concentrations were minimized by placing stainless steel plugs at the location of the mounting pin penetrations during the manufacture of the sandwich panels. The only other penetration into the vacuum chamber provided on the present prototypes was the handle and latch mechanism well which was installed with internal and external flanges brazed in place during the overall box assembly.

HANDLE AND PIN RETRACTION MECHANISMS

The mounting pins on either side of the box must be retracted to permit removal of the container. To achieve this, the handle assembly is first pressed inward, then rotated. Detents are provided in both the mounting and carrying positions. The unit was designed so that all rotating and reciprocating parts slideon fluorocarbon bushings with the exception of the rod bearing ends which are standard precision miniature bronze bushings.

The push rods which actuate the mounting pins were fabricated of aluminum, while the mounting pins are stainless steel to provide maximum shear strength. The handle and most interconnecting parts were fabricated of hollow aluminum to minimize weight.

Steel snap rings were used for retaining pin assemblies, while threaded parts were assembled with lock-tight compound and lock washers. The handle assembly is designed to be readily removable from the front of the unit.

INTERNAL CANISTERS

The internal canisters used for sample protection were fabricated of 6061-T6 aluminum, 0.015 in. thick at the upper edges, chemical milled to 0.005 in. on the side walls and bottoms. The chemical milling of the exterior surfaces of the canisters was done subsequent to forming and heli-arc welding. The internal surfaces are smooth and free from projections which might snag on the flexible sample bags.

SEAL HARDWARE

The female gland is a formed section of 0.030 in. PH15-7MO stainless steel. The internal gland wall which supports the lid has a 0.060 in. fluorocarbon cap. The external wall has a 5^{o} outward bend to minimize the danger of cutting the redundant silicone rubber O-ring seal.

The male is a formed section of 0.010 in. PH15-7MO stainless steel. The heater unit consists of two parallel stainless steel tubes, 1/16 in. o.d. containing ceramic insulation and nichrome resistance wire each producing slightly under 5 watts per lineal inch. The total power of both heaters in parallel is 800 watts. The connector is a standard AN series unit used on an interim basis until the interface between the sample box and the LEM power cable has been defined.

Dimensions and material specifications may be found in the Drawing Supplement.

APPENDIX A

STRUCTURAL CALCULATIONS

1.0 Material Properties - Stainless Steel PH15-7MO

Ultimate Tensile Strength	=	220 000 psi
0.2% Tensile Yield Strength	=	190 000 psi
Shearing Strength	=	60% of Tensile Strength
Elongation, % in 2 in.	=	5
Hardness, Rockwell	=	C45
Modulus of Elasticity	=	30×10^6 psi
Density (Solid Material)	=	0.3 lb/in.^{3}

2.0 Sandwich Design

2.1 Lid

2.1.1 Primary Moment

To determine honeycomb section required, consider the lid as a simply supported plate under uniformly distributed load of 20 psi due to external pressure.

$$\frac{b}{a} = \frac{18.91}{11.45} = 1.65$$

$$M = \beta q a^2 \qquad (1A)$$

$$M_{max\ primary} = 0.0908 \times 20 \times 11.45^2$$

$$= 238 \text{ in.-lb/in. at center of plate}$$

where β = moment coefficient

q = uniform pressure = 20 psi

a = short edge dimension = 11.45 in.

b = long edge dimension = 18.91 in.

A basic design objective was to minimize wall thickness to make available maximum box volume. With core thickness of 0.3 in. (minimum practical fabrication dimension), the maximum primary bending stress in sandwich facings is

$$f \approx \frac{M}{t_f t_c} \qquad (2A)$$

where f = calculated stress

M = bending moment

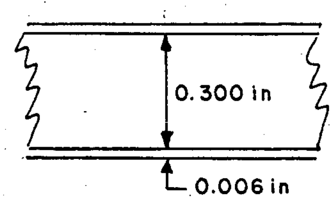
t_f = facing thickness

t_c = core depth

For stainless steel facing of 0.006 in. thickness

$$f = \frac{238}{0.3 \times 0.006}$$

$$= 132\ 200 \text{ psi}$$



Weight of basic panel

The core density for stainless steel honeycomb is 8.3 lb/ft^3. This is equivalent to 0.0014 $lb/in.^2$ for 0.3 in. core. The density of faces is

$$2 \times 0.006 \times 0.3 = 0.0036 \text{ lb/in.}^2$$

The density of the stainless steel sandwich

$$= 0.0050 \text{ lb/in.}^2 \text{ of panel}$$

2.1.2 Secondary Stresses in Lid

In addition to the primary moment, effects of in-plane loads must be considered. These loads are due to the pressure on side plates. Taking a unit strip from the center of the box and considering it as a rigid frame with hinged lid supports under 20 psi exterior pressure, maximum reactions on the lid may be calculated by the moment distribution method. Horizontal components of the reactions will be equivalent to shear forces at the seal and in-plane loading on the lid.

Fixed end moments

$$M = \frac{1}{12}qL^2 \qquad (3A)$$

$$M_{AB} = M_{BA} = \frac{1}{12} \times 20 \times 7.00^2 = 82 \text{ in.-lb}$$

$$M_{BC} = M_{CB} = \frac{1}{12} \times 20 \times 11.45^2 = 219 \text{ in.-lb}$$

$$M_{CD} = M_{DC} = \frac{1}{12} \times 20 \times 7.00^2 = 82 \text{ in.-lb}$$

Stiffness coefficient

$$K = \frac{I}{L} \qquad (4A)$$

$$K_{AB} = \frac{I}{7.00} = 0.143\ I$$

$$K_{BC} = \frac{I}{11.45} = 0.087\ I$$

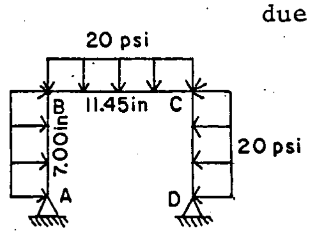
Modified stiffness coefficient

$$K'_{AB} = \frac{3}{4} \times 0.143\ I = 0.107\ I \qquad (5A)$$

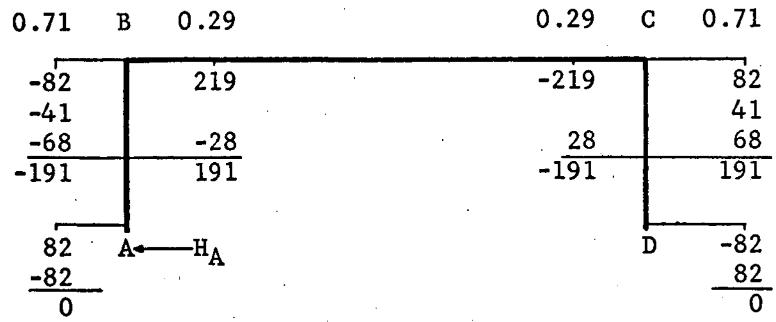
due to hinged end

$$K'_{BC} = \frac{1}{2} \times 0.087\ I = 0.044\ I$$

due to symmetry



MOMENT DISTRIBUTION DIAGRAM



$$M_B = H_A \times 7.00 - \frac{1}{2} \times 20 \times 7.00^2 = 191 \text{ in.-lb/in.}$$

$$H_A = 97.3 \text{ lb/in.}$$

This is the shear force at the seal or the in-plane loading at the lid. For conservative design, the buckling strength of the lid is calculated by considering it to be a simply supported rectangular plate compressed by uniformly distributed loads of equal magnitude (approximately 90 lb/in.) in two perpendicular directions.

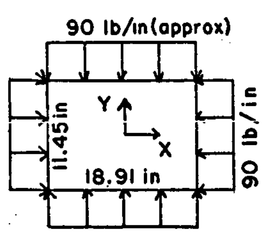
Consider general biaxial compression buckling

where μ = Poisson's ratio = 0.30

s = core cell size = 0.25 in.

f_x = calculated stress parallel to x-axis

FORCE DIAGRAM



f_y = calculated stress parallel to y-axis

D = sandwich bending stiffness

U = transverse shear stiffness

G = shear modulus of elasticity = 11.5×10^6 psi

G_c' = modified shear modulus of elasticity of core

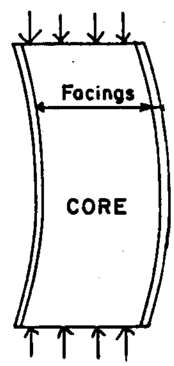
$$\gamma = \frac{f_y}{f_x} = 1 \qquad (6A)$$

$$\gamma_i = \sqrt{1 - \gamma + \gamma^2} = 1 \qquad (7A)$$

$\rho_c{}'$ = theoretical square cell core density

ρ_c = material density = 0.3 lb/in.^{3}

$t_c{}'$ = core ribbon gauge = 0.002 in.



GENERAL BUCKLING

$$\rho_c{}' = \frac{2t_c{}'}{s}\,\rho_c = \frac{2 \times 0.002 \times 0.3}{0.25} \qquad (8A)$$

$$= 0.0048 \text{ lb/in.}^3 = 8.3 \text{ lb/ft}^3$$

$$G_c{}' = 2.43\left(\frac{\rho_c{}'}{\rho_c}\right)^{1.54} G \quad \text{if } \rho_c{}' < 16.7 \text{ lb/ft}^3$$

$$= 2.43\left(\frac{0.0048}{0.3}\right)^{1.54} \times 11.5 \times 10^6 \qquad (9A)$$

$$= 48{,}000 \text{ psi}$$

$$f_x = \frac{90}{2 \times 0.006} = 7500 \text{ psi} = f_y$$

$$\frac{b}{c} = 38.2$$

$$U = G_c{}'\,(c + 2t_f) = 48\ 000\ (0.3 + 2 \times 0.006)$$

$$= 15\ 000 \text{ lb/in.} \qquad (10A)$$

$$D = \frac{Et_f\ (c + t_f)^2}{2\ (1 - \mu^2)} = \frac{30 \times 10^6 \times 0.006\ (0.306)^2}{2\ (1 - 0.3^2)}$$

$$= 9250 \text{ lb-in.}^2\text{/in.} \qquad (11A)$$

$$J = \frac{b^2 U}{\pi^2 D} = \frac{11.45^2 \times 15\ 000}{\pi^2 \times 9250} = 21.6 \qquad (12A)$$

K_x = 1.5 determined from empirical data

$$\frac{K_{x_{cr}}}{\eta} = \frac{K_x U}{J2t_f} = \frac{1.5 \times 15\ 000}{21.6 \times 0.012}$$

$$= 87\ 000 \text{ psi} \tag{13A}$$

$F_{x_{cr}}$ = critical stress parallel to x-axis

$F_{x_{cr}} = 190\ 000 \times 0.6 = 114\ 000$ psi

determined from empirical data

Margin of safety

$$= \frac{F_{x_{cr}}}{f_x} - 1 = \frac{114\ 000}{7500} - 1 = 14$$

Multiply primary moments by

$$\frac{1}{1 - f/f_{cr}} \tag{14A}$$

as an estimate of secondary effects.

$$M_{max} = 238 \times \frac{1}{1 - 7500/114\ 000} = 255 \text{ in.-lb}$$

$$f_m = \frac{255}{0.3 \times 0.006} = 142\ 000 \text{ psi}$$

Combined stress due to moment and in-plane load

$$= f_m + f_x = 142\ 000 + 7500 = 149\ 500 \text{ psi}$$

2.2 Bottom

Since the honeycomb plate is brazed to the frame, the examination of the bottom demands more rigorous treatment due to boundary conditions which are somewhere between simply supported and built-in. For a conservative design for moment a simply supported rectangular plate under uniformly distributed load is considered.

Note that for fixed edges, $M_{max} = 0.08\ qa^2$. This coefficient is less than that for a comparable simply supported plate.

Dimensions are the same as those of thelid. Therefore, the previously calculated honeycomb section is adequate for the bottom panel.

2.3 Sides

Based on the same concepts, the stresses on the side plates were calculated and the same honeycomb section was determined to be adequate.

2.4 Local Behavior of Sandwich

2.4.1 Core Shear Properties

Isotropic square celled honeycomb core is considered.

$$F_s' = 1.307 \left(\frac{\rho_c'}{\rho_c}\right)^{1.34} \frac{F_{su}}{c^{0.44}} \qquad (15A)$$

for $\rho_c' < 18$ lb/ft^3

where F_s' = design core shear strength

F_{su} = ultimate allowable stress of core

$$F_s' = 1.307 \left(\frac{0.0048}{0.3}\right)^{1.34} \frac{220\ 000}{0.3^{0.44}}$$

$$= 1920 \text{ lb/in./in.}$$

Shearing stress is assumed to be taken by honeycomb core.

$$\text{Shearing force} = V_{max} = 0.496\ qa \qquad (16A)$$

$$= 0.496 \times 20 \times 11.45$$

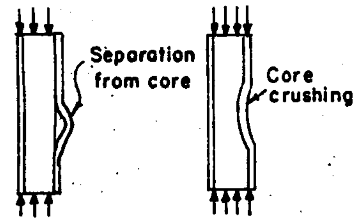
$$= 114 \text{ lb/in.}$$

$$\text{Shearing force per unit area} = \frac{V_{max}}{bc}$$

$$= 114 \times \frac{1}{0.3 \times 1} = 380 \text{ lb/in./in.}$$

$$< 1920 \text{ lb/in./in.}$$

2.4.2 Face wrinkling due to biaxial loading



$$\frac{s}{t_c'} = \frac{0.25}{0.002} = 125$$

$$\frac{F_{cw}}{\eta_2} = 270\ 000 \text{ psi}$$

determined from empirical data

where F_{cw} = allowable wrinkling stress of core

$$\eta_2 = \sqrt[3]{\frac{3\ E_t + E_s}{4\ E}} \tag{17A}$$

= modified plasticity coefficient

E_t = tangent modulus

E_s = secant modulus

γ_i = 1

$$\frac{F_{cw_x}}{\eta_2} = \frac{F_{cw}/\eta_2}{\sqrt[3]{1+\gamma^3}} = \frac{270\ 000}{1.26} = 214\ 000 \text{ psi} \tag{18A}$$

$F_i = \gamma_i\ F_{cw_x}$

$$\frac{F_i}{\eta} = 214\ 000 \times 1 = 214\ 000 \text{ psi}$$

$$\frac{F_{cy}}{F_i/\eta} = 0.89$$

F_{i_x} = 190 000 x 0.88 = 169 000 psi

determined from empirical data

$$F_{cw_x} = \frac{169\ 000}{1} = 169\ 000 \text{ psi}$$

Margin of safety

$$= \frac{F_{cw_x}}{f_x} - 1 = \frac{169\ 000}{150\ 000} - 1 = 0.13$$

2.4.3 Shear Crimping

$$s \times t_c = 0.25 \times 0.002 = 0.0005$$

$$G_c' = 48\ 000 \text{ psi}$$

Then the maximum allowable shear crimping stress in the direction of the maximum principle stress is

$$F_{cs_{max}} = \frac{G_c'\ (c + 2t_f)}{2t_f} = \frac{48\ 000\ (0.3 + 0.012)}{0.012} \qquad (19A)$$

$$= 1\ 250\ 000 \text{ psi}$$

Margin of safety

$$= \frac{F_{cs_{max}}}{f_{max}} - 1 = \frac{1\ 250\ 000}{15\ 000} - 1 = 82$$

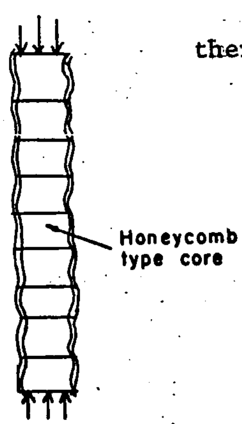
2.4.4 Dimpling of Facings

F_{ci} = intracell buckling strength of core

$$R_x^n + R_y^n = 1 \quad \text{for critical condition} \qquad (20A)$$

2.4.4.1 For skin thickness of 0.006 in.

$$\frac{s}{t_f} = \frac{0.3}{0.006} = 50 > 15.63$$



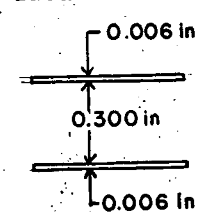
therefore

$$n = 3$$

$$\frac{F_{ci}}{\eta} = 64\ 000 \text{ psi} \qquad (21A)$$

determined from empirical data

$$\frac{F_{cy}}{F_{ci}/\eta} = \frac{190\ 000}{64\ 000} = 2.97$$



f_x' = combined stress (bending and in-plane load) parallel to x-axis

f_y' = combined stress (bending and in-plane load) parallel to y-axis

$$F_{ci} = 190\ 000 \times 0.365 = 67\ 500 \text{ psi}$$

$$R_x = \frac{f_x'}{F_{ci}} = \frac{150\ 000}{67\ 500} = 2.22$$

$$R_y = \frac{f_y'}{F_{ci}} = 2.22$$

$$R_x^n + R_y^n = 2.22^3 + 2.22^3 = 22$$

2.4.4.2 For skin thickness of 0.020 in. (at edges)

$$\frac{s}{t_f} = \frac{0.3}{0.02} = 15 < 15.63$$

therefore

$$n = 2 + \left(\frac{15.63}{15}\right)^2 = 3.09 \qquad (22A)$$

$$\frac{F_{ci}}{\eta} = 390\ 000 \text{ psi}$$

determined from empirical data

$$\frac{F_{cy}}{F_{ci}/\eta} = \frac{190\ 000}{390\ 000} = 0.49$$

$$F_{ci} = 190\ 000 \times 0.945 = 180\ 000 \text{ psi}$$

determined from empirical data

$$R_x = \frac{f_x'}{F_{ci}} = \frac{150\ 000}{180\ 000} = 0.833$$

$$R_y = \frac{f_y'}{F_{ci}} = 0.833$$

$$R_x^n + R_y^n = 0.833^{3.09} + 0.830^{3.09} = 1.1 \qquad (20A)$$

2.4.4.3 It is recognized, therefore, that intracell buckling may occur in regions of maximum stress. This does not constitute failure, however, and is an indication of efficient design in this application.

2.5 Interior Loading on Panels

Inner containers are allowed to collapse during shock load. However, the effect of contents on the bottom and side panels of the container must be checked.

During the impulse of 85 G (78 G maximum plus any effects of elasticity of supports etc.) the load reacted by the panel due to the contents under the above impulse is maximum, considering that 40 lb of samples are contained in the box.

Maximum load = 85 x 40 = 3400 lb

Equivalent uniform distributed load on bottom panel is:

$$\frac{3400}{18.91 \times 11.45} = 15.7 \text{ lb/in.}^2$$

Note:

This provides a safety factor of 20/15.7 = 1.27 over design for uniform pressure of 20 psi.

Equivalent uniform distributed load on front panel is:

$$\frac{3400}{6.24 \times 18.91} = 28.8 \text{ lb/in.}^2$$

$$\frac{b}{a} = \frac{18.91}{6.24} = 3.04$$

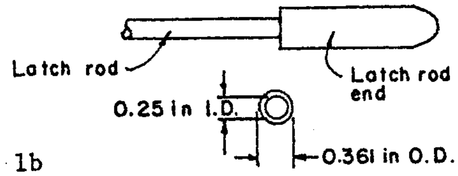
$$M_{max} = 0.1189 \times 28.8 \times 6.24^2 \qquad (1A)$$

$$= 133 \text{ in.-lb/in.}$$

Note:

This provides a safety factor of $\frac{255}{133}$ = 1.9 over the design moment at the center of the lid. Hence the honeycomb section is capable of sustaining the load.

3.0 Latch



3.1 Latch Rod End (stainless steel)

Total weight of box = 50 lb

When the box is under 85 G impulse the total force acting at the pins is

$$50 \times 85 = 4250 \text{ lb (each pin takes 2125 lb)}$$

The cross section area of the pin is

$$\frac{\pi}{4}(0.361^2 - 0.25^2) = 0.067 \text{ in.}^2$$

Allowable shearing force

$$0.067 \times 105\ 000 = 7000 \text{ lb}$$

Margin of safety

$$\frac{7000}{2125} - 1 = 2.3$$

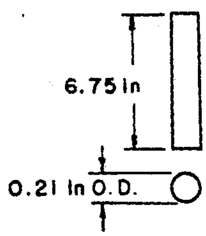
3.2 Latch Rod (aluminum)

The friction of the pin during operation is assumed to be 20 lb. This force is transferred to the latch rod as compression.

$$I = \frac{\pi d^4}{64} = \frac{\pi \times 0.21^4}{64} = 0.0000955 \text{ in.}^4 \tag{23A}$$

$$P_{cr} = \frac{\pi^2 EI}{L^2} = \frac{\pi^2 \times 10 \times 10^6 \times 0.0000955}{6.75^2} \tag{24A}$$

$$= 208 \text{ lb}$$



Margin of safety

$$\frac{208}{20} - 1 = 9.4$$

3.3 Push Rod Pivot Pin

$$\text{o.d.} = 0.11 \text{ in.}$$

$$A = \frac{\pi}{4} \times 0.11^2 = 0.0095 \text{ in.}^2$$

For double shear use aluminum. Allowable shearing force

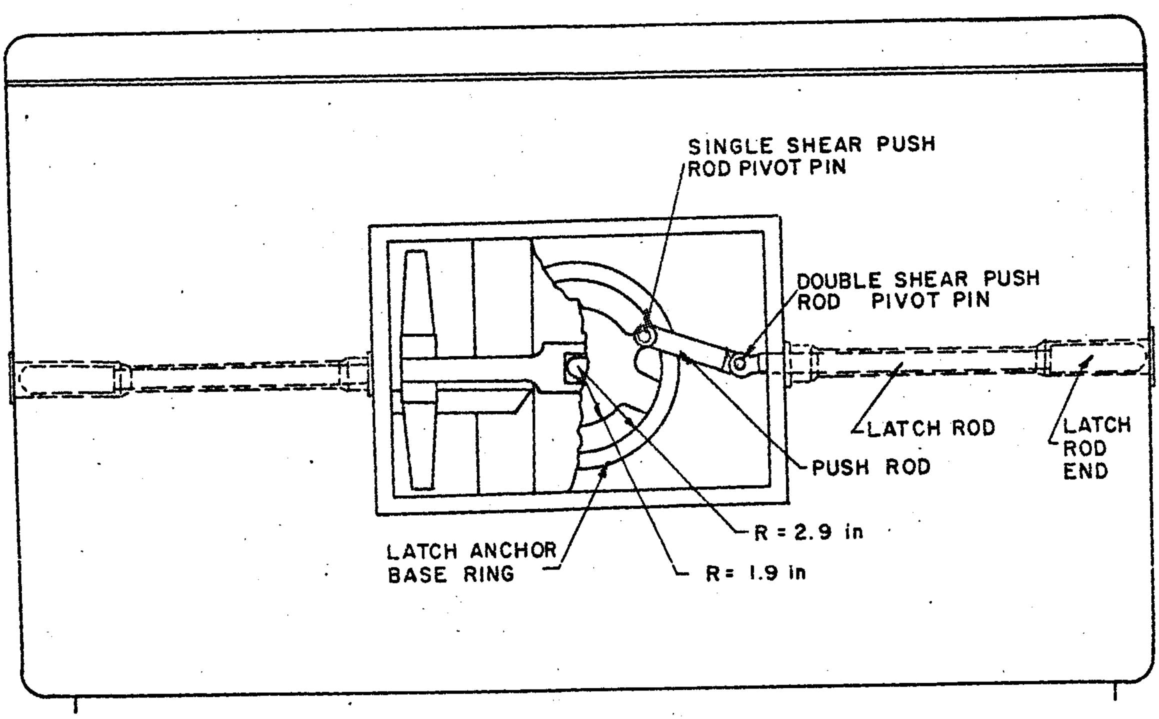
$$2 \times 0.0095 \times 9000 \quad = \quad 171 \text{ lb} > 20 \text{ lb}$$

For single shear use stainless steel. Allowable shearing force

$$0.0095 \times 105{,}000 \quad = \quad 1000 \text{ lb}$$

Margin of safety

$$\frac{1000}{20} - 1 \quad = \quad 49$$



3.4 Latch Anchor Base Ring

Check the bearing stress of the base ring. For conservative design, assume half of the ring is cut out.

Bearing area

$$\frac{1}{2} \times \frac{\pi}{4} (2.9^2 - 1.9^2) = 1.88 \text{ in.}^2$$

The bearing materials are aluminum and stainless steel. The bearing strength of aluminum is less and is therefore critical.

Allowable bearing strength for aluminum

$$= 15\ 000 \text{ psi}$$

Allowable bearing force

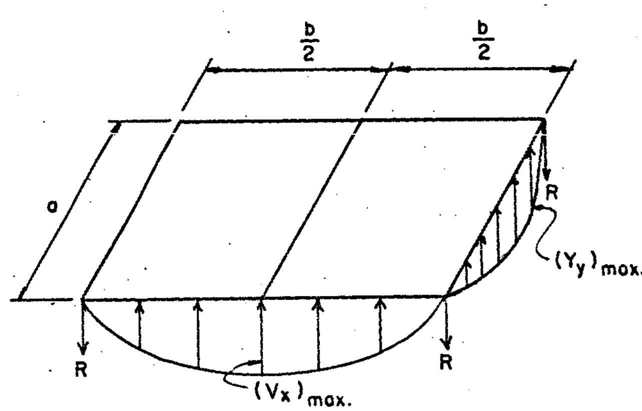
$$15\ 000 \times 1.88 = 28\ 200 \text{ lb}$$

All other members have been checked using the same concepts.

4.0 Seal

4.1 Load Distribution

Considering the container lid as a simply supported rectangular plate (i.e., assuming failure of secondary latching mechanism), the distribution of reactions will be approximately as shown below.



Note that the simply supported plate has concentrated reactions at corners. The corners of the lid will be held firmly in place by the latching device discussed in Section 4.2.

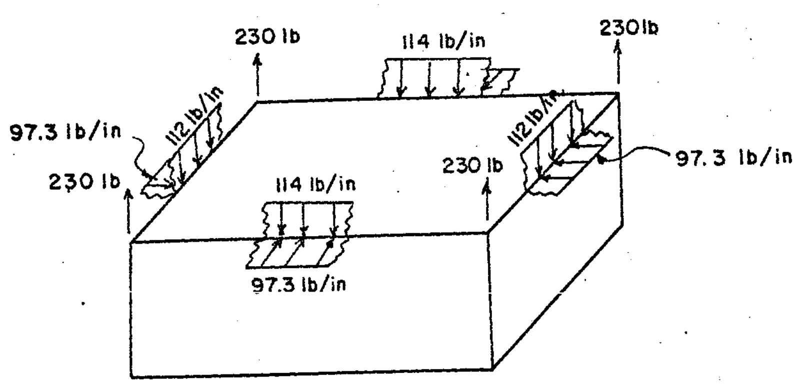
Magnitude of reactions is:

$$R = 0.088\ qa^2 = 0.088\ (20)(11.45)^2 = 230\ \text{lb} \qquad (25A)$$

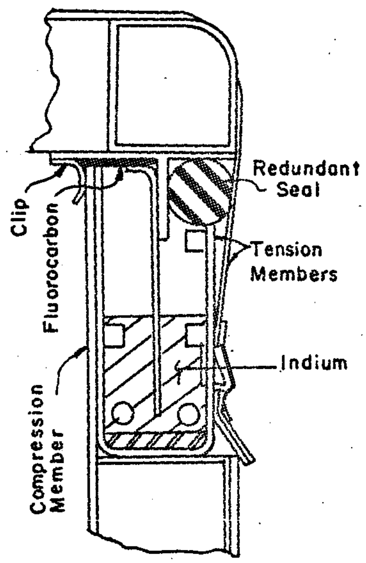
$$(V_x)_{max} = 0.496 \times 20 \times 11.45 = 114\ \text{lb} \qquad (16A)$$

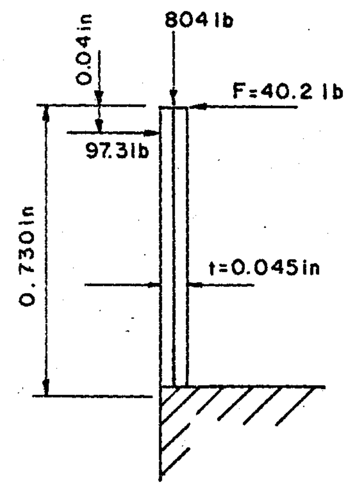
$$(V_y)_{max} = 0.488 \times 20 \times 11.45 = 112\ \text{lb}$$

These reactions will be transmitted to sides of container as shown below:



Note also that across the seal there will be a shear force from the side panels. The magnitude of this force will be 97.3 lb/in. maximum. This force is transferred to the shear member.





COMPRESSION MEMBER

Assume coefficient of friction between fluorocarbon and polished steel $= 0.05$

$$F = fN = 0.05 \times 804 = 40.2 \text{ lb} \qquad (26A)$$

Therefore net shear force

$$97.3 - 40.2 = 57.1 \text{ lb}$$

Shear stress on clip:

Force per in.of clip

$$\frac{57.1 \times 18.56}{4 \times 2.25} = 118 \text{ lb}$$

Shear stress $$\frac{118}{0.010 \times 1} = 11\,800 \text{ psi}$$

Shear Stress on 0.045 in. member

$$\frac{57.1}{0.045 \times 1} = 1270 \text{ psi}$$

Check 0.045 in. compression member

$$M_{max} = 57.1\ (0.730 - 0.040)$$

$$= 39.4 \text{ in.-lb}$$

$$I = \frac{bh^3}{12} = \frac{1 \times 0.045^3}{12} = \frac{0.000091}{12} \quad (27A)$$

$$= 0.0000076 \text{ in.}^4\text{/in.}$$

$$f_b = \frac{Mc}{I} = \frac{39.4 \times 0.0225}{0.0000076} \quad (28A)$$

$$= 117\,000 \text{ psi}$$

The distributed compressive load is 114 lb/in. Add to this the compressive force of 690 lb/in. induced by the secondary latching mechanism (see Section 4.3).

This member will behave as a wide column.

$$P = 114 + 690 = 804 \text{ lb/in.}$$

$$f_c = \frac{P}{A} = \frac{804}{0.045 \times 1} = 17\,850 \text{ psi}$$

For elastic behavior

$$q_e = \frac{2\ Et^3}{12(1 - \mu^2)L_e^2}$$

Where q_e = critical distributed force in lb/in.

$$L_e = 0.73 \text{ in. (simply supported)}$$

$$q_e = \frac{3.14^2 \times 30 \times 10^6 \times 0.045^3}{12\ (1 - 0.3^2)\ 0.730^2}$$

$$= 4600 \text{ lb/in.}$$

$$F_{cr_c} = \frac{q_e}{A} = \frac{4600}{0.045 \times 1} = 102\ 000 \text{ psi}$$

$$\frac{f_c}{F_{crc}} + \frac{f_b}{F_{cy}} = \frac{17\ 850}{102\ 000} + \frac{117\ 000}{190\ 000}$$

$$= 0.790 < 1.0 \qquad (20A)$$

4.2 Secondary Latching Mechanism

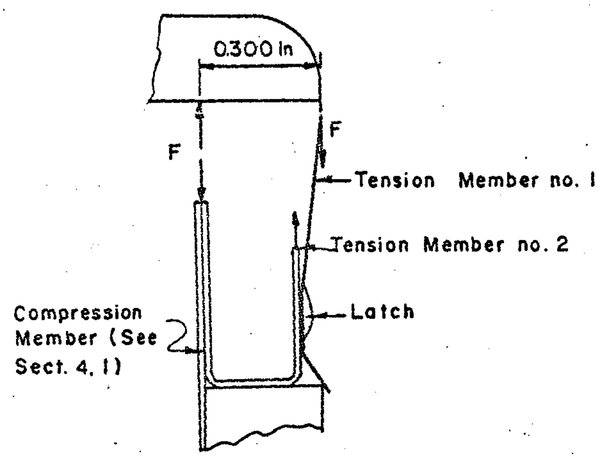
A secondary latching mechanism is provided around circumference of lid to prevent rotation of edges. This will decrease both lid deflection and seal stresses (indium). The maximum fixed-end moment which can be developed is:

$$M = (0.079)(20)(11.45)^2 = 207 \text{ in.-lb/in.} \qquad (1A)$$

This moment will be developed as a 0.30 in. couple.

therefore

$$F = \frac{207}{0.30} = 690 \text{ lb/in.}$$



Increase thicknesses in vicinity of latches

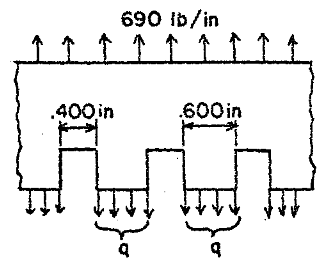
$$q = \frac{690}{0.60} = 1150 \text{ lb}$$

Use thickness = 0.020 in.

$$f = \frac{1150}{0.020} = 57\ 500 \text{ psi}$$

Margin of safety

$$\frac{190\ 000}{57\ 500} - 1 = 2.30$$



TENSION MEMBER NO. 1

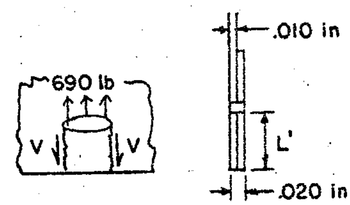
A high margin of safety is required due to the stress concentrations.

Bearing stress

$$\frac{690}{0.333 \times 0.020} = 103\ 600 \text{ psi}$$

Single shear force

$$V = \frac{690}{2} = 345 \text{ lb}$$



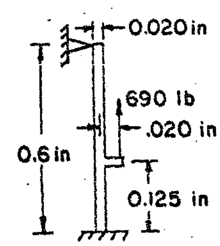
TENSION MEMBER NO. 1

Allowable shear stress = 115 000 psi

Area required to resist shear

$$\frac{345}{115\ 000} = 0.003 \text{ in.}^2$$

$$L'_{min} = \frac{0.003}{t} = \frac{0.003}{0.020} = 0.150 \text{ in.}$$



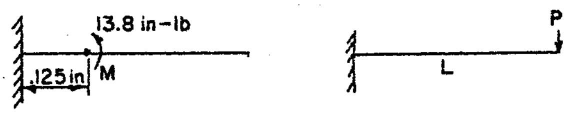
TENSION MEMBER NO. 2

Shear force on latch = 690 lb

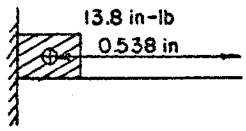
Minimum thickness of latch = t_{min}

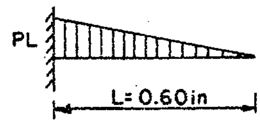
$$t_m = \frac{690}{0.333 \times 115\ 000} = 0.018 \text{ in.}$$

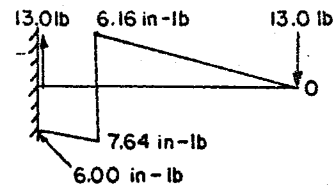
Moment M = 690 x 0.020 = 13.8 in.-lb



LOADING DIAGRAMS







MOMENT DIAGRAMS

deflection at right hand $=$ 0

$$\frac{13.8 \times 0.125}{EI} \times 0.538 = \frac{\frac{1}{2}PL^2 \times \frac{2}{3}L}{EI} \qquad (29A)$$

$$0.93 = \frac{1}{3}P \times 0.6^3$$

$$P = 13.0 \text{ lb/in.}$$

$$M_{max} = 13.0 \times 0.475 = 6.16 \text{ in.-lb}$$
over an area of 0.333 in.

Reinforce tension member #2 to distribute the load over the entire width

$$I = \frac{1 \times 0.020^3}{12} = 0.00000067 \text{ in.}^4\text{/in.} \qquad (27A)$$

$$f_b = \frac{7.64 \times 0.010}{0.00000067} = 114\ 000 \text{ psi} \qquad (28A)$$

$$f_a = \frac{690}{1 \times 0.020} = 34\ 500 \text{ psi}$$

$$f = f_b + f_a = 148\ 500 \text{ psi}$$

Margin of safety

$$\frac{190\ 000}{148\ 500} - 1 = 0.27$$

4.3 Lid Deflection

The latch mechanism provides a form of edge fixity. For fixed edges the deflection at the center of the lid is

$$\omega = 0.0023 \frac{qa^4}{D} = 0.085 \text{ in.} \approx 0.1 \text{ in.} \quad (30A)$$

5.0 Chemical Milling

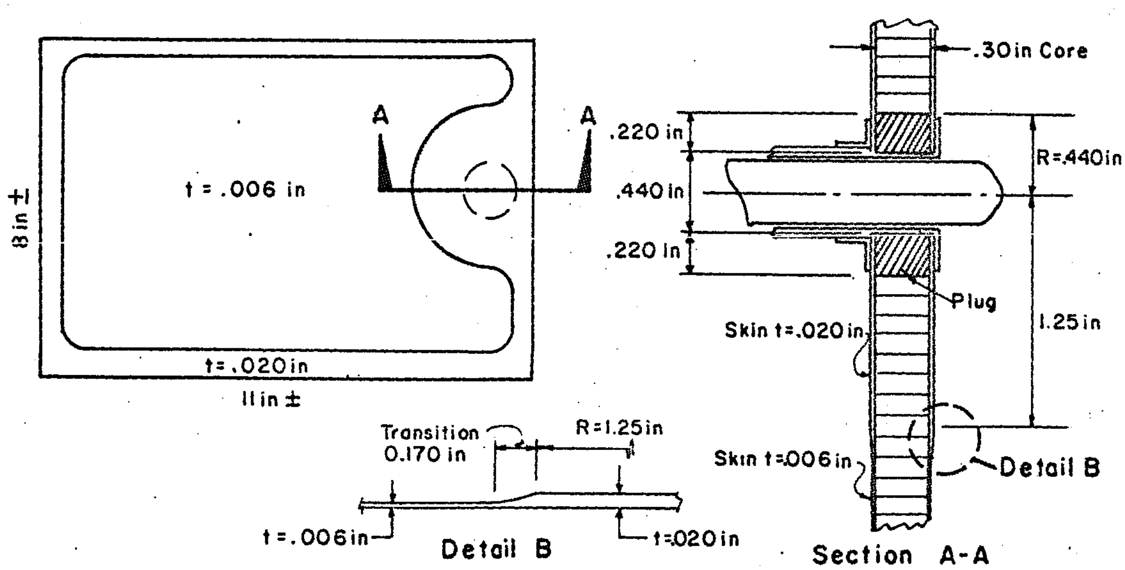
Sandwich panels will be fabricated using 0.020 in. face sheets which will then be chemical milled to desired nominal gauge. This will also allow the incorporation of reinforced sheet in areas of stress concentration by using a selective chemical milling process. Increased skin thicknesses will be maintained at the panel edges and at the pin mounting areas to resist these stress concentrations.

5.1 Side Panel Pin Support

The two side panel pins are assumed to carry the total 85 G impulse load. Load P per pin does not exceed

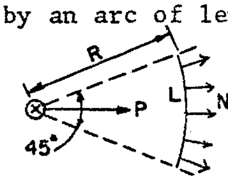
$$50 \times \frac{85}{2} = 2100 \text{ lb}$$

Reinforce the sandwich core with a solid plug and a thicker skin in the vicinity of the hole.



Assume the force due to pin reaction is distributed outward from the pin to the skin over an area subtended by an arc of length L.

therefore



N = force per inch of arc = P/L

Then at a distance R from the pin center, and for an arc defined by a 45^{o} angle

$$N = \frac{2100}{\pi R/4} = \frac{2680}{R} \text{ lb/in.} \tag{31A}$$

At the inner edge of the solid plug

$$R = 0.220 \text{ in.}$$

$$N = \frac{2100}{0.220} = 9540 \text{ lb/in.}$$

Bearing stress

$$\frac{N}{t} = \frac{9540}{0.340} = 28\ 000 \text{ psi}$$

At the inner edge of 0.020 in. skin (outer edge of plug)

$$R = 0.440 \text{ in.}$$

$$N = \frac{2100}{0.440} = 4780 \text{ lb/in.}$$

Compressivestress $f_a = \frac{N}{t}$

$$= \frac{4780}{2 \times 0.020} = 120\ 000 \text{ psi}$$

At the outer edge of the 0.020 in. skin (where it begins the transition to a 0.006 in. skin)

$$R = 1.250 \text{ in.}$$

$$N = \frac{2100}{1.250} = 1680 \text{ lb/in.}$$

$$f_a = \frac{N}{t}$$

$$f_a < \frac{1680}{2 \times 0.006} = 140\ 000 \text{ psi}$$

At the inner edge of the 0.006 in. skin (where the transition ends)

$$R = 1.250 + 0.170 = 1.420 \text{ in.}$$

$$N = \frac{2100}{1.42} = 1480 \text{ lb/in.}$$

$$f_a = \frac{N}{t} = \frac{1480}{2 \times 0.006} = 123\ 000 \text{ psi}$$

Add to the compressive stresses the stresses due to the exterior pressure of 20 psi, assuming the edges are fixed.

$$\frac{b}{a} \approx \frac{11}{8} \approx 1.4$$

$$M_{max} = 0.0568 \times 20 \times 64 = 73 \text{ in.-lb/in.} \tag{1A}$$

At the inner edge of the 0.020 in. skin

$$f_b = \frac{M}{t_f t_c} = \frac{73}{0.020 \times 0.3} = 12\ 200 \text{ psi} \tag{2A}$$

$$f = f_a + f_b = 120\ 000 + 12\ 200$$

$$= 132\ 200 \text{ psi}$$

At the inner edge of the 0.006 in. skin

$$f_b < \frac{73}{0.006 \times 0.3} = 40\ 600 \text{ psi}$$

$$f < 123\ 000 + 40\ 600 = 163\ 600 \text{ psi}$$

At the beginning of the transition to the 0.006 in. skin

$$f_b < \frac{73}{0.006 \times 0.3} = 40\ 600 \text{ psi}$$

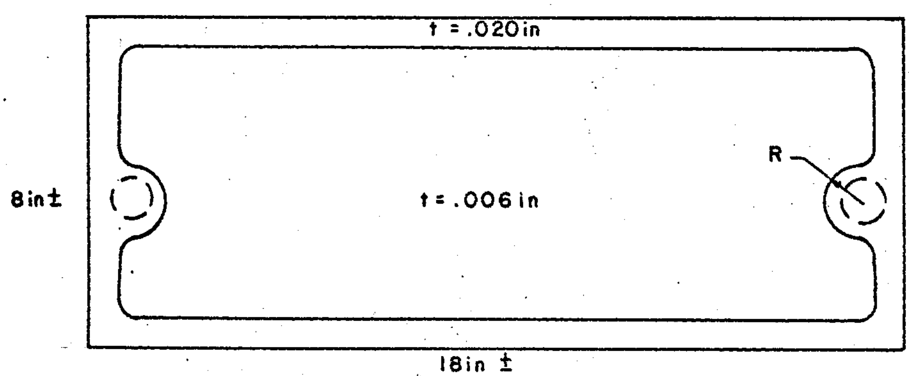
$$f < 140\ 000 + 40\ 600 = 180\ 600 \text{ psi}$$

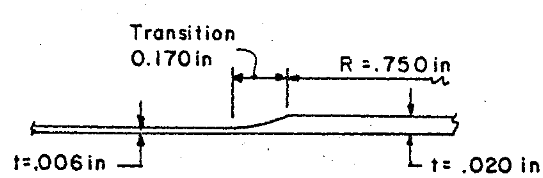
5.2 Rear Mounting Pins

The major load on rear pins will result from transverse impulse of 30 G. As an approximation, it will be assumed that these pins react entire force of container (although, for equilibrium under transverse acceleration, side pins must also be loaded)

$$P = 50 \times \frac{30}{2} = 750 \text{ lb per pin}$$

For simplification in fabrication and additional safety, the same plugs are used for the rear pin mounts as were used to reinforce the sandwich core at the side pins.





Use the same method employed in Section 5.1 and with

$$M = \beta q a^2 = 0.0571 \times 20 \times 64 \qquad (1A)$$

$$= 73 \text{ in.-lb/in.}$$

At the inner edge of the 0.020 in. skin

$$f = f_a + f_b = 54\ 200 + 12\ 000 = 66\ 200 \text{ psi}$$

At the inner edge of the 0.006 in. skin

$$f < 86\ 500 + 40\ 600 = 127\ 100 \text{ psi}$$

At the beginning of the transition to the 0.006 in. skin

$$f < 106\ 000 + 40\ 600 = 146\ 600 \text{ psi}$$

5.3 Inner Latch Housing

As an approximation, consider it as a rectangular plate under 20 psi uniform distributed load, with four edges fixed.

$$\frac{b}{a} = \frac{6.4}{3.75} = 1.7$$

$$M_{max} = 0.0799 \times 20 \times 3.75^2 \qquad (1A)$$

$$= 22.2 \text{ in.-lb/in.}$$

$$t = 0.032 \text{ in. (stainless steel)}$$

$$I = \frac{1}{12} \times 1 \times 0.032^3 = 0.0000027 \text{ in.}^4 \qquad (27A)$$

$$f_b = \frac{22.2 \times 0.016}{0.0000027} = 133\ 000 \text{ psi} < 190\ 000 \text{ psi} \qquad (28A)$$

APPENDIX B

SUMMARY OF OPINIONS FROM SCIENTIFIC COMMUNITY

INTRODUCTION

The opinions of scientific experts are an essential component in the solution of the lunar sample acquisition problem. This appendix reports a sampling of comments and suggestions by various members of the Early Apollo Sciences Teams and other persons suggested by NASA. It should be noted that the following summary is the contractor's best attempt to present often diverse opinions of the experts interviewed, each of whom spoke principally from the viewpoint of his own discipline. The material is segregated into the following categories:

- Box Material Selection
- Sample Protection System
- Sterilization
- Bacteriological Sampling
- Gas Sampling
- General Design Considerations

Each section has been arranged in sub-sections according to the fields of interest of the contributors. Those contacted included:

- Dr. James R. Arnold, Univ. of Calif., San Diego, Calif.
- Dr. P. R. Bell, Oak Ridge National Laboratories, Oak Ridge, Tenn.
- Dr. Klaus Bieman, MIT, Cambridge, Mass.
- Dr. M. Calvin, Univ. of Calif., Berkeley, Calif.
- Dr. Clifford Frondel, Harvard Univ., Cambridge, Mass.
- Dr. V. W. Green (for Dr. Gaylord Anderson), Univ. of Minn.
- Dr. A. J. Haagen-Smit, Calif. Inst. of Tech., Pasadena, Calif.
- Dr. Kurt Hemenway, Dudley Observatory, Albany, N. Y.
- Dr. R. V. Hoffman (for Dr. C. R. Phillips), Ft. Detrich, Frederick, Md.
- Dr. R. M. Lemon, Univ. of Calif., Berkeley, Calif.
- Dr. J. Hoover Mackin, Univ. of Texas, Austin, Texas
- Dr. Brian Mason, Am. Museum of Natural History, New York, N. Y.
- Dr. Wayne Meinke, National Bureau of Standards, Washington, D. C.
- Dr. John W. Salisbury, Air Force Cambridge Research Laboratories, Mass.
- Dr. Peter Signor (for Dr. Paul Gast), Univ. of Minn., Minneapolis, Minn.
- Dr. Karl Turekian, Yale Univ., New Haven, Conn.
- Dr. Aaron Waters, Univ. of Calif., Santa Barbara, Calif.

Comments by individual contributors are noted by separate numbers within the sub-headings. Letters in parentheses (A), (B), etc., following each comment, may be keyed to the disciplines of the individual contributor as follows:

(A) Bio-Sciences
(B) Geo-Chemistry
(C) Mineralogy and Petrology
(D) Geology
(E) Other Sciences

BOX MATERIAL SELECTION

1. Any container contaminant should be a common identifiable material. The most undesirable contaminants would be uranium, thorium, lithium, berilium, boron, and lead. Next in importance would be rubidium, strontium, and the rare earths. In general, all contamination by elements with higher molecular weights than nickel should be avoided if possible. (A)

2. Iron, aluminum, and silica would be satisfactory packaging contaminants. Packaging materials should be gas-free. (A)

3. Catalysts used in the manufacture of many plastics may contain trace metals which would mask parts of the investigations. (A)

4. No plastics of any kind should be used except compounds such as fluorocarbons with known signatures. Polyester films would have to be very carefully analyzed and identified. Gold, aluminum, titanium are satisfactory minerals. (A)

5. Suggest a high purity aluminum for inner bag liner. (B)

6. Fluorocarbon or polyethylene are satisfactory as sample containers. No strict constraints except container should not generate particles. It would be a good idea to have two kinds of containers, such as stainless steel and fluorocarbon, to check one against the other. Should not use silicone or titanium. (E)

7. Polyester films must be degassed before coating. (E)

8. Should not use lead, gold, or indium for seal. Avoid rare gases. (E)

9. Pure TFE fluorocarbon, monitored from factory and cooked in a mass spectrometer for signature checkout, is acceptable. It should be degassed by frying in vacuum. (B)

10. Extensive work should be done on signature identification of fluorocarbon, particularly after subject to bombardment. Extreme care must be exercised controlling the manufacture of the fluorocarbon used in the sampling material. (B)

11. Thorough controls must be exercised of all materials used in the container system and such controls must be extended to the element and compound level as required for quality assurance. (B)

12. Inconel 718, stainless steel, and titanium are all acceptable for container materials. Copper is satisfactory for inner bags. (B)

13. Fluorocarbon is acceptable provided that it is pure. (B)

14. Gasket material in order of preference is (1) fluorocarbon, (2) gold, (3) indium. (B)

SAMPLE PROTECTION SYSTEM

1. The amount of packing materials depends on the ratio of dust versus hard rocks. If primarily dust, only a small amount (100 cc) needs be preserved in structural form. Changes in sample make-up with depth are important to preserve and identify. (A)

2. The physical condition of the samples is important only from a surface contamination standpoint, i.e. the smaller the samples the larger the ratio of surface area to volume. (A)

3. Protect samples by keeping them rigidly fixed, not cushioned. (B)

4. Rock protection is not a primary concern. Broken rock samples will be acceptable. (B)

5. Rock samples are apt to be either very fragile or very tough. (B)

6. Most of project objectives will be met even with unprotected samples. (C)

7. At least one special sample should be protected against vibration to preserve surface texture. (C)

8. Abrasion important from standpoint of sample container strength, not the effect on samples. (D)

9. Lunar surface may be covered with a thick dust layer which is structurally weak. Except to preserve a structural sample, packaging should not be critical. (E)

10. Low density dust material is not anticipated since particles should fall back to lunar surface at high velocity due to lack of atmosphere. (E)

11. Doubt that trace contamination in a reasonably protected sample will impede analysis work. (B)

12. Maintain 2-10 lb of samples in ultra-high vacuum. Remainder of samples should have reasonable protection. Suggest that high purity or equivalent is adequate for all but the ultra-high vacuum canister. (B)

13. Contamination from packaging materials could be a serious problem. Aluminum is one of the materials which would be satisfactory for an inner bag. (B)

14. Diffusion of gas from one bag into another is not a serious problem. (B)

15. Bags should be carried to the moon in a hyper-clean state. Ion bombardment is a much better method than electron bombardment for precleaning due to higher energy levels. (B)

16. Effective outgassing of container cannot be done at temperatures below 600-800°C. Recommend copper rather than aluminum foil because of this. (B)

17. Interaction between samples, individually bagged in rock box is likely to be negligible. (C)

18. Inner sample bags need not maintain vacuum. However, special containers should be provided for lunar gas samples. (C)

19. Very particular about sample orientation - which side up, lunar north, etc. (B)

20. Sample orientation (up, north) and temperature not too important. (B)

21. Several hundred 1-1/2 in. diameter bags should be provided. Five-gram samples (pebble size) are adequate. Generally prefer a large number of small samples about 1/2 in. The astronaut should have a device for determining the temperature of samples. (C)

22. Special sampling tubes should be provided for dust samples, gas samples, and surface texture preservation. (C)

23. Orientation (up, north, etc.) is important for geophysical but not for most geological purposes. (D)

24. Anticipate high electrostatic charge. (E)

25. Rather see more weight of sample brought back than trade payload for sophisticated packaging techniques. Want a representative sample. (B)

26. Thermal protection between high and low temperature samples is not important for first mission. (B)

27. Most important to have at least one large rock 8 to 10 lb. (C)

28. Thermal conditions not important - temperature cycling has occurred on the moon surface. (D)

29. Age determination will require a large bulk sample. (D)

30. Samples should impart no particular radioactive hazard. However, warming of cold samples may anneal dislocations or crystallization due to radiation. (E)

31. Specific gravity is expected to vary from 1.5 to 3.0. (E)

32. Expect to see high electrostatic forces, adhesion through Van der Wahl's forces. Otherwise, low physical characteristics have been exhibited by sifted dust layers used in laboratory experiments. (E)

33. Special containers should hold the specimens in a compass orientation. Prefer that some samples be maintained under slight pressure to hold the laminates or laminations of the specimen. (B)

STERILIZATION

1. Satisfactory sterilization procedure would be to heat innermost components to 135°C for 24 hours, with correspondingly higher temperatures on outer walls. (A)

2. Five (5) percent of spacecraft electronic components have been found to be contaminated. (A)

3. The exterior of sample box could be sterilized upon return to earth by washing with fuming nitric acid, then washing with distilled water. (A)

4. The technology for sterilization and acquisition of lunar biologic samples is similar to earth procedures. Sample containers must be sterilized by classical techniques. Baking at 600-800°C is satisfactory. (A)

5. The entire box must be sterilized before shipment. (A)

6. When sample boxes arrive they should be checked to see if leakage has occurred either from outside in or from inside out. Boxes should then be disinfected and placed in secondary containers at 10^{-6} torr, to minimize chances of further terrestrial contamination. (B)

BACTERIOLOGICAL SAMPLING

1. A small inner container should suffice for ultra-hard vacuum preservation of the biological samples. All other samples should be stowed in the vacuum sample container. (A)

2. Inert gas atmosphere in sample box is satisfactory. A few spores would not particularly hurt organic chemical evaluation. Silicone should be avoided. Rocket fuel combustion products are very important. A single batch should be made sufficiently large such that the spacecraft requirements and subsequent evaluations can be completed on the same batch. (A)

3. Probably will not find any germs on moon. (A)

4. Viruses are not likely to be found because of their specialized nature. Sterilization is aimed at bacteria, not virus. (A)

5. Samples should be packed in containers in which experiments will later be done, rather than risk transferring samples. Ports for the insertion of a syringe for innoculation of broth directly into samples would be helpful. It would also be helpful if these sample containers were transparent.(A)

6. Biological findings are likely to be prejudiced by minimal packaging protection - but this is small part of overall objective. (C)

7. The spacecraft appears to be the major contamination source. (C)

8. Acquisition of microbiological samples might be done with a hollow coring tube, using fluorocarbon plugs as spacers, and keeping the tube as a storage device. (A)

9. It is more important to obtain reliable samples than to maximize returned sample weight. Would prefer, for biosciences purposes, 25 1-gram samples, 5 or 10 samples weighing 100 to 250 grams, and one sample weighing 1000 grams. (A)

10. Astronaut training is a most important facet of acquiring biologic samples. Microbiological data may also be acquired from geological samples. Configuration of sample container is not a constraint, but transparency would be useful. Initial acquisition sample containers should be designed to accommodate later laboratory experiments. (A)

11. Microbiologists must have access to samples first in order to examine for presence of organisms. Need only 5 to 10 samples weighing a few grams for microbiological tests. Formaldehyde and alcohol or ethylene oxide in gaseous form can be used to sterilize the outside of the container. (A)

GAS SAMPLING

1. Should not use getters, and containers should not be pumped. Otherwise, gas production analysis would be invalidated. (B)

2. Control bags identical to those in the sample box should be analyzed for outgassing during the mission. High vacuum samples should equal five

percent of total sample weight. Would prefer these to be in many two to four-gram containers rather than one large container. Glass breakoff containers should be designed to weigh under 30 grams, and would provide a total of 50 samples in the 5% weight allowance. (B)

3. Interested in analyzing gases in the sample, as well as on the sample. Therefore, would like one surface sample and several at increasing depths. (B)

4. Must have several gas sample containers so experiments can be repeated to check for reproducibility and quality of work. (B)

5. Suggest copper foil rather than aluminum for bags, since copper can be degassed at 800°C while the temperature limitation for aluminum is 450°C. In addition, copper is better for pinch sealing, since aluminum must have a clean surface which is highly reactive, and copper can be crimped without special surface treatment. Suggest manufacturing technique investigations involving dipping copper mesh into copper. (B)

6. Signal to noise ratio for gas studies is bad with small bags, and must have several large bags for higher quality experiments. Bags must have navel with puncture diaphragm 1/8 to 3/8 in. diameter for gas sampling. (B)

7. Gas sampling port should be provided in the sample box for preliminary check of interior at receiving laboratory. Suggest fitting to accept pointed probe from analyzing equipment which would rupture disk in vacuum liner. (B)

GENERAL DESIGN CONSIDERATIONS

1. A pressurized box with inert atmosphere would not be harmful. Satisfactory inert gases are helium, argon, and nitrogen. (A)

2. Partial pressures of suit and gloves may be important source of contaminating gases. (B)

3. Pressure of 10^{-7} torr is adequate for most samples. Preserving the lunar environment is important for only a very small percentage of samples. (B)

4. A pressure relieving device is probably essential, since a possibility exists that certain samples could evolve large volumes of gas. (B)

5. If 10^{-14} torr cannot be maintained in box or around samples, then 10^{-3} or 10^{-2} may be as acceptable as 10^{-8} or 10^{-9}. (C)

6. Sample box should maintain 10^{-8} torr vacuum. Another approach may be to use a controlled atmosphere of nitrogen. (C)

7. Anticipate difficulty in achieving seal due to flying dust particles. Recommend seal be protected with a non-sticky gas or liquid film. (E)

8. During the first mission, general reconnaissance is of prime importance. Therefore, many small containers should be used so as to get representative materials. Samples must be labeled. Notation of orientation may be important to ascertain cosmic ray and solar wind activity, and the astronaut should therefore attempt to denote vertical and north orientation. Try to bring back coherent and semi-coherent dust layers in separate bags, if possible. (A)

9. Fill one box first, then the other to simplify packaging. (B)

10. Rupture disk should be provided in the sample box as a gas relief valve. (B)

11. Receiving laboratory will want to place four hooks on top of box for handling purposes. (B)

12. Carrying handle should be kept flush with face of box. (B)

13. Passive thermal coatings may degrade due to electrostatic dust layers deposited on box surface. Advise use of sunshade rather than thermal coatings if elevated box temperature is a problem. (E)

14. Doubt that sticking within the container is a serious problem. (B)

15. Designers should keep in mind that the man mobility and simplicity are uppermost. (B)

16. Rare gas as a storage preservative should not be used. Clean nitrogen, if used, would have to be superclean, but would prefer no gas. (B)

APPENDIX C

SUMMARY OF TESTS AND SPECIAL ANALYSES

INTRODUCTION

Four areas of special significance in supplying data in support of the hardware designs presented in this report are summarized in the sections to follow. (1) Cold welding tests were performed with a variety of materials and loading conditions. (2) A series of indium seal tests was performed to evaluate the melting, wetting, adhesion, sealing, and vapor pressure characteristics of the material under a variety of conditions. (3) An outgassing analysis was performed to determine the pressure rise due to the release of sorbed gases from lunar material of an assumed physical characteristic when packaged within the sample container. (4) A series of packaging analyses was performed in support of the bag dispenser preliminary design program.

Each section is arranged independently and contains applicable descriptions, remarks, and conclusions.

COLD WELDING TESTS

Purpose

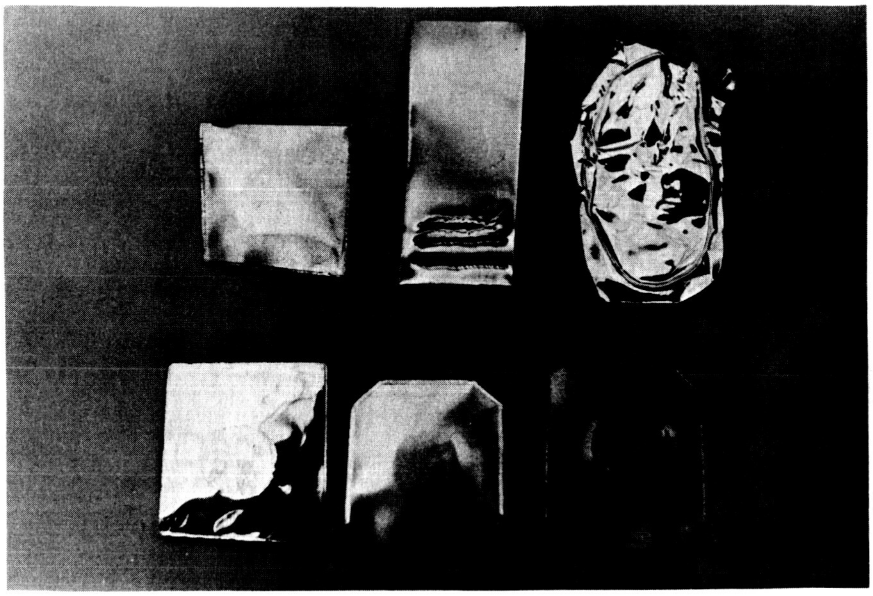
The objective of the cold welding or foil seal test program was to determine, if an effective means could be found to seal layers of metallic foil together for possible use as a backup to the principal box seal, as well as providing an effective closure for the flexible foil bags.

Equipment and Procedures

For this purpose, coupon tests were evolved, in which one inch square pillows were fabricated using a standard copper pinch-off tool and effecting an extrusion type compression seal. The pinch-off tool resembled a large bolt cutter with the contact edges fitted with a roller of hard steel. Using this technique, 25 pillows were fabricated of the following materials:

FIGURE 20

1 2 3



4 5 6

1. 0.004 in. copper foil, shear seal
2. 0.003 in. copper foil, vibration tool
3. 0.002 in. aluminum foil, vibration tool
4. 0.005 in. aluminum foil, shear seal
5. 0.003 in. copper foil, shear seal
6. 0.004 in. copper foil, shear seal

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COLD WELDING TEST
SEAL PILLOWS

0.003 in. copper
0.004 in. copper
0.002 in. aluminum
0.005 in. aluminum

Leakage tests were performed by placing these sample pillows in a vacuum chamber, evacuating the chamber to approximately 500 microns, pressurizing with Krypton 85 gas to one atmosphere (zero differential), evacuating to 2 mm, and then backfilling with air. By this technique parts which had gross leakage would be first evacuated and then backfilled with Krypton gas.

Following the above procedure, the samples were taken to a sodium iodized inhalation counter, where they were measured to determine the amount of gas which was admitted. The test was repeated with a 15 psi gauge pressure applied to the part for an 18 hour soak. This technique permitted 10^{-8} standard cc per second leak rate sensitivity to be obtained with the sample pillows. Test results were as follows:

Test No. 1 (0.003 and 0.004 in. copper). - The copper foil appeared to be too thick to perform effectively in the test configuration. As each edge was compression welded, the corner of the previous weld yielded. Although the technique used for these tests has been applied for many years to seal vacuum chamber tubulations, the stiffness of the material contributed to the leaks by concentrating forces from adjacent sealing activities. This was particularly true in areas work-hardened by compression sealing.

Test No. 2 (0.002 and 0.005 in. aluminum). - Test results for the aluminum samples were excellent. The 0.002 in. foil was successful , with 25 pillows passing the gross leak test and 21 passing a 10^{-8} leak test. The 0.005 in. foil gave similar results with 22 pillows passing the gross leak test and 20 passing the 10^{-8} test.

Test No. 3 (copper and aluminum foil). - Qualitative experiments were performed to determine if a pointed vibration tool could be used to effect a bond between two layers of foil. Using a hard substrate to back up the foil, reliable seals were obtained with both thicknesses of aluminum but were unsuccessful with the copper. While of some interest, the application appeared limited, and further tests to optimize the frequency and shape of vibration head tool were not conducted.

Test No. 4 (canning apparatus). - In addition to the foil evaluations, a series of tests was performed using commercial canning apparatus to determine if a reliable seal could be evolved using copper and gold plate and standard canning geometry. Considerable difficulty was encountered in obtaining reproducible results, a problem common to many cold welding experiments currently reported in the literature. Because of the satisfactory results obtained with the aluminum foil crush tests, further activities in the direction of adapting canning techniques did not appear warranted and the project was discontinued.

Conclusions

The quantitative results contained in this test series, while not eliminating copper, demonstrate that considerable work may be required to evolve a satisfactory technique. Results with aluminum demonstrated that a reliable compression weld could be obtained using compression techniques at ambient conditions. Translated to hard vacuum usage, there appears little doubt that an effective compression seal can be evolved for the flexible sample bags.

INDIUM SEAL TESTS

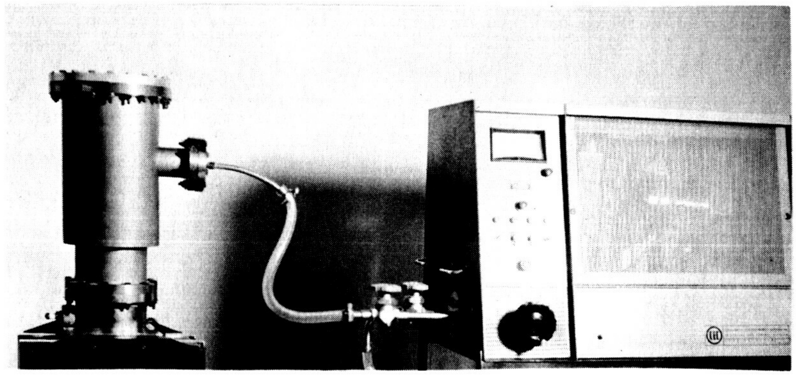
Purpose

The objective of this phase of the laboratory investigation was to evaluate the use of high purity indium metal as a sealing medium. Phases of this program included handling, cleaning, wetting, adhesion, and heating characteristics in a gland containing a heater unit similar to that proposed for the final design. A second test series was designed to check sealing and reliability characteristics, while a third group was performed at high temperature to determine vapor pressure characteristics of the metal at hard vacuum.

Equipment

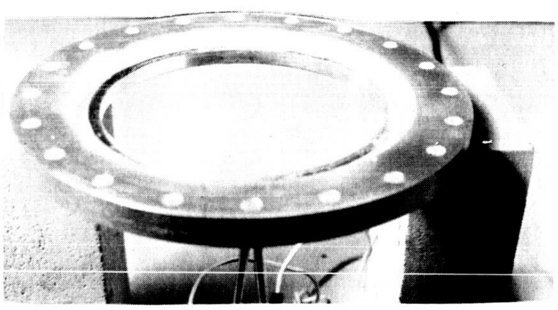
The ion pump test fixture and CEC helium mass spectrometer combination are shown in Fig. 21. Details of the test fixture, less cover, used during early indium heating and wetting evaluations are shown in Fig. 22 without the surrounding bell jar vacuum container. The flange was fabricated as a cover plate for an ultra-high vacuum system normally operating in the 10^{-9} to 10^{-10} torr range.

FIGURE 21



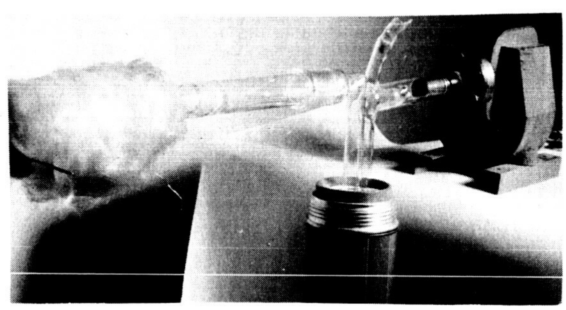
SEAL TEST VACUUM EQUIPMENT
AND MASS SPECTROMETER
LEAK DETECTOR

FIGURE 22



SEAL TEST FIXTURE
UNCOVERED

FIGURE 23



INDIUM CONDENSATION
TEST FIXTURE

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SEAL TESTS

Test No. 1 (melting and wetting characteristics). - The first series of tests, aimed at experimenting with the indium in a directly heated seal gland, uncovered several areas of potential difficulty. For instance, it was discovered that the area under the heated glands had not been sufficiently cleaned because of poor accessibility, and considerable slag was formed on the surface of the indium which had to be scraped away mechanically. Following the removal of this material, and by performing subsequent melts under vacuum or with an inert gas purge, further slag forming tendencies were virtually eliminated.

Difficulties were also encountered in the mild steel test fixture due to excessive differential expansion and contraction compared to the indium. Further, the mass of the flange and lid configuration detracted from the thermal studies, making it difficult to establish valid heat-time profiles.

Test No. 2 (seal leakage test). - Indium-solder seal tests were performed using a revised seal gland combination of thin-walled stainless steel. Wetting characteristics, although unsatisfactory on bare metal, were found to be considerably improved over those of the plated carbon steel, heavier fixture used in Test No. 1. Several plating combinations were used to improve wetting efficiency. With gold, excellent wetting occurred during the first melt, although almost immediate amalgamation with the indium was noted. Using the inert gas purge or vacuum melt conditions established for the previous test, nickel plate was found to be acceptable for establishing good wetting characteristics.

Although subject to mechanical difficulties, such as centering and leveling, the well-wetted indium-solder seal was found to have zero leakage characteristics as measured by the helium mass spectrometer equipment used for these tests.

Test No. 3 (indium vapor pressure and purification evaluations). - The apparatus shown in Fig. 23 consisted of a small ion pump, a liquid helium condensation trap, and a glass tube surrounded at the test section by a fiberglass insulated heater blanket with externally mounted thermocouple temperature sensors located at several points close to the test specimen.

A sample of 99.99% indium metal was placed in the system next to the heater blanket and evacuated to 2×10^{-8} torr, at which time the specimen was heated through its melting point to a temperature of 500°F. At this time, an equilibrium pressure of 8×10^{-8} torr was reached due to the outgassing of the indium. The vacuum equipment was designed to allow the test chamber to be evacuated through a liquid nitrogen condensation jacket.

The specimen was held for a total of 72 hours without evidence of sublimation or recondensation of the liquid metal.

The sample was then heated to a temperature of 700°F in two increments. The first step was an increase in temperature to 625°F held for 24 hours at a chamber pressure of 2.5×10^{-8} torr. The next increment raised the temperature to 700°F at a vacuum of 7×10^{-9} torr which was held for 72 hours without evidence of sublimation or volatilization of the indium. The temperature was then raised to 725°F and a pressure rise to 2×10^{-8} torr was noted. This pressure slowly reduced to approximately 7×10^{-9} torr for a 24 hour period. During this time there was a slow deposition of metallic vapor on the walls of the glassware. A deposit of approximately 2 mm width by 3 cm length occurred on the wall of the glassware immediately adjacent to the heated zone. A pressure plateau of approximately 7×10^{-9} torr was held for five days, as shown in Fig. 24.

A second deposit was noted during these tests at the bend in the glass tubing immediately above the liquid nitrogen condensation trap. The deposition occurred simultaneously with the deposit in the glass ware adjacent to the heated zone and continued for a total of approximately one week, after which time it appeared to cease. This specimen was retained at this pressure and temperature for an additional five days without any detectable change.

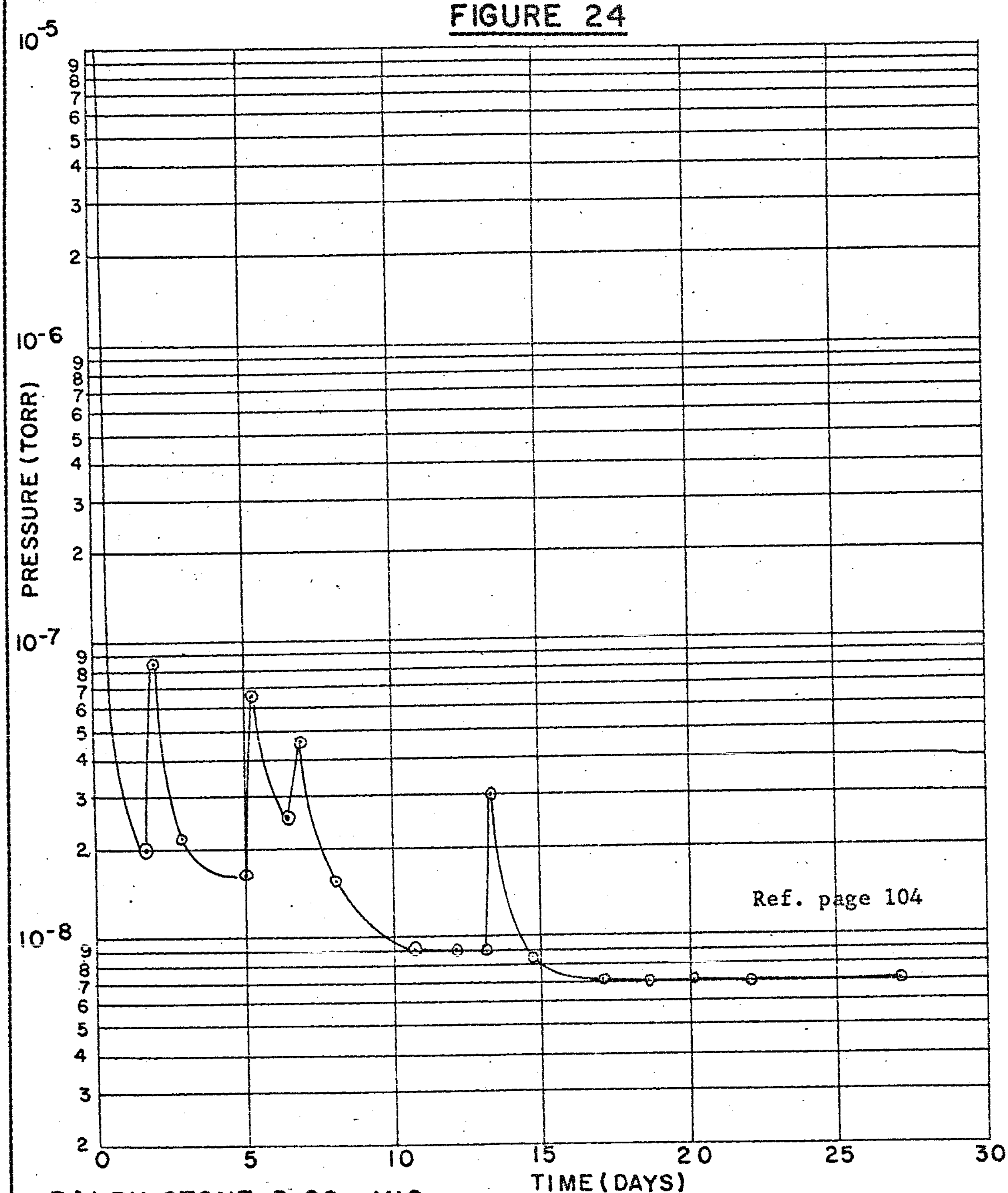
The physical properties of indium indicate the vapor pressure at these temperatures is in the vicinity of 10^{-11} torr (based on the R.C.A. vapor pressure curves). Although no chemical analyses were performed on the deposit, the extremely small amount present could easily represent all or part of the 0.01% impurity.

Conclusions

1. The difficulties experienced with slag formation on top of the indium were apparently due to improper cleaning procedures and were not a continuing problem.

2. The difficulties experienced with wetting characteristics indicate care should be exercised in the physical cleaning of the parts. Plating of gland surfaces by gold is excellent for the first melt and should be considered for the male seal member. Nickel plate, properly protected by inert or vacuum atmosphere prior to use, should be adequate preparation for the female indium seal gland walls.

FIGURE 24



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VACUUM TEST DATA

3. Differential expansion may be minimized by utilizing materials with as low a coefficient of expansion as possible and by using designs allowing some flexibility.

4. Sealing tests with thin wall stainless steel glands indicated that with proper wetting highly effective vacuum seals can be achieved.

5. Vaporization of significant quantities of contaminants, if present, may be expected from the indium at temperatures of 700°F. The highest purity of indium possible should be used to minimize this effect.

PACKAGING ANALYSIS

Purpose

While not a contractual objective during the current phase of work, a study was made on the effect on total sample bag tare weight of using very small (1 in. diameter by 1 in. long) bags for individually packaging double-size samples as opposed to the multiple packaging of 3 in. diameter by 5 in. long bags recommended during the prior study contract. The work was done in connection with studies of the semi-automatic dispensing devices for flexible bags proposed in Part V of this report. Results of the study are summarized in Table III.

Conclusions

Individually packaging small samples in large bags results in the expected gross reduction in available sample weight and excessive bag weight. An alternate solution is to individually package small samples in small bags which may now be practical using the packaging tool. Packaging efficiency results were obtained which were reasonably comparable to those achieved in the prior study contract, where many samples were packaged together in the large sample bag.

OUTGASSING ANALYSIS

Introduction

The sample box design as now proposed contains relatively large amounts of fluorocarbon coating to help ensure against unwanted sticking between metal parts. In addition, the outside of the flexible bags will be of fluorocarbon film. Until the practical results of minimizing outgassing

TABLE III

COMPARISON OF SMALL AND LARGE SAMPLE BAGS

	Sample Size (diam. in inches)	# per package	# of packages	Sample Volume (in.^{3})	Sample Weight (lb) Specific Gravity 0.5	1.0	2.0	3.0	Bag Wt. (lb)
Large bags (3-1/2 in. dia. by 5 in. long)	1/2	1	1215	79.5	1.5	2.9	5.8	8.7	13.5
	1	1	356	187	3.4	6.8	13.6	20.4	4.0
Small bags (1 in. dia. by 1 in. long)	1/2	4	1215	318	5.8	11.5	23.0	34.5	.85
	1	1	1215	631.8	11.4	22.8	45.6	68.4	.85
Large bags, filled with small samples per previous study	1	5	70	-		17.3	34.8	52.2	1.12

Note: Bag weights are <u>not</u> added to sample weights.

of the fluorocarbon by pretreatment, control during manufacturing, heat and vacuum applications can be assessed, further work on estimating the passive vacuum level to be retained within the box will not be attempted. However, a request was received to estimate the amount of pressure increase which might occur within the box due to the presence of a large amount of samples having an arbitrary surface exposure of 25 square feet per gram of weight.

Discussion

At density of 1.14 gm/cm^3, one gm occupies approximately one cm^3. Assume one cm^3 is cut up into N^3 smaller cubes of identical size. The surface area is then

$$\sum A = N^3 \times 6 \times \frac{1^2}{N^2} = 6\ N \quad [cm^2]$$

If total surface area is about 25 ft^2, then

$$N = \frac{\sum A}{6} = \frac{25 \times 144 \times (2.54)^2}{6}$$

$$= 3900$$

Since the average dimension of a particle is about

$$\frac{1}{3900}\ \text{cm} \longrightarrow 2.5 \times 10^{-6}\ \text{meter}$$

$$\longrightarrow 2.5\ \text{microns}$$

For the JPL experiments, the average particle size was about an order of magnitude larger. For speculative estimates (as both of these are), this is a remarkably good agreement.

This is very little information on which to estimate gas sorption, and too much importance should not be attached to the calculation.

We can calculate the amount of gas corresponding to a monolayer coverage. For reactive gases (not noble gases) the unit coverage is about 10^{-15} atoms/ cm^2. For 1 gm of lunar dust as above, we have

$$\sum A = 3900 \times 6 = 23\ 000\ cm^2$$

The sorbed gas is

$$\frac{10^{15} \times 23\ 000}{6 \times 10^{23}} \times 22.4 \quad = \quad 8 \times 10^{-4} \text{ torr liters/gm}$$

A box of volume 14 liters (850 in.^{3}) containing 23 kg (50 lb) of lunar dust will develop a pressure of

$$p \; = \; \frac{8 \times 10^{-4} \times 23 \times 10^{3}}{14} \quad = \quad 1.6 \text{ torr}$$

Dust on the exposed surface of the moon which periodically exceeds 200°F for 14 days is likely to have substantially less absorbed gas - probably none detectable compared to outgassing of bag materials.

On the other hand, at depths of several feet, where the temperature is perhaps -30°F, there may possibly be accumulated ice (not necessarily water) which could develop into appreciable gas volumes on warming.

It may be seen from the speculative nature of the assumptions used in the foregoing calculations, conclusions based on this analysis would be premature. The figures are therefore presented for information only and are offered without further comment.

APPENDIX D

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