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GRUMMAN

Final Report

MAINTAINABILITY DESIGN CRITERIA FOR PACKAGING OF SPACECRAFT REPLACEABLE ELECTRONIC EQUIPMENT

June 1970

Contract NAS 8-24690

244

FINAL REPORT

MAINTAINABILITY DESIGN CRITERIA FOR PACKAGING OF SPACECRAFT REPLACEABLE ELECTRONIC EQUIPMENT

June 1970

Prepared Under Contract NAS 8-24690
for
George C. Marshall Space Flight Center
NASA
Huntsville, Alabama

by

Reliability and Maintainability Engineering
Grumman Aerospace Corporation
Bethpage, L. I., New York 11714

ABSTRACT

An eight-month program was conducted by Grumman for the NASA Quality and Reliability Assurance Laboratory of MSFC to develop maintainability design criteria for the packaging of space electronic equipment in the 1970-73 era. The purpose of the criteria is to assure rapid and easy removal and replacement during space mission operations. The criteria were defined for general application in extra-vehicular activity (EVA) and intra-vehicular activity (IVA). A mock-up was designed and fabricated to demonstrate and verify the design criteria under dry simulated Zero-g test conditions.

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SECTION 1

INTRODUCTION

The NASA S&E Qual-F Branch at Marshall Space Flight Center recognizes that a capability for repairing electrical/electronic equipment during long duration complex space missions must be provided if a high probability of mission success is to be achieved. Previous studies concluded that redundancy alone cannot produce necessary mission reliability for long-duration missions but an onboard repair capability can do the job. Such a repair capability requires that damaged and malfunctioning equipment be replaced quickly and easily under mission conditions. The best way to achieve an efficient equipment interchange capability is to design the replaceable equipment and the vehicle installations for maintainability beginning with the earliest possible layout or concept formulation stage.

This highlighted the need for a special set of criteria that would provide the equipment design engineer with the basic requirements for this essential onboard maintenance function. Accordingly, the Marshall Space Flight Center awarded Grumman Aerospace Corporation Contract No. NAS-8-24690 to:

- Define "Remove and Replace" design criteria for use in the 1970-73 era
- Provide a mock-up to demonstrate the feasibility of these design requirements under simulated Zero-g conditions.

SECTION 2

SUMMARY

This study formulated a specific set of design criteria to facilitate the removal and replacement of maintainable electronic equipment in space. These design criteria requirements are generally applicable now and throughout the 1970-73 era. They are cognizant of and compatible with the capabilities and shortcomings of current electronic hardware. If applied across the board to all electronic equipment in maintainable long-duration space vehicles, these design requirements will provide the onboard maintenance capability necessary to achieve the desired high probability of mission success.

The study also resulted in the production of a mock-up that met all of the requirements of the contract. The mock-up was fabricated specifically for the MSFC dry Zero-g simulation test facilities where on April 1 and 2, 1970, the feasibility of the design criteria was demonstrated. The mock-up now serves as an evaluation tool for NASA in the final determination of acceptable design concepts for maintainable spacecraft equipment. A color motion picture taken during the official demonstration included sequences of all actions.

Maintainability analysis of the mock-up designs, followed by one-g and Zero-g demonstration time trials, indicated that space electronic equipment can be designed to permit "remove and replace" action of typical equipment in less than six minutes. This is an order of magnitude better than the remove and replace (hereafter, R&R) performance available from current space equipment designs, and represents what can be achieved when necessary maintainability requirements are satisfied.

In many instances, dramatic improvements in maintainability performance can be achieved through proper design at little or no increase in weight, cost or complexity.

The following general conclusions were drawn from the results of the successful simulated Zero-g demonstration tests on the mock-up at MSFC:

- One-hand-operated, simple-motion mounting mechanism for EVA black boxes are not only feasible but desirable for fast-action replacement
- Self-alignment of black boxes, modules and fasteners were proven necessary to reduce astronaut exertion and frustration especially when performing maintenance in a pressure suit.
- All R&R actions were performed well within the contract time limitations of 20 minutes maximum.
- Actual performance of all IVA shirtsleeve tasks in an EVA pressure suit without foot or body restraints verified the contention that equipment designed to facilitate shirtsleeve maintenance would be capable of pressure suit manipulation.
- Single-point mount mechanism with center jacking of printed circuit-board type modules were proven feasible and found desirable for quick and easy maintenance without a card extractor.
- Maintainability predictions for the maintenance workload under space conditions were found to be reasonably accurate when prepared in accordance with MIL-HDBK-472, Method II modified for Zero-g and pressure suit conditions.

SECTION 3

STUDY OBJECTIVES

The general objective of this study was to satisfy the contractual requirements and develop a practical set of design criteria that could be applied to space electronic equipment for the purpose of facilitating onboard maintenance operations. Quick and easy replacement of equipment was to be done without affecting the functional or structural integrity of the maintainable equipment.

The study concentrated on the R&R portion of the total onboard maintenance repair task as this portion was most amenable to improvement through proper design. Since the design criteria must be suitable for various types of spacecraft, they must be universal enough for general application yet specific enough to achieve the desired results. Accordingly, the design criteria had to be developed to comply with the ground rules and assumptions of Section 4 of this report.

The second objective was to construct a mock-up to incorporate as many of the design criteria as possible.

The third objective was to demonstrate the R&R design criteria built into the mock-up (see Figure 3-1).

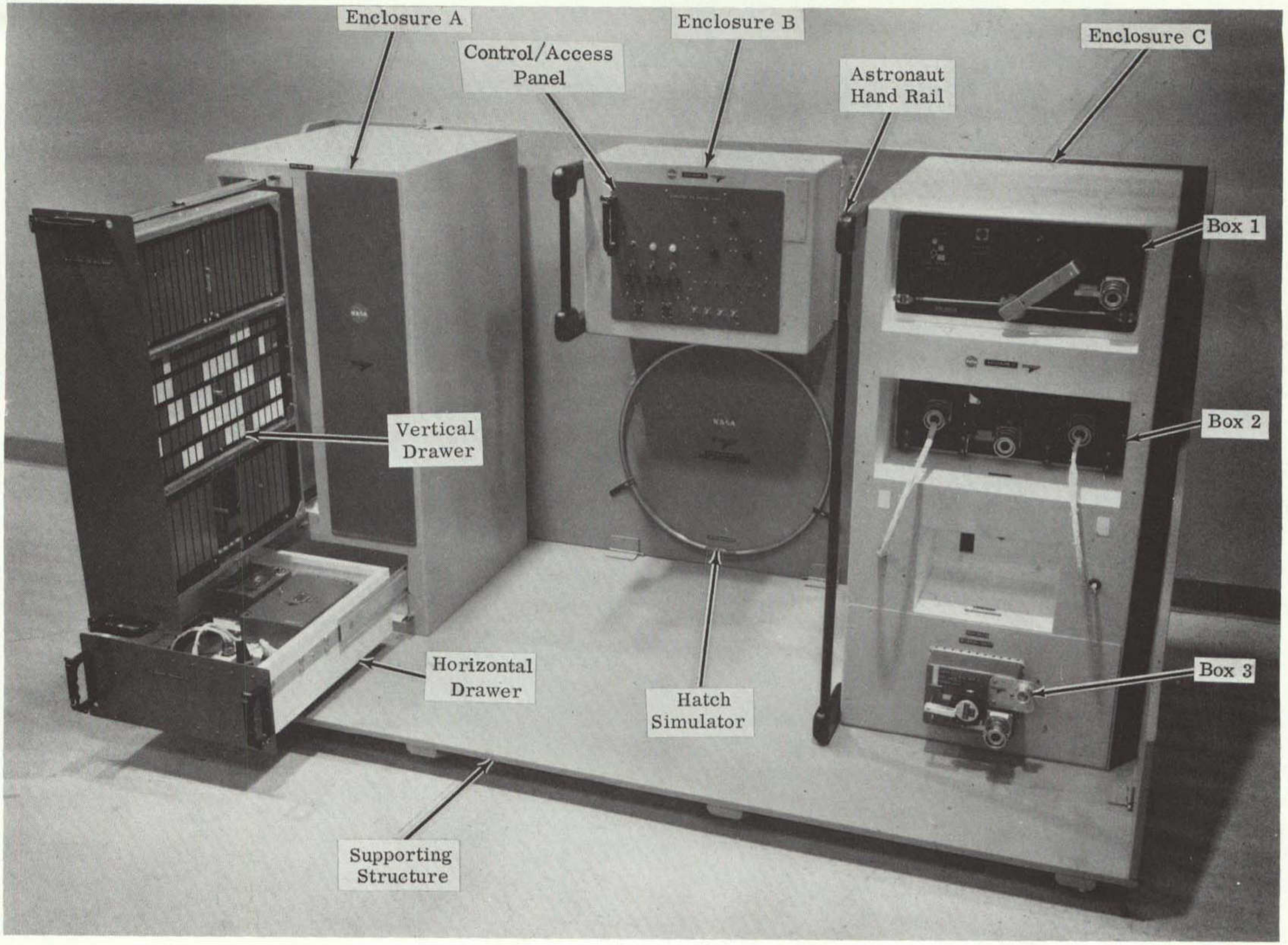


Figure 3-1. Space Maintainability Electronic Packaging Mock-up

SECTION 4

GROUND RULES AND ASSUMPTIONS

A. Ground Rules

The following ground rules for the design criteria were established by NASA in the contract statement of work:

- Artificial gravity will not be provided.
- Incorporation of easy removal and replacement features will not degrade the item during launch or other severe environmental conditions.
- Repair will be performed by one crewman using one hand, if possible.
- Approximately 90% of repairs will be Intra-Vehicular Activity (IVA).
- Differences in criteria for replacement in a shirtsleeve and pressurized suit environment will be minimized.
- Functional operation of item will not be a consideration of the task.
- Use of tools and test equipment to be minimized.
- Astronaut effort to be minimized.
- Replaceability at black box and module levels only.
- Interface parameters and work space to perform repairs must be considered
- Astronaut in space environment shall be capable of R&R action within 20 minutes if design complies with criteria.
- Criteria to be in a format readily usable to define specifications for flight items.

B. Assumptions

In order to ensure uniformity of effort and reduce the variables to a manageable level, it was necessary to make certain assumptions covering items outside the scope of this study. These assumptions were reviewed and approved by the NASA Contracting Officer Representative early in the program. A few of the more important assumptions are summarized below. For a complete list, see Appendix B.

Fault-isolation capability will exist onboard the spacecraft consistent with mission and maintainability requirements.

All shirtsleeve maintenance actions will be accomplished at the module or subassembly level with no more than one univeral hex drive internal wrenching hand tool.

Adequate illumination will be provided for the repair task.

Foot restraints will be used during intravehicular activity (IVA) equipment replacement

SECTION 5

SCOPE OF THE STUDY

The original scope of this program was defined by the contract statement of work. This has been restated for the criteria in Section 4 of this report as "Ground Rules" for the study.

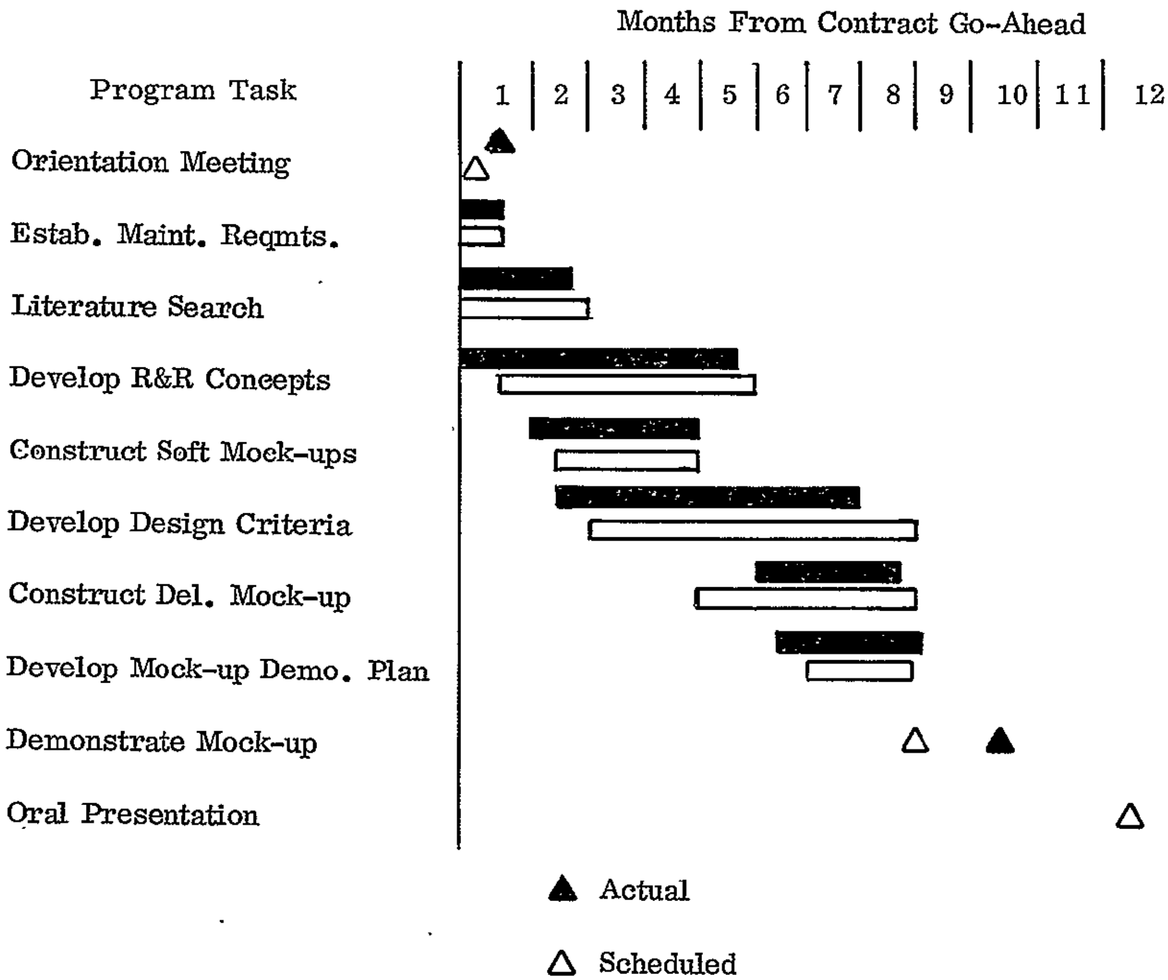
The MSFC S & E Qual-F office became concerned that unless all of the effort in this study program were directed specifically toward the main problem of designing for R&R action, the end result could be a diversion of effort into many other facets of the total onboard maintenance problem. Consequently, a number of meetings were held with the Contracting Officer's representative, supplemented by telecons, to provide necessary decisions and direction as required during the program to achieve MSFC's objective. The resulting changes in scope were fully documented in the Contractor's monthly progress reports.

SECTION 6

PLAN OF ACTION

The study program plan was prepared to be consistent with the contract schedule. The accompanying milestone chart, Table 6-1, indicates the tasks and schedules that were followed throughout the study.

TABLE 6-1. PROGRAM MILESTONES



SECTION 7

DEVELOPMENT OF MAINTAINABILITY DESIGN CRITERIA

7.1 LITERATURE SEARCH AND EQUIPMENT EVALUATION

A literature search to determine accomplishments in the area of electronic equipment maintainability in space vehicles was fruitless. The two primary sources for such information were the Defense Documentation Center at Alexandria, Virginia, and the Scientific and Technical Information Division of NASA.

A wealth of information was obtained, however, on various aspects of electronic packaging and also on astronaut capabilities for performing various physical tasks in a space environment. The more pertinent documents have been compiled into a reference bibliography which is included in Section 15 of this report.

Two principal reference documents utilized in the establishment of the design criteria are noted below:

- Extravehicular Activity Design Criteria, latest revision of CSD-X-012 NASA Manned Spacecraft Center, Crew System Division, undated.
- Study of Astronaut Capabilities to Perform Extravehicular Maintenance and Assembly Functions in Weightless Conditions CR-859, NASA Manned Spacecraft Center, Crew Systems Division, undated.

During review of the various pertinent documents, areas of interest to the packaging study were recorded on data evaluation work sheets for use during the program. See Figure 7-1 for a typical example.

In addition to the need for the data search described above, it was necessary to establish a conceptual base for the three essential remove and replace equipment interfaces: structural, thermal and electrical. This was accomplished by evaluating selected

TITLE: Extravehicular Acitvity Design Criteria

CSD-X-012 NASA Document - MSC

DOCUMENT DATE - 9-27-68 M ENG Young DATE 7-2-69

ITEMS OF INTEREST TO M

(By Page No. and Par. No.)

ABULAR DATA REGARDING THE A6I

Space Suit, Umbilicals, Liquid-Cooled

Garment and Pressure Control Unit

Complete Description of Astronaut's Capabilities for

EVA Operations as a Function of the Type of Equipment Available -

MAX. EXERTABLE PUSH FORCE - 75# (One Hand on Hand-Hold Restrainer

MAX. EXERTABLE PULL FORCE - 75# (One Hand on Hand-Hold Restrainer

MAX. EXERTABLE TORQUE WITH 6" ARM - 24# Ft.

HUMAN FACTORS CRITERIA

Gives Complete Anthropomorphic Measurements

Gives Complete Anthropomorphic Requirements for Astronaut

Capabilities in Space Suit

VALUE OF DOCUMENT TO PACKAGING STUDY

Many Necessary Parameters are Provided Relative To Limitati

Imposed By a Pressure Suit.

Figure 7-1. Data Evaluation

electronic designs of various inhouse space and aircraft programs, and entering pertinent information on work sheets as shown in Figure 7-2. This file provided an excellent cross-section of current electronic equipment packaging and mounting methods for use during the concept formulation phase of this program.

7.2 APPROACH USED TO ESTABLISH MAINTAINABILITY REQUIREMENTS

The second major effort in the development of the criteria was to establish the basic maintainability requirements for the remove-and-replace task in space. These requirements were generated as a result of:

- Specific contract requirements
- Aircraft Maintainability design and operational experience
- Current space Maintainability advanced development studies

Early in the study it was determined that a general Maintainability concept would be required prior to establishment of the maintainability requirements. Major categories which impacted that general concept, and the resulting requirements, are outlined below. For detailed information on development of specific maintainability concepts see Sections I and II of Appendix B.

7.2.1 Level of Maintenance

It was necessary to determine a logical break point for the R&R action. From the general maintainability concept the following requirements evolved.

- All system level EVA repairs are to be accomplished by removing and replacing faulty "black boxes" as the replaceable elements.
- System level repairs in IVA are to be accomplished at the black box level for critical systems and equipment, and at the module level for systems not considered critical to safety or survival.

7.2.2 Fault-Isolation Capability

Built-in-test (BIT) and onboard checkout (OBC) must be capable of detecting and isolating system faults down to the above established level for effective maintenance action.

NOMENCLATURE Pulse Code Modulation & Timing Electronics Ass'y

PART NO. LSC 360-2 DATE 7/2/69 M ENGR M. Klugman

BLACK BOX SIZE 19.75 x 6.72 x 5.12 WEIGHT 23#

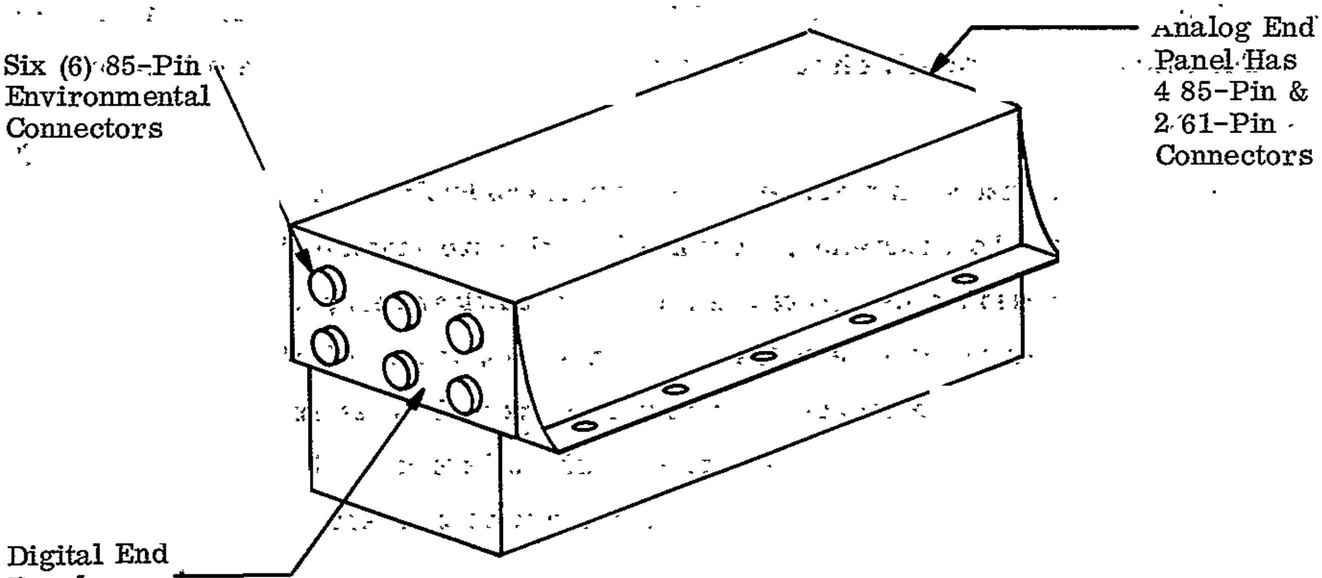
- MOUNTING - Flange Mounted
- INTERCONNECT (TYPE & DENSITY) - 10 85 Pin Connectors
  2 61 Pin Connectors
- TEST PROVISIONS - Std & Special Test Equip't For Checkout Prior To Install'n
- ACCESS FOR MAINTENANCE - Top Cover Removable
- THERMAL CONTROL - Box Mounted on Cold Rail
- SUBASSEMBLY COMMONALITY - None

SUBASSEMBLY 26 Cards Wired In A "Fan"

- MOUNTING - Cards are "Squeezed" Between BHDS
- INTERCONNECT (TYPE & DENSITY) - Point-To-Point Wiring
- TEST PROVISIONS - Cards Tested As Part Of Ass'y
- TYPE OF PARTS - Transistors, Diodes, Resistors, Capacitor
- THERMAL CONTROL - Conduction Via Encapsulent To Sides
- CONFORMAL COATING - Potting

Welded Ass'y Of All Subsystems Including P. S

26 Removable Cards Containing 50-Pin (Single) or 100-Pin (Double) Componen



Elapsed Time Ind. & Osc. Adj. Plugs Are Mounted In Top Cover

HAS MOISTURE SEAL PROVISIONS

CONTAINS:

Analog Matrix Logic	Digital Multiplexing
Hi-Level Analog Multiplexing	Output Register & Data XFR Buffers
Calibrator	Power Supply
Coder	Timing Equipt.
Programmer	

TYPICAL CARD

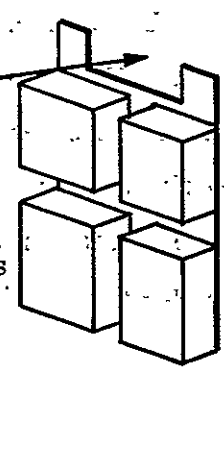


Figure 7-2. Equipment Evaluation

Isolation to a group of units, or with ambiguous test results, will only complicate the repair and dissipate the vehicle's resources of time, manpower, and spares. In addition to fault detection and isolation, OBC with BIT must of course be capable of verifying that the repair has been successful. This can usually be combined with the basic OBC functional performance evaluation capability required for operation of the vehicle.

Definition of detailed fault isolation requirements was beyond the scope of this study. However, a number of minimum requirements were included in the criteria.

7.2.3 Allowable Time Constraints

The elapsed time permitted for any onboard repair will be a function of:

- The criticality of the faulty equipment
- The allowable downtime for the affected system
- Pressure suit requirements and limitations
- The availability of manpower for maintenance

The high cost of training, equipping and orbiting an astronaut dictates that vehicle maintenance manpower requirements be minimized so as to maximize payload availability for other operational and scientific purposes of the mission. All of these factors have entered into the general requirement that electronic equipment R&R action shall not exceed 20 minutes. The permissible elapsed time (less than 20 minutes) for specific equipment in any given mission will have a direct bearing on the type of fasteners used for mounting and the access arrangements that must be designed into the equipment.

7.2.4 Work Area Environment

The limitations on the amount of force, kinds of motions, and endurance of the astronaut that can be utilized for maintenance in a Zero-g environment resulted in a number of criteria requirements. Pressure suit limitations are much more restrictive as indicated by NASA documents such as the CSD-X-012 extravehicular activity design criteria, and CR-859 study of astronaut capability to perform extravehicular maintenance and assembly functions in weightless condition. These factors plus the limited visibility in a pressure suit will affect:

-
- The design of mounting fasteners and mechanisms
- The requirements for alignment features
- The number of mounting fasteners
- The design of tools
- Size, type and number of interface connections.
- Tether provisions

All electronic equipment subject to onboard maintenance must be designed to comply with the established physical restrictions on astronaut performance in space.

7.2.5 Electric Arcing

Because electric sparks in a spacecraft, particularly in other than a normal ear atmosphere, pose a very serious safety hazard, it becomes imperative that steps be taken to prevent arcing when removing and replacing electronic equipment. Investigation of possible solutions to this problem were inconclusive because energy level standards required to cause an explosion in a two gas atmosphere, with a possible third or contaminating gas, have not been established. Possible use of the MSFC specifications 40M39580 connector as the primary means of preventing an explosion was rejected by the Grumman safety personnel, therefore use of either a "deadface connector" or "down-powering" procedure was included in the design criteria.

- "Dead-facing" is the deactivation or removal of all signals from all the leads in both halves of a connector prior to separating the connector for removal and replacement of the equipment. This includes all power, signal and monitoring leads.
- "Down-powering" is the deactivation of an entire replaceable unit, subsystem, or system to remove all electrical potential from all leads in all connectors prior to a maintenance action.

7.2.6 General Requirements

The criteria general requirements were extracted from documents of a number of active aircraft programs on which Grumman is the prime contractor. These requirements are based on broad experience gained over a number of years, and are directly applicable to space maintainability.

7.3 DEVELOPMENT OF MAINTAINABILITY REMOVE AND REPLACE CONCEPTS

Concurrent with the literature and existing hardware research efforts, meetings were held with in-house personnel having broad experience in packaging of electrical and electronic equipment for aircraft and space vehicles. Since Grumman is currently working on a series of advance development studies in the field of space maintainability, a ready exchange of ideas was conducted between this study and other projects with similar interests.

In fact, several design concepts for one-hand, simple-motion, mounting mechanisms were developed under Grumman's in-house packaging study and were made available for the mock-up in this program.

7.3.1 Basic Black Box Construction Concepts

From the above studies and investigations, it became apparent that black boxes and box-type modules fall into the following four basic categories of construction (see Figure 7-3):

- A single base plate upon which the electronics are mounted. In this arrangement structural attachment and thermal interfaces are provided by the plate.
- A base plate with a shelf attached. Structural attachment and thermal interface are the same as the single base plate design.
- The right angle base plate, in which structural attachment and thermal interface may be on either face of the right angle.
- The four or five sided box, the number of sides depending on the number of covers used. This configuration is generally used where maximum structural integrity is required.

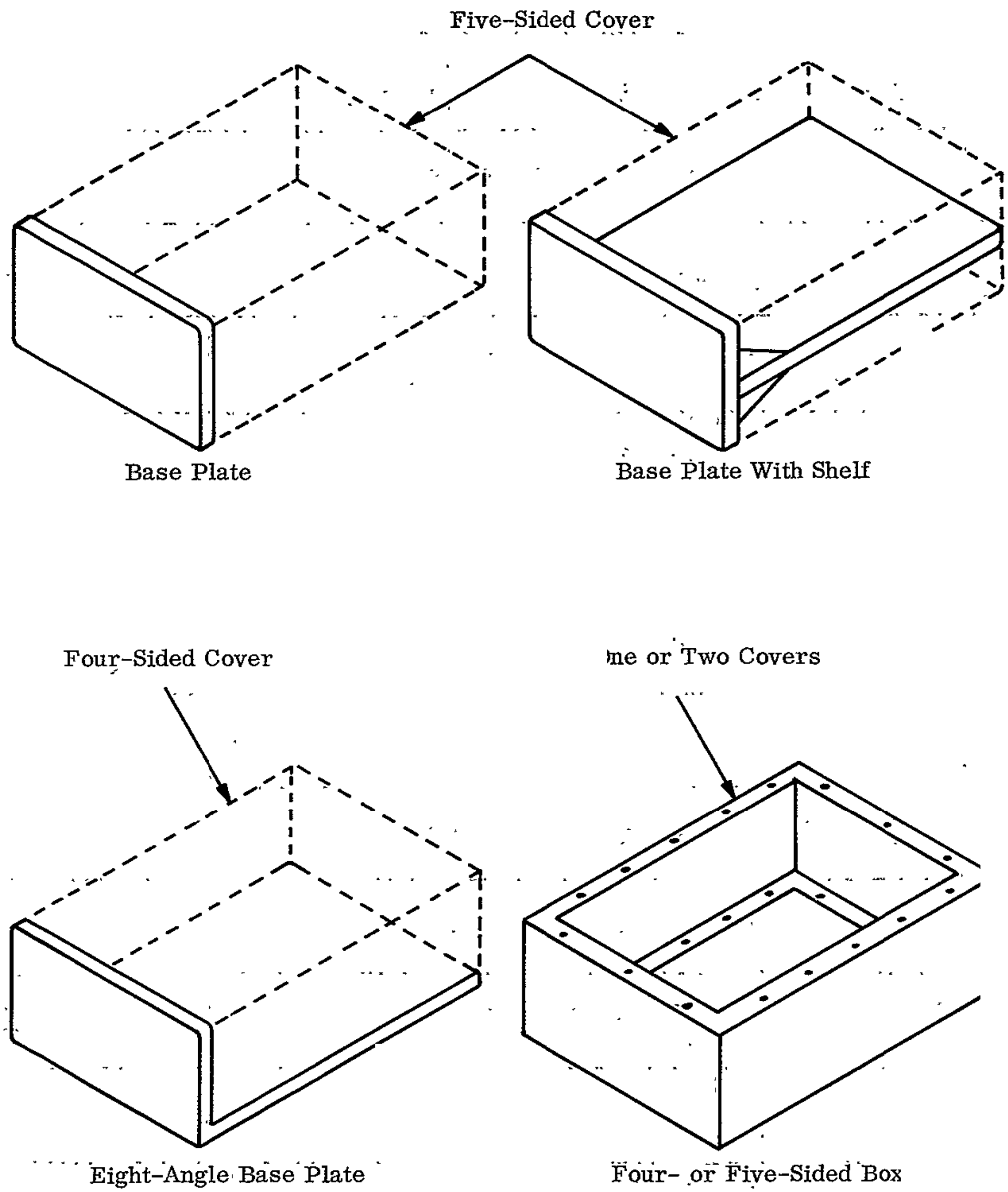


Figure 7-3. Basic Boxe

7.3.2 Basic Module Construction Concepts

a. Box type modules. Various module configurations were investigated and it was determined that, other than printed circuit boards, modules fall into the same general categories relative to basic construction as "black boxes". Methods of mounting would be essentially the same as for the boxes, with the possible exception of permissible use of standard or universal hand tools in an IVA application.

b. Printed Circuit Board (PCB) type modules. Printed circuit boards were placed in a separate category for the following reasons:

- The rather delicate nature of the typical PCB construction indicates remove and replace action in shirtsleeves only.
- Placing a protective cover over the PCB to permit handling by a suited astronaut would place the card in one of the four box-type module categories described above.

7.3.3 Quick-release Mounting Methods.

Having established the total spectrum of packaging to be covered, an investigation was undertaken to determine acceptable methods for quick release and lock up of the three basic interfaces; i.e., structural, thermal, and electrical.

a. The large box. It was decided to approach the most difficult task first by postulating the following black box conditions:

- The heaviest EVA box (up to 150 pounds)
- High heat rejection requirement
- High density interface connector requirement

Human factors and EVA evaluation documents indicate a need for the astronaut to accomplish the remove and replace action using one hand wherever possible. This requirement resulted in the following tentative criteria for the above EVA box:

- The use of rack and panel connectors
- A single handle to provide the mechanical forces needed for removal and installation of the box, said handle also to be used for handling of the box when removed.

A study was accomplished to determine the feasibility of various mechanical actions which would provide single handle removal and replacement of the EVA box, using as a base:

- State-of-the-art high density digital equipment packaging designs for thermal and electrical interface.
- Mating forces of military type rack and panel environmental connectors.

During the study it was found that there were no available mechanisms which would provide a one-handed lock-up of all three interfaces. A double acting wedge mechanism meeting the requirements outlined above, was developed for use on the mock-up, see Figure 7-4.

Reduction of remove and replace time to a minimum, and the attendant reduction of astronaut frustration, were the prime factors governing selection of the double-acting wedge mechanism. Other factors considered in selection of the wedge mechanism are outlined below:

- Structural Interface It was requested in the contract statement of work that the R&R action be accomplished by the suited astronaut using one hand if possible. Using the torque force of 24 foot-pounds (with a 6-inch moment arm), as given in the MSC Extravehicular Acitivity Design Criteria document, a two-to-one ratio for the jacking wedge, and the forces obtained when approaching the on-center position of a rotary mechanism, it was relatively easy to obtain the force necessary to mount the large box. This mechanism is described in Section 8 of this report.

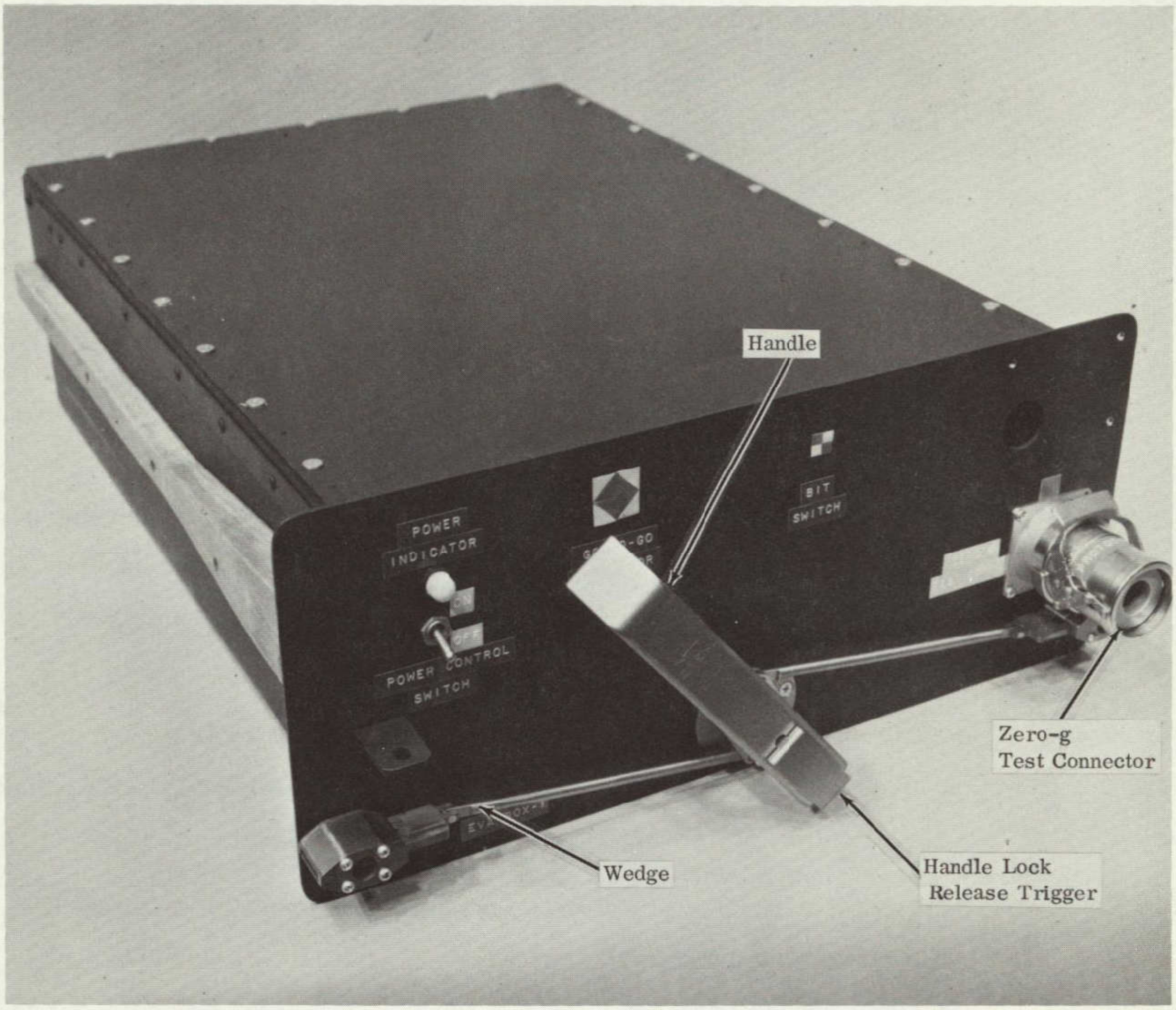


Figure 7-4. Box #1 Double Acting Wedge Mechanism

- Thermal Interface An investigation of present and projected electronic box and module heat dissipation requirements indicated serious disagreement within the industry, especially in the area of projected heat dissipation. As a result of this investigation, and based on dissipation of selected state-of-the-art equipments, a value of 200 watts/ft^3 was selected for purposes of this study.

  Using the 200-watt value, it is feasible to use the double-acting wedge mechanism to provide the force needed to mate the heat sink of the box, with a spacecraft-mounted cold plate.

  Early in the study two of the six sides (front and back) were selected as the most feasible for a "quick release" heat transfer. This decision was based on the requirement for all three interface disconnects to be accessible from the surface of the box facing the astronaut. Development of a mechanism which operates at right angles to the surface on which the operating forces are applied would introduce unnecessary complexity into the design.

  Methods of thermal disconnect, where air is the cooling medium, were not investigated since this method is not applicable for EVA, and because of the potential for reduced pressure in an IVA situation.

- Electrical Interface Following an investigation of various state-of-the-art equipments, which included consideration of the increased use of multiplexing to reduce interface wiring, a value of 350 wires was selected as a worst case condition for purposes of this study.

  Limited space available on the front panel of a box for the operation of approved EVA connectors, the number of connectors which would be required to provide a 350-pin interface, the remove/replace time for numerious connectors and storage of same during replacement of the box, all contributed to selection of rack and panel connectors for this application.

- <u>Large box conclusions</u> Based on the studies and investigations outlined above, it was concluded that it is feasible to provide simultaneous lock-up of all three interfaces, using one hand and a single motion.

b. <u>Medium-Sized Box</u>

Investigation into the structural, thermal and electrical interface of medium sized boxes indicated the following:

- It is feasible to provide a quick disconnect for both structural and thermal interfaces using an overcenter latching mechanism.
- Box size would dictate a reduction in electrical interface, thereby permitting the use of hand-mated connectors if rack and panel types could not be accommodated.
- There are no existing mechanisms (off the shelf) that provide the clamping action needed for the structural and thermal interfaces and which can be operated by one hand.

A mechanism was designed for the mock-up, which provides the required one handed lock-up, see Figure 7-5.

c. <u>Small Box</u>

One of the items to be included in the mock-up was the smallest box feasible for replacement by a suited astronaut using only one hand. A study, undertaken to determine this size, revealed the electrical interface to be the limiting factor for the following reasons:

- The hand mated connectors which are currently approved for suited astronaut use (MSFC Specification 40M39580) are quite large and require considerable additional space for the connect/disconnect action. Depending on the number of connectors required for the electrical interface, the "smallest box" could be rather large.

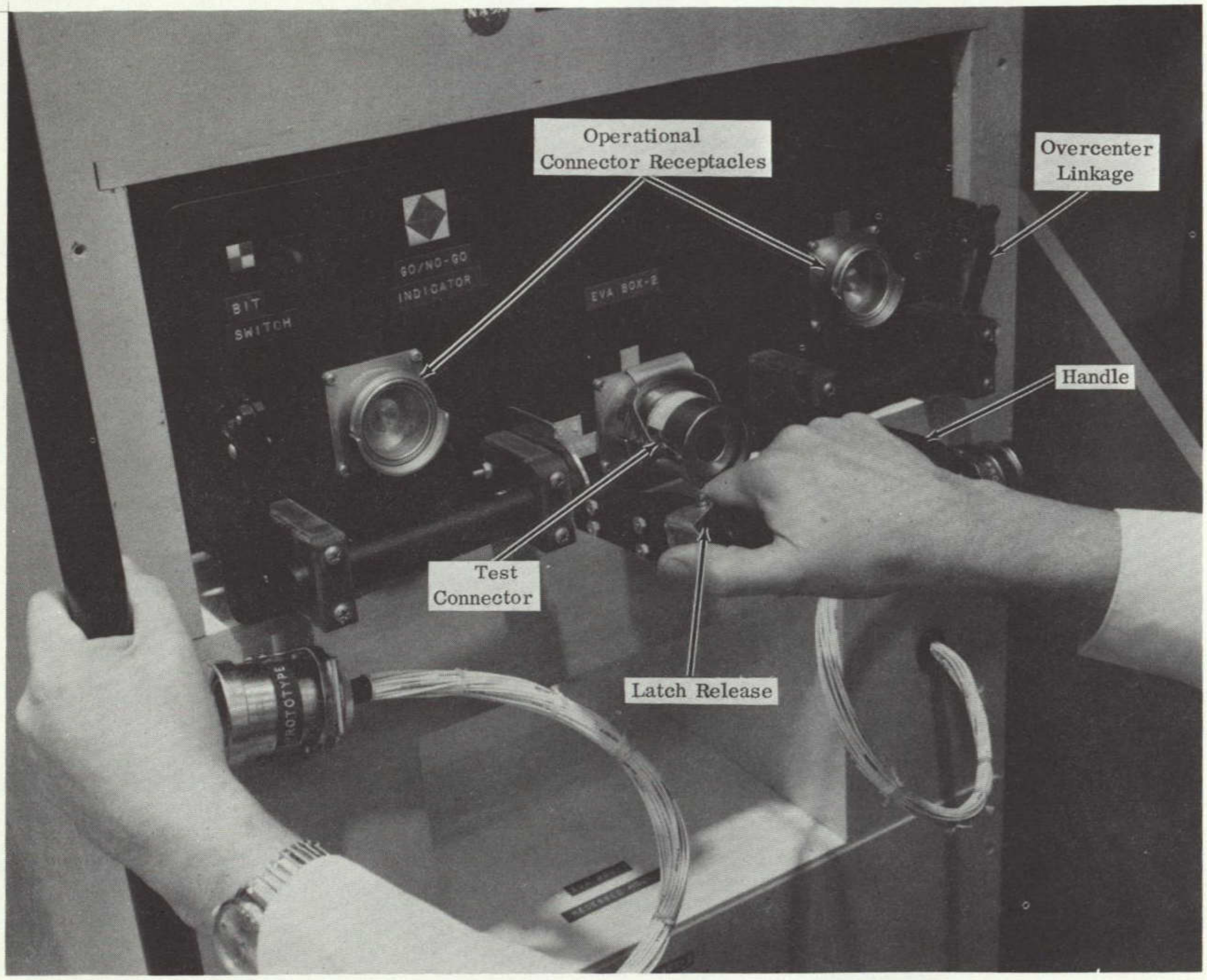


Figure 7-5. Box #2 One Hand Lock-up Mechanism

- Rack and panel connectors would permit a reduction in box size; however, alignment prior to mating of the connector poses additional problems. The use of rack and panel connectors on a small box is further complicated by the mechanism needed for the jacking and unjacking action.

A solution to the problems outlined above appears to be the development of a connector which requires zero mating force during mounting of the box, to be followed by a separate single lever motion to mate the pins. A prototype of such a connector was installed on the mock-up.

The ability to provide a quick release of a structural and thermal interface with conventional fasteners did not pose a serious problem. The snap slide and trunk type fasteners were rejected for mounting of the small box for the following reasons:

- The snap slide provides little, if any, clamping action for structural and thermal interfaces.

- The trunk type latch requires access to the sides of the box for operation.

The size selected for demonstration of a small box on the mock-up was 6"W x 8"L x 3"D. This represents a minimum size black box that can accomodate a system connector with zero mating force, a Zero-g type test connector, a one handed lockup mechanism, BIT and down power provisions, and mechanical alignment provisions. See Figure 7-6.

d. Modules

As was indicated in paragraph 7.3.2a, box type modules are essentially "black boxes" and the three basic elements of structural, thermal and electrical interface were generally approached in the same manner as the three boxes described above.

Based on the established maintainability concept, it was found that the box type module could use conventional quick release hand mated connectors, and that the structural and thermal interfaces were possible using conventional quick release captive fasteners.

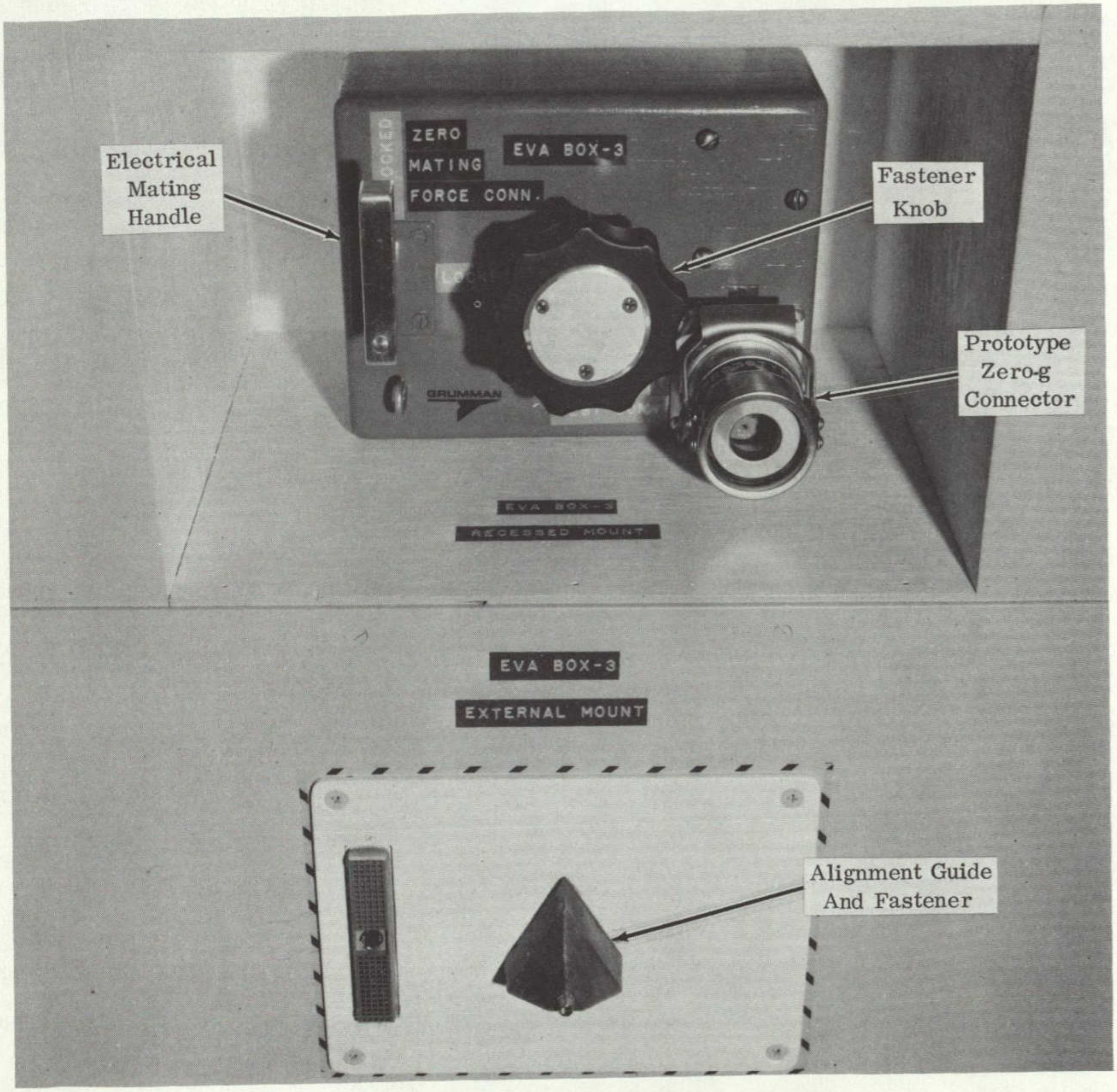


Figure 7-6. Box #3 Mounting Provisions

Research into methods of removing and replacing the conventional family of printed circuit boards indicated the following:

- Special tools (card extractors) are generally used to remove the PCB's, and the replacement action consists of plugging a new card in by hand. On all cards however having high electrical interface density, jacking mechanisms are definitely required since in some cases these forces exceed 90 pounds.

- Retention of the PCB during shocks and vibration requires a separate device which must be removed prior to removal and replacement of the card.

In a study to eliminate the need for "special" tools, various methods of jacking and unjacking printed circuit card connectors were investigated. The use of a center jacking screw was found to offer the greatest number of advantages:

- Jacking and unjacking in the shortest time.
- Minimum astronaut operation force.
- Operation by a conventional standard tool.
- Elimination of the separate hold down device.
- Additional thermal path at the center of the card.

A working model of the center jacking screw was developed for use on the mock-up. (Refer to Figure 8-11 in Section 8).

7.3.4 Mechanical Alignment - box and module

During development of the various remove-and-replace techniques, it became evident that new methods were needed to guide boxes and modules into place. Slight modification of conventional methods will meet most of the IVA requirements, however EVA requires special consideration.

The ideal arrangement would be a funnel wherein the astronaut could simply aim the box and it would fall into place. Backing off from this ideal funnel situation, the problem of box/module alignment breaks down into three phases.

a. The first phase involves a coarse or gross alignment, such as obtaining correct orientation of two dimensions of a rectangular block when placing said block in a mating but slightly larger hole. This alignment is visual and would normally be supplied by adjacent spacecraft equipments; however, where the box or module is free standing, visual or mechanical guides will be required (see paragraph 8.7).

b. The second phase of alignment requires that the box/module properly contact the opening in the fine alignment device.

c. The third phase aligns the box/module into the close tolerance devices needed to carry the structural loads, and provides alignment for rack and panel connectors.

In order to demonstrate typical examples of the alignment devices described above, four different alignment guides were developed for use on the mock-up.

7.4 EVOLUTION OF CRITERIA FORMAT

In conjunction with the literature search, a listing was prepared of the parameters that were affected by the design requirements established in Section 7, paragraph B. The major parameters affecting removal and replacement requirements were found to be:

- Maintainability Concept The equipment levels at which the maintenance was to be performed and the fault isolation capability of BIT and OBC was of major importance.
- Work Area Environment-EVA or IVA The necessity to wear a pressure suit with gloves had an impact on the astronaut's ability to perform even the simplest tasks.
- Removal and Replacement time The time available to comple the task has a direct bearing on the mounting designs and types of fasteners employed.

Various types of documents presently in use in the aerospace industry were reviewed for method of presentation of their contents. The reviewed documents included:

- MIL specifications
- Standards
- o Guides
- Reference handbooks
- Reports

As a result of this effort, preliminary outlines were prepared and NASA was consulted. It was determined by NASA that the criteria document should reflect a best mix between a specification and a handbook. NASA did not have a document that would be representative of the desired format and none were found among those previously reviewed.

Armed with this information, an outline and format of the criteria document was prepared. It was divided into four major sections:

- Introduction
- Factors affecting Maintainability in design
- Maintainability Requirements for design
- Examples of designs that meet the criteria requirements.

The outline was reviewed by cognizant inhouse personnel and coordinated with the NASA Contracting Officer's representative to assure that all pertinent aspects had been included. After establishing the basic ground rules and assumptions, defining interface parameters, and establishing preliminary hardware requirements, it was then possible to prepare the design criteria.

Preparation of the contents was no simple matter since there were many topics to cover. It was an even tougher job to explain the specific requirements in a few words. However, using the outline as a guide, the main body of the design criteria document was written, coordinated, reviewed by in-house personnel, and forwarded to NASA for approval as a rough draft.

NASA reviewed the draft, found the document to be too lengthy for use as a specification, and requested an abbreviated version. The basic design requirements were subsequently extracted from the larger document and forwarded to NASA as a summary list of Maintainability remove and replace design criteria. This list is suitable for use as specification inputs and is enclosed as Appendix A. Note that there are three categories of requirements: general for both EVA and IVA, specific for IVA and specific for EVA. Also note that there are few real differences between EVA and IVA requirements for maintainability equipment designs.

The main body of the design criteria document with design recommendations and explanation of requirements thus became a companion document that would serve as a handbook or design guide for maintainable spacecraft equipment. This document is included as Appendix B.

7.5 LIMITATIONS IN USE OF CRITERIA

There are no limitations in use of the criteria (Appendix B) when maintainable spacecraft equipment is required.

It was recognized that factors such as cost, critical system downtime, lift-off weight, and astronaut available time will govern application of the criteria. Different levels of mounting hardware complexity were shown in the various sections of the criteria for that reason.

As an example, fasteners are given in order of preference, permitting selection of the best configuration for any given mission or vehicle.

SECTION 8

DEVELOPMENT OF MOCK-UP

8.1 BASIC REQUIREMENTS

The basic requirements for the mock-up were established in the contract statement of work:

"The contractor shall provide a mock-up to demonstrate and verify the established criteria. The remove-replace capability will be demonstrated by a repairman in shirtsleeve and in a pressurized suit performing the task in a simulated Zero-g environment. MSFC Simulated Gravity Facilities can be made available by scheduling. The remove-and-replace task in a pressurized suit shall be accomplished within 20 minutes.

"The mock-up as a minimum shall consist of three different sized black boxes mounted in close proximity on rack or mounting structures typical of mission conditions. Each black box shall consist of a minimum of three different sized replaceable modules. Although each black box or module will not demonstrate all the criteria, the mock-up shall demonstrate a maximum number of the criteria except those criteria which can only be feasibly demonstrated during mission operation. The mock-up shall demonstrate the smallest black box and the smallest module determined as feasible for replacement by a pressure-suited astronaut."

The requirement to incorporate modules in the black boxes referred to in the above paragraphs was deleted via a telecon (see Section 5).

The mock-up was also required to demonstrate the following:

- Fasteners for mounting the smallest item and for mounting an item of 150 lbs. (Earthweight).
- Connectors suitable for high and low current use and connectors of two pins up to 61 pins.

- Capability of astronaut to de-energize power prior to breaking connection. Electrical circuitry will not be provided.
- Passage of item through 24-inch round opening.
- Only correct orientation and correct electrical connection of the replaced item.
- Astronaut aids to facilitate easy, rapid removal and replacement.
- Features incorporated to assure astronaut safety.

It should be noted that the mock-up was developed to display feasible concepts only. Further, it should be recognized that the fasteners on the mock-up were representative only and that additional fasteners may be needed in some instances to meet all environmental requirements. It should also be recognized that lighter, smaller, and simpler mechanisms could and should be developed for actual flight hardware.

8.2 EVOLUTION OF MOCK-UP DESIGN

During contract negotiations, alternate I to the contractor's proposal was selected by NASA. This alternate deleted the requirements for Zero-g testing in a water tank, thereby permitting construction of a "dry" mock-up and eliminating the need for under-water neutral buoyancy provisions.

The mock-up was originally conceived as a one-piece unit having curved surfaces to simulate a compartment in a sylindrical spacecraft. During the orientation meeting, various methods of mock-up testing were discussed and it was determined that the original configuration could not be adapted to the available Zero-g simulator test facilities. As a result, the configuration was changed to permit installation and testing of individual portions of the mock-up provided that the sections did not exceed the 200-pound limitation of the MSFC facilities.

The mock-up supporting structure and the three removable demonstration units were shown in Figure 3-1. The supporting structure was designed to provide support and storage for all units of the mock-up as an integrated assembly. This assembly also permits demonstration in a one-g situation. Enclosures "A" and "B" are removable for demonstration of Zero-g IVA maintenance actions while Enclosure "C" is removable for demonstrations of Zero-g EVA maintenance actions.

Enclosure "A" provides support for the two sliding drawers or compartments. Housed within the drawers are seven removable modules which demonstrate typical IVA maintainability characteristics as required by the design criteria.

Enclosure "B" contains a hinged electrical control panel and three modules. This enclosure demonstrates typical EVA maintainability design characteristics for equipment that must have a covered or panel access arrangement.

Enclosure "C" contains three typical EVA black box configurations; one large size, one medium sized, and one small sized unit. This enclosure is used to demonstrate typical EVA maintainability characteristics required by the criteria for pressure suit maintenance. The three black boxes required by the contract are thus contained in Enclosure C.

8.3 SOFT MOCK-UPS

Soft mock-ups were constructed for early concept evaluation and spatial dimensioning of:

- The overall mock-up configuration including the supporting structure and the three removable enclosures
- The latching mechanism for black box number one
- The latching mechanism for black box number two
- The alignment guide and fastening device for black box number three
- The alignment guide and fastening device for module number one

These soft mock-ups were very helpful in that they provided an early three dimensional view of the proposed mock-up configurations prior to committment for manufacture.

8.4 DEVELOPMENT OF ONE-HAND LATCHING MECHANISMS

Development of the criteria established one hand latching requirements for removal and replacement of boxes one, two and three. A search for off-the-shelf mechanisms to fulfill these requirements indicated that none were available.

This problem was studied by Grumman's Space Maintainability Advanced Development group and basic designs for all three mechanisms were developed as part of an in-house packaging effort. A number of subcontractors were contacted regarding the completion of the designs and manufacturing of sample units.

Limited funding for procurement of mock-up materials resulted in the development of a mechanism of Box #1 on a cost sharing arrangement with the Brownline Division of Tridair Industries. Design and fabrication of the handle mechanisms for boxes numbers two and three was accomplished by Grumman's Space Maintainability Advanced Development group as part of the previously mentioned in-house packaging study effort.

8.5 SELECTION OF CONNECTORS

Criteria development indicated a need for "state-of-the-art" and in some cases, development of new type connectors for certain critical areas of the mock-up.

Various connector manufacturers were contacted and, based on the contract schedule and funds available, the following connectors were selected:

- Box #1: Four ITT Cannon rack and panel units used on the rear face. Three with 101 pin inserts and one with 48 pins including 30 ampere contacts. This quantity of pins was selected as past experience on aerospace programs has shown that the maximum density of connector pins rarely exceeds 350. The Zero-g connector on the front panel is the BIT connector, to provide the necessary interface during fault isolation. All Zero-g connectors were supplied by MSFC as Government furnished material-properly.
- Box #2: Uses three Bendix Zero-g prototype connectors meeting NASA specification 40M39580. Two provide the electrical interface, the third is the BIT connector. These are the only approved Zero-g connectors for space use at the present time. This type of connector was necessary since the design called for manually applied units.

- Box #3: A prototype of ITT Cannon's "zero mating force" connector was used for the electrical interface along with one Bendix Zero-g type. The zero mating force connector is a zero insertion and withdrawal force connector. After mating, a pair of cams are turned, actuating devices that press the connector fingers against the pins. It has been used on the mock-up to show an alternate to use of the Zero-g connector. The Zero-g connector on the front panel simulates either an operational or a BIT connector.
- Modules #2, 3, 4, 5, 6, 8, and 9 used conventional aerospace printed circuit and hand-mated connectors.
- Module #1 - Hughes high density connector, modified for rack and panel application with a single, captive, self-locking screw drive.
- Module #7 - Burndy printed circuit board, high density connector currently in use on IBM's 4Pi computer.
- Module #10 - Contains a simulated small module connector as there were none available in the size desired for this small module.

8.6 DEVELOPMENT OF QUICK-RELEASE AND SELF-ALIGNING FASTENERS

Based on a need for black box and module alignment guides, identified during development of the criteria, attempts were made to locate off-the-shelf guides for use on the mock-up. These attempts were unsuccessful.

Various manufacturers of similar equipment were contacted in an attempt to generate sufficient interest and to have prototypes of the necessary guides developed. This attempt was also unsuccessful. The problem was then given to the advanced development group within Grumman for basic design development, and the units needed for the mock-up were fabricated by a local sub-contractor. See Figures 8-1, 8-2 and 8-3, showing the quick-release, self-aligning fasteners used on module #1 and Box #3.

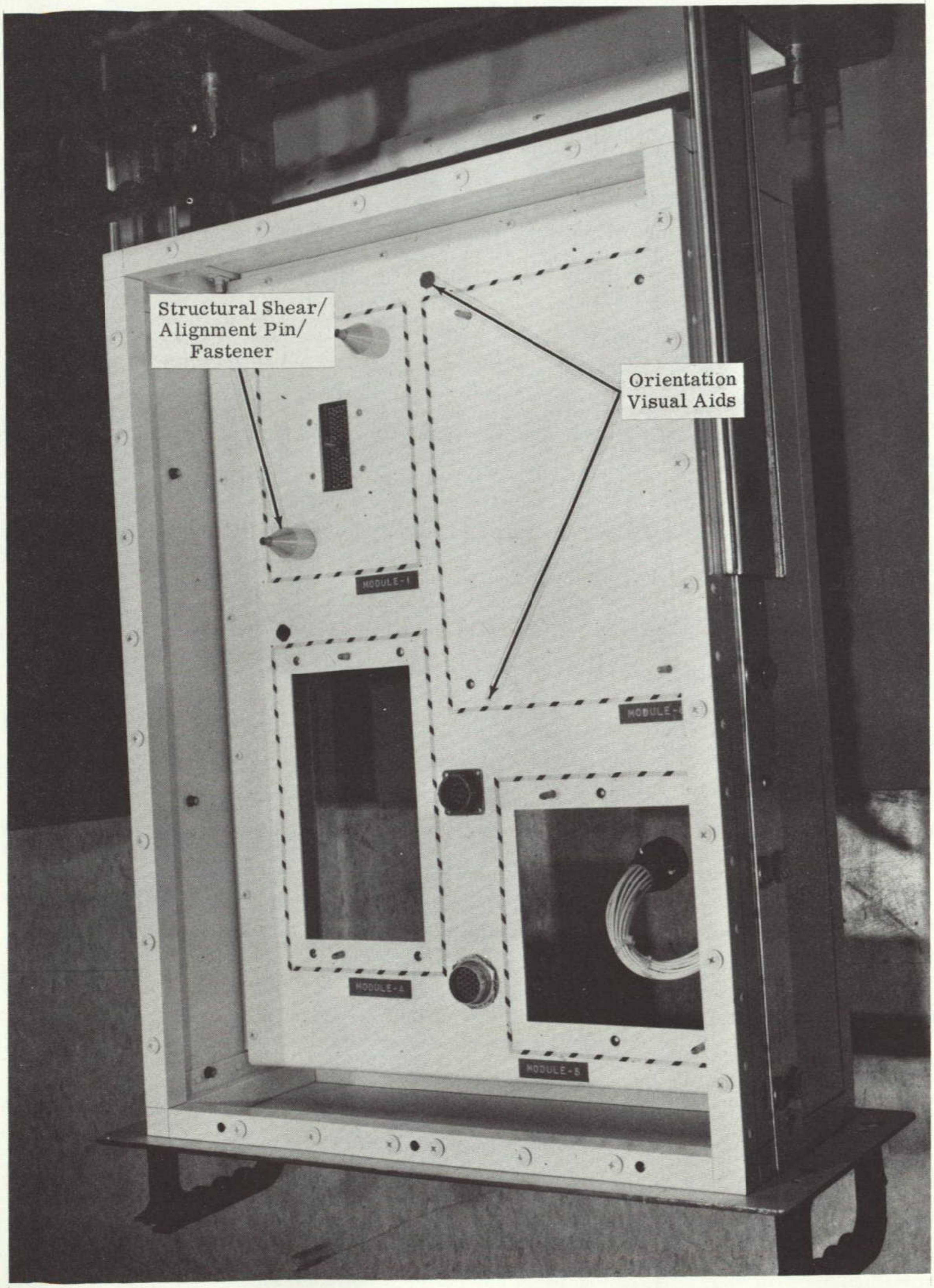


Figure 8-1. Module Alignment and Visual Aids

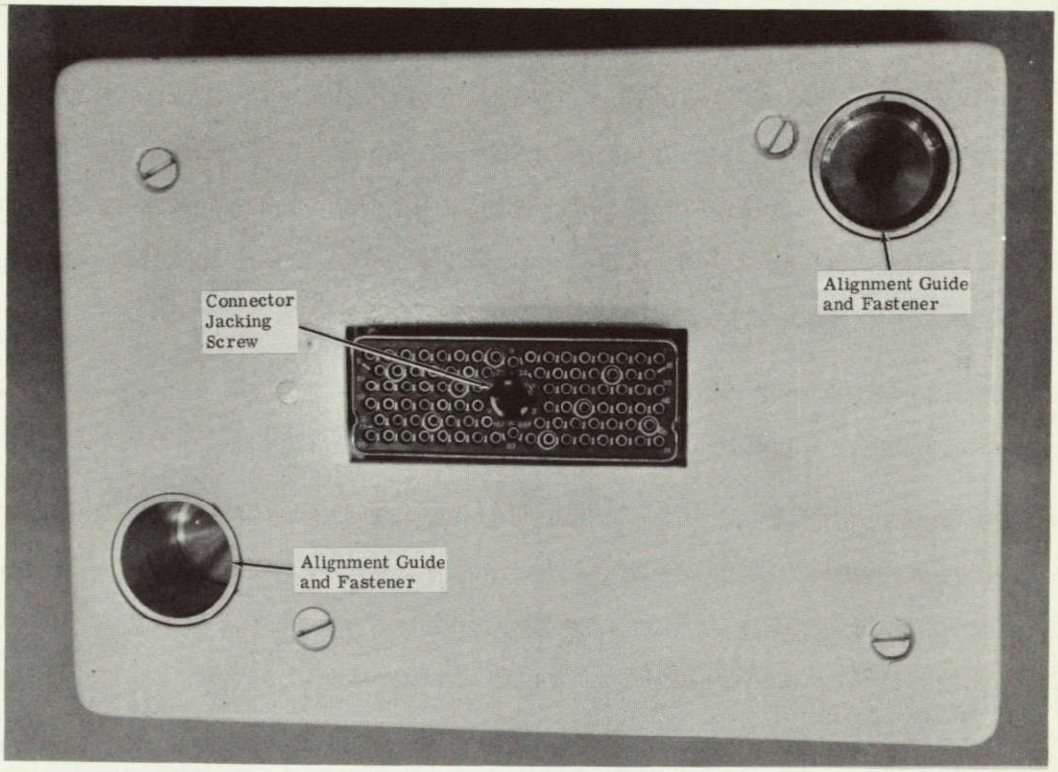


Figure 8-2. Module 1 Alignment Guide/Fastener

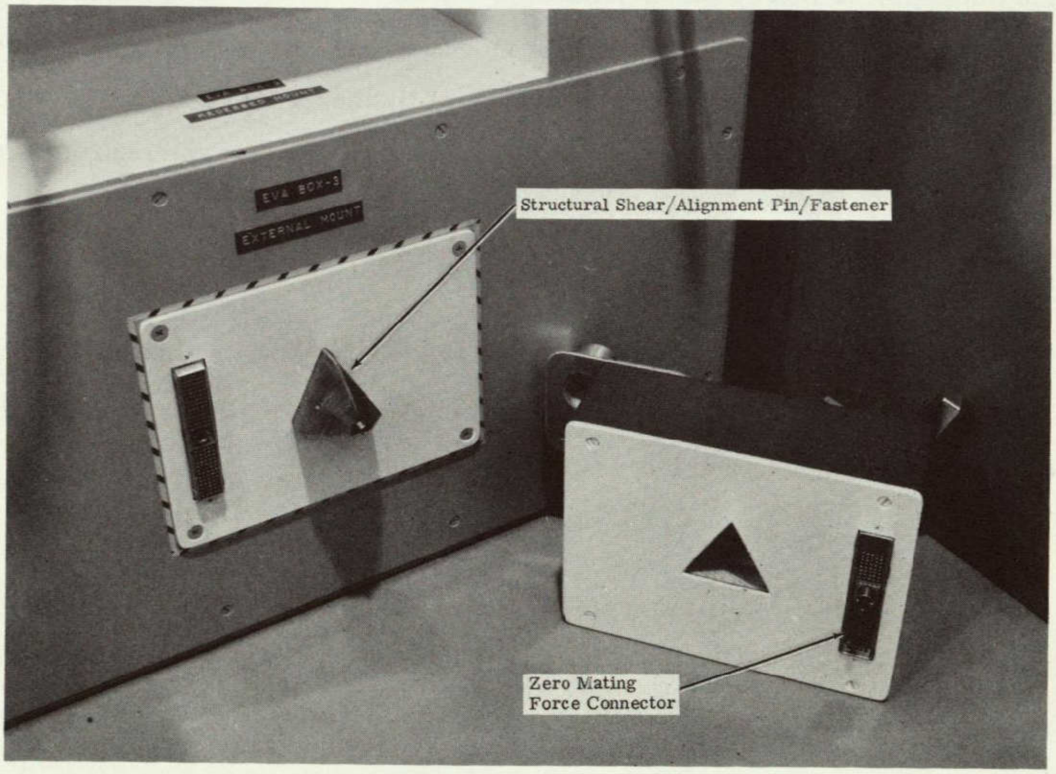


Figure 8-3. Box #3 Alignment Guide/Fastener

8.7 ALIGNMENT AND VISUAL ORIENTATION FEATURES

Early investigation indicated that conventional methods of alignment could be used to guide modules 2, 3, 4 and 6 into the quick release fasteners. These guide or alignment devices consist of slightly tapered pins (bull pins) mounted on the supporting structure. The pins mate with holes in the heat sink of the module. Asymmetrical location of the pins provides the necessary module keying.

In addition to the mechanical alignment guides described in paragraph 7.3.4, two types of visual aids were found to be necessary:

- A border or outline of the removable unit is needed when the item removed is free standing; i.e., where the removable unit is not surrounded by other boxes or modules. This outline is most important where the locating pins for the removable unit are hidden during the replacement action.
- Markings, on both the removable unit and the mounting surface, which can provide correct visual orientation when the unit is replaced.

The mounting of Box #3 on enclosure "C" of the mock-up shows an example of the visual orientation described above. Here, the mounting provisions on the front face of the enclosure contain a colored tape to form an outline of the box. Colored tape is also used to outline the correct mounting spot for modules 1, 2, 3, 4, 5 and 6 in enclosures A and B. (Refer to Figure 8-1.)

8.8 BLACK BOX AND MODULE DESIGN DEVELOPMENT

Three EVA boxes, ten IVA modules, one IVA control/access panel, one IVA vertical drawer, and one horizontal drawer form active parts of the mock-up. A description of the boxes and modules, and their development follows:

8.8.1 <u>Box #1</u> (See Figure 8-4)

Box One is representative of a large, heavy EVA box in which the thermal requirements dictate a relatively large surface for heat rejection, an electrical interface that requires rack and panel connectors, and structural attachment is required at all four corners of the box.

Figure 8-4. Box #1 Installed In Enclosure C

- **Configuration**

  - Four-sided box with removable top and bottom covers
  - Metal box of welded and bolted construction
  - Dimensions - box 17"W x 7"H x 24"D; front panel 19 1/2"W x 8 1/2"H

Modules were not included as a part of box #1 design as this requirement was deleted on boxes 1, 2, and 3 by mutual agreement. See paragraph 5-3. With the exception of the four flashlight batteries used to operate the "downpower" indicator light, box #1 is empty. Box #1 is the only unit of the mock-up which displays the methods of electrical shock protection, two methods can be demonstrated:

- Electrical interlock, wherein a short pin in one of the rack and panel connectors turns electrical power off automatically during box removal.
- "Down powering" of the subsystem as a procedural step, by having the astronaut turn a switch located on the box front panel to the "off" position.

- **Structural Interface**

The physical size and weight of Box #1 dictated support at four points on the structure. Two 1/4" shear pins were provided to tie the rear surface of the box into the simulated spacecraft structure and two 1/2" shear pins were incorporated as a part of the latch mechanism on the front panel.

Quick release of the structural and thermal interfaces was accomplished by a mechanism having the following features:

- A single handle to operate the mechanism and serve as a box carrying handle.
- The travel and force necessary to jack and unjack the rack and panel connectors: 3/8" travel and 240 lbs of force for four high-density connectors.
- The compression force necessary to mechanically lock up the box and the thermal interface.

The mechanism combines two double acting wedges with an overcenter linkage to develop the travel and forces required. The mechanism passes overcenter to provide locking action when the box is installed. The mechanism operating handle is locked by a spring loaded latch in the open or unlocked position, thereby permitting use as a box carrying handle.

It was recognized that a latching action was required to prevent movement of the handle in both the open and closed positions, and that a thumb release of this latch was the ideal method. Due to limited funds however a simpler latch, operated by the palm of the hand with a lock in the open position only, was selected for the mockup.

- Thermal Interface (See Figure 8-5.)

The quick release thermal interface was simulated by a flat plate mounted on the rear surface of Box #1. Area of the plate is approximately 103 sq. inches and the same plate is used for mounting the electrical connectors and the female portions of the structural shear/alignment pins.

Heat generated in the box would be transferred through the rear surface of the box into a spacecraft mounted cold plate. Contact pressure between the two plates is supplied by the front panel latching mechanism.

- Electrical Interface (See Figure 8-5.)

Four high-density (351 pins total) ITT Cannon rack and panel connectors are mounted on the rear surface of Box #1. These are environmental type connectors having MIL approval. A similar type of the same connector family was approved for use on Apollo.

The mating force of approximately 240 lbs. for the four connectors is supplied by the latching mechanism on the front panel. During installation, Box #1 is guided into the structural shear/alignment pins, followed by contact of the connector shells which are tapered for final alignment before mating of connector pins. The connector receptacles are attached to the spacecraft mounted cold plates by a floating, spring loaded mount which accomodates minor mounting tolerances.

- Mechanical Alignment (See Figure 8-6.)

Three stages of alignment are provided to guide Box #1 into the enclosure:

- The first stage uses the rectangular cross section of the box, combined with the off center location of the second stage guides, to prevent improper orientation during the initial installation action.
- The second stage uses wedge shaped guides which are attached to both sides of the box. These wedges guide the box to the edge of the structural shear/alignment pins.
- The third and final stage consists of tapered ends on each of the four shear/ alignment pins, which guide the close tolerance mating holes of the box onto the pins.

Spacecraft mounting provisions were simulated by a wrap around sheet metal structure, which in turn was mounted in enclosure "C". This sheet metal structure also contains the simulated spacecraft heat sink, the female portion of Box #1 alignment guides, supporting brackets for the front panel structural shear/alignment pins, and the structural shear/alignment pins for the rear corners of the box.

8.8.2 Box #2 (See Figure 8-7.)

Box 2 represents a medium-sized EVA electronic housing in which: the thermal requirements will permit dissipation of the heat through the front panel flanges of the box; the weight and size which will permit cantilevering from the front panel (base plate construction); and the electrical interface requirements combined with remove/replace time restrictions will permit use of hand-mated connectors. The design permits one-handed lock-up of structural and thermal interfaces without the use of tools. The electrical interface is hand mated.

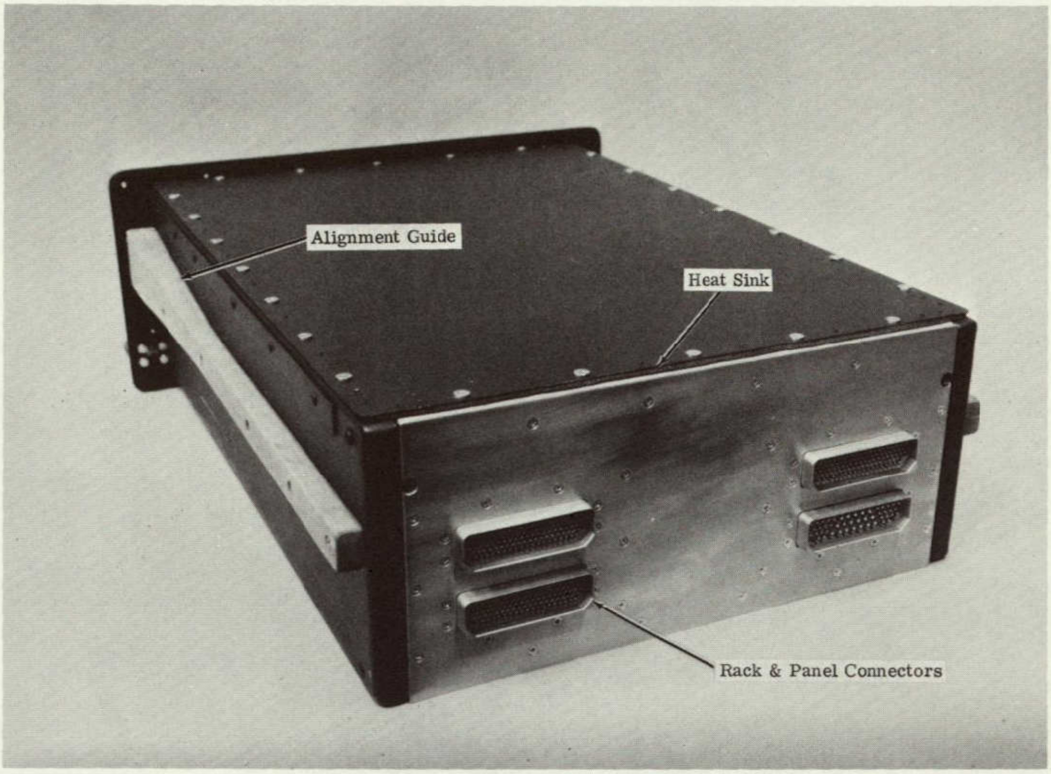


Figure 8-5. 3/4 Rear View of Box #1

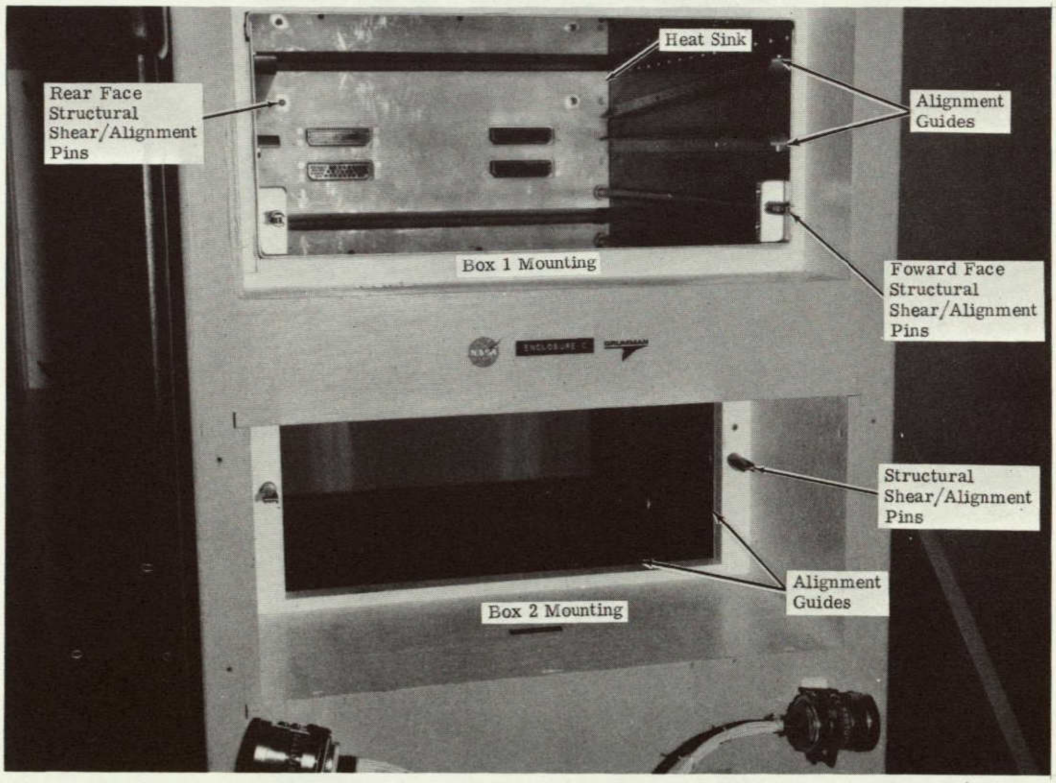


Figure 8-6. Boxes 1 & 2 Mounting Provisions On Enclosure C

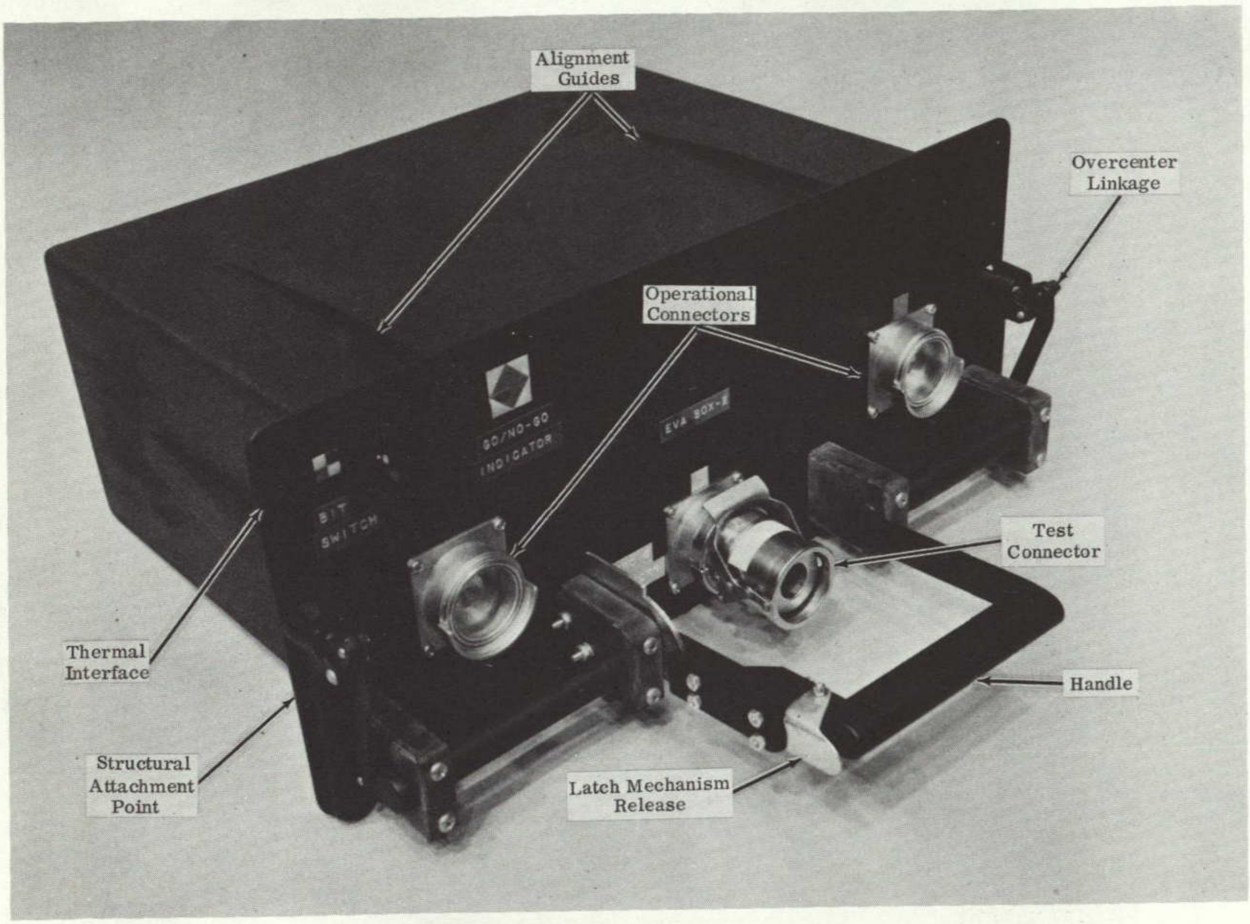


Figure 8-7. Box #2

- Configuration

  - Basic base plate design
  - Wood box with a metal front panel to simulate the heat sink
  - Dimensions - box 17"W x 7"H x 12"D, simulated heat sink (front panel) 20"W x 8 1/2"H.

  The base plate configuration was selected for display on the mock-up because it is typical of a basic design which has been used extensively on existing hardware. The use of flange mounting permits a base plate location which is close to the astronaut, thereby simplifying the attachment mechanism.

- Structural Interface

  Box #2 is attached to the structure at 2 points using 1/2" diameter shear/alignment pins. These pins form a part of the latching mechanism, which was designed to accomplish the following:

  - Lock up the structural and thermal interface using one hand, in a single 90° motion
  - Incorporate the box carrying handle into the lockup mechanism in such a way that the astronaut never removes his hand from the handle in order to perform the lockup
  - Apply an operating force of 800 lbs. at each of the attach points.

  In fabricating the mechanism, parts of two Hartwell Corporation latch handles were modified to interconnect with the box handle and other linkages. This provides an overcenter device which is capable of generating forces in excess of 1000 lbs. at each of the attach points.

- Thermal Interface

  Heat generated within the box would be removed through the front panel flanges of box 2. Contact pressure between the flanges and the spacecraft mounted cold rails is supplied by the latching mechanism described above.

- Electrical Interface

  Three MSFC Specification 40M39580 (Bendix Zero-g) connectors provide the electrical interface for Box 2. Two of these connectors represent the box to spacecraft interface and one represents a test connector.

- Mechanical Alignment

  To provide the alignment needed for guiding the box into the structural shear/alignment pins, all four box sides were tapered 1/2" from front to back. The tapered sides of the box mate with the enclosure as described in the following paragraph. The shear/alignment pins were also tapered, thus permitting quick final alignment of the front panel holes on the shear/alignment pins.

- Mounting to Enclosure (See figure 8-6.)

  Provisions were made to mount Box 2 in either of two positions on Enclosure "C".

  - The first position recesses the front face of the box approximately 8" from the forward face of the enclosure, this provides the space necessary for the Bendix connectors and associated wire harness when the box is mounted behind a cover or hatch.

  - The second position brings the front panel within 1" of the enclosure front surface and represents open access to the box.

  The box mount also contains a tapered sheet metal assembly which mates with the tapered sides of Box 2, providing quick and easy initial alignment of the box during the remove/replace action.

8.8.3 Box #3 (See figure 7-6.)

Box 3 is representative of the smallest EVA Box that is considered feasible for removal and replacement by a suited astronaut. It was designed for one handed lockup of the structural and thermal interfaces, without the use of tools. The electrical interface is hand actuated.

- Configuration
  - Single base plate design
  - Wood block with a metal plate to simulate the heat sink
  - Dimensions 8"W x 6"H x 3"D
  - No internal modules

  The controlling factor which limited a further reduction in the size of Box 3 was the electrical interface, see paragraph 7.3.3c.

- Structural Interface

  Physical size and the light weight (estimated 8 lbs) of box 3 makes it feasible to attach the box by means of one fast acting structural fastener. The fastener selected for the mock-up has an ultimate tensile strength of 1400 lbs, ultimate single shear of 2500 lbs, and a tightening torque of 25-inch lbs. The fastener is tightened by a three inch fluted knob to provide the "no tools" feature required by the criteria.

- Thermal Interface

  The basic thermal design of this unit removes self generated heat by conduction through the base plate on the rear surface of the box to a mating spacecraft mounted heat sink.

- Electrical Interface

  Two connectors were provided on Box 3. The connector problem, outlined in paragraph 7.3.3 (Box 3 concepts), resulted in selection of a prototype ITT Cannon HQ6243-103 connector for the box to spacecraft system interface. This connector contains 103 pins and requires no force to mate the connector half with the receptacle shell. Electrical connection is made by rotating a separate cam shaft 90° which drives the connector pins sideways into the receptacle pins.

Box 3 also contains a prototype MSFC 40M39580 (Bendix Zero-g) plug and a dummy receptacle. Since the ITT Cannon connector mentioned above is not an approved connector, the Zero-g was included to show space requirements for either an operational manual connector or a test connector.

- Mechanical Alignment (See Figure 8-3.)

  A unique triangular alignment guide was developed for Box 3. The male portion of the guide was mounted on the spacecraft structure and contains the ramps necessary to positively orient and align the box prior to engagement of the electrical connector. This feature permitted repeated "blind" installations by a suited astronaut during the demonstration tests.

- Mounting in Mock-up Enclosure (See Figure 7-6.)

  Provisions were made to mount Box #3 in two different locations on Enclosure "C". The first, and most difficult for the remove and replace action, was recessed 8 inches into the enclosure to simulate a recessed box installation. The second mounting position was located on the front face of the enclosure and simulated a free standing external box installation.

8.8.4 Modules (See Figures 8-8 and 8-9.)

The ten modules displayed in the mock-up can be roughly described as follows:

- Modules 1, 2, 3, 4, 5, 6, and 10 are of a rectangular or box type construction. These units demonstrate various types and methods of accomplishing quick disconnect of the structural, thermal and electrical interfaces.

- Modules 7, 8, and 9 are printed circuit boards. Numbers 7 and 9 demonstrate quick disconnect of the three basic interfaces. Number 8 demonstrates a typical aircraft type of PCB installation.

A more detailed description of the modules is contained in the following paragraphs.

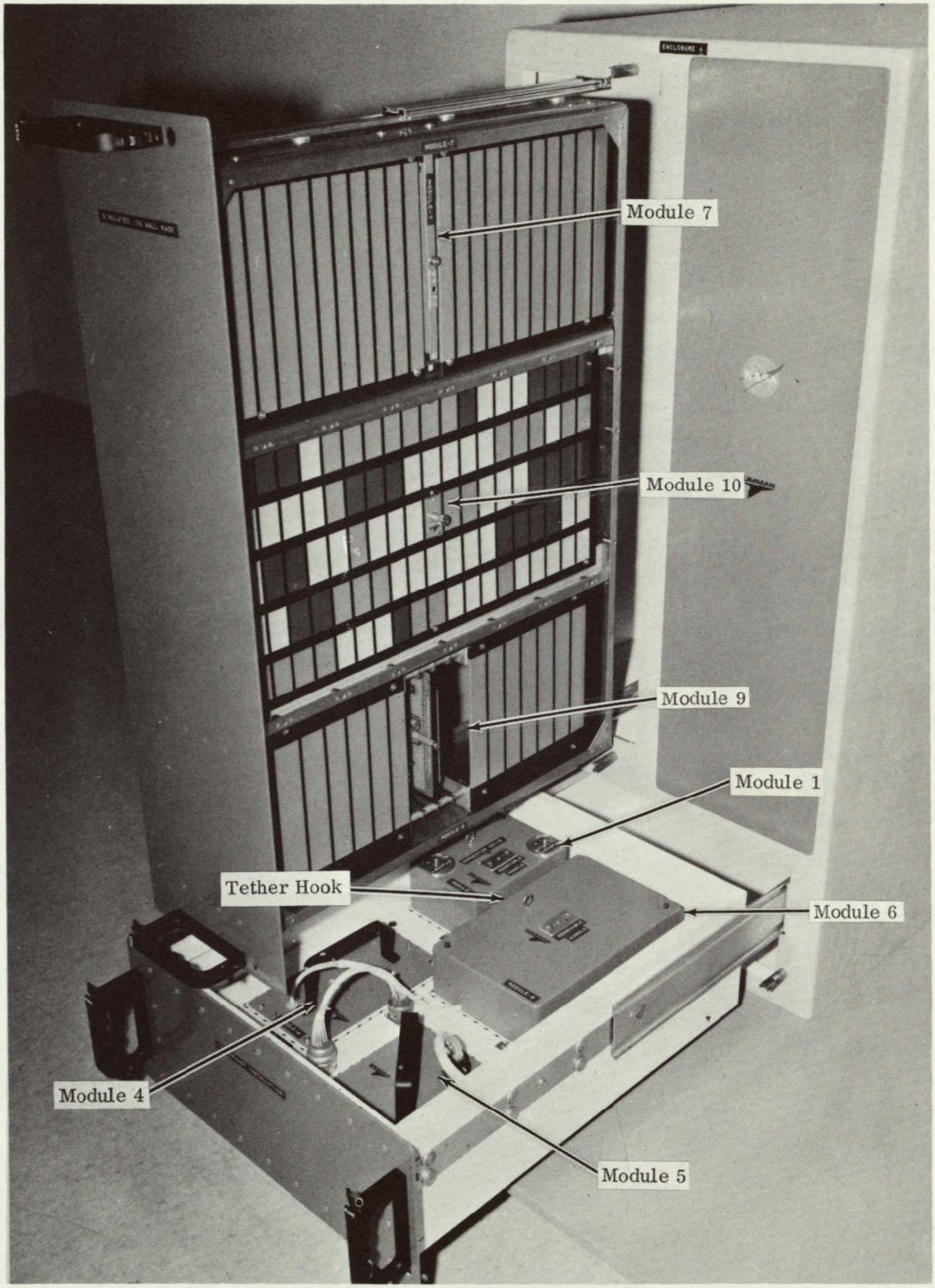


Figure 8-8. IVA Enclosure "A"

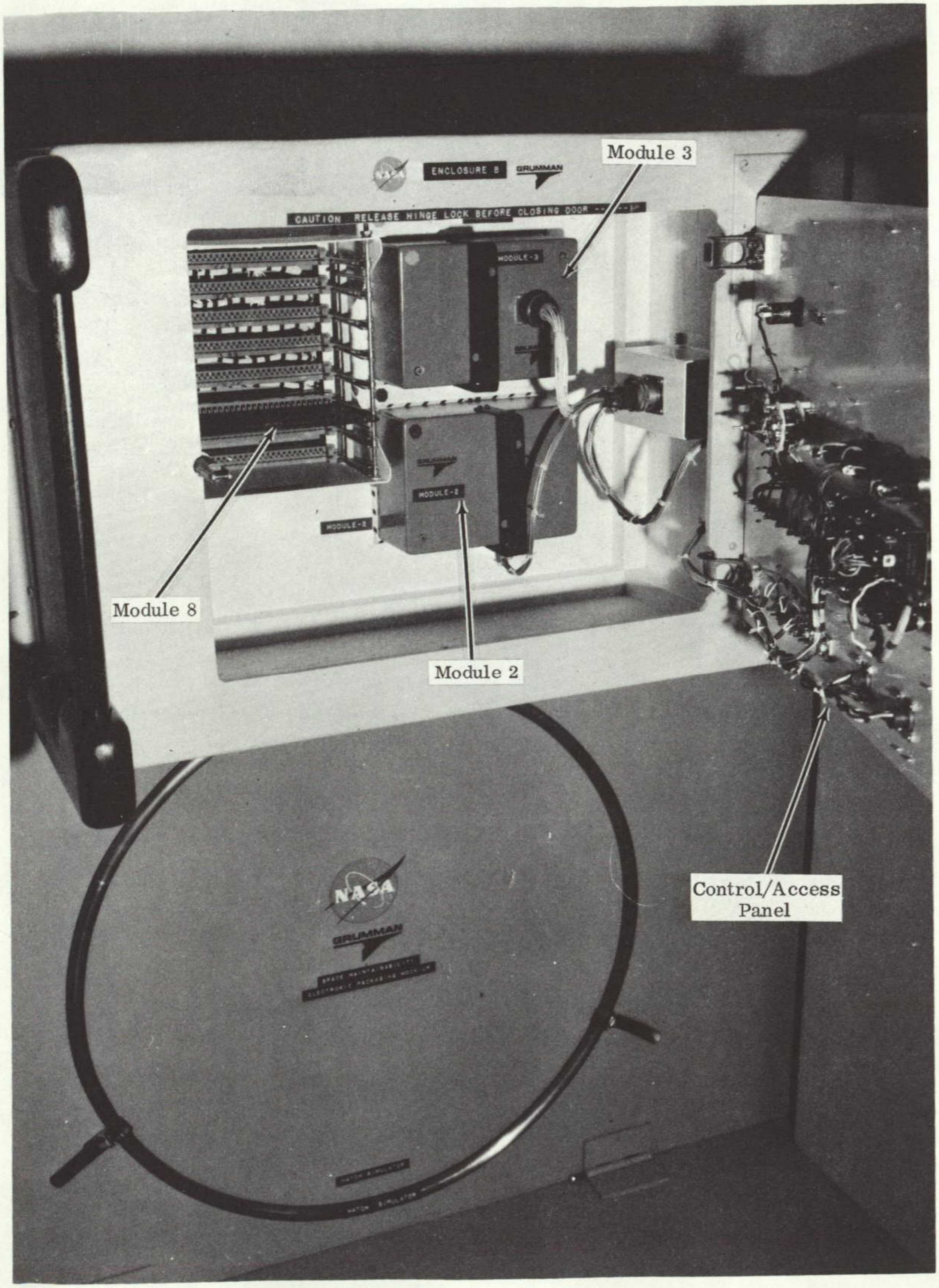


Figure 8-9. IVA Enclosure "B"

8.8.4.1 Modules 1, 2, and 3 represent single base plate designs wherein the plate serves as the structural base for mounting of electronic items and as a heat sink for transfer of module heat to the spacecraft.

- Configuration
  - Rectangular shape 5"W x 7"L x 3"D (Modules 1, 2, and 3)
  - Metal base plate with wood block to simulate volumetric requirements.
  - The three modules differ in the methods used to accomplish electrical interface and mechanical alignment.

- Structural Interface

  Module 1 was attached to the drawer by two combination alignment guide/fasteners. Two off-the-shelf (Calfex) 1/4" screws and plate nuts were modified to permit combining the features of alignment, structural shear pin, and retaining fastener.

  Modules 2 and 3 are attached to the horizontal drawer structure at two points, by means of captive quick release, structural type fasteners. Off-the-shelf (Calfax) fasteners were modified by adding an extension shaft and raising the fastener head to the module surface which faces the astronaut.

- Thermal Interface

  The metal plate, mounted on the rear surface of modules 1, 2, and 3, simulates the heat sink and a typical method of removing heat from the modules. The thermal path is from the module heat sink to the spacecraft mounted coldplate on which the modules are mounted. The structural mounting fasteners provide the pressure needed to make thermal contact between the two surfaces.

- Electrical Interface

  Module 1 incorporates a Hughes high-density, center jacking, rack and panel connector mounted in the rear surface of the module.

This connector was selected to demonstrate the ability of an astronaut to hand-mate the module with a rack and panel connector under conditions where the connector is not visible.

Modules 2 and 3 use a drop cable and a module mounted receptacle respectively. The connectors used on these modules represent conventional environmental types, requiring less than one turn to release each connector.

- Mechanical Alignment

Module 1 has two unique alignment guides which provide the alignment needed to mate a rack and panel connector and the structural fasteners under adverse module alignment conditions. These guides correct for module misalignment of up to 1/2" and provide complete connector alignment prior to engagement of the connector center jacking screw.

The guides also serve to structurally attach and module to the drawer, and asymmetrically location of the guides on the horizontal drawer mounting surface provides the necessary module keying, preventing improper module installation.

- Modules 2 and 3 were provided with conventional 3/16" diameter alignment pins which have tapered ends to correct a module misalignment of approximately 1/16". These alignment pins are positioned asymetrically on the module mounting plate to prevent improper module installation.

- Handles

Module 1 has provisions for use of a removable handle during the remove-and-replace action, since inadequate space in the horizontal drawer precluded use of a fixed handle.

Modules 2 and 3 have handles which are permanently attached and which also contain provisions for the tether hook.

2

8.8.4.2 Modules 4 and 5 incorporated all of the module 2 and 3 features, the basic difference being in the structural and thermal interfaces. Modules 4 and 5 are attached to the drawer by conventional (Calfax) quick release, captive fasteners. Two flanges which extend beyond the body of the module are the structural supporting members, and the thermal path from the module to the drawer cold plate is also carried through the flanges.

- Configuration

  Rectangular in shape, using a metal base plate with a wood block to simulate volumetric requirements:

  Module 4 Base plate 5"W x 9"L, wood block 3 3/4"W x 7 1/4"L x 2 1/2"D

  Module 5 Base plate 6"W x 7"L, wood block 4 3/4"W x 5 1/4" x 2 1/2"D

Module 6 was configured to represent a module wherein the environmental requirements are such that a metal casting is needed to enclose the electronics contained in this module.

- Configuration
  - Rectangular shape 7"W x 11"L x 3"D
  - Metal Base plate, with wood block to simulate volumetric requirements

- Structural, Thermal and Electrical Interfaces

  The methods of accomplishing structural, thermal and electrical interfaces are the same as those described for modules 2 and 3 above.

- Mechanical Alignment

  Module 6 was provided with two standard 3/16" diameter alignment pins which have tapered ends to correct a module mechanical misalignment of approximately 1/16". These alignment pins are positioned asymmetrically on the module mounting plate to prevent improper module installation.

- Handle Provisions

  Module 6 has provisions for use of the removable handle which was supplied with the mock-up. See paragraph 8.9 for a description of the handle.

8.8.4.3 Modules 7, 8, and 9 represent three different configurations of printed circuit boards (see Figures 8-8 and 8-9).

Module 7 is representative of an IBM 4Pi computer page, which would typically provide mounting space for a total of 170 integrated circuits on two multilayer boards.

- Configuration

  Masonite block 1/2" x 4 1/2" x 8 1/2"

- Structural interface

  - Supporting guides on each side of the module
  - A single multi-threaded fastener (Calfax) mounted in the center of the module provides the force needed for the structural, thermal and electrical interfaces.

- Thermal Interface

  Provides at three points on the module, one at the structural fastener in the center of the board and one on each end of the module.

- Electrical Interface

  Consists of two Burndy ML 98, 98-pin high-density connectors. Mating force for the module is approximately 90 lbs and the unmating force is approximately 70 lbs. The above forces are supplied by the structural mounting screw.

- Mechanical Alignment

  Consists of guide rails on each side of the module. These rails were tapered at the outer ends approximately 30°, to a depth of 3/8".

- Handle

  Provisions consist of a plate mounted Dzus fastener spring which accepts the removable handle that was supplied with the mock-up (simulated universal tool).

Modules 8 and 9 are conventional printed circuit boards with conduction on both sides of the board

- Configuration

  Module 8 5"H x 6 5/8"W

  Module 9 4 3/4"H x 7 3/8"W

- Structural Interface

  - Module 8 has supporting guides on each side of the board
  - Module 9 has supporting guides on each side and one multi-threaded fastener mounted in the center of the board to provide the force needed for structural and electrical interface

- Thermal Interface

  Module 8 represents a module with extremely light heat loads wherein the heat could be taken out through the edges of the board by the supporting guides.

  Module 9 thermal interface is provided at the center jacking screw and at each edge of the board.

- Electrical Interface

  Module 8 contains an Elco connector which has individual contacts that are mounted to the printed circuit board. The connector is mated by hand and a printed circuit board extractor was supplied with the mock-up for extraction of the module. This conventional module was included in the mock-up to permit evaluation of the astronaut's ability to manipulate the aircraft-type PCB extractor in a Zero-g environment.

  Module 9 uses a Hughes 136 pin edge type connector. Jacking forces for mating and unmating of the connector are supplied by the structural fastener discussed in a previous paragraph.

- Tether fitting

  Module 9 is the only PCB in the mock-up which incorporates provisions for attaching a tether hook. Since a standard size for tether hooks could not be determined, an oblong hole of approximately 3/8" x 1/2" was provided. The method of displaying tethering provisions on module 9 was considered typical, therefore no tether fittings were provided on modules 7 and 8.

8.8.4.4 Module 10 represents the smallest module considered feasible for replacement by a suited astronaut. This module was mounted in a simulated electromagnetically shielded enclosure, behind a cover plate which is attached with 22 quick-release fasteners (see Figure 8-10).

- Configuration

  Encapsulated cord wood module, 3/4"H x 15/16"W x 13/16"L

- Structural Interface

  Module 10 was mounted on the vertical drawer cold plate using a single #6 Deutsch fastener. The fastener is captive and has a 1/2" diameter knurled knob for removal and replacement of the module.

- Thermal interface

  Heat dissipation for this module would be small (milliwatts), therefore the metal land around the structural fastener was used to simulate the thermal path. The fastener would supply the force needed for the thermal interface.

- Electrical Interface

  Electrical provisions consisted of the 15 pins molded into the module and a simulated mating receptacle.

- Mechanical Alignment

  Alignment was combined with connector pin protection in the form of phenolic strips extending beyond the sides of the module. One corner of the alignment guide was notched to provide mechanical keying, thereby preventing improper installation of the module. The fastener knob is used as a handle for module 10 (refer to Figure 10-16).

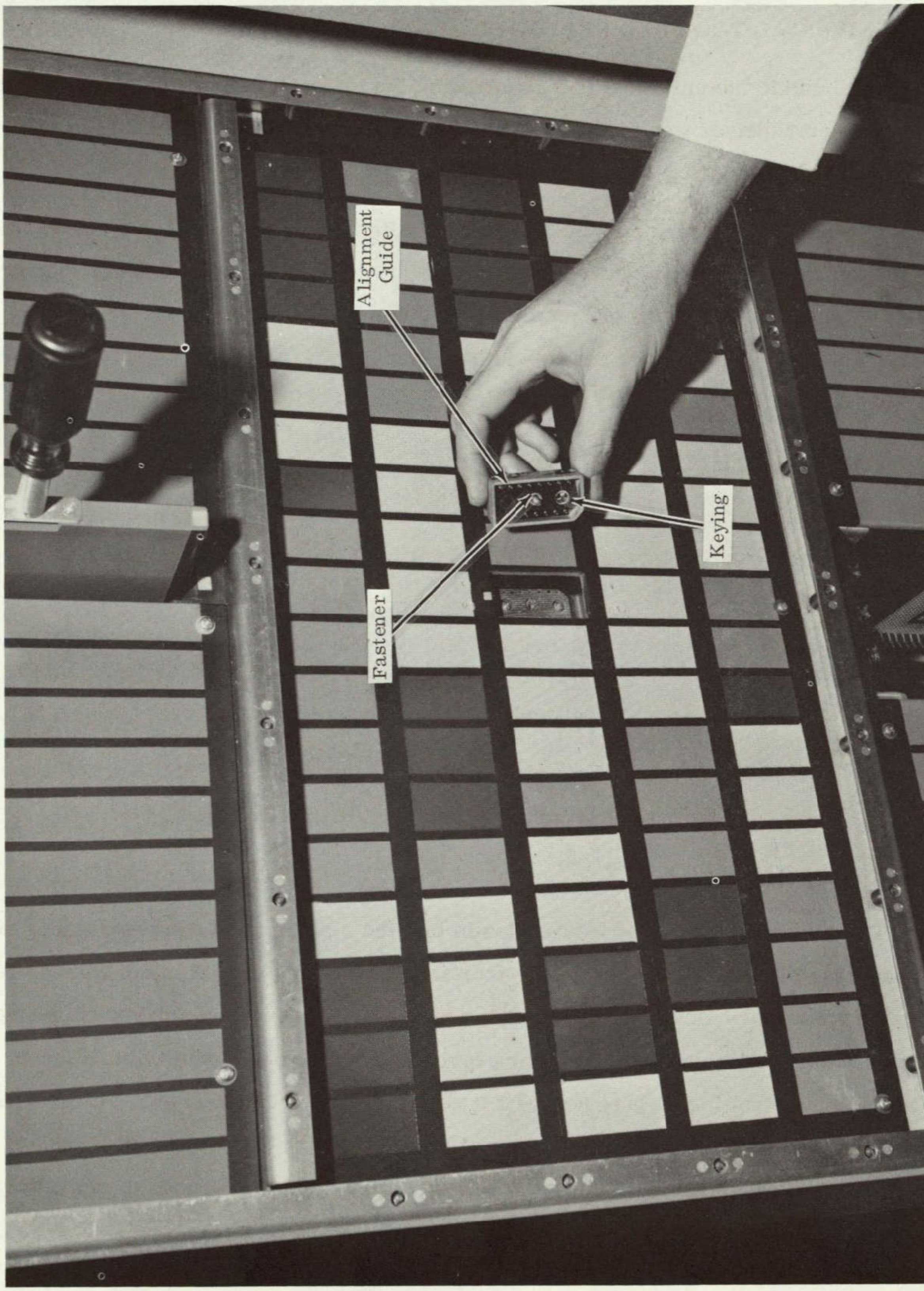


Figure 8-10. Module #10 Installation

8.9 UNIVERSAL TOOL AND REMOVABLE HANDLE

To simulate the universal tool required by the criteria, a commercially available "allen head" screw driver was modified to accept the two sizes of hex drives used. This tool was supplied as a part of the mock-up.

The need for a removable handle (space limitation) on modules 1, 6, and 7, was met by mounting a Dzus fastener screw on a screw driver handle. The matching springs for the Dzus screw/handle were mounted flush into the surface of the above mentioned modules. Figure 8-11 shows the removable handle in use.

8.10 TETHER PROVISIONS (See Figure 8-8.)

Provisions were made for tethering all but three of the thirteen removable units contained in the mock-up. A hole size of 3/8 inch was selected for attachment of the tether hook, since the various documents reviewed did not indicate hook standardization.

The three units which do not contain tether provisions are:

- Modules 7 and 8. Since module 9 has provisions for a tether hook, this is considered typical for all printed circuit boards.
- Module 10. The physical size of this unit (approximately 1 x 2 x 3/4 inches) makes it impractical to install provisions for a tether hook.

8.11 HATCH SIMULATOR

The contract established a ground rule that the maintainable equipment being replaced must readily pass through a twenty-four inch round opening. This dimension presumably represents the smallest hatch opening presently contemplated for use on manned spacecraft. The opening was simulated by providing a large copper ring with an inside diameter of twenty-four inches (see Figure 3-1). A ring was selected over a cut out in the mock-up since it will be much easier to manipule under one "g" conditions than passing the large boxes through a simulated hatch opening. Provisions were made to store the ring on the front face of the back panel, below Enclosure B.

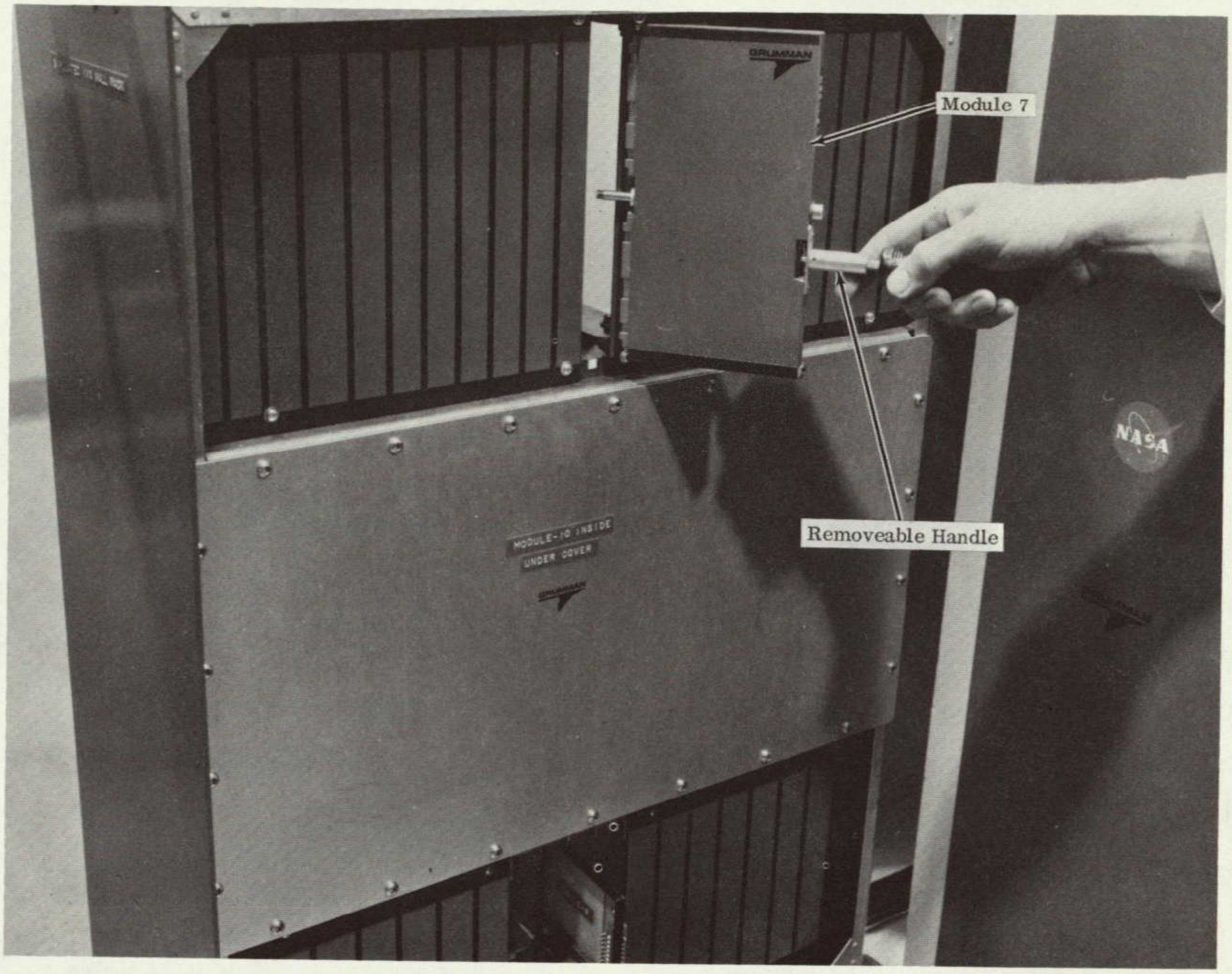


Figure 8-11. Use Of Removable Handle

During demonstrations, the ring can be passed over the EVA boxes to verify that the boxes will pass through the hatch opening. Because of their size, all of the modules in this mock-up will obviously pass freely through the opening. The vertical and horizontal drawers are not required to pass through the hatch opening since modules within the drawers are to be removed and replaced for a typical maintenance action.

8.12 DESIGN FREEZE AND RELEASE TO PRODUCTION

Final configuration of the mock-up was presented to MSFC during a meeting on 24-25 November 1969. This meeting resulted in agreement on mock-up basic design, and a design freeze.

Minor changes which resulted from the above meeting were incorporated in the mock-up engineering sketches, and the first sketches were released to manufacturing on 10 December 1969. Mock-up fabrication continued through 27 February 1970.

8.13 NEUTRAL BUOYANCY PROVISIONS

The EVA boxes in Enclosure "C" of the mock-up must be counterbalanced to permit realistic manipulation and to prevent movement of the Zero-g simulator during removal and replacement operations. This has been accomplished by providing a "C" frame tool which contains provisions for attachment to weather balloons. See Figure 8-12. The tool attaches to a bracket mounted on the upper right hand face of each box. The tool has three holes, one for each box as described in Appendix C. When mounted and balanced for neutral buoyancy, the tool provides relatively easy Zero-g manipulations.

Since only one box was to be removed and replaced at a time, only one adapter bracket is provided for the three boxes. Accordingly, the bracket must be placed on the appropriate box for each R&R operation. The other end of the "C" frame tool contains a micarta block which can be moved in and out to provide the proper leveling. The micarta block is grooved to allow attachment of the counterweighting balloons provided by NASA.

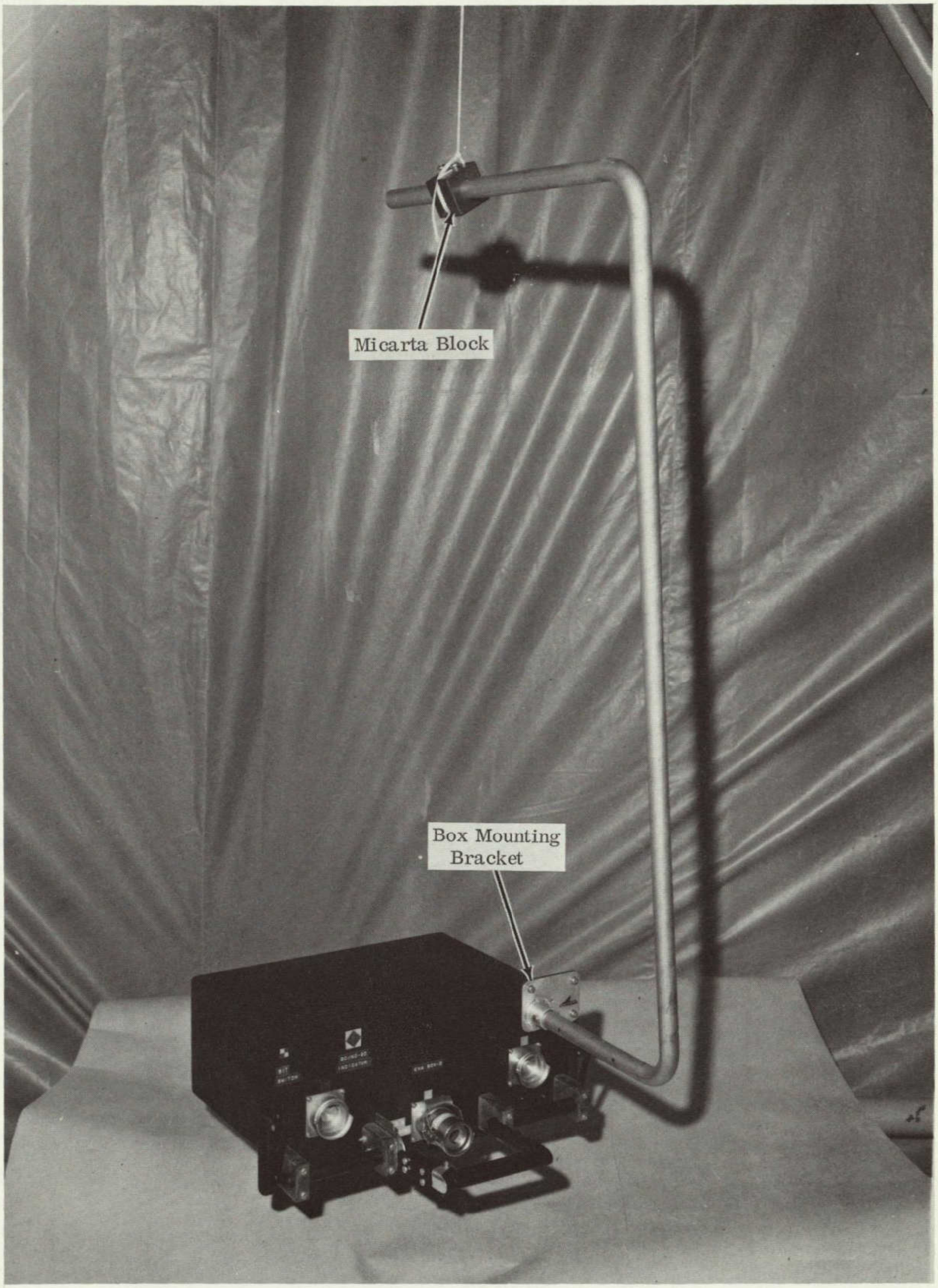


Figure 8-12. "C" Frame Tool

8.14 ZERO-G FACILITY MOUNTING PROVISIONS

During the evolution of the mock-up design, the configuration of the mock-up was altered to adhere to the 200-pound limitation of the MSFC Zero-g facilities. These changes resulted in the EVA boxes and IVA modules being built into three separate enclosures which individually weighed less than 200 pounds with all modules and boxes installed. Weights of the individual enclosures are listed in Appendix C.

Each of the enclosures has been provided with metal angles at the rear panel for attaching to the Zero-g simulator panel. The angles are bolted to the enclosure at several places and provisions are likewise made to bolt the angle to the simulator.

To prevent the Zero-g simulator from moving during R&R operations, the EVA boxes and IVA modules must be counterbalanced. The EVA boxes were provided with a means of counterblaancing as noted in Section 8.13. No provisions were made for counterbalancing the weight of individual modules in Enclosures A and B.

SECTION 9

CRITERIA DEMONSTRATED ON MOCK-UPS

The contract called for demonstration on the mock-up of a maximum number of the maintainability remove and replace design criteria. It was possible to incorporate a total of 31 out of the 35 basic design criteria listed in Appendix A. In addition, 44 out of a total of 48 criteria variations were also demonstrated in one form or another on the mock-up. The four criteria not demonstrated on the mock-up are functional-performance-oriented and cannot be displayed on a mock-up.

The following table summarizes the individual criteria and the mock-up hardware that incorporates or symbolically displays the design features.

TABLE NO. 9-1. CRITERIA AND DESIGN FEATURES

Criteria No.	Design Feature or Requirement	Incorporated in Mock-up		
		Enclosure	Box	Module
G-1	One hand R&R action	A C	Drawers 1, 2, 3	1, 4, 5, 6, 7, 9
G-2	R&R within 20 minutes	A, B, C	1, 2, 3	All 10
G-3	Easy alignment provisions	A, B, C	1, 2, 3	All 10
G-3a	Visual orientation aids	A, B, C	1, 2, 3	1, 2, 3, 4, 5, 6, 7, 10
G-4	Mechanical keying provisions	A, B, C	1, 2, 3	All 10
G-5	Connector keying provisions	A, B, C	2, 3	2, 3, 4, 5, 6
G-6	Tethering provisions	A, B, C	1, 2, 3	1, 2, 3, 4, 5, 6, 9, 10
G-7	Interface protection (electrical)	A, B, C	1, 2, 3	1, 2, 3, 4, 5, 7, 10
G-8a	One hand, single motion, 3 way lock-up	C	1	--
G-8b	One hand, single motion, 2 way lock-up	C	2, 3	--
G-8c	Simultaneous 3 way lock-up, fast screws	A, B	--	7, 8, 9, 10
G-8d	Simultaneous 2 way lock-up, hand connectors	A, B, C,	2	1, 2, 3, 4, 5, 6

TABLE NO. 9-1. CRITERIA AND DESIGN FEATURES (cont)

Criteria No.	Design Feature or Requirement	Incorporated in Mock-up		
		Enclosure	Box	Module
G-9	Mounting hardware captive	A, B, C	1, 2, 3	All 10
G-10a	Mount hardware with hex sockets	A, B	--	1, 2, 3, 4, 5, 6, 7, 9, 10
G-10b	No more than two sizes of hex	A, B	--	All 10
G-11	Minimize number of interface connections	A, B, C	2, 3	1, 2, 3, 4, 5, 6, 8, 9, 10
G-12	Fault isolation capability	C	1, 2	(N.A.)
G-13	Alignment guide restraining feature	B, C	1, 2, 3	8
G-14a	Permanent handles	A, B, C	1, 2, 3	2, 3, 4, 5, 10
G-14b	Temporary handle provisions	A	--	1, 6, 7, 9
G-15	Automatic and positive shock protection	C	1	(N.A.)
G-16	Universal tool, two heads, handle	A, B	--	All 10
G-17	No requirements for scheduled maintenance	(N.A.)	(N.A.)	(N.A.)
G-18	Eliminate mechanical hazards	A, B, C	1, 2, 3	All 10
G-19	Maximum weight 150#. Design goal 40#.	A, B, C	1, 2, 3	All 10
G-20	Clearance for hands and tools. EVA=2".	A, B, C	1, 2, 3	All 10
G-21	Interface design prevents cold welding	(N.A.)	(N.A.)	(N.A.)
G-22	All R&R fasteners, controls, etc., facing astronaut	A, B, C	1, 2, 3	All 10
	Total "G" items incorporated = 20 out of 22 basic criteria and 27 out of 29 criteria variations.			
I-1a	IVA System Level repairs at black box for critical equipment	C	1, 2, 3	--
I-1b	IVA System Level repairs at module level	A, B	--	All 10

TABLE 9-1. CRITERIA AND DESIGN FEATURES (cont)

Criteria No.	Design Feature or Requirement	Incorporated in Mock-up		
		Enclosure	Box	Module
I-2a	Critical System BIT remote control and indicator	C	1, 2, 3	--
I-2b	Critical System BIT test connector	C	1, 2, 3	--
I-3a	Access plate with one hand latch action	B, C	--	--
I-3b	Access plate with fast acting fasteners	A, C	1	Access to Module #10
I-3c	Access with single thread fasteners	A	--	Module #1 connector Module #10 fastener
I-4a	Minimum physical size for pressure suit handling	C	3 and dummy	--
I-4b	Minimum physical size for shirtsleeve handling	A	--	#10
I-5	No requirements for adjustment or alignment in critical equipment	(N.A.)	(N.A.)	(N.A.)
	Total "I" items incorporated = 4 out of 5 basic criteria and 9 out of ten criteria variations.			
E-1	EVA system repairs at black box level	C	1, 2, 3	--
E-2	EVA installation to have visual and targeting aids	C	1, 2, 3	--
E-3	EVA hand mated connectors must be zero "g" and approved	C	1, 2, 3	--
E-4	No tools for EVA R&R actions	C	1, 2, 3	--
E-5	EVA boxes to have remote BIT and indicator	C	1, 2	--
E-6	No alignment or adjustments for R&R	(N.A.)	(N.A.)	N.A.)
E-7a	Minimum physical size box is 2-1/2" x 4" face	(dummy box)		--
E-7b	Minimum physical size with current hardware	C	3	--

TABLE 9-1. CRITERIA AND DESIGN FEATURES (cont)

Criteria No.	Design Feature or Requirement	Incorporated in Mock-up		
		Enclosure	Box	Module
E-8	Maximum physical size: 24" hatch, 24" long	C	1,2,3	--

Total "E" items incorporated = 7 out of 8 basic criteria and 8 out of 9 criteria variations.

Overall total incorporated = 31 out of 35 basic criteria and 44 out of 43 criteria variations.

SECTION 10

MAINTAINABILITY ANALYSIS, PREDICTIONS AND RESULTS OF DEMONSTRATION IN BOTH A ONE-g AND ZERO-g TEST CONDITION

10.1 MAINTAINABILITY ANALYSIS AND PREDICTIONS

A number of maintainability analysis and prediction techniques have been developed by the military and aerospace industry but to date none have been applied to space. For this study we drew upon our past experience in aircraft, marine and space programs including the NASA Experiment aboard the Ben Franklin Gulf Stream Drift Mission. A modified method II from MIL-HDBK-472 was used to analyze the maintenance tasks inherent in the mock-up demonstration and predictions were made for the amount of time required to accomplish each task. The sum of the individual task times then indicated the total estimated time to perform each remove and replace action in a Zero-g environment. Table 10-1 summarizes the estimates for each of the actions involved in the maintainability demonstration. The estimates include only directly chargeable time, and do not include indirect or waiting time.

The only demonstration possible at the contractor's facility prior to shipment, was a one-g shirtsleeve checkout operation, the times for which are shown in Table 10-2. All of the R&R actions on this mock-up were designed to be "quick and easy". In fact, these maintenance actions turned out to be so fast that ordinary application of either Method II or III would not permit usable predictions. A variation of this analysis technique was employed to inject the added complications of a pressure suit and the Zero-g test facilities. This permitted the development of elapsed time predictions that were at least feasible for a simulated Zero-g pressure suit application.

The demonstration of R&R concepts on the mock-up under simulated Zero-g conditions at MSFC produced the actual elapsed times in Tables 10-3 through 10-6. The predictions and the actual elapsed times to perform all of the maintenance actions in both a One-g shirtsleeve and simulated Zero-g environment are compared in the Tables 10-2 and 10-7. The results of these comparisons indicated that there is a derating or "K" factor that can be used to provide more accurate predictions of the onboard maintenance effort.

The elapsed time predictions for the demonstration tasks, Table 10-1, were prepared from the test procedures reommended for the MSFC demonstrations (see Appendix C). The predictions were purposely made prior to the actual One-g check-out demonstration at Grumman Aerospace Corporation. As it turned out, the Grumman demonstration did not include some of the Zero-g task elements performed in the actual demonstration at MSFC: therefore, in order to permit a more direct comparison, the missing task elements were added to the One-g scores as indicated in Table #10-7. The elemental times were obtained from Table 10-1.

In a similar manner, the actual Zero-g demonstrations at MSFC varied from the demonstration script (Appendix C). In order to make a more direct comparison of the predictions with the demonstrations, those task times in the predictions which were not applicable were deleted and new predicted totals for each black box and module were compiled and listed in Table 10-7. The deleted tasks included demonstration of manual down-powering plus installation and removal of tethers from all units except Boxes #1 and 2.

It should be noted that the prediction for the replacement of small Module #10 in 526 seconds includes removal and replacement of a stress type cover plate simulating a worst case installation. Removal and replacement of this module without the cover plate was otherwise predicted at 76 seconds including opening and closing of the equipment drawer. The stress type cover plate does represent however, a typical problem area that is encountered in almost all vehicle designs. For that reason it was considered a valid part of the maintainability mock-up and demonstration.

10.2 RESULTS OF ONE-g DEMONSTRATION

A comparison of the predictions vs. one-g actuals is shown in Table 10-2. As expected, one-g demonstration of these tasks was faster in every case than the predictions for the same task in Zero-g conditions. This demonstrates the benefits that can be obtained from space maintainable equipment on earth prior to launch. The "single-motion" mounting of black boxes was especially effective on terra-firma, taking only 46% of the allotted time for Zero-g. The module designs also permitted R&R in 58.7% of the allotted IVA Zero-g performance figures.

TABLE 10-1. MAINTAINABILITY ANALYSIS - ELAPSED TIME PREDICTIONS FOR DEMONSTRATION TASKS

TASK / SET-UP - RUN UNIT	1-1 Box 1	1-2 Box 2	1-3 Box 3	2-1 Mod 2	2-2 Mod 3	2-3 Mod 8	3-1 Mod 7	3-2 Mod 9	3-3 Mod 10	3-4 Mod 1	3-5 Mod 4	3-6 Mod 5	3-7 Mod 6
Grasp Handrail	3	3	3	-	-	-	-	-	-	-	-	-	-
Demo. Dwn. Powering	10	-	-	-	-	-	-	-	-	-	-	-	-
Open Drawer/Panel	-	-	-	10	10	10	15	15	15	15	15	15	15
Inst. Tether	5	5	5	5	5	-	-	5	-	5	5	5	5
Remove Panel	-	-	-	-	-	-	-	-	165	-	-	-	-
Disc. Elect Conn.	-	30	-	15	15	-	-	-	-	-	15	15	15
Unlock Elect. Conn.	-	-	3	-	-	-	-	-	-	-	-	-	-
Oper. Fastening Mech.	3	3	4	12	12	15	10	10	5	15	25	15	15
Unjack Elect. Conn.	-	-	-	-	-	-	-	-	-	5	-	-	-
Install Handle	-	-	-	-	-	-	10	-	-	10	-	-	10
Withdraw Unit	4	4	3	3	3	5	3	5	3	3	5	5	3
Retract to Body	10	10	10	10	10	10	10	10	10	10	10	10	10
Position Unit	20	15	10	5	5	10	5	8	5	5	8	8	5
Jack Elect. Conn.	-	-	-	-	-	-	-	-	-	8	-	-	-
Remove Handle	-	-	-	-	-	-	8	-	-	8	-	-	8
Oper. Fast. Mech.	5	5	5	15	15	15	12	12	8	20	30	20	20
Lock Elect. Conn.	-	-	3	-	-	-	-	-	-	-	-	-	-
Reinstall Elec. Conn.	-	60	-	20	20	-	-	-	-	-	20	-	-
Install Panel	-	-	-	-	-	-	-	-	285	-	-	-	-
Remove Tether	5	5	5	5	5	-	-	5	-	5	5	5	5
Close Drawer/Panel	-	-	-	10	10	10	30	30	30	30	30	30	30
Demo. Down Power.	5	-	-	-	-	-	-	-	-	-	-	-	-
Total (Seconds)	70	140	51	110	110	75	103	100	526	139	168	128	141

The "actual" times in Table 10-2 were those recorded during the demonstration run at Grumman. The "predicted" times were taken from the Table 10-1 estimates.

For comparison with contemporary space installation, a few sample R&R times were obtained from the LM Project Group for representative equipment. A typical small black box on the LM takes an average of 40 minutes to replace in a one-g shirtsleeve environment. Replacement of an LM battery takes an average of two hours, again in a one-g shirtsleeve environment.

10.3 RESULTS OF ZERO-g DEMONSTRATIONS

10.3.1 Shirtsleeve-EVA

The EVA black boxes in mock-up enclosure "C" were first removed and replaced by the test subject in a shirtsleeve Zero-g environment, without foot restraints. See Figures 10-1 and 10-2. This was to determine the feasibility of these actions before attempting pressure suit operations. The test times were recorded and noted in Table 10-3.

Although these conditions will not exist in space, the performance of these tasks without the pressure suit provided orientation for the test subject and additional baseline data. The times for this test will be useful if similar black boxes are ever replaced in IVA. The elapsed times for performing these R&R tasks in a shirtsleeve environment were faster than those recorded for the same tasks in a pressure suit, Table 10-5, but not too far off when allowances are made for the problems encountered with the tests in Table 10-5. The actual shirtsleeve EVA times are directly comparable to the predictions of Table 10-1 since these tests were performed without foot restraints. (See Table 10-7.)

Black Box R&R times for one-handed operation in shirtsleeve averaged 26 seconds for large Box #1, 82 seconds for medium Box 32 with manual connectors, and 30 seconds for small Box #3.

* Simulated Zero-g environment was provided by the Five-Degree-of-Freedom Simulator on air bearings for the astronaut test subject, and the Frictionless Air Bearing Parallelogram (Lunar Gravity and Earth Orbital Simulator) for the equipment under test. Together these two test units provided six degrees of freedom on the polished floor of Manufacturing Engineering Laboratory at MSFC. Neutral buoyancy was provided by means of helium-filled balloons for the three black boxes during EVA operations.

TABLE 10-2

COMPARISON OF PREDICTED ZERO-g AND ONE-g
REMOVE AND REPLACE TIMES

	Predicted Zero-g R & R Times *	Actual One-g R & R Times
1. EVA Black Boxes (Pressure Suit)		
Box #1	32 Secs.	12 Secs.
Box #2	117 Secs.	45 Secs.
Box #3	28 Secs.	25 Secs.
2. IVA Equipment (Shirtsleeve)		
Module #1	119 Secs.	95 Secs.
Module #2	90 Secs.	37 Secs.
Module #3	90 Secs.	37 Secs.
Module #4	148 Secs.	80 Secs.
Module #5	108 Secs.	65 Secs.
Module #6	121 Secs.	61 Secs.
Module #7	93 Secs.	26 Secs.
Module #8	65 Secs.	24 Secs.
Module #9	80 Secs.	26 Secs.
Module #10	516 Secs.	390 Secs.

* Does not include times in Table 10-1 for:

1) Grasping Handrail
2) Demo of manual down powering
3) Installation/removal of tethers
4) Retract to Body element simulating stowage and retrieval of spare.

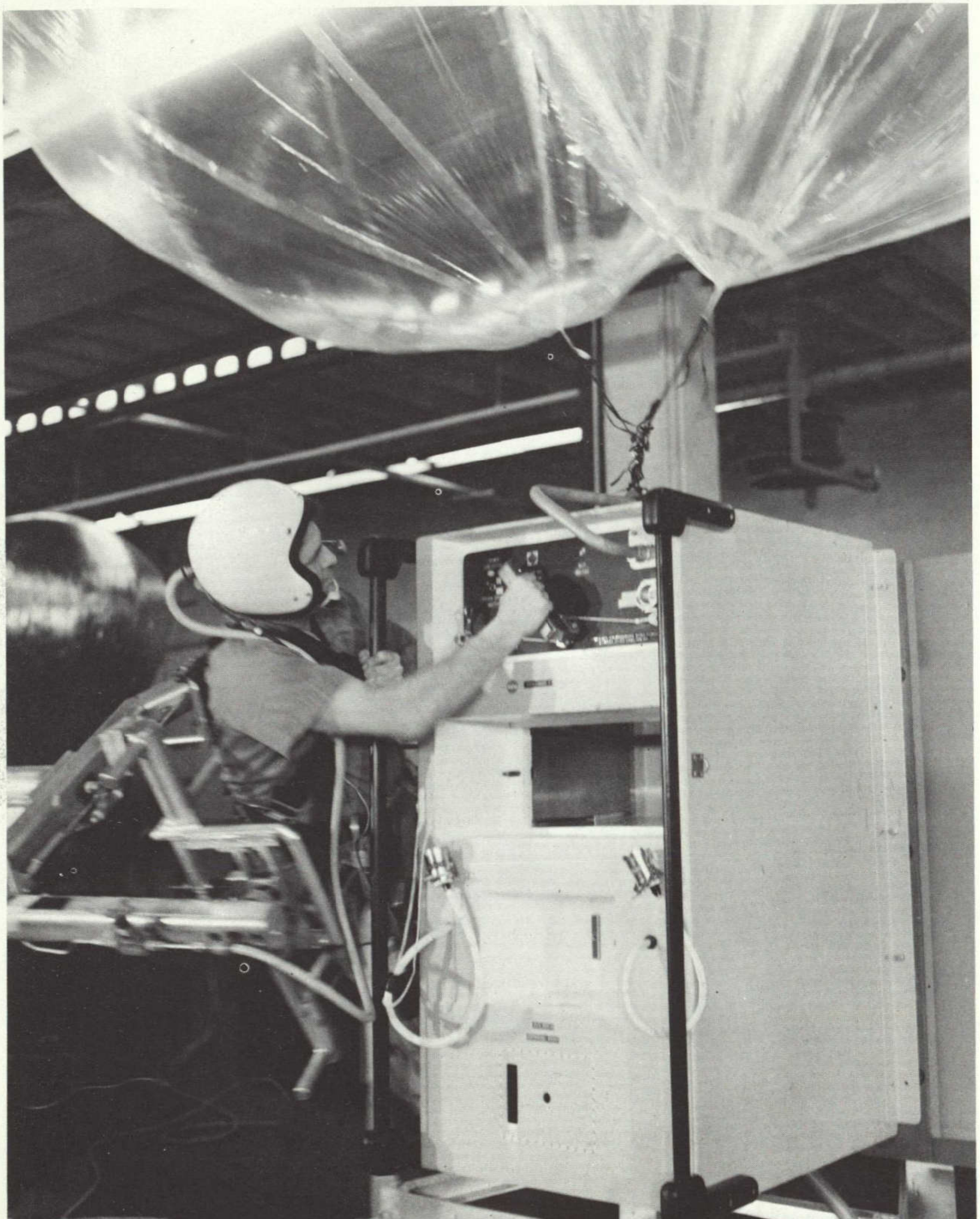


Figure 10-1. Test Subject Orientation Removing Eva Box #1 In Shirtsleeve Zero-g Simulation

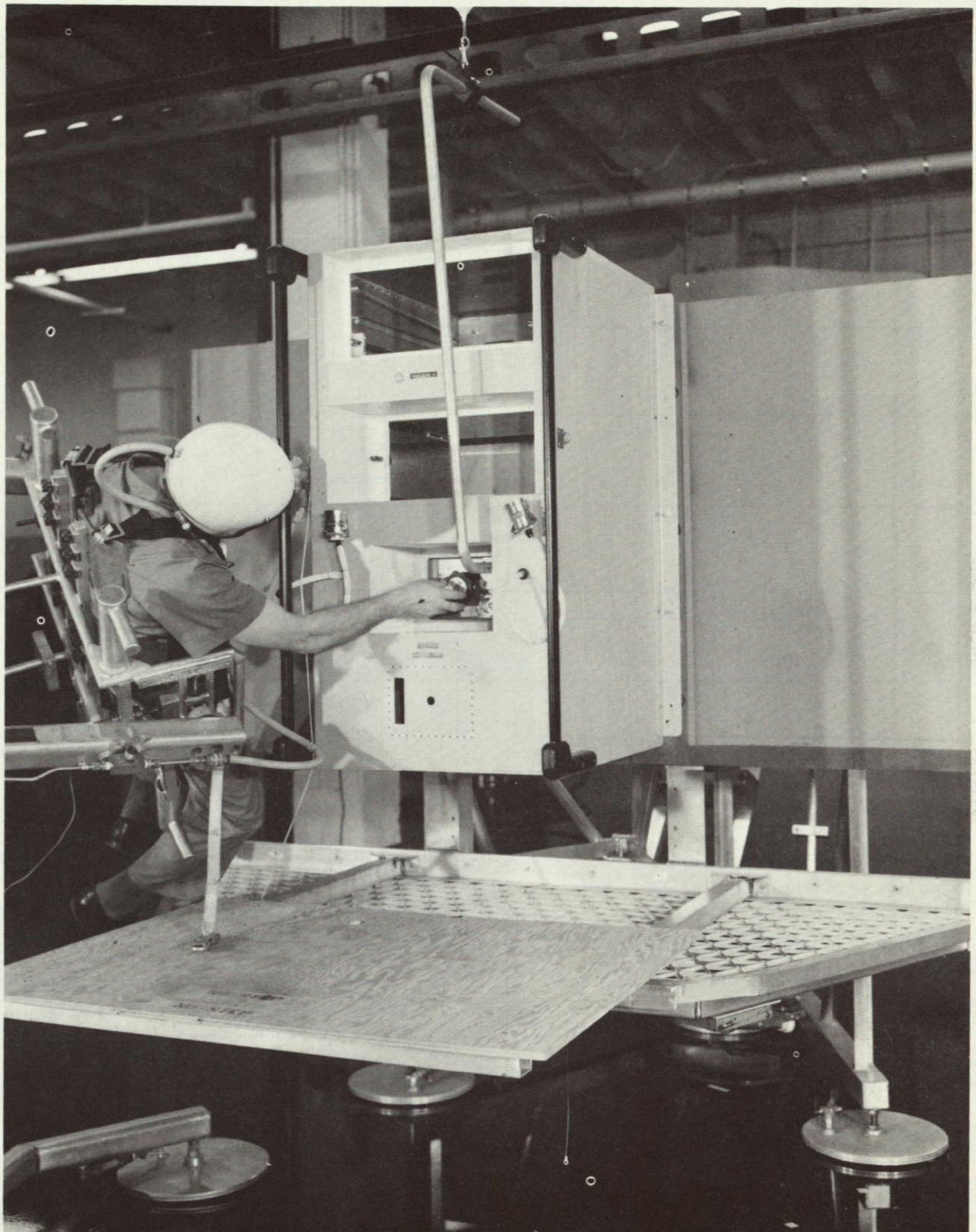


Figure 10-2. Test Subject Orientation Removing Eva Box #3 In Shirtsleeve Zero-g Simulation

TABLE 10-3. ZERO-g DEMONSTRATION TIMES, BOXES
(DEMONSTRATION TIME IN SECONDS)

	BOX 1					BOX 2		BOX 3					
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 1	Run 2	Run 1	Run 2				
Open Drawer/Panel													
Remove Panel													
Withdraw				8	10	40		11					
Install				15	17	50		22					
Replace Panel													
Close Drawer Panel													
Total (Seconds)	24	27	28	23	27	90	73	33	27				

___ IVA
_x_ EVA

_x_ Shirt Sleeve
___ Pressure Suit
___ IVA Gloves

Foot Restraints
___ Yes _x_ No

10.3.2 Shirtsleeve - IVA

Next, all modules except No. 4 in enclosures A and B, were exercised (see Fig. 10-3) under conditions assumed to exist within a typical maintainable space vehicle: a shirtsleeve Zero-g environment with foot restraints. The recorded times for these tasks are listed in Table 10-4. Since no serious problems occurred during these tests, the times are directly comparable to the predicted values of Table 10-1 as corrected in Table 10-7. Removal of these modules provided the test subject with equipment familiarization before he donned his pressure suit for the final runs. A minor problem appeared when it became obvious that the foot restraints were anchored too close to the vertical pull out drawer for a comfortable view of the lower P.C.B. type Module #9 during the interchange.

In order to gain access to Module No. 10, it was necessary to remove a cover having 22 fast-acting fasteners which simulated a "worst-case" condition. Had Module No. 10 not been placed behind this cover and, instead, made as accessible as the other modules, its actual removal and replacement time in the drawer assembly would have been the fastest (57.2 sec.) of all the modules.

The average R&R time for all of the IVA modules, excluding the cover panel but including the drawer operation, was 76.5 seconds in this shirtsleeve Zero-g demonstration with foot restraints.

10.3.3 Pressure Suit - EVA

The black boxes of mock-up enclosure "C" were removed and replaced with the test subject in a pressure suit without foot or body restraints to simulate EVA maintenance conditions expected in space. (See Figs. 10-4 thru 10-11.) The elapsed times for these tests were recorded and noted in Table 10-5. Three problems occurred during these test runs that increased the time for removal and replacement:

- Difficulties were encountered in operating the Zero-g connectors (GFE) on box #2, run #1. The problems were associated with mating of the two halves and operation of the lever mechanism to provide the electrical contact after mating. It should be noted that these are prototype connectors salvaged from another project and their problems are not indicative of flight hardware. Despite these problems, Box #2 R&R did not exceed three minutes.

Figure 10-3. Removing Module #7
In Shirtsleeve Zero-g Simulation

TABLE 10-4. ZERO-g DEMONSTRATION TIMES, MODULES (DEMONSTRATION TIME IN SECONDS)

Module	1 Run 1	2 Run 1	3 Run 1	5 Run 1	6 Run 1	7 Run 1	7 Run 2	8 Run 1	9 Run 1	9 Run 2	10 Run 1		
Open Drawer/Panel	16	10	10	16	16	18	18	10	18	18	18		
Remove Panel											119.5		
Withdraw	39	21	21	28	22			22			8.5		
In-Out Total						46	36		66	36			
Install	34	39	37	26.5	19			23			10.7		
Replace Panel											255		
Close Drawer/Panel	19	11	11	19	19	20	20	11	20	20	20		
Total	108	81	79	89.5	76	84	74	66	104	74	431.7		

x IVA
___ EVA

x Shirt Sleeve
___ Pressure Suit
___ IVA Gloves

Foot Restraints x Yes ___ No

- During removal of Box #3 on Run 1, the test subject removed the box rapidly from the enclosure. The box counterbalance mechanism (balloons) moved very slowly causing the man to wait until the balloons caught up with his movements. Insertion presented the same problem with the box tending to arc up as it was moved into the enclosure rather than move in a straight line. This problem would not exist in space. Having the balloons at a considerable distance from the box unfortunately increased the inertia effect but was necessary to clear the top of the enclosure (see Figs. 10-10 & 10-11).
- During both runs of Box #3, the installation of the box was made "blind", while the test subject's helmet was around the side of the enclosure where he could not see the installation! It appeared that this problem was also associated with the long arm on the counterbalance mechanism. The man, while trying to install the box with his other hand on the handrail, was forced into this position as he tried to overcome the inertia effects of the counterbalance mechanism. Again, this problem will not exist in space. Despite this handicap, the self-aligning mount feature of the installation permitted a record R&R time of 33 seconds to be clocked for the second run.

When allowance is made for the problems with the counterbalance mechanism, the R&R time for Box 3 closely approximated the predictions as noted in the final comparison of R&R actuals vs. predictions in Table 10-7.

The average R&R times, in a pressure suit without foot restraints or body tethers for the three one-hand mounted black boxes were: 39.8 seconds for large Box #1, 140 seconds for medium Box #2, and 57.8 seconds for small box #3 (blind installation).

10.3.4 Pressure Suit IVA

The Zero-g demonstration tests at MSFC progressed so well that an additional unplanned test run was completed to determine how much of the IVA maintenance work on this mock-up could be done in a pressure suit without foot restraints. The times for these events were recorded in Table 10-6. See Figs. 10-12 thru 10-21.

The only real difficulty encountered during this test run concerned the metal stress type cover, panel over module No. 10. The cover had been removed readily by the test

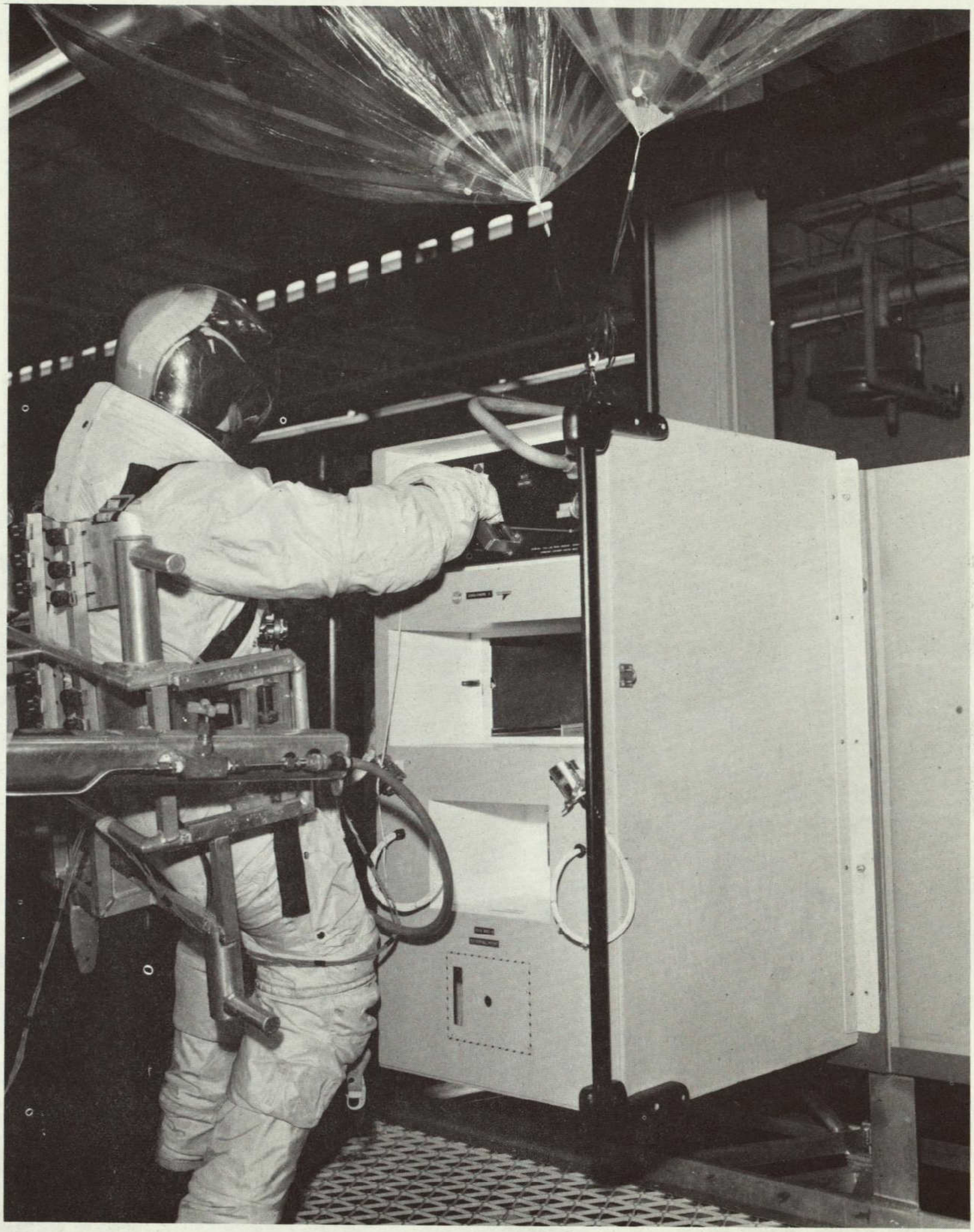


Figure 10-4. Removing Eva Box #1 Pressure Suit
Zero-g Simulation With Eva Gloves

Figure 10-5. Eva Box #1 Removed From Enclosure
Pressure Suit Zero-g Simulation

Figure 10-6. Left Handed Removal of Eva Box #1
Pressure Suit Zero-g Simulation

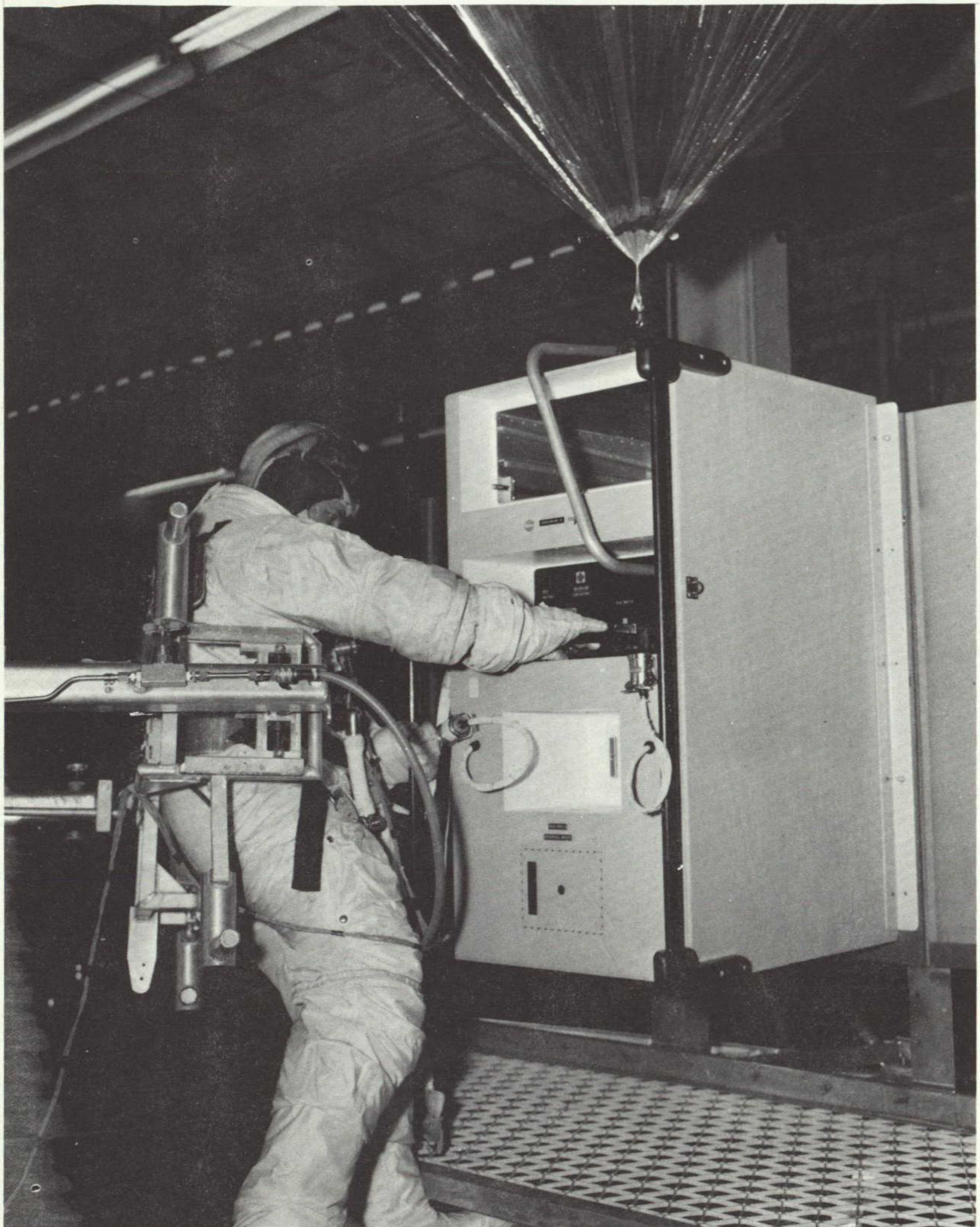


Figure 10-7. Removing Eva Box #2
Pressure Suit Zero-g Simulation

Figure 10-8. EVA Box #2 Removed From Enclosure
Pressure Suit Zero-g Simulation

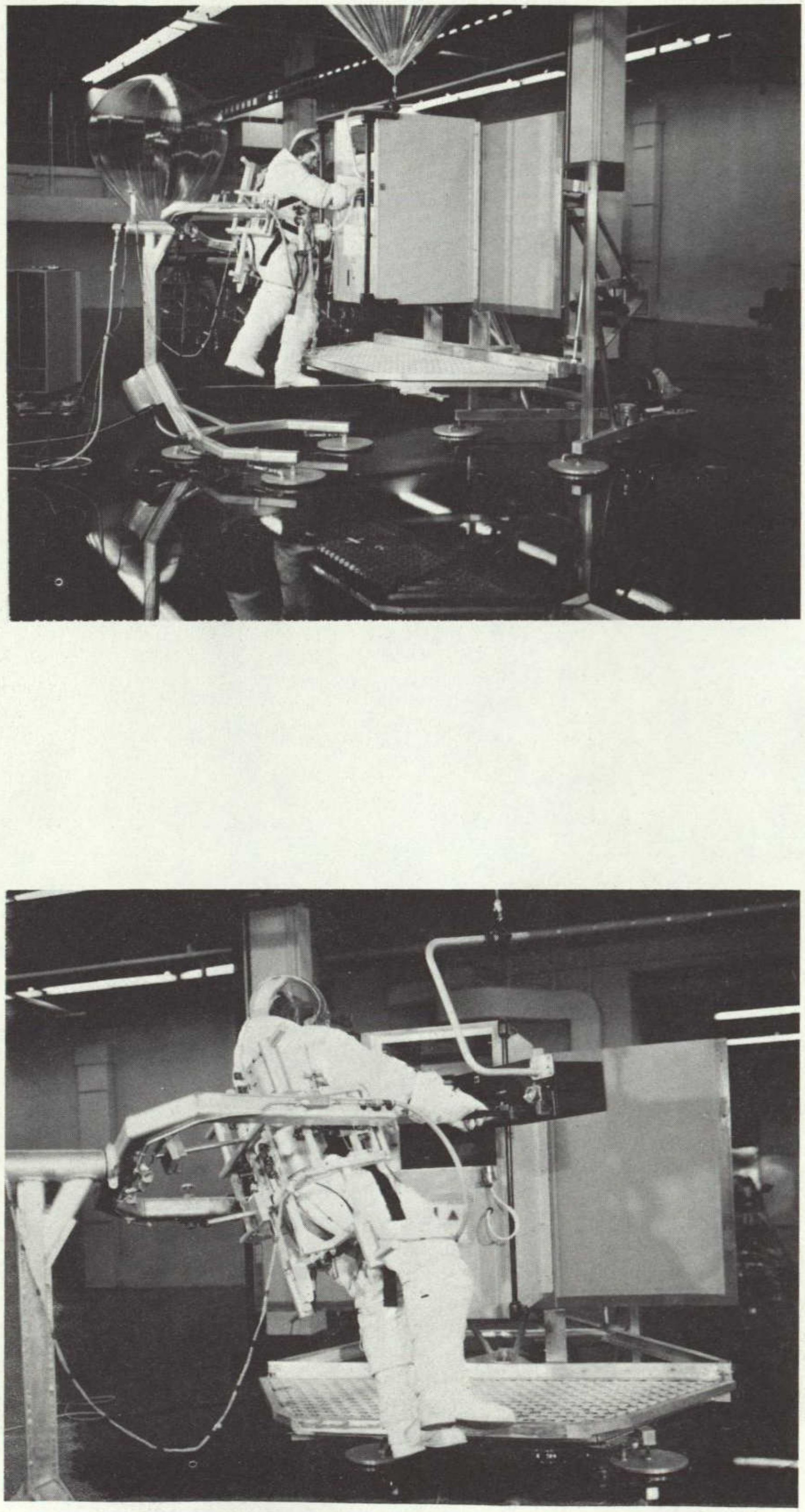


Figure 10-9. Removal and Replacement of EVA Box #2
Pressure Suit Zero-g Simulation

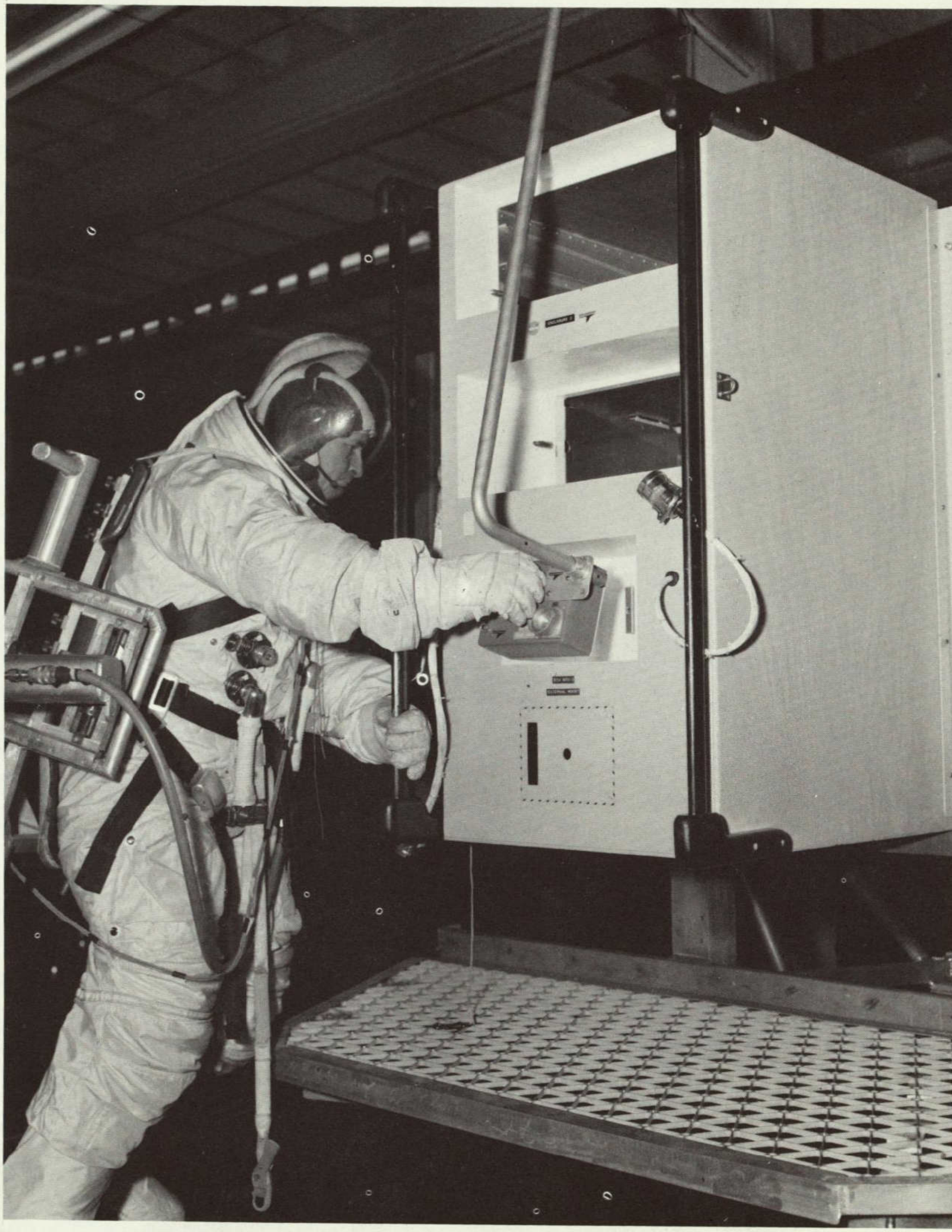
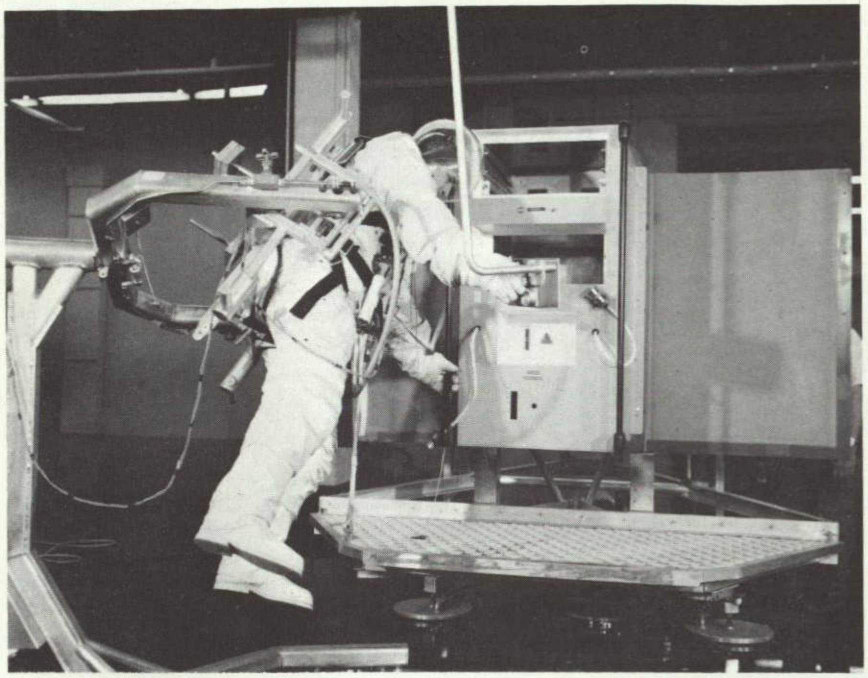


Figure 10-10. Removing EVA Box #3
Pressure Suit Zero-g Simulation



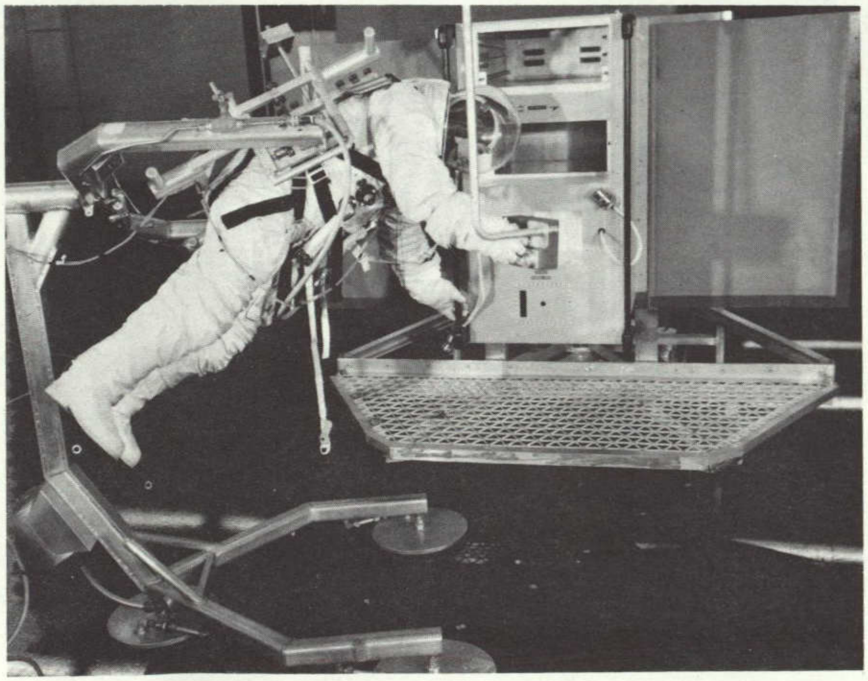


Figure 10-11. Installation of EVA Box #3
Pressure Suit Zero-g Simulation

subject and handed along with the tool to an assistant standing beside the mockup. When the test subject was ready to reinstall this cover designed for a two handed operation, the assistant handed him both the cover and the tool in close sequence. This created a problem as he had no foot restraints and not enough hands to properly hold onto these items and the mockup handrails. Somehow, through great ingenuity, dexterity and concentration, he was able to place the cover panel unassisted into position and engage the first of the fasteners. The test run was terminated at this point since it was quite obvious the test subject was becoming fatigued. The remaining fasteners would normally be easy to insert now that the cover panel was in proper position therefore the time to install the remaining fasteners was extrapolated to complete the test run data.

The results of this extraordinary feat indicated that the human body is capable of performing difficult tasks under extremely trying circumstances. We can count on this reserve for back-up emergency action but we can and should avoid placing the astronaut into such situations by proper foresight and design for maintainability.

The fact that all of the shirtsleeve IVA R&R tasks could be performed in a pressure suit without foot restraints at the module level and with tools is significant. In fact, the total demo time for the actual events performed (Modules #1, 5, 6, 7, 9, 10) was 2,392.6 seconds as compared to the predicted total of 1,333 seconds for the same tasks in shirtsleeves with foot restraints. This works out to be a derating factor of only 1.794 to do these same IVA tasks in a pressure suit without foot restraints. This factor was applied in extrapolating similar values for Modules #2, 3 & 8 from the Zero-g shirtsleeve actuals in Table 10-7.

10.4 SUMMARY OF DEMONSTRATION RESULTS

A comparison of the predictions vs. actual times in Table 10-7 shows that on the average, the actual Zero-g remove and replace time for the EVA black boxes were quite close to the predictions, in fact within 1%. Had allowance been made for the difficulties encountered during the simulated Zero-g tests, the actual times would have been slightly less than the predictions in all cases.

The actual Zero-g remove and replace times for the IVA modules in all cases averaged 20% less than the predicted values indicating that these tasks were easier to perform

TABLE 10-5. ZERO-g DEMONSTRATION TIMES, BOXES (II)
(DEMONSTRATION TIME IN SECONDS)

	BOX 1		BOX 2		BOX 3	
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Open Drawer/Panel						
Remove Panel						
Withdraw	10	11	39	40	19.5	11
In & Out Total						
Install	46	12.5	130	71	63	22
Replace Panel						
Close Drawer/Panel						
Total	56	23.5	169	111	82.5	33

____ IVA
_x_ EVA

____ Shirt Sleeve
_x_ Pressure Suit
____ IVA Gloves

Foot Restraints
____ Yes _x_ No

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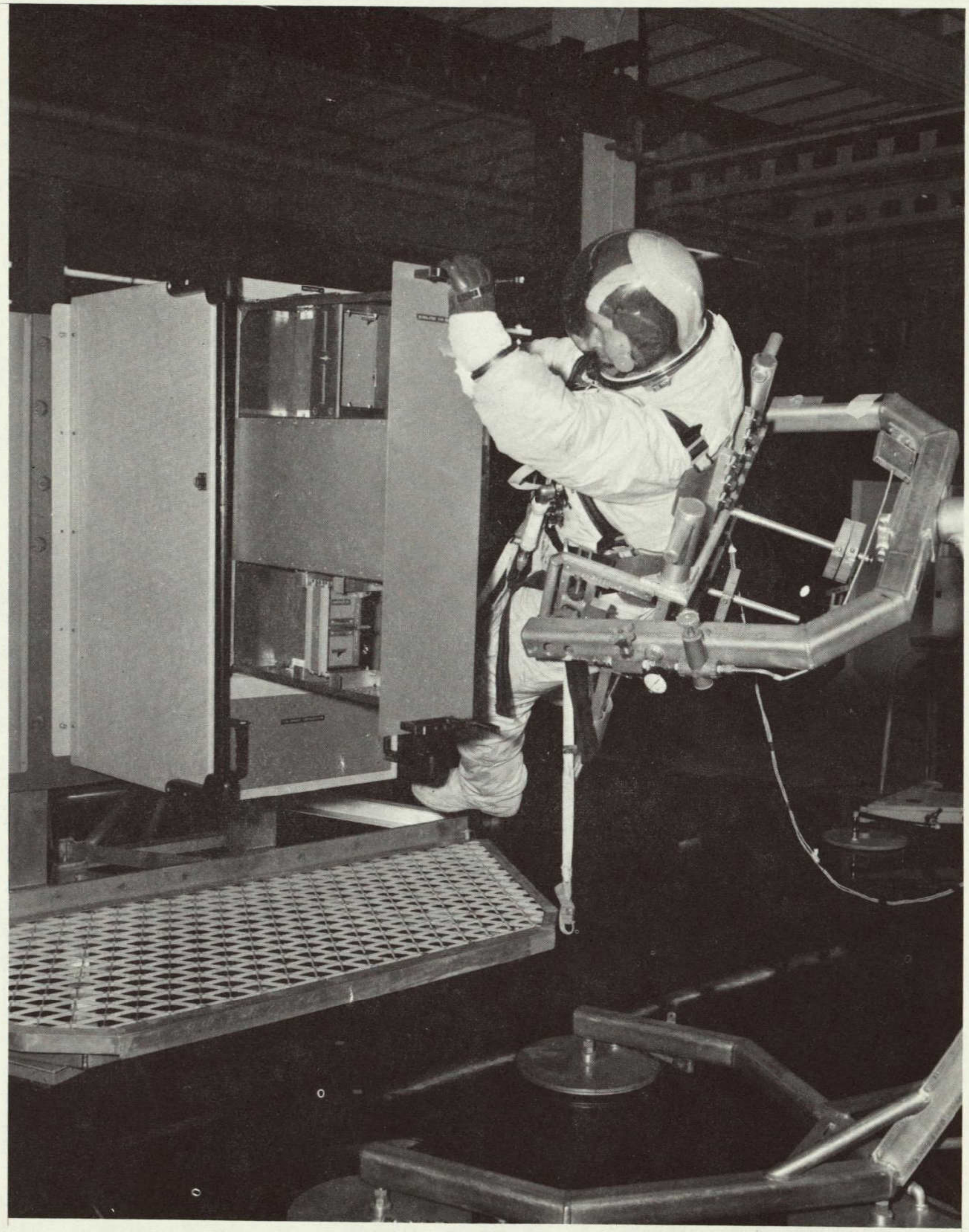


Figure 10-12. Opening IVA Vertical Drawer Pressure Suit with IVA Gloves Zero-g Simulation

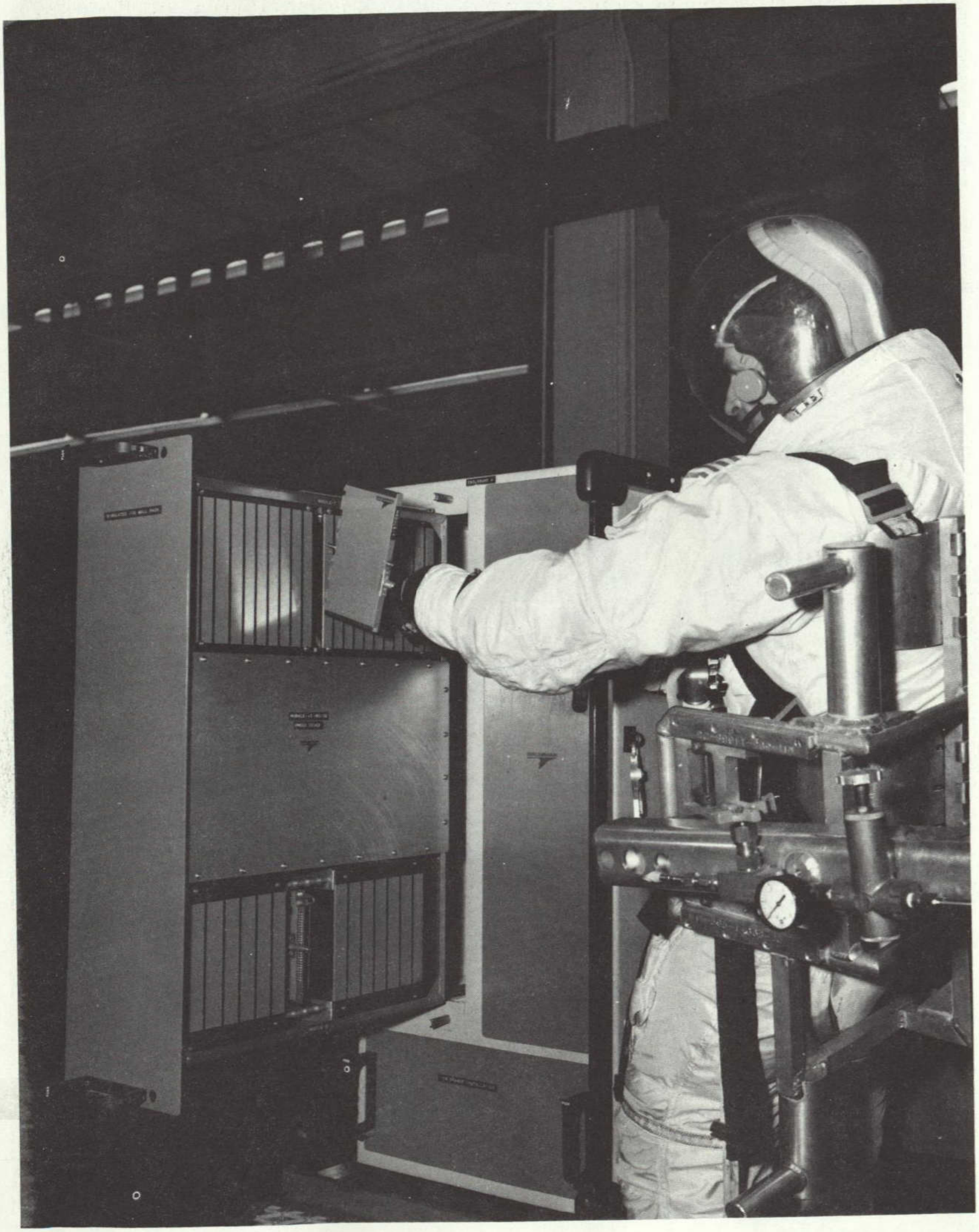


Figure 10-13. Removing IVA Module #7 Pressure Suit With IVA Gloves Zero-g Simulation

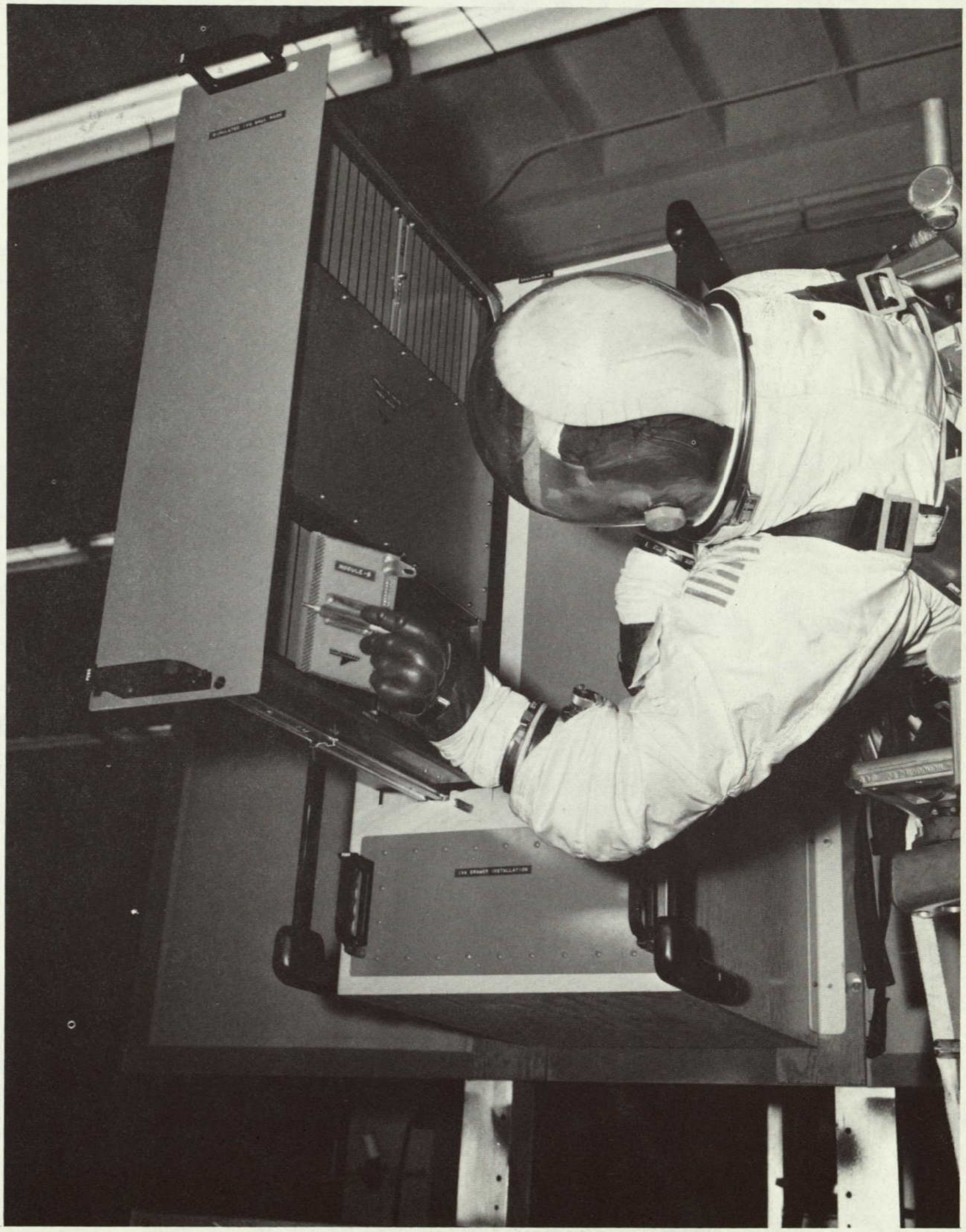
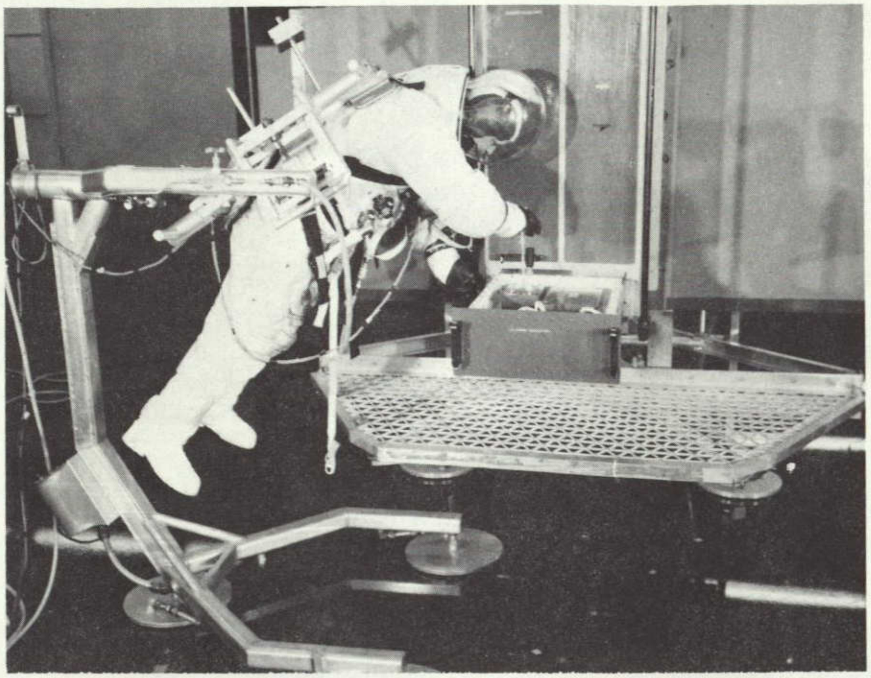


Figure 10-14. Installing IVA Module #9 Pressure Suit With IVA Gloves Zero-g Simulation



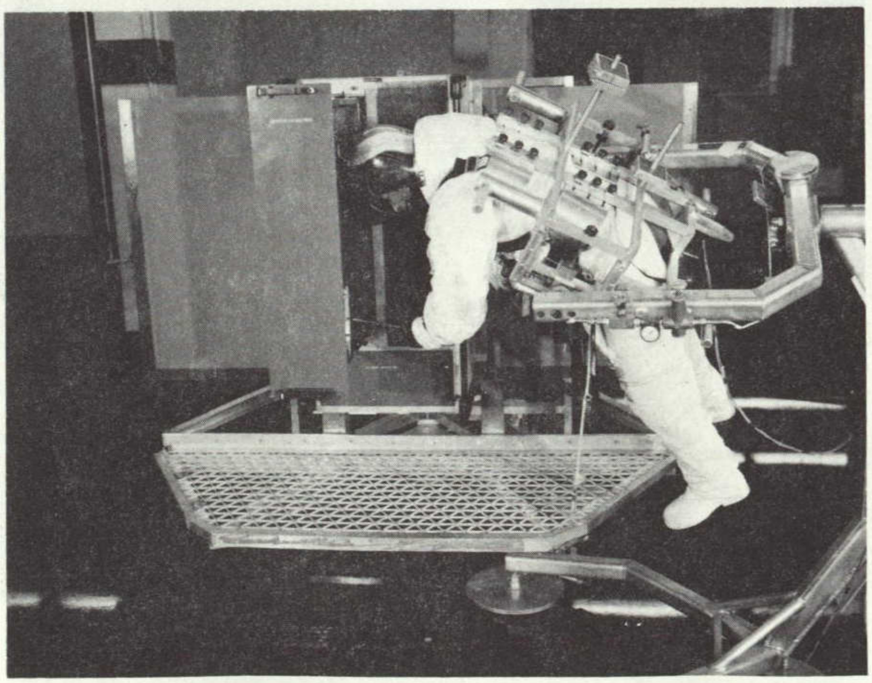


Figure 10-15. Removing IVA Modules 1 and 9 Pressure Suit With IVA Gloves Zero-g Simulation

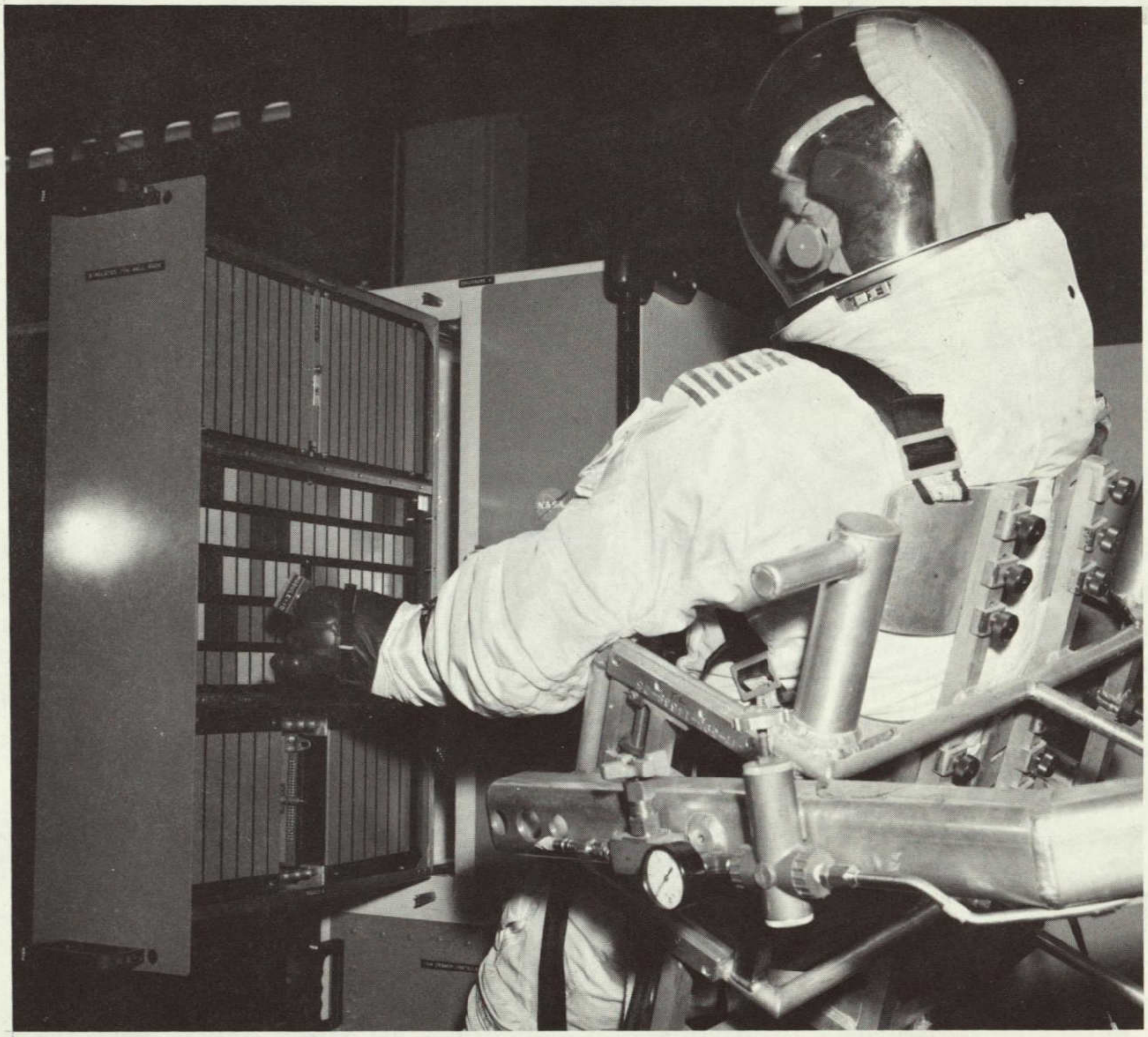


Figure 10-16. Installing EVA Module #10 Pressure Suit With IVA Gloves Zero-g Simulation

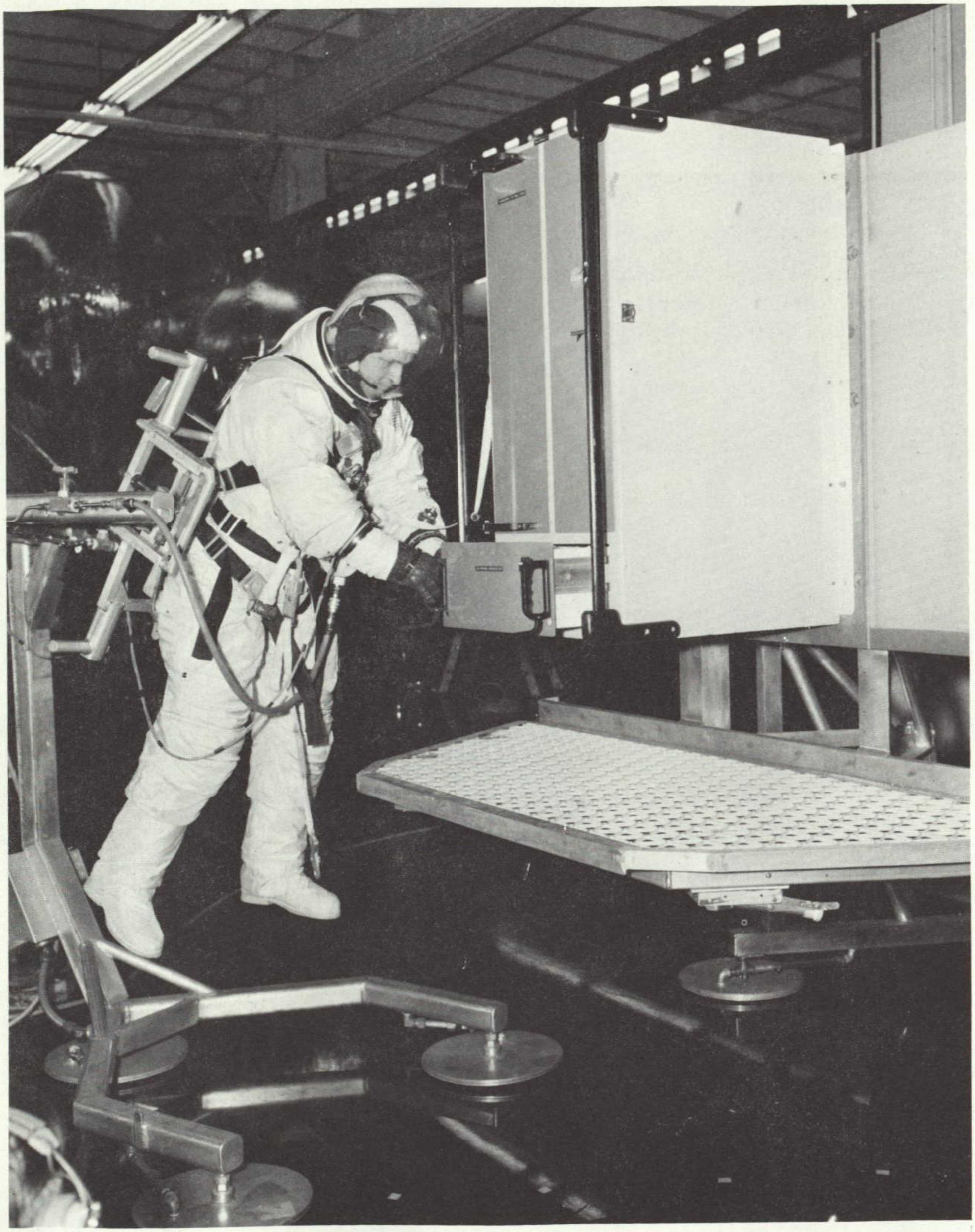


Figure 10-17. Opening IVA Horizontal Drawer Pressure Suit With IVA Gloves Zero-g Simulation

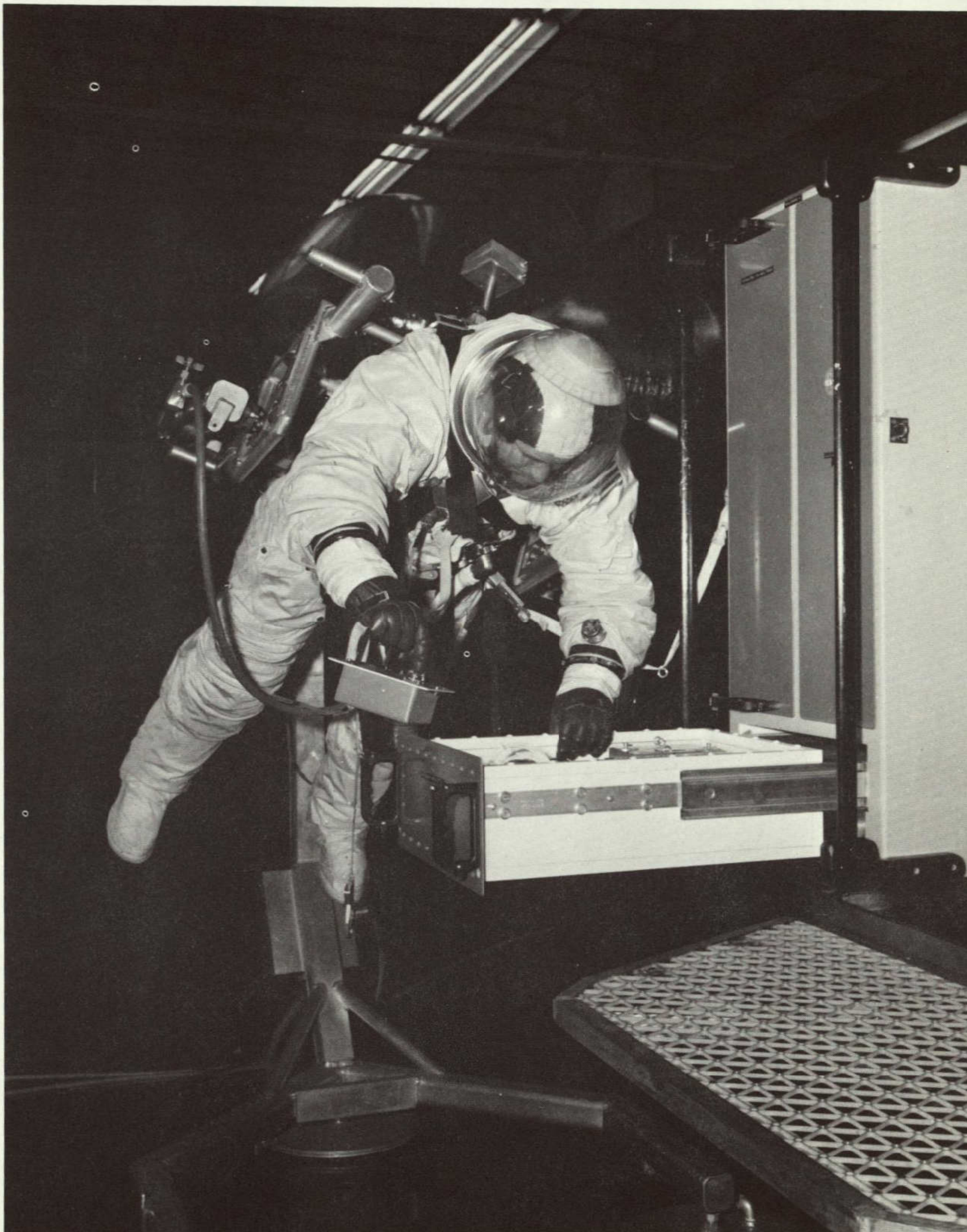


Figure 10-18. Installing IVA Module #5 Pressure Suit With IVA Gloves Zero-g Simulation

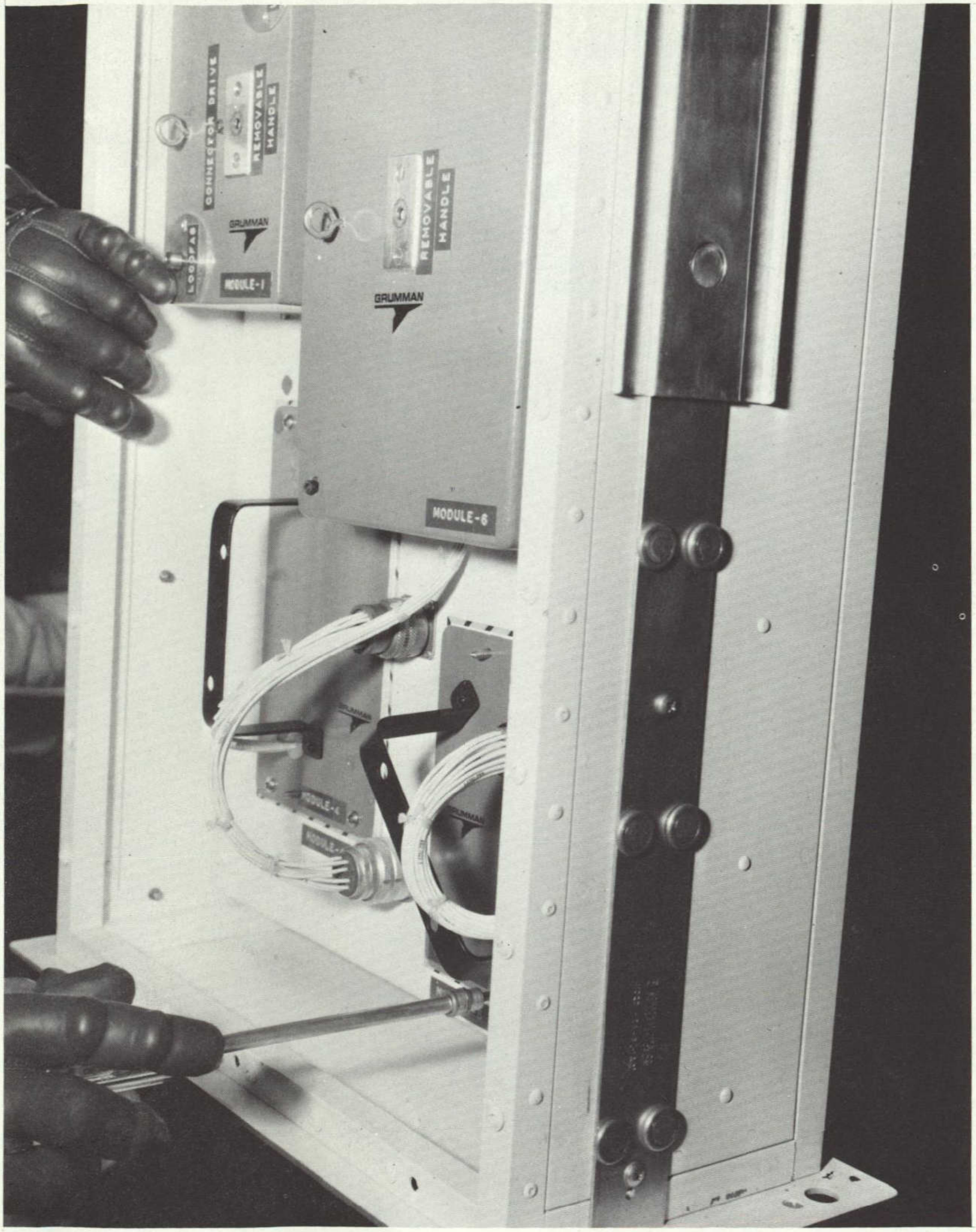


Figure 10-19. Tightening Fastener On IVA Module #5 Pressure Suit With IVA Gloves Zero-g Simulation

Figure 10-20. Releasing Fastener On IVA Module #1 Pressure Suit With IVA Gloves Zero-g Simulation

Figure 10-21. Removing IVA Module #1 Pressure Suit With IVA Gloves Zero-g Simulation

TABLE 10-6. ZERO-g DEMONSTRATION TIMES, MODULES (II)
(DEMONSTRATION TIME IN SECONDS)

Module	1 Run 1	5 Run 1	6 Run 1	7 Run 1	9 Run 1	10 Run 1
Open Drawer/Panel	38	38	38	23	23	23
Remove Panel						242
Withdraw	106	47	55	81	131	24
In & Out Total						
Install	78	46	59	75	100	20
Replace Panel						440
Close Drawer/Panel	54	54	54	102	102	102
Total	276	185	206	281	356	851

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___ IVA
_x_ EVA
___ Shirt Sleeve
_x_ Pressure Suit
___ IVA Gloves
Foot Restraints
___ Yes _x_ No

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on the mockup in simulated Zero-g than we anticipated. All of the actual recorded times for Table 10-7 were taken from Tables 10-4 thru 10-6. The predicted values were obtained from Table 10-1.

As a technique, the modified Maintainability prediction Method II from Mil Handbook 472 appears to be acceptable in view of the overall prediction score of 1608 seconds vs. 1237.2 seconds for all the demonstrated tasks. This represents a total over-estimated error of only 16.8% for extremely fast remove and replace actions that averaged less than two minutes each in the demonstration. In fact, the overall average error in the individual predictions was the same figure, 16.8%. This can be improved considerably when the technique itself is adjusted to account for the relative ease with which the test subject was able to perform R & R actions under simulated Zero-g test conditions on equipment designed to facilitate maintenance.

Maintenance derate of "K" factors were derived from the demonstrated performance of these tasks in one-g shirtsleeve, Zero-g shirtsleeve (foot restraint) and Zero-g pressure suit (no foot restraint) conditions. These factors are listed in Table 10-8.

A motion picture was taken of the entire series of demonstration tests at MSFC. This film provides an action summary of the various maintenance tasks described in this section.

An interesting correlation was obtained between our IVA Module installation "K" factor of +25.19% (to go from One-g to Zero-g in shirtsleeves) and a "K" factor of 30% obtained by the Aerospace Medical Research and Aero Propulsion Labs in a previous study* for operation of fasteners in One-g and Zero-g environments.

A broader base with more trials would be necessary before these factors can be used with confidence. It is interesting to note, however, that when equipment is designed for easy maintenance such as the black box quick mounts in the mock-up, the derate factor was only 1.79 to go from One-g shirtsleeve to Zero-g pressure suit operation. A similar

*Paper # AMRL-TR-68-117, entitled "Quick Release Fasteners for Space Application" read at the 2nd National Conference on Space Maintanance and EVA at Las Vegas, Aug. 6-8, 1968.

TABLE 10-7

MAINTAINABILITY PREDICTIONS VS ACTUAL DEMONSTRATION RESULTS FOR REMOVE & REPLACE ACTION IN ONE-g & ZERO-g TESTS

EQUIPMENT	a. ZERO-g PREDICTIONS * PER MODIFIED METHOD II OF MIL-HDBK 472	b. CONTRACTOR DEMO IN ONE-g AND SHIRT SLEEVES *	c. ZERO-g DEMO IN SHIRTSLEEVES WITH FOOT RESTRAINTS	d. ZERO-g DEMO PRESSURE SUIT & NO FOOT RESTRAINTS	e. EXTRAPOLATED ZERO-g PRESSURE SUIT RESULTS FOR COMPARISON *	f. ADJUSTED ONE "g" SHIRTSLEEVE RESULTS FOR COMPARISON *
A. EVA BLACK BOXES			(AVERAGE TIMES)			
BOX #1	55 SECONDS	12 SECONDS	26 SECONDS	39.8 SECONDS	39.8 SECONDS	31 SECONDS
BOX #2	140 SECONDS	45 SECONDS	82 SECONDS	140 SECONDS	140 SECONDS	64 SECONDS
BOX #3	41 SECONDS	25 SECONDS	30 SECONDS *	57.8 SECONDS *	57.8 SECONDS	38 SECONDS
EVA SUBTOTALS	(236) SECONDS	(82) SECONDS	(138) SECONDS	(237.6) SECONDS	(237.6) SECONDS	(133) SECONDS
B. IVA MODULES						
MODULE #1	129 SECONDS	95 SECONDS	108 SECONDS	276 SECONDS	276 SECONDS	108 SECONDS
MODULE #2	100 SECONDS	37 SECONDS	81 SECONDS	- SECONDS	179.4 SECONDS	50 SECONDS
MODULE #3	100 SECONDS	37 SECONDS	79 SECONDS	- SECONDS	179.4 SECONDS	50 SECONDS
MODULE #4	- SECONDS	80 SECONDS	- SECONDS	- SECONDS	- SECONDS	- SECONDS
MODULE #5	118 SECONDS	65 SECONDS	89.5 SECONDS	185 SECONDS	185 SECONDS	78 SECONDS
MODULE #6	131 SECONDS	61 SECONDS	76 SECONDS	206 SECONDS	206 SECONDS	74 SECONDS
MODULE #7	103 SECONDS	26 SECONDS	79 SECONDS	281 SECONDS	281 SECONDS	39 SECONDS
MODULE #8	75 SECONDS	24 SECONDS	66 SECONDS	- SECONDS	134.6 SECONDS	37 SECONDS
MODULE #9	90 SECONDS	26 SECONDS	89 SECONDS	356 SECONDS	356 SECONDS	39 SECONDS
MODULE #10	526 SECONDS	390 SECONDS	431.7 SECONDS	851 SECONDS	851 SECONDS	403 SECONDS
IVA SUBTOTALS	(1372) SECONDS	(841) SECONDS	(1099.2) SECONDS	(-) SECONDS	(2648.4) SECONDS	(878) SECONDS
TOTALS	1608 SECONDS	923 SECONDS	1237.2 SECONDS	- SECONDS	2886 SECONDS	1011 SECONDS
	*LESS DOWNPOWERING, TETHERING ON ALL MODULES & BOX #3, ALSO LESS MODULE #4 NOT DEMONSTRATED.	*LESS HANDRAIL, DOWN POWERING, TETHER, & RESTRAINT ELEMENT.	*BALLOON INERTIA COMPLICATED THE R&R ACTION.	*BOX #3 TEST RUNS WERE MADE "BLIND" AND WITH TEST RIG INERTIA PROBLEMS.	*DERATE FACTOR OF 1.794 DERIVED FROM 9 EVENTS APPLIED TO THE OTHER THREE TO OBTAIN TOTAL FOR COMPARISON	*ADDED HANDRAIL, DOWNPOWERING TETHER, & RETRACT ELEMENTS FOR TOTAL COMPARISON

TABLE 10-8

MAINTENANCE DERATING OR "K" FACTORS FOR MAINTAINABILITY PREDICTIONS DERIVED FROM ZERO-g DEMONSTRATIONS

A. From One-g to Zero-g in Shirtsleeves & Foot Restraints

For EVA Black Boxes: $K = \dfrac{\text{138 Seconds (Zero-g in S.S.)}}{\text{133 Seconds (One-g in S.S.)}} = 1.0376$

For IVA Modules: $K = \dfrac{\text{1099.2 Seconds (Zero-g in S.S.)}}{\text{878 Seconds (One-g in S.S.)}} = 1.2519$

B. From Zero-g in Shirtsleeves & Foot Restraints to Zero-g in Pressure Suit with No Foot Restraints

For EVA Black Boxes: $K = \dfrac{\text{237.6 Seconds (Zero-g P.S.)}}{\text{138 Seconds (Zero-g S.S.)}} = 1.732$

For IVA Modules: $K = \dfrac{\text{2648.4 Seconds (Zero-g P.S.)}}{\text{1099.2 Seconds (Zero-g S.S.)}} = 2.4085$

C. From One-g Shirtsleeves to Zero-g Pressure Suit Without Foot Restraints

For EVA Black Boxes: $K = \dfrac{\text{237.6 Seconds (Zero-g P.S.)}}{\text{133 Seconds (One-g S.S.)}} = 1.7865$

For IVA Modules: $K = \dfrac{\text{2648.4 Seconds (Zero-g P.S.)}}{\text{878 Seconds (One-g S.S.)}} = 3.0164$

comparison of moderately easy maintenance, such as in the 1VA module designs of the mock-up, produced a derate factor of 3.02, again to go from One-g shirtsleeve to Zero-g pressure suit operation.

A verified set of these derating or "K" factors would be an extremely valuable tool for planning and evaluating future space vehicle performance requirements.

In summary, the simulated Zero-g demonstrations at MSFC on the Grumman-built mock-up resulted in the following observations: (refer to Tables #10-7 and 10-8).

- The contractual requirement for a 20 minute maximum R & R demonstration was more than satisfied by the maximum observed elapsed time of 7 minutes 12 seconds for the "worst case" installation.
- EVA black bos R & R times closely approximated the predictions as a group, within 1%.
- Module 1VA R & R times were consistantly faster than the prediction by approximately 23%.
- All of the 1VA R & R tasks were performed satisfactorily in a pressure suit.
- The value of designs that permit "blind" installation was established. This includes self'aligning fasteners and visual orientation aids.
- The value of one-hand, single-motion mount mechanisms, quick-release fasteners, quarter-turn manual connectors, and a Universal tool, was demonstrated.
- In general, designs for Zero-g maintenance were equally applicable to shirtsleeve and pressure suit operation.
- Close body tethers were not as useful as foot restraints and only complicated the EVA.
- All EVA & 1VA R & R actions were demonstrated without foot restraints. This established the need for adequate hand holds and guide rails in the area of the unit being replaced.

- Foot restraints were a hindrance when they were too close to the unit being replaced.
- Equipment tethers were a source of annoyance since they were not designed to minimize interference with the maintenance action.

SECTION 11

PREPARATION OF DEMONSTRATION PLAN FOR MOCK-UP IN MSFC ZERO-g TEST FACILITIES

At the request of the MSFC contracting officer representative, a draft copy of Grumman's recommended mock-up demonstration plan was developed and forwarded to MSFC on 24 February 1970. This plan was refined to agree with the facility limitations and hand-carried to Marshall for use during the scheduled demonstration test on 26-27 March 1970. A copy of this demonstration plan is included as Appendix C of this report.

SECTION 12
CONCLUSIONS AND RECOMMENDATIONS

12.1 DESIGN CRITERIA

The general objectives of this study have been achieved. A set of design criteria (Appendices A & B) has been generated for application to spacecraft and equipment where onboard maintenance is to be performed. Imposition of these design requirements will minimize the problems associated with removal and replacement of electronic equipment in space. An important by-product of any design to enhance onboard maintenance will be the improvement of pre-launch maintenance operations for both long duration and short duration vehicles.

Certain minimum standards have been established for maintainable electronic equipment designs by the "Remove and Replace" criteria. These include:

- Maximum and minimum sizes of replaceable equipment for astronaut handling in both shirtsleeve and pressure suit environment.
- Maximum elapsed time for the remove and replace task in space.
- Use of one universal tool for the remove-and-replace task of electronic equipment.
- Use of one-hand mounting mechanisms where foot restraints are not provided.
- Use of self-aligning guides, visual orientation and targeting aids.
- Use of protective features for both astronaut and the equipment.
- Recommended levels of maintenance for EVA and IVA.

Every attempt must be made to make the astronaut's maintenance work on electronic equipment in space quick and easy, especially in a pressure suit. All reports to date indicate that repetitive arm, wrist, and hand motions, as encountered during maintenance work in a pressure suit, will quickly lead to fatigue and frustration unless the equipment has been designed to minimize these conditions for the astronaut. Use of the R & R criteria in specifications for vehicle and electronic equipment design will provide maintainability features that will assure achievement of the desired quick and easy maintenance action.

12.2 MOCK-UP

A major secondary objective of this program was the construction of a mock-up that would serve as a demonstrator for packaging designs incorporating as many of the design criteria features as possible within the limited budget of this contract. An intensive effort was made to obtain and install hardware representative of current aerospace configurations including the latest NASA-approved Zero-g connectors.

This mock-up was constructed and shipped to MSFC for demonstration testing in the NASA dry Zero-g test facilities. The mock-up incorporated the following features:

- Suitability for demonstration testing in either pressure suit or in shirtsleeve.
- Suitability for both Zero-g (Dry) and One-g demonstration of remove and replace techniques.
- Three removable black boxes, 10 removable modules, 2 slide-out drawers, and one hinged panel, all installed for remove/replace maintenance demonstrations.
- EVA and IVA mounting arrangements for typical black boxes, modules, drawers, walls, racks and panels.
- Smallest black box and module recommended for space handling.
- Demonstration of 31 design criteria out of a total of 35. Mock-up actually incorporates demonstration or simulation of 44 out of a total of 48 individual criteria variations.
- Largest black box recommended for space handling with passage through a 24"-diameter hatch opening.

- Black box removal and replacement using one hand without tools as in EVA.
- IVA activities such as large assembly access and module replacement.
- Safety features such as power de-energizing, tethering, and handling provisions.
- Universal tool (prototype), high density rack and panel connectors, manual 1/4 turn connectors, Bendix Zero-g connectors, and a prototype ITT Cannon Zero Mating Force connector.

12.3 DEMONSTRATIONS

The successful Zero-g demonstrations performed on the mockup in the MSFC dry Zero-g test facilities verified the feasibility of designs that meet the Maintainability design criteria requirements. Typical electronic black boxes and modules, packaged specifically for space maintenance, were easily removed and replaced by an astronaut test subject under simulated zero-g conditions.

The contract requirement of 20 minutes maximum for any remove and replace action was satisfied by the maximum recorded test time of 7 minutes 11.7 seconds for the wrost case module #10 installation. Excluding this deliberate access problem behind a stress plate with 22 fasteners, the longest R & R time recorded for equipment designed for normal EVA and IVA action was 2 minutes and 20 seconds.

Usable maintainability predictions can be generated to estimate the elapsed times and man hours required to maintain a given space vehicle, system, or equipment set. This can be done for large and small maintenance jobs through the application of Mil-Hdbk-472, Method II prediction technique modified to account for zero-g and pressure suit application. The demonstration results indicated that certain "K" factors could be applied to obtain more accurate estimates of the maintenance workload in space.

The last test run at MSFC demonstrated the capability of performing emergency work in a pressure suit on equipment designed for IVA shirtsleeve maintenance. This capability will be inherent in all equipment designed in accordance with the criteria requirements.

12.4 RECOMMENDATIONS

The following recommendations are made to assist NASA in making full use of the items developed under this program:

Criteria:

- Use appendix A in specifications for electronic equipment in maintainable vehicles & systems.
- Use appendix B as a general design guide or reference for electronic equipment maintainability in space.
- Identify and publish these documents in NASA techni listings as requirements for new designs.

Mock-up:

- Use existing mock-up to acquaint design and development personnel with maintainability features that enhance remove & replace action.
- Conduct additional test runs to provide a data base for verifying the derating or "K" factors for more accurate maintainability predictions.
- Use the existing mock-up for training of astronaut types and to evaluate the worth of maintainable designs.
- Modify existing mock-up to incorporate new features and concepts for test and evaluation.

Final Report:

- Identify and publish the document as a NASA reference work to "spread the gospel" among design personnel.

3

SECTION 13

AREAS REQUIRING ADDITIONAL STUDY

As this study progressed, additional details became known regarding problem areas which impact the development of maintainable designs. Due to the limited scope of this packaging study, the items listed below could not be covered and are thus candidates for future study effort.

13.1 ELECTRICAL ARCING

Removal and replacement of electrical/electronic equipment is an oxygen enriched atmosphere may be disastrous due to the possibility of arcing at the electrical interfaces. The following problem areas should be investigated and solved before maintenance remove and replace actions are attempted in space:

- Determine energy levels and conditions under which arcing may occur in a spacecraft atmosphere.
- Determine effects of arcing in a spacecraft atmosphere.
- Determine specific methods of preventing arcs and minimizing the effects of arcing at maintainable equipment interfaces.
- Compile a list of available "state-of-the-art" hardware and arc preventions techniques suitable for use in designing space equipment.
- Develop new hardware as required to achieve safe and dependable techniques.
- Test and demonstrate the effectiveness of recommended hardware and techniques.

13.2 FAULT ISOLATION REQUIREMENTS

The packaging study was accomplished by making a number of assumptions concerning fault detection and isolation. The ground rules merely noted the problem but excluded this item from the scope of the program. During the study, a number of factors were noted, however, and these require a thorough investigation before long duration spacecraft can be effectively maintained in flight.

The ability to perform fault isolation to the required levels for maintainability aboard a spacecraft must be established and defined. Some of the items requiring study are:

- Identify the Maintainability fault isolation requirements to establish the level of maintenance for given mission conditions.
- Identify the Maintainability advantages of various methods of fault isolation, local and remote, manual and automatic.
- Extent of man in fault isolation loop must be determined.
- Fault indication techniques, local and remote, must be examined for Maintainability advantages.
- Location of test points must be established.
- Fault isolation capability in current and future hardware must be assessed.
- Test connectors and associated equipment must be defined.
- Extent of specialized training required for astronauts, for both fault isolation and repair, must be defined.
- Harness and connector breakdowns, fault isolation and repair requirements must be defined.

13.3 TETHER PROVISIONS

During the packaging study, the need for a standardized method of tethering or fastening units involved in the remove and replace task was established. The device carried or transported by the astronaut when in space, whether under EVA or IVA under Zero-g conditions, cannot be allowed to float free. Under EVA conditions, tethering is required to prevent the loss of the unit. Under IVA conditions, it is required to prevent damage to the unit and anything else within the vehicle with which it could collide. A study should be made to determine the following:

- The best methods of tethering each type of loose unit, i.e., by hook, clamp, snap fastener, etc.

- The best line or cord arrangement, i.e., retractable, coilable, etc.
- The number of tethers needed at one time
- Design and location of tether attachments on:
  - Boxes
  - Modules
  - Tools
  - Other removable equipment
- Standardization of vehicle and equipment tethering provisions

13.4 UNIVERSAL TOOL

A definite conclusion, provided by the mock-up for demonstrating electronic package removal and replacement, was the realization that a "universal" tool is needed for these tasks. The astronaut's movement, vision, and endurance will be restricted when performing EVA in a pressure suit. He will also be operating under a handicap due to confinement and Zero-g conditions when performing IVA maintenance actions which a variety of tools can only intensify. One tool for removal and replacement of all maintainable electronic equipment will go a long way to alleviate the handicap and permit efficient maintenance operations. A study should be undertaken to provide a simple universal tool that will meet the following requirements:

- The tool should serve as a removable handle for use during handling of replaceable equipment.
- The tool should be hand portable and small in size so that it can be stowed or carried in a belt loop.
- The tool should be usable for all electrical/electronic equipment.
- The number of recessed hex drive fastener head sizes should be limited to a selected pair of sizes.
- The tool should provide a mechanical advantage through its handle and ratchet.
- Torque applied on small diameter fasteners should be limited by the tool.

13.5 BOX AND HARDWARE STANDARDIZATION

Before an efficient onboard spacecraft maintenance approach can be realized and a feasible spares concept can be determined, the maintainable electronic equipment hardware must be standardized in form, fit, and function wherever possible. The electronic packaging study reaffirmed the need for standardization and commonality in:

- Black box designs
- Module designs
- Box and module interfaces
- Box and module mount hardware
- Spacecraft installation provisions for electronics

At present, the size of removable electronic equipment for the spacecraft is limited only by the size of the hatch opening. The optimum or ideal dimensions for width and length of replaceable units have not been established. The most convenient shapes and sizes to handle and work on in the space environment have yet to be specified. Specific modularity and commonality requirements in the design of black boxes, modules, and the associated mounting hardware remain to be determined.

13.6 QUICK DISCONNECTS FOR COAX CABLES AND WAVEGUIDES

Available connectors for airborne coax and waveguide applications are not intended for in-flight maintenance procedures. Consequently, they are totally unsuitable for such procedures by a pressure suited astronaut in a space environment.

Multi-contact coaxial connectors are desirable from a Maintainability viewpoint; however, they generally perform poorly, particularly at higher frequencies. A study should be undertaken to

Develop ideal characteristics for coax and waveguide connectors

Develop designs for quick-disconnect coaxial connectors suitable for the space maintenance environment

Develop designs for quick-disconnect waveguide connectors suitable for the space maintenance environment

- Develop designs for quick-disconnect multi-contact coaxial connectors with controlled electrical parameters suitable for the space maintenance environment

- Prepare standards for application to equipment design

13.7 WIRING HARNESS AND CONNECTOR REPAIR TECHNIQUES

Long duration space mission crews will be faced with failures occuring in spacecraft wiring, harnesses, and connectors. They will have to locate and isolate these failures, and then repair or replace the failed items. The packaging study was limited in this area to the electrical interface problem with the associated alignment guides, locking features, keying, quick release designs, and similar packaging characteristics. Therefore, the harness, wire, and connector failure problem was beyond the scope of the packaging study and could only be noted as a potential additional study candidate. The methods involved in providing for onboard disconnect and repair of the following should be studied:

- Racks and panels
- Walls, drawers, and enclosures
- Motherboards
- Ribbon cable and flat harnesses
- Connectors
- Compact harnesse

Standardization of connectors, harnesses and wiring at each assembly level must be accomplished for all long duration manned space vehicles; therefore, this study must result in a recommended set of standards and specifications for general application.

13.8 LATCHING MECHANISMS

Investigations during the electronics packaging study revealed the lack of a one handed simple mechanism for quickly latching a removable unit to the mating structure. Two unique latching mechanisms for boxes and a device for jacking and unjacking modules were designed, fabricated, and installed on the packaging study mock-up, but these designs were for concept verification and demonstration only, and are not considered optimum devices. A study is needed to provide firm designs, standards and specifications covering generally:

- Torque bars and other methods to limit forces on fasteners
- Removable handles
- Single point and dual point mechanisms with self-aligning features
- Methods of jacking and unjacking black boxes, modules, and connectors
- One hand mechanisms for black boxes and modules
- Lightweight mechanisms
- Use of designs that will accommodate a universal or standard tool

13.9 BOX AND MODULE ALIGNMENT GUIDES

During the packaging study, a variety of methods for guiding replaceable units into position for latchup were examined. The mock-up, which was developed as a part of this study contains a number of alignment device concepts to facilitate space maintenance. However, good designs for alignment mechanisms to fulfill the criteria requirements must still be sought because:

- No existing guide design combines both fastening and alignment to save space and weight, as well as to minimize the actions necessary for removal and replacement.
- In the spacecraft there is a need to retain the unit in the guide for one hand latchup. No such designs exist at present.
- Visual targeting aids need to be developed for space replaceable equipment at all levels.
- Standards and specific design requirements must be established.

13.10 BOX AND MODULES INTERFACE PROTECTION

It is obvious that, even if tethered, electronic black boxes and modules will be susceptible to damage when removed from their normal secured positions. The critical thermal electrical and structural interfaces of these removable units will then be exposed to various kinds of handling damage. It will be necessary to provide designs that will protect these critical areas. Handling during EVA, IVA, transport maintenance, and storage require study to develop feasible techniques, concepts, and designs for the protection of:

- Thermal interfaces (pressure plates, heat sinks, thermal compounds, etc.)
- Electrical interfaces (connector pins, inserts, shells)
- Structural interfaces (fasteners, threads, pins, etc.)

13.11 COLD WELDING

The potential problem of cold welding, as it applies to the maintenance removal and replacement of black boxes and modules, requires study and testing which was beyond the scope of this study. It is recommended that NASA develop the materials and techniques required to eliminate the cold welding problem from future maintainable equipment designs.

SECTION 14

DEFINITIONS AND ABBREVIATIONS

14.1 DEFINITIONS

BLACK BOX	An assembly or any combination of parts and modules, usually a plug-in unit, which is replaceable as a whole to correct a malfunction in a subsystem.
CHASSIS	A physical structure which retains and electrically interconnects a group of modules which perform higher level functions.
DEAD FACING	Deactivation or removal of all signals from all leads in both halves of a connector prior to separation of the connector.
DOWN POWERING	Deactivation of an entire replaceable unit, subsystem, or system to remove all electrical potential from all leads of all connectors prior to removal of a unit during a maintenance action.
INTERCHANGE	The removal and replacement of equipment.
LEVEL OF MAINTENANCE	The level of assembly, e.g., Black Box, module or piece part, at which the system or equipment is normally maintained.
MAINTAINABILITY	A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

MAINTAINABILITY CONCEPT	A comprehensive statement of the elements and/or extent of maintenance to be performed and their application to the program/equipment.
MAINTENANCE ACTION	An act of maintenance (repair or service performed on a unit, system or vehicle to return it to a specified condition.
MODULE	An assembly forming part of a larger assemblage, both of which may be designed for complete replacement as units. It can be a subassembly within a black box or the system replaceable item in IVA for maintenance repair.
REMOVAL AND REPLACEMENT TASK	The task of physically interchanging the malfunctioning equipment with serviceable equipment and does note include preparation tasks such as gaining access to the equipment, obtaining spare parts, fault isolation, etc.
REPAIR	The process of returning a system/equipment to a specified condition by repair including preparation, fault detection, fault isolation, access, removal and replacement of defective equipment, verification tests, close out and secure action.
SOFT MOCK-UP	A low cost model built accurately to scale chiefly for in-house study, testing or display.
COUNTERBALANCE MECHANISM	Any one of a number of mechanisms employed during the simulated zero-g demonstration tests of the packaging mock-up to counteract gravity and provide neutral buoyancy in air.

14.2 ABBREVIATIONS

BIT	Built In Test
EVA	Extra-vehicular Activity
IVA	Intra-vehicular Activity
MMH/OH	Maintenance Man Hours per Operating Hour
OBC	Onboard Checkout
MTTR	Mean Time To Repair
R & R	Remove and Replace
M	Maintainability
PCB	Printed Circuit Board
IC	Integrated Circuit

SECTION 15

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APPENDIX A

SUMMARIZED LIST OF MAINTAINABILITY DESIGN CRITERIA

APPENDIX A

TO

FINAL REPORT OF CONTRACT NAS-8-24690

This appendix contains a list of recommended Maintainability Design Criteria for the "quick and easy" removal and replacement of space electronic equipment.

The list of Design Criteria has been prepared in three sections:

I. GENERAL REQUIREMENTS FOR EVA AND IVA APPLICATION

II. REQUIREMENTS FOR IVA

III. REQUIREMENTS FOR EVA

APPENDIX A

LIST OF MAINTAINABILITY DESIGN CRITERIA FOR REMOVAL AND REPLACEMENT OF SPACE ELECTRONIC EQUIPMENT

I. GENERAL REQUIREMENTS FOR EVA AND IVA APPLICATION

G-1 Two-handed remove-and-replace action will be permitted with or without pressure suit on only when approved foot or body constraints are provided. Where no constraints are provided, Remove-and-Replace action must be accomplished with one hand and a hand-hold must be provided on the spacecraft for the other hand.

G-2 The remove-and-replace task must be completed in 20 minutes or less under either zero or partial g conditions.

G-3 All replaceable unit installations must have quick and easy mechanical alignment and visual orientation to assist astronaut during replacement.

G-4 All replaceable units must have mechanical keying provisions to prevent improper installation. Connectors are not to be used for this purpose.

G-5 All hand-mated connectors must be fast-acting and mechanically keyed to prevent improper installation. Connector pins are not to be used for keying purposes.

G-6 All replaceable units must have tethering provisions. These provisions:

- must be compatible with quickly applied snap fittings
- must be standardized throughout the vehicle.

G-7 All replaceable unit critical areas such as thermal, structural and electrical interfaces must be designed for protection from damage as a result of handling.

G-8 All replaceable units must have fast-acting lock-up and release of thermal, electrical and structural interfaces. Depending on the criticality of the item replaced, the following mounting arrangements are recommended in order of preference:

- simultaneous lock-up of all three interfaces with one hand and a single motion mechanism
- simultaneous lock-up of thermal and structural interfaces with single motion but with hand mated connectors
- simultaneous lock-up of all three interfaces with fast-acting bolts or screws
- simultaneous lock-up of thermal and structural interfaces with fast-acting bolts or screws and hand-mated connectors.

G-9 All replaceable unit mounting hardware must be captive.

G-10 In any given vehicle, all replaceable unit mounting fasteners that require use of a tool shall:

- incorporate an internal wrenching hex head which will mate with the universal tool called for in item #G-16 below
- be limited to no more than two sizes of hex drive to accommodate smallest through largest electronic packages.

G-11 System designs for replaceable units must minimize the number of electrical interface connections in order to reduce the number, size, and mating forces of the connectors on these units.

G-12 Built-in fault isolation capability must be provided to the replaceable element in the system.

G-13 All designs for remove-and-replace operation that require use of one hand <u>and</u> a tool, must incorporate a restraining feature built into the alignment mechanism to hold the replaceable unit in position while transferring the free hand to the tool.

G-14 All replaceable units must have provisions for handling during installation and removal operations. Handles may be permanently attached to the replaceable units or temporarily attached by the astronaut. Temporary handles, if used, must be incorporated into the universal tool called for in Item #G-16 below.

G-15 All designs for maintenance replaceable units must incorporate provisions for automatic and positive protection of the astronaut from electrical shock hazard when replacing these items.

G-16 All requirements for tools in remove-and-replace actions must be combined into one universal tool which has provisions for the two standard sizes of internal wrenching hex head fasteners referred to in Item #G-10 above. This tool shall also incorporate provisions for use as a temporary handle where required by equipment design as indicated in Item #G-14 above.

G-17 Electronic equipment shall be designed to eliminate all requirements for scheduled maintenance.

G-18 Replaceable units and their mounting hardware must be designed to eliminate all possible mechanical hazards to the astronaut or his pressure suit such as sharp corners, or edges, dangerous protuberances, exposed moving mechanisms, and extreme temperatures.

G-19 Maximum earthweight for replaceable units must not exceed 150 pounds. Design goal for safety in handling is 40 pounds maximum earth weight.

G-20 The design and installation of replaceable units must provide clearance for the use of hands and required tools during the remove-and-replace action. In general, a minimum clearance of 2" must be provided for the gloved hand of an astronaut in a pressure suit.

G-21 The interfaces (thermal, electrical, and structural) of all replaceable units shall be designed to prevent cold welding in space.

G-22 All fasteners, handles, connectors, controls, and indicators either manipulated by or observed by the astronaut during remove-and-replace maintenance action must be located on the side of the replaceable unit facing the astronaut.

I. REQUIREMENTS FOR IVA

I-1. System-level repairs in IVA are to be accomplished at the following replaceable unit levels:

- Black box level for critical systems and equipment.
- Module level for systems not considered critical to safety or survival.

I-2. All IVA replaceable items critical to mission safety and survival must have provi sions for fault isolation at each critical unit independent of the system OBC test capability. In order of preference, this may take the form of:

- Activation of unit built-in-test at the unit with display of Go/No-Go status. The status indicator must be of the mechanical latching type that holds the last test result initiated either by system test or locally at the unit.
- Test connector on the unit suitable for determining unit status upon interr gation. This test connector must be protected from shorts and interferen by use of an easily installed tethered cap or other suitable method.

I-3. All covers and cover plates on maintainable black boxes and equivalent assemblie such as drawers, wall racks, and panels must be mounted with captive, quick and easy fasteners of a type that will facilitate the required maintenance operations. Recommende fasteners are listed below in descending order of preference:

- Quick release fasteners (single motion, rotary, lever or latch action)
- Fast acting fasteners (multi threaded and/or fractional turn)
- Screws and bolts (single threaded)

I-4. Minimum physical size for handling of replaceable units in IVA under:

- Emergency pressure suit conditions in critical systems and equipment sh be no less than 2-1/2" x 4" in the two dimensions facing the astronaut.

- Shirt sleeve conditions in other than critical systems and equipment shall be no less than 1" x 2" in the two dimensions facing the astronaut.

I-5. Critical system electronic equipment must be designed to eliminate all requirements for adjustment or alignment as a result of remove-and-replace action.

III. REQUIREMENTS FOR EVA

E-1. All systems-level EVA repairs are to be accomplished by removing and replacing faulty "black boxes" as the replaceable elements.

E-2. All EVA installations must have visual orientation and targeting aids to assist the suited astronaut during placement of the unit into the mechanical mounting or alignment positions.

E-3. All EVA hand-mated connectors must be of an approved type suitable for Zero-g operation by an astronaut in a pressure suit.

E-4. When minimum elapsed time is of the utmost importance, EVA remove-and-replace actions are to be accomplished without tools.

E-5. Every EVA replaceable unit must incorporate provisions at the unit for activation of built-in-test and display of Go/No-Go status. The status indicator must be of a mechanical latching type that holds the last test result initiated either by system test or locally at the unit.

E-6. Electronic equipment must be designed to eliminate all requirements for EVA adjustment or alignment as a result of remove-and-replace action.

E-7. Minimum physical size for handling of EVA replaceable units in a pressure suit shall be no less than 2-1/2" x 4" in the two dimensions facing the astronaut. Minimum size will also be determined by system fault-isolation capability and the requirements for thermal interface, connectors, mount hardware, and elapsed time.

E-8. Maximum size for handling of EVA replaceable units in a pressure suit will be limited by the specific requirement for easy passage through a 24"-diameter round hatch opening. The length of EVA units should not exceed two feet for reasonable handling control.

APPENDIX B

MAINTAINABILITY DESIGN CRITERIA FOR PACKAGING OF SPACECRAFT REPLACEABLE ELECTRONIC EQUIPMENT

APPENDIX B

TO

FINAL REPORT OF CONTRACT NAS-8-24690

This appendix contains the recommended Maintainability Design Criteria for the "quick and easy" removal and replacement of space electronic equipment.

The Design Criteria has been prepared in four major sections with seventeen subject chapters to permit easy reference to a topic of interest.

APPENDIX B

MAINTAINABILITY DESIGN CRITERIA FOR PACKAGING OF SPACECRAFT REPLACEABLE ELECTRONIC EQUIPMENT

CONTENTS

ILLUSTRATIONS

TABLES

SECTION I

INTRODUCTION TO THE PROBLEM OF MAINTAINABILITY IN SPACE

Chapter 1 The Maintenance Problem

1-1 INTRODUCTION

Future long-duration space vehicles must include the capability for quick and easy onboard repairs in order to restore malfunctioning equipment to an operative state and thereby attain the required long-term mission reliability. The ability to perform onboard repair depends on whether the equipment has been designed for the replacement of malfunctioning items. To facilitate optimum onboard repairs, all affected spacecraft hardware items must be designed for quick and easy malfunction detection and isolation to the desired level of replacement. The equipment must also be designed for easy replacement under mission conditions. The purpose of this criteria is to define the replaceable characteristics required for housing and packaging of electrical/electronic items in order to assure rapid and easy removal and replacement during the mission as well as during ground operations.

1-2 OBJECTIVES

In order to provide a feasible set of "remove and replace" criteria for the designer, the following primary objectives are established for onboard repairs in space. These repairs must:

(1) Require minimum astronaut effort

(2) Require minimum use of tools and test equipment

(3) Minimize the difference in equipment design between replacement in a shirtsleeve and pressurized suit environment

(4) Require replacement of removable items by one astronaut using one hand, if possible

(5) Require minimum expenditure of astronaut time.

1-3 BACKGROUND

On previous short-duration space missions, the reliability goals were achieved by redundancy in design and the use of high-reliability parts. Long-duration space missions, however, will require onboard maintenance to back up the redundancy and high-reliability designs in order to achieve the desired goal of $\geq .95$ overall probability of mission success. To maintain these desired mission performance levels, it will be necessary to place man in the loop. This means that equipment must be designed for quick and easy maintenance consistent with mission requirements. This also requires the establishment of maintainability concepts early in any program to insure incorporation of the necessary maintainability features into the design by the equipment designers.

The following major factors must be considered when establishing the maintainability concepts:

- Crew Safety
- Allowable downtime of equipment (criticality of function)
- Crew maintenance manhours per operating hour (MMH/OH)
- Alternate operating modes
- Crew skills and training
- Reliability
- Logistics complications (spares, tools, test equipment, technical information, resupplying interval, etc.)
- Weight, power, and cost.

Once the maintainability concepts are defined for a particular mission, it will then be possible to establish:

- Levels of maintenance (black box, module, subassembly, or part)

- Built-in-test (BIT) and OBC requirements
- Tools, test equipment and technical data requirements
- Personnel requirements (skill levels, training, etc.)
- Onboard spares and earth logistics requirements
- Allowable time constraints.

These factors in turn will establish and define:

- Test point requirements
- Mounting provisions
- Accessibility requirements
- Equipment design features for maintainability
- Design Commonality and Modularity requirements
- Weight, size, and shape of equipment
- Spares allocations & logistics requirements.

These criteria do not establish a universal maintainability concept. The purpose of the criteria is to provide the equipment designer with the remove-and-replace design requirements that must be met if maintainable equipment is to be installed on space vehicles.

The criteria also provides the equipment designer with interface requirements for tl particular levels of maintenance established for his equipment.

1-4. ASSUMPTIONS

The design criteria are based on the requirement that maintainable space electronic equipment must be removed and replaced quickly and easily. Extensive testing has already indicated* that relatively simple but repetitive maintenance operations in Zero-g, especially in a pressure suit, can produce early fatigue and frustration on the part of an astronaut. As a result, it becomes imperative that replaceable equipment be designed to facilitate quick and easy maintenance operations.

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*Refer to NASA Report #CR-859 (MSC) for emphasis of this point (pages 237, 241)

The following assumptions are necessary to cover requirements outside the scope of this remove-and-replace criteria:

- The ability to fault-isolate to the defective black box or module exists on-board the spacecraft consistent with the mission requirements
- Accessibility will be adequate for the level of maintenance selected
- Astronaut time (MMH/OH) is extremely expensive and must be minimized for all maintenance actions
- Adequate illumination will be provided for the repair task (Reference MSFC-STD-267 23 September 1966)
- Remove-and-replace action is to be performed by one crewman using one hand, if possible
- All shirtsleeve maintenance actions will be accomplished at the module or subassembly level with no more than one universal hex drive internal wrenching hand tool having no more than two sizes of hex drive to accommodate smallest through largest packages
- Foot or body restraints will be used during intravehicular activity (IVA) equipment replacement
- All replaceable unit interfaces (thermal, electrical, and structural) will be designed to avoid the problem of cold welding in space.

SECTION II

FACTORS AFFECTING MAINTAINABILITY IN DESIGN

Chapter 2 Maintainability Concept

Chapter 3 Work Area Environment

Chapter 4 Available Removal and Replacement Time

Certain factors will influence the choice of electronic equipment packaging design features as described in this criteria, i.e., the maintainability concept, the work area environment, and the remove-and-replace time available. Early decisions on these factors are necessary in order for the designer to extract maximum benefit from the design choices available in the criteria. However, it is not within the scope of this criteria to provide a detailed discussion of these factors, which are listed below with a short explanation of their effect on overall design.

Chapter 2 Maintainability Concept

2-1 LEVEL OF MAINTENANCE

One of the most important factors influencing the maintainability concept is the requirement for Built-in-Test (BIT), supplemented by onboard checkout (OBC) and the operator, to fault-isolate malfunctions to the replaceable item level. The equipment items are then packaged to coincide with this fault-isolation capability. That portion of the overall maintainability concept dealing with the level of maintenance must therefore be established early. The level of maintenance must not be arbitrarily assigned. Instead, it should be analyzed and traded off carefully to provide maximum benefits to the mission in the areas of minimum overall weight (spares included), minimum program cost, and maximum mission reliability.

Every EVA replaceable unit must incorporate provisions at the unit for activation of the built-in test features and display of GO/NO-GO status. The status indicator must be of the mechanical latching type with reset feature that holds the last test result initiated either by system test or locally at the unit.

All IVA replaceable units critical to mission safety and survival must also incorporate provisions for fault isolation at each critical unit independent of system built-in test capability. In descending order of preference this may take the form of:

- Activation of unit built-in test at the unit with display of GO/NO-GO status as required for EVA units
- Test connector on the unit readily accessible to the astronaut and suitable for determining unit status upon interrogation. This test connector must be protected with a quickly removed and easily installed tethered cap.

Chapter 3 Work Area Environment

3-1 PRESSURIZED VS. UNPRESSURIZED AREA

The item to be replaced could be located either in a pressurized or unpressurized area and access may be from inside or outside the spacecraft. Pressurized areas within the spacecraft allow equipment interchange to be performed in a shirt-sleeve environment using a minimum of hand tools. All unpressurized areas require the astronaut to wear a pressure suit whether or not the equipment is located inside or outside the spacecraft. There is no restriction on the use of a universal tool except that EVA interchanges are to be made without the use of a tool when minimum elapsed time is of utmost importance.

Under certain conditions the normally pressurized portion of the spacecraft may be depressurized when effecting an equipment interchange. During this period, the astronaut would have to wear a pressure suit. The design recommendations presented herein have taken this factor into consideration.

One of the objectives of this criteria has been to minimize the differences in design for replacement in a shirt-sleeve vs. pressure suit environment. It would be ideal to design all interior equipment for shirt-sleeve maintenance only, but safety and reliability considerations may require that certain levels of maintenance must be performed in the interior of the spacecraft with a pressure suit on. For this reason, emergency system-level repairs inside the normally pressurized portion of the vehicle must have the capability of both module and higher level assembly (Blackbox) replacement.

Chapter 4 Available Removal and Replacement Time

4-1 GENERAL

The maximum time for the astronaut to perform the removal and replacement task either in or out of a pressurized suit under zero or partial g conditions shall not exceed twenty minutes. The actual elapsed time permitted will be a function of mission reliability requirements, system downtime limitations, and crew manpower constraints. As a design goal, designers should aim for a five-minute or less replacement capability.

A complete "repair" action would normally consist of the following task segments:

(1) Preparation
(2) Fault detection
(3) Fault isolation
(4) Access
(5) Removal and Replacement or Repair
(6) Verification Test
(7) Close out and secure.

The removal and replacement task is defined herein as the time necessary to physically interchange the defective and replacement items and does not include any of the astronaut's preparatory or post-replacement tasks such as going through hatches, gaining access to the equipment, obtaining spare parts, fault isolation, closing the access, etc.

Normally a complete repair action should be completed in thirty minutes or less to prevent excessive manpower expenditure. This means that the individual repair action segments must consume small portions of the total time available depending on:

- Mission reliability requirements
- System downtime requirements
- Design redundancies available
- Priority of defective function
- Safety of the crew and equipment
- Manpower availability.

Because of the relatively small amount of time available to perform the replacement task segment during a repair action, the equipment design must be carefully selected to meet the specific mission requirements.

All EVA and those IVA systems critical to mission safety and survival should be repaired by removing and replacing faulty black boxes as the replaceable element. All other IVA systems should be repaired by removing and replacing faulty modules as the replaceable element. The distinction between a module and a black box in this context means only that the black box must be capable of replacement under pressure suit conditions.

SECTION III

MAINTAINABILITY REQUIREMENTS FOR GENERAL DESIGN APPLICATION

Chapter 5 Equipment Interfaces

5-1 GENERAL

In order to select the proper equipment to meet the conditions discussed in Section II, it is necessary to consider the interface between the spacecraft and the equipment.

In general, all replaceable units must have fast-acting lock-up and release of thermal, electrical and structural interfaces. Depending on the criticality of the item being replaced, the following mounting arrangements are recommended in order of preference:

- Simultaneous lock-up of all three interfaces with one hand and a single-motion mechanism
- Simultaneous lock-up of thermal and structural interfaces with single motion but with hand-mated electrical connectors

- Simultaneous lock-up of all three interfaces with fast-acting bolts or screws
- Simultaneous lock-up of thermal and structural interfaces with fast-acting bolts or screws and hand-mated electrical connectors.

This chapter discusses the interface parameters and makes recommendations for the selection of equipment to meet these conditions.

5-2 INTERFACE REQUIREMENTS

In any equipment interchange operation, it will be necessary to disconnect and reconnect electrical cables, structural attachments and thermal paths. Provisions shall be made at these interfaces for the prevention of cold welding on all removable units. The design of electronic equipment must therefore minimize the number of interface connections in order to reduce the number, size and mating forces of the functional interface connections.

The incorporation of quick and easy replacement design features must not degrade the performance of the equipment during launch or other severe environmental conditions as defined in the equipment specifications. In many instances, proper design can provide the desired maintainability features at no additional cost or penalty. When cost or weight penalties appear inevitable, they must be carefully traded off against the benefits of the maintainability features such as: reduced overall spares weight and cost, improved overall reliability, decreased requirements for crew time, training, test equipment, tools, and technical information.

The interfaces are critical areas and the package designs must protect them from damage as a result of handling. The interface requirements differ for EVA locations, IVA (normal systems) and IVA (survival and safety systems) installations as follows:

5-2.1 EVA Locations

For EVA pressure suit locations, the remove-and-replace task will be limited to the interchange of black boxes under the following general conditions:

- Astronaut wearing a pressure suit (gloved hand)
- Zero-g (space) environment
- Only one hand normally available for repair task since astronaut may not be constrained by foot or body restraints
- Basically no tools allowed when minimum elapsed time is required
- Maximum permissible elapsed time for EVA repair determined by mission requirements but EVA remove and replace action limited to 20 minutes or less.

5-2.1.1 Electrical Interface - EVA or pressure suit criteria allows electrical connection/disconnection to be either automatic or manual. The use of one hand to perform this task is preferred, thereby permitting use of the other hand to grip a handhold on the spacecraft to stabilize the astronaut. All EVA electrical interface connections must comply with the requirement for de-energizing power prior to making or breaking the connection (refer to Chapter 8-3).

5-2.1.1.1 Automatic - Automatic connection/disconnection occurs when the action is simultaneous with removal and insertion of a black box as when rack and panel connectors are employed. The structural latching mechanism for the box must provide the required jacking/unjacking forces. This force can be quite large (≈60# for a 101 pin unit) when a number of high density connectors are ganged and mated together, therefore every effort must be made to reduce the number of electrical interface connections to a minimum.

The automatic method however provides the quickest electrical interface and is preferred for EVA maintenance.

5-2.1.1.2 Manual - Manual connection/disconnection must be capable of being performed under Zero-g conditions by one hand. Only NASA approved Zero-g type manual connectors will be permitted since they will allow the astronaut to perform the replacement task while in a pressurized space suit. These connectors are bulky due to the lever-action and explosion-proofing requirements; therefore they should not be used when high-density wiring requires multi-connector installations or where the minimum 2-inch gloved hand clearance cannot be provided.

5-2.1.2 Structural Interface - To meet the EVA equipment interchange time requirements, a mechanism is needed to quickly and easily secure the box to the structure. The mechanism must also provide the forces required for the electrical and thermal interfaces. The actuation of the mechanism must be simple with astronaut forces not to exceed CSD-X-012 (refer to Chapter 7).

Whenever possible, the same handle used for locking/unlocking of the box to the spacecraft structure should be used for handling of the box during the repair action in the space environment. This arrangement will permit the astronaut to unlock and remove the box in one motion of the hand in a minimum amount of time. Additional handles may be needed for handling in an earth environment (refer to Chapter 11) in the event that the box is heavy and/or bulky).

5-2.1.3 Thermal Interface - The requirement for the performance of EVA maintenance work in a pressure suit with minimum elapsed time dictates that the thermal path be of the quick-disconnect type. The use of tools to install interface connections for a thermal path is not recommended and must be avoided. Fluid cooling lines must not be opened as a thermal interface for electronic black boxes.

The preferred method of providing the required quick-disconnect thermal interface is to use a mechanically separable heat sink that is actuated automatically by the black box mounting mechanism. The use of thermal bonding agents such as pastes and greases will not be permitted for EVA action unless the pregreased thermal interface is protected from wipe-off during handling and installation.

5-2.2 IVA Locations

For IVA shirt-sleeve locations, the remove-and-replace task will normally involve interchange of modules under the following conditions:

- Zero or partial g, shirt-sleeve environment
- Minimum number of tools
- Maximum permissible elapsed time for repair determined by mission and system requirements, but IVA remove-and-replace action limited to 20 minutes or less
- Foot or body restraints utilized, if possible
- One-hand operation, if possible.

5-2.2.1 Electrical Interface - Shirt-sleeve area design criteria allows a wider choice of electrical connectors since the astronaut will not normally be restrained by the gloved hand of a pressure suit. The nominal thirty-minute maximum time for a space repair requires that connection/disconnection of modules be made using either automatic plug-in or quick-release (less than one turn) connectors. Use of a drawer, wall, or rack to contain the modules will facilitate the interchange since these larger storage items will not normally be removed from the supporting structure thereby eliminating the need for drawer/wall/rack electrical quick-disconnects. Refer to Section Four for examples.

All IVA electrical interface connections must comply with the requirement for de-energizing power prior to making or breaking the connections (refer to Chapter 8-3).

5-2.2.2 Structural Interface - The lessening of the requirements allows greater flexibility in the design for shirt-sleeve areas. Since there is no requirement to remove-and-replace the IVA equipment drawer/wall/rack assembly, this assembly can be mounted on slides or hinged to provide access. A latch and a handle may be required to unlock and position the IVA drawer/wall/rack assembly to gain access to the modules.

A minimum number of tools (ideally one universal tool) are to be used, thus allowing quick acting fasteners to be employed for removal/replacement of modules. The quantity of fasteners must be kept to a minimum to meet the time requirements for the installation.

The module mounting fasteners must provide sufficient forces to mate the thermal and electrical interfaces properly, as well as the structural interface as required by the equipment design specification.

Whenever possible, modules should be mounted without the use of tools. In the event that quick-release levers or knobs are employed, they should also be used for handling of the unit. Additional handles may be needed in an earth environment (refer to Chapter 11) if the module is heavy and/or bulky.

Wherever possible, modules should be installed with a single mechanical fastener such as one central fast-acting device on printed circuit boards and computer pages.

5-2.2.3 Thermal Interface - The time limit for removal and replacement of modules dictates that the thermal path be of the quick-disconnect type. The use of tools to install interface connections for a thermal path is not recommended and must be avoided. Fluid cooling lines must not be opened as a thermal interface for electronic modules.

The preferred method of providing the required quick-disconnect thermal interface is to use a mechanically separable heat sink that is actuated automatically by the module mounting fasteners or mechanism. The use of thermal bonding agents such as pastes and greases is not recommended and should be avoided.

5-2.3 Emergency System Level Repairs in IVA Shirt Sleeve-Areas (Survival and Safety Systems)

When failure occurs to critical systems and equipment affecting mission safety and survival, (such as the Life Support System) the paramount consideration is to restore the function in the least amount of time in accordance with system downtime limitations.

Under these circumstances, unless the BIT and OBC systems are inherently capable of fault isolation to the defective module in all failure modes, provisions must be made for quick repair by replacement of a larger assembly consistent with the BIT and OBC degraded mode capability.

The designated critical equipment, either modules or larger assemblies, must be designed for replacement in a pressure suit as in Paragraph 5-2.1 with the following change. Since the astronaut can be restricted by IVA foot or body constraints, he will have two hands with which to effect the repair.

5-3 ALIGNMENT GUIDES

In order to facilitate the installation of either black boxes or modules under Zero-g conditions particularly when only one hand is free, it will be necessary to provide visual aid and a mechanical means of guiding the item into position for attachment to the spacecraft structure. The guide must provide a restraint in all but the direction of insertion.

A retaining feature must be provided in the alignment mechanism to hold the box/module in position should it be necessary to transfer the free hand to a tool when securing the box/module to the spacecraft structure. Several types of guides are incorporated into the examples of Section IV.

Visual aids to facilitate alignment can take the form of a contrasting color outline or silhouette representing the shape of the item in its installed position. Color coded orientation dots or markers can be placed on one corner of the item and on the mount structure in the installed position.

Chapter 6 Accessibility

6-1 GENERAL

Accessibility is a prime maintainability problem. Ineffective maintenance is often the result of inaccessibility. It is a proven fact that inaccessible items will tend to cause delays or omission of maintenance tasks, cause mistakes, and cause accidental damage to equipment if the equipment cannot be adequately seen, reached or manipulated. Good accessibility also becomes a requirement for the manufacturing and test operations prior to launch in order to reduce costs.

In planning for accessibility, each maintainable item must be analyzed to determine the type of maintenance it will require. Next, the best type of access, covers, method of mounting and required dimensions are determined. Once the type of access has been selected for a given item, the designer must make certain that it is large enough for physical interchange and for the employment of test and service equipment as required. Requirements for the designer in planning for ease of maintenance include the following:

- All hand or tool-manipulated hardware, BIT status indicators, BIT controls, power controls, power indicators, and hand-mated connectors installed must be mounted and visible on the front panel of the replaceable unit facing the astronaut
- Maintainable equipment must not be installed in a manner that requires sequential removal for access to the failed item
- Locate black boxes and modules so that structural units and other equipment do not block the access to them
- Equipment corresponding to the selected level of maintenance (black box/module) shall be easily and quickly removable and replaceable
- Design, locate, and fasten accesses in such a manner as to avoid the necessity for removing components, wires, etc., in order to reach the item requiring maintenance

- When the access is located near unavoidable and dangerous mechanical or electrical components, the designer must provide covers, safety interlocks & warning labels as befits the degree of severity (refer to Chapter 8).

6-2 MAINTENANCE ACCESSES

A quick access should be provided whenever a frequent maintenance operation would otherwise require removing a case or cover, opening a connection, or dismantling a component. When structural, environmental, operational and safety conditions permit, equipment should be left exposed for maintenance This is particularly true of test and service points, maintenance displays, controls, and rack or wall mounted black boxes or modules. The access should be designed to make the repair or servicing operation as simple as possible. Recommended equipment accesses are given in Table 6-1.

TABLE 6-1. RECOMMENDED EQUIPMENT ACCESSES

Desirability	For Physical Access	For Visual Inspection Only	For Test and Service Equipment
MOST DESIRABLE	Pullout shelves or drawers.	Opening with no cover.	Opening with no cover.
DESIRABLE	Hinged door (if dirt, moisture or other foreign materials must be kept out).	Plastic window (if dirt, moisture or other foreign materials must be kept out).	Spring-loaded sliding cap (if dirt, moisture or other foreign materials must be kept out).
LESS DESIRABLE	Removable panel with captive, quick-opening fasteners (if there is not enough room for hinged door).	Break-resistant glass (if plastic will not stand up under physical wear or contact with solvents).	—
LEAST DESIRABLE	Removable panel with smallest number of the largest fasteners that will meet requirements for stress, pressure, or safety.	Cover plate with smallest number of largest fasteners that will meet requirements for stress, pressure, or safety.	Cover plate with smallest number of largest fasteners that will meet requirements for stress, pressure, or safety.

6-2.1 Openings for Physical Access

Make accesses the shape necessary to permit easy passage of components. Use a hinged door, instead of a cover plate held in place by fasteners, where physical access is required. If lack of space prevents the use of a hinged opening, use a cover plate with captive quick-opening fasteners. If a hinged access or quick-opening fasteners will not meet stress, pressurization, safety, or other requirements, use the minimum number of the maximum practical size fasteners consistent with those requirements.

6-2.2 Accesses for Visual Inspection Only

Use no cover unless exposure is likely to degrade equipment or system performance. If the entrance of dirt, moisture, or other foreign materials is a problem, use a plastic window. If physical wear or contact with solvents will cause optical deterioration of plastic, use a break-resistant glass window. If glass will not meet stress or other requirements, use a quick-opening metal cover.

6-2.3 Accesses for Tools and Servicing Equipment

Use no cover unless exposure is likely to degrade equipment or system performance. If the entrance of dirt, moisture, or other foreign materials is a problem, use a spring-loaded sliding cap. If a cap will not meet stress or other requirements, use a cover plate with quick-opening fasteners.

6-3 SIZE AND SHAPE OF ACCESSES

Access openings should be designed in whatever shape necessary to permit passage of the required items and servicing equipment. The opening need not necessarily be round, square, or rectangular, but the removable item itself must pass readily through a 24"-diameter round hatch opening with consideration given to the safe handling of the item during the remove and replace operation. The size of access openings is determined by the following four factors:

(1) Size and shape of the module or black box to which access is desired.
(2) Whether or not the object must be removed and replaced through the opening.
(3) Movements of the human body member or members required once access is gained (turning, pulling, pushing, etc.).
(4) Size of the body member or members (with required garments) that must enter through the access opening.

The first two factors can only be determined by an analysis of the task or tasks involved. The last two factors are determined by body measurements (refer to Chapter 11). In general, a minimum clearance of 2" must be provided for the gloved hand of an astronaut in a pressure suit around all knobs, handles, levers, fittings, tools and connectors that he must manipulate.

Chapter 7 Fasteners

7-1 GENERAL

The design selection and application of fasteners must take into account the following general maintainability requirements:

- All fasteners must be captive
- Pressure suit area black boxes shall not require the use of tools
- The length of time allowed for operation of the fasteners must be minimized
- The frequency with which the fasteners will be operated dictates type and material selection
- The environmental factors including wear that the fastener must withstand
- Standardization and commonality as required throughout the vehicle
- Workspace, tool clearance, and wrenching space required around each type of fastener
- Allowable forces which can be exerted in a pressure suit as given by CSD-X-012, Extravehicular Activity Design Criteria, prepared by MSC, Crew Systems Division, latest revision
- A standard internal wrenching head style to fit the universal hex drive tool of paragraph 1-4 shall be used for all bolts, screws and panel type fasteners that require removal by an astronaut.

7-2 TYPES OF FASTENERS

The paragraphs which follow list general recommendations and application of each type of fastener IN ORDER OF PREFERENCE for maintainability.

7-2.1 Quick-Release Fasteners

Quick-release-type fasteners are required when the item being replaced is a black box that is only accessible to an astronaut in a pressure suit, or in other applications where an extremely fast interconnection is needed and only one hand may be used.

Quick-release fasteners can be classified as follows: (reference Figures 7-1 through 7-3)

- Rotary
- Lever
- Latches and Catches
- Panel Fasteners

The types recommended for use in a space environment are described herein.

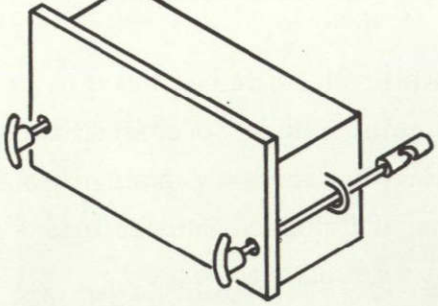
7-2.1.1 Rotary Handle Type - Provides simultaneous engagement of electrical, thermal and structural interfaces. A rotary handle type mechanism should be used where jacking of rack and panel connectors is required to produce high insertion/removal forces and where these forces must be sufficient to maintain large thermal contact areas. Typical rotary handle mechanisms are shown in Figure 7-1. The rotary handle mechanism secures the black box to the structure through a wedge at the sides. The wedge engages the structural shear pin and exerts the force needed to:

(1) Engage and disengage the connectors
(2) Provide the contact needed for the heat sink and the EMI bond
(3) Secure the box to the structure

In Type A, the handle in the latched position has a mechanical stop to provide positive latching and prevent overtravel. To disengage the box from the structure the handle is rotated in the opposite direction. The wedge on the structural shear pins now provides the jacking force necessary to disengage the electrical connectors.

Type B operates in a similar fashion except two handles are provided requiring two separate actions.

Type B



Type A

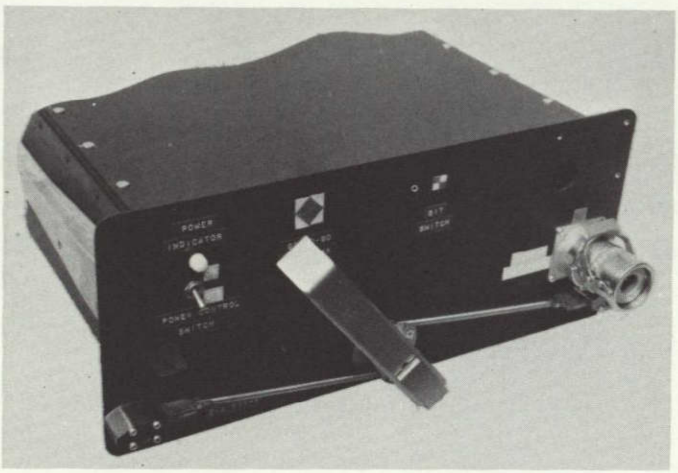
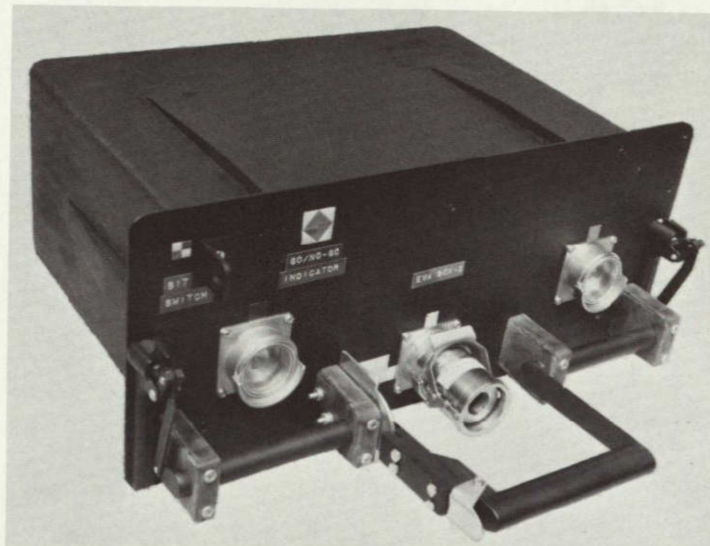


Figure 7-1. Typical Rotary Handle Mechanisms

7-2.1.2 Lever Handle Type - Provides simultaneous engagement of thermal and structural interfaces. A lever handle type mechanism should be used where a medium size thermal contact area is required and electrical interface is by other than rack and panel connectors. Typical lever handle type mechanisms are shown in Figure 7-2. The lever handle mechanism secures the black box to the structure through a jacking wedge at the sides on the front of the box but does not provide enough travel and force for connector lock-up. Raising the handle engages the structural shear pin and exerts the force needed to:

- Provide the contact needed for the heat sink and the EMI bond
- Secure the box to the structure

Type B



Type A

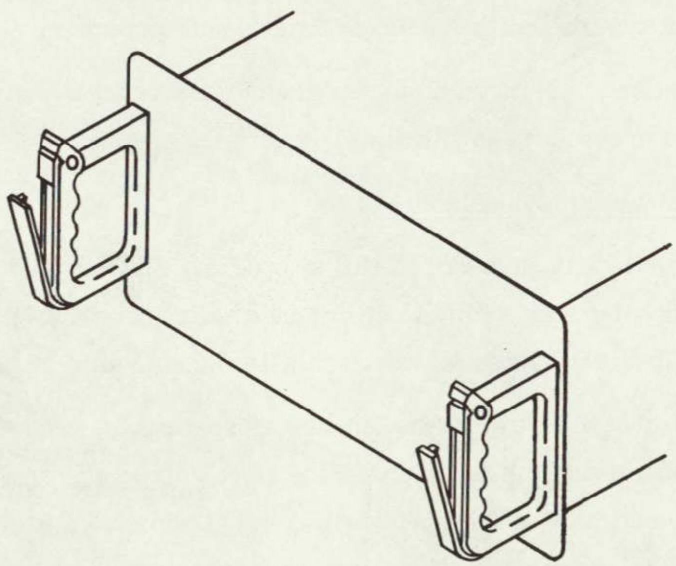


Figure 7-2. Typical Lever Mechanisms

Type A mechanism usually has a mechanical latch to prevent overtravel whereas Type B has an overcenter position to provide positive latching and prevent overtravel. To disengage the box from the structure, the lever is moved in the opposite direction, positioning the dog clear of the shear pin allowing unobstructed removal of the box.

7-2.1.3 Latches and Catches - Latches as shown in Figure 7-3 can be used when no clamping, high structural loads, or jacking forces for rack and panel connectors are required. Latches are very fast and easy to use, require no tools, have relatively poor thermal path and are good for securing large items such as panels, covers and cases. They normally cannot be used where strength and a smooth surface are required. Latch should be captive and spring loaded so that they do not require manual loading.

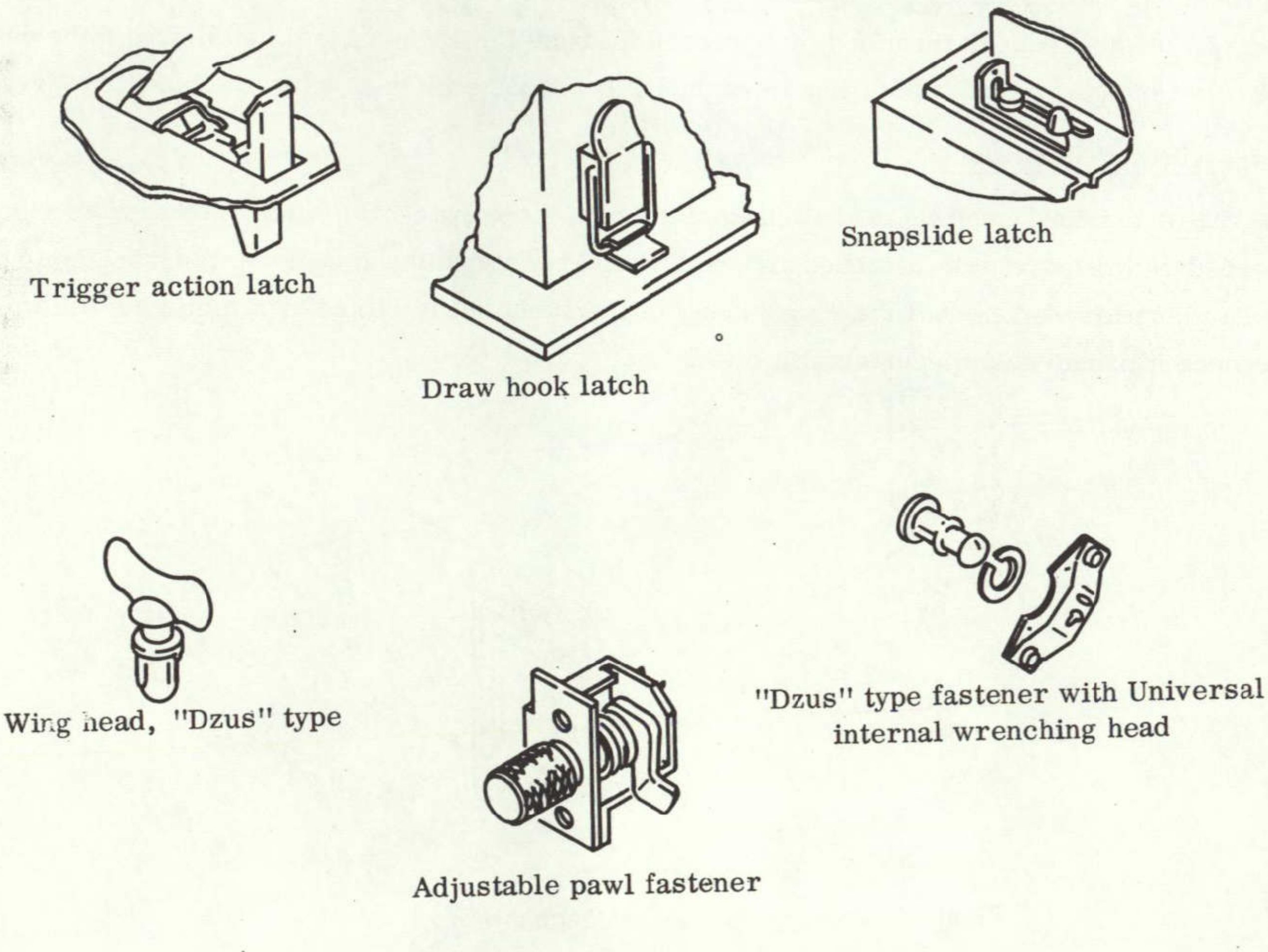


Figure 7-3. Typical Latches Panel Fasteners

7-2.1.4 Panel Fasteners - The panel fasteners shown in Figure 7-3 are fast and easy to use, do not always require tools and may be operated by one hand. They should be carefully evaluated on the basis of type and application when used for items that must be frequently dismantled or removed. These fasteners should lock up and release easily (maximum of one complete turn) without the use of tools if possible. If a tool is required, it should be the universal hex drive internal wrenching tool called for in Chapter 1-4. All panel fasteners must be captive in their basic design.

7-2.2 Bolts and Screws

Bolts and screws can be divided into two types:

- Fast-Acting
- Machine Screw Types (slow acting).

Examples of fast-acting bolts and screws as well as machine screws are shown in Figure 7-4. All bolts and screws must have heads compatible with the universal hex drive internal wrenching tool called for in Chapter 1-4. Slotted or recessed screw driver heads must be avoided in Zero-g applications especially where the maintenance may be performed in a pressure suit.

7-2.2.1 Fast Acting Fasteners - Fast acting bolt and screw fasteners can be used except where high structural loads, or high jacking loads for rack and panel connectors are required. Figure 7-4 illustrates several commercial types. These fasteners lock-up and release easily, preferably without the use of tools.

They are normally slower and more difficult to use than quick release fasteners but they do have more strength than latches, catches, and panel fasteners. In addition, they can provide the travel necessary to lock-up and mate small electrical connectors without the tedious action required for ordinary machine screw threads. They can be used in low stress applications and should be captive as well as self-locking.

7-2.2.2 Machine Screw Types - Ordinary or slow-acting machine screw fasteners are the least desirable fastener for maintenance applications in space vehicles. For shirt sleeve area applications such as subassembly and module mounting, they may be used when other types of fasteners cannot be employed because of compelling strength, cost, weight, or other important trade-off factors. When used, they must be made captive as shown in Figure 7-4.

The self tapping screw is not to be used under any circumstances in the basic design of space electronic equipment.

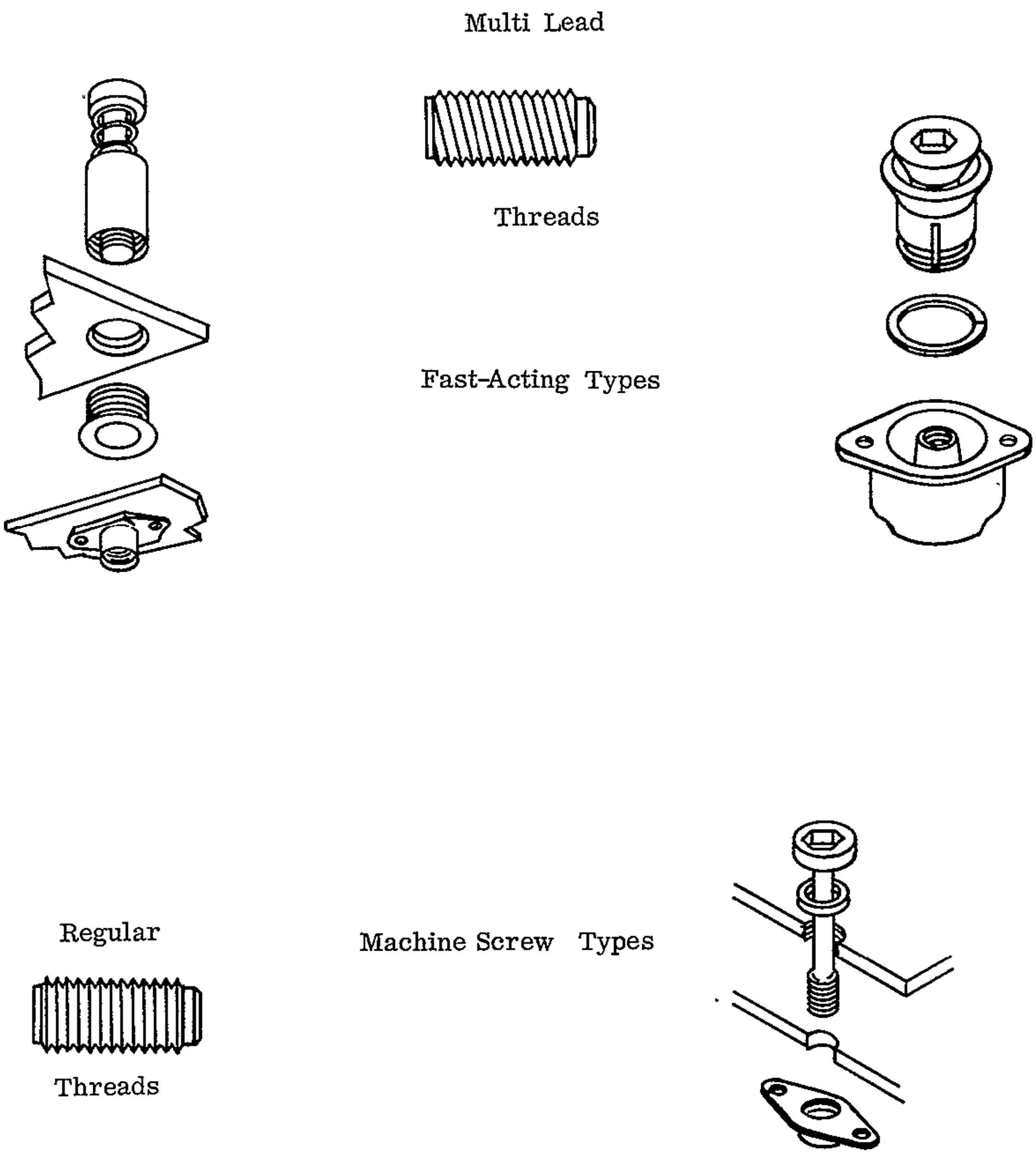


Figure 7-4. Bolts and Screws

7-2.3 Permanent Type Fasteners

Three techniques for permanently fastening objects together are:

- Riveting
- Welding
- Brazing.

These methods must not be used to fasten equipment which is to be removed and replaced for maintenance. Welding and brazing are the most permanent types of fastening. Rivets are not reusable and require more time, tools and effort for replacement than do screws or bolts.

Chapter 8 Safety

8-1 GENERAL

Design of all space-maintainable equipment must embody features for the protection of both personnel and equipment from electrical, mechanical, and thermal hazards. If an astronaut must divert attention from his maintenance task in order to observe safety precautions, the remainder of his attention might be inadequate for doing his job well. At the very best it will certainly take him longer to do the job. If hazards cannot be completely designed out of space systems, it is imperative that those that remain be clearly recognized and that measures be provided to protect both the astronaut and the equipment against them. Equipment design for safety during maintenance must take into account the following:

- Black boxes and modules subject to maintenance shall be located and mounted so that access to them may be gained without danger from electrical charge, heat, moving parts or other hazards.
- Access openings shall be fitted with fillets and rounded edges to remove all sharp edges.
- Black boxes or modules with equipment that can easily be damaged should be protected by guards or other structure.
- Black boxes must have provisions for handling. This means that every unit must have at least one handle or more depending on size and weight. (Refer to Chapter 11.)

8-2 MECHANICAL HAZARDS

8-2.1 Edges and Surfaces

To minimize the possibility of physical injury, all edges and corners should be rounded to maximum practical radii. Thin edges should be avoided and construction should be such that the item can be handled without danger of cutting the space suit or the astronaut's hands. All exposed surfaces should be smooth, covered or coated to prevent the possibility of abrasion. Small projections, especially in areas where rapid movement can cause injury, should not be left uncovered.

8-2.2 Rotating Devices

Shields and guards should be made part of the equipment to prevent personnel from accidentally contacting rotating or oscillating parts such as gears, couplings, levers, cams, or heavy solenoid equipment. Moving parts should be enclosed or shielded by guards. Where such protection is not possible, adequate warning signs should be provided. Guards should not prevent the inspection of any moving mechanisms, the failure of which will cause a hazardous condition. Guards should also be designed to permit inspection without removal whenever possible.

Where access to rotating or oscillating parts is required for maintenance, it is desirable to equip the protective covers or housings with safety switches or interlocks that automatically downpower the equipment. The cover or housing should bear a warning sign such as:

CAUTION
KEEP CLEAR OF ROTATING PARTS

8-2.3 Explosion

Equipment that may be operated, maintained, or stored in an explosive atmosphere should be designed so as to eliminate the possibility of an explosion. All electrical equipment that will be used in the vicinity of flammable gases or vapors must be explosion-proof. Danger to personnel from an explosion should be avoided by separation of hazardous substances from heat sources and by incorporation of spark arrestors, suitable vents and drains, and other fire prevention measures.

An oxygen enriched atmosphere presents another hazard to manned spacecraft. Maintenance disconnects, particularily electrical connectors, must be designed to prevent ignition of concentrated oxygen flash fires and combustion. The use of zero-g type connectors which break electrical leads in a confined cavity are not recommended in an oxygen enriched atmosphere as the only means of preventing explosion and flash fire. The arc control methods of Chapter 8-3.2 must be employed for this purpose.

8-2.4 Implosion

Direct view storage tubes and cathode ray tubes are special hazards in that physical damage can result from implosion of these devices. If a tube is accidentally nicked or scratched, resultant implosion might not occur until days later. The tube face therefore, should be shielded by a shatterproof glass attached to the panel. Signs warning personnel that the neck of the tube is easily broken, and must be handled with caution, should be posted inside the equipment.

The terminal end of these tubes should be located within the equipment housing whenever possible. If the terminal end does extend outside the equipment housing, a strong cover for the tube must be provided. The cover should be firmly anchored to the main structure of the housing to prevent external pressures from being exerted on the wires and terminal end of the tube.

8-2.5 Tether Provisions

To prevent equipment from floating away under zero-g conditions provisions must be made to tether the equipment being removed and the equipment to be installed. The tethering devices must:

- Be quickly applied (by using spring loaded snap fittings, for example)
- Be standardized throughout the spacecraft
- Be easily operable in both shirtsleeve and pressure-suit environment
- Be designed to minimize interference with the astronaut's maintenance performance.

8-3 <u>ELECTRICAL HAZARDS</u>

8-3.1 Electric Shock

The danger to personnel from electric shock must be eliminated by providing suitable safety interlocks, grounding enclosures or other protective devices plus a method of de-energizing power prior to making or breaking a connection. During IVA maintenance activity, some contact with electric potentials can be expected where personnel are, by the very nature of their maintenance duties, exposed to live terminals. Both shocks and burns, however, can be eliminated by excercising care in design and by a thorough understanding of electrical power characteristics.

Table 8-1 shows the relative lethality of various combinations of voltage and contact area.

TABLE 8-1. HAZARD CLASSIFICATION OF VOLTAGES TO GROUND

Shock hazard class	Voltages (V) and contact area (A) in sq cm[a]						
	$A \leq 0.5$	$0.5 < A \leq 1$	$1 < A \leq 2$	$2 < A \leq 3$	$3 < A \leq 4$	$4 < A \leq 5$	$5 < A$
Lethal	← All voltages greater than for the "possibly lethal" class →						
Possibly lethal:							
Ventricular fibrillation[b]	$150 \leq V < 400$	$150 \leq V < 400$	$150 \leq V < 270$	$115 \leq V < 210$	$100 \leq V < 210$	$90 \leq V < 160$	$80 \leq V < 115$
Asphyxiation[c]	$90 \leq V < 150$	$90 \leq V < 150$	$55 \leq V < 150$	$40 \leq V < 115$	$35 \leq V < 100$	$30 \leq V < 90$	$25 \leq V < 80$
Painful shock	$60 \leq V < 150$	$35 \leq V < 150$	$25 \leq V < 150$	$15 \leq V < 115$	$15 \leq V < 100$	$10 \leq V \leq 90$	$10 \leq V \leq 85$

NOTES

[a] The table classifies the range of voltages, measured from ground, according to the contact area of the component. The range of contact areas is arbitrarily divided into intervals of 1 sq cm, and arbitrarily ends at 5 sq cm, because it is expected that larger contact with live components will be uncommon. The ground contact area is assumed to be 150 sq cm.

[b] A discordant beating of the heart, usually it is rapidly fatal.

[c] Applies only in cases in which it is likely that a victim will become frozen to the circuit.

8-3.1.1 Prevention of Electric Shock - Provisions must be made to protect both personnel and the equipment when black boxes and modules are replaced. Typical ways of providing shock protection are listed below. The methods selected will depend on the voltages involved, the type of mounting, and the electrical interface used:

- Electrical interlock system with short pins in the unit interface connectors that turn power off as the unit is withdrawn.
- A micro-switch, mechanically connected to the replaceable unit movement which turns power off as the unit is withdrawn.
- Automatic discharging devices in all medium and high voltage power supplies to prevent retention of charge.
- Power-on light or indicator on each replaceable unit.
- Down-powering the replaceable unit with controls on or near the unit.
- Down-powering of the entire subsystem as a procedural step before removal of the black box. Refer to paragraph 8-3.2.

8-3.2 Arcing

Because electric sparks in a spacecraft and particularly in other than a normal earth atmosphere pose a very serious safety hazard, it becomes imperative that either the "deadface" connector or "down powering" procedure be employed as the solution to the arcing problem.

"Dead-facing" is the deactivation or removal of all signals from all the leads in both halves of a connector prior to separating the connector for removal and replacement of the equipment. This includes all power, signal and monitoring leads.

"Down-powering" is the deactivation of an entire replaceable unit, subsystem, or system to remove all electrical potential from all leads in all connectors prior to a maintenance action.

Down-powering or dead facing can be activated automatically via the methods called out in Chapter 8-3.1.1 with one exception: For protection against arcs, the voltage potentials must be removed completely from the connector pins prior to separation or the connector design must incorporate an explosion/flameproof design feature.

Down-powering as a procedural step can be activated manually at the system, subsystem or unit level by the astronaut prior to removal of a defective piece of equipment.

In order of preference, the following methods are recommended:

- Automatic dead-facing of individual connectors
- Automatic down-powering with zero disconnect voltage
- Automatic down-powering with arc containing connectors
- Manual down-powering with zero disconnect voltage
- Manual down-powering with arc containing connectors
- Manual down-powering.

8-4 SAFETY MARKINGS

Markings should be provided to warn personnel of hazardous conditions and precautions to be observed to ensure safety to personnel and equipment.

Warning signs marked, "CAUTION-HIGH VOLTAGE," or "CAUTION-HIGH VOLTS," should be placed in prominent positions on safety covers, access door, and inside equipment wherever danger might be encountered. These signs should be durable, easily read, and placed so that dust or other foreign matter will not, in time, obscure the warnings. Because signs are not physical barriers, they should be relied on only if no other method of protection is feasible.

The predominant color of equipment designed for safety, protective or emergency purposes should be Insignia Red, Color No. 11136 of FED STD 595.

8-5 THERMAL HAZARD

Shields and guards must be used to prevent personnel from accidentally contacting items that are either hot or cold enough to cause personnel injury. Gloves or other protective clothing must be worn when it is necessary to perform maintenance in close proximity to hot or cold equipment such as Life Support water storage tanks during sterilization processes or cryogenic tanks, lines, and fittings.

Chapter 9 Servicing

9-1 GENERAL

One of the basic maintainability design criteria ground rules for electronic equipment is that there shall be no scheduled or preventive maintenance. Periodic test to detect incipient failure and degradation is not considered scheduled maintenance. Electronic equipment shall be designed to eliminate all requirements for routine replacement of parts, components, and lubricants or other expendables.

Chapter 10 Prevention of Improper Installation

10-1 GENERAL

All electronic equipment designs must incorporate features such that it is mechanically and electrically impossible to install replaceable units in an improper manner or position. Connectors are not to be used for this purpose. Mechanically keyed mating, different size connectors, etc., shall be used to eliminate all such possibilities. Color coding, labeling, etc., shall not be used as the primary means of preventing an improper or reverse installation of equipment. Connector pins shall not be used as a means of keying either a connector or the unit on which it is mounted.

All EVA and IVA installations must have visual orientation and targeting aids to assist the astronaut during placement of the unit into the mechanical mounting or alignment position. Refer to paragraph 5-3 of this report for alignment guide requirements.

Chapter 11 Human Engineering

11-1 GENERAL

MSFC-STD-267 "Human Engineering Design Criteria" shall be utilized to optimize man as a component in the vehicle system, by controlling the design of any piece of equipment which interfaces with him. It can also be used to validate man/machine compatibility particularily in the following specific areas involved in the removal and replacement of electronic equipment in a space environment:

- Human Capabilities
- Work Space
- Illumination
- Safety
- Handles.

In addition, a means must be provided for proper handling during removal and replacement of units in both earth and space environment. This may be in the form of fixed or removable handles of sufficient number, minimum of one, to meet the human engineering requirements. Refer to Chapter 17.

Chapter 12 Identification

12-1 GENERAL

All electrical/electronic equipment (black boxes and modules) subject to removal and replacement shall be marked or stamped for identification. The reference designation system noted in MSFC-STD-349 "Standard, Electrical and Electronic Reference Designations" shall be utilized. The reference designations shall be marked on and adjacent to each unit where they will be visible to the astronaut when he performs maintenance. The purpose of reference designations is to physically locate and identify a unit when performing maintenance without disturbing other units and to prevent loss of location identification for removed units.

Chapter 13 Interchangeability and Commonality

13-1 INTERCHANGEABILITY

All electronic equipment subject to maintenance shall be designed for easy interchange of replaceable components, modules or black boxes without:

- Adjustment or alignment as a result of the remove-replace action
- Resorting to selective assembly of any type
- Modification to accommodate spares.

13-2 COMMONALITY

Equipment design commonality must be maximized in order to permit achievement of onboard maintenance survival flexibility and a feasible spares concept.

Electronic equipment designers should give high priority to the use of standard size housings, modular construction, common types of connectors, mounting hardware, instruments, components, and controls suitable for application across the board in any long duration space vehicle. Standard size boxes and modules will also permit future update or reconfiguration of existing onboard systems with a simple exchange of replaceable units.

Chapter 14 Electrical/Electronic Connectors and Terminations

14-1 GENERAL

Connectors are normally used for electrical interface on maintainable equipment that will be removed and replaced. Terminals and other terminations normally are used for interface with non-maintainable equipment not intended for removal.

Connectors and terminations shall be selected in descending order of preference for maintainability as follows:

- Automatic Connectors-Rack and Panel. Refer to paragraph 5-2.1.1.1
- Manual Connectors - Hand mated, quick release or Zero-g type. Refer to Paragraph 5-2.1.1.2
- Quick Connect Terminals - Simple push on, pull off terminal on a wire. Used where quantity of wires does not warrant a connector
- Terminal Strips - Wires with terminations secured by machine screws or wir wrap, usually within an enclosure. Used only when necessary and where ther will be no onboard maintenance
- Welded Leads - Used only when necessary and where there will be no maintenance replacement.

Maintainability design requirements for connectors on removable equipment must include:

- Use of NASA approved Zero-g type connectors designed for pressure suit applications
- Multi-lead thread engagement
- Use of materials to prevent cold welding
- Commonality in design and type
- Method of keying other than by connector pins
- Removable and replaceable pins
- Method of de-energizing power prior to making or breaking the connection.
- Reduction of the number of interface signals or pins to the absolute minimum.

Chapter 15 Enclosures

15-1 GENERAL

Area enclosures decrease accessibility and should only be provided when required for:

- Protection of the contained equipment against environmental conditions
- Personnel safety
- RFI protection or containment.

15-2 ENCLOSURE FASTENERS

All black boxes, drawers, wall racks, panels, etc., that have replaceable parts enclosed by covers or cover plates must have these covers or cover plates mounted with captive, quick and easy fasteners of a type that will facilitate the required maintenance operation. Recommended fasteners are listed below in descending order of preference:

- Quick release fasteners (single motion, rotary, lever or latch action)
- Fast acting fasteners (multi threaded and/or fractional turn)
- Screws and bolts (single threaded).

Chapter 16 Size of Black Boxes and Modules

16-1 GENERAL

Remove-and-replace maintenance actions performed in a pressure suit environment will be at the black box level. Maintenance actions performed in a shirtsleeve environment will be at the module level. For discussion of these basic ground rules, refer to Paragraph 1-4.

All replaceable units shall be capable of readily passing through a 24-inch diameter round hatch opening. The length of these units should not exceed two feet for reasonable handling control. The weight of these units shall not exceed 150 pounds earthweight with a design goal for safety in handling at 40 pounds maximum earthweight. Minimum size will be determined by system fault isolation capability and the requirements for thermal interface, electrical connectors, mount hardware and elapsed time available for the repair.

16-2 PRESSURE SUIT APPLICATIONS

The minimum size of black boxes replaced in a pressure suit environment will be determined by the size, type and quantity of connectors and hardware needed to provide the electrical, structural, and thermal interface requirements. For example, should the black box require one operational connector and one test connector of the Zero-g (MSFC specification 40M39580) type with Number 25 shell size, the black box minimum size would have to be approximately 6" x 8" by the depth required. Refer to example #3 in Section IV.

Reduction in the size of the test connector or use of rack and panel connectors would reduce the size of the black box but the connectors and mechanical interface requirements would still be the limiting factors. Should these limiting factors not exist, this black box could be reduced to no less than 2-1/2" x 4" facing the astronaut. These dimensions represent the minimum size black box a suited astronaut should handle.

16-3 SHIRTSLEEVE APPLICATIONS

The minimum size of modules replaced in a shirtsleeve environment will be determined by the requirements for:

- Electrical Interface
- Structural Interface (mounting, hardware)

- Thermal Interface
- Fault Isolation Capability

For example, assume that: fault isolation capability exists to the smallest module level, there is an operational electrical connector containing fifteen pins, there are no test points, and the thermal and structural interface is accomplished with an 8/32 fast lead captive screw. The size of this minimum module would be approximately 1" x 2" by the depth required. Refer to example #11 of Section IV for an illustration of this smallest unit. This size unit could be handled with a pressure suit on if the mount screw has a head of at least 3/4" diameter and sufficient clearance is provided between modules to permit the pressure suit gloved hand to manipulate the modules in an emergency.

Chapter 17 Tools

17-1 TOOL REQUIREMENTS

All requirements for the use of tools in remove-and-replace actions must be combined into one universal tool which will have the following characteristics:

- Maximum of two standard sizes of internal wrenching hex drive
- Utilization as temporary handle
- Provision for tethering.

The universal tool can be used by the astronaut where necessary to remove and replace electronic equipment items as called for in Section IV. It shall have a maximum of two internal wrenching hex drives to fit the standardized structural fasteners utilized in the remove-and-replace operation for electronic equipment throughout the spacecraft. When permanent handles are not provided in equipment designs and a temporary handle is to be utilized, it shall be combined with and made a part of the universal tool.

Use of the universal tool is allowed for all conditions except when minimum elapsed time is of paramount importance. EVA remove-and-replace actions are to be designed for accomplishment without tools.

SECTION IV

EXAMPLES OF REMOVE AND REPLACE CRITERIA APPLIED TO THE DESIGN OF MAINTAINABLE ELECTRICAL/ELECTRONIC EQUIPMENT

EXAMPLE NO. 1
PRESSURE SUIT EVA APPLICATION
LARGE BOX WITH HEAT TRANSFER AT REAR FLANGE
ONE-HANDED LOCK-UP

E1-1 General

This example illustrates a housing design for a large EVA box which has the following characteristics:

- Simultaneous engagement of electrical, structural and thermal interfaces with one hand, in one motion
- Size and weight which requires structural attachment at front and rear faces of box
- High density electrical interface
- Thermal loads which require a large contact area of the box with a spacecraft-mounted heat sink.

Primary considerations, which have the greatest impact on maintenance performed in an EVA environment, are given in the following paragraphs.

E1-2 Structural Interface Considerations

A rotary-type, quick-release latching mechanism can be used as shown in Figure E1-1 to secure the black box to the structure when one handed operation is required. Use of this type mechanism provides the additional travel and force needed to jack and unjack the rack and panel type connectors as well as the force required for the structural and thermal interfaces.

Structural shear pins located at front and rear panels, transfer structural loads from the box to the spacecraft structure. These shear pins are also used for alignment of both the box and the rack and panel connectors.

The illustrated mechanism was designed to provide a total lock-up force of 1600 pounds to mate properly the three interfaces of this large EVA box.

E1-3 Electrical Interface Considerations

One of the basic ground rules for EVA pressure suit maintenance is that it must be quick and easy to perform, with one hand, if at all possible. On that premise, EVA Black Box design should incorporate rack and panel type connectors as a first choice especially when:

- Space available on the front panel is insufficient for both the connectors and the necessary glove clearance to engage and disengage the connectors. For glove clearance refer to Chapter 6-3.
- Time required for removal and replacement of the black box must be reduced to the absolute minimum. Excessive time could be consumed by the number and types of hand mated connectors which the astronaut must disengage and re-engage.
- Black box and spacecraft structural design will permit installation of the necessary hardware.

Figure E1-1 shows four 101 pin rack and panel type connectors mounted in the spacecraft heat sink, using the box alignment pins to provide connector shell alignment, and a floating spring backed receptacle to permit positive connector engagement prior to heat sink surface mating. These connectors require $\approx$ 240 pounds of force to mate properly.

The test connector is shown mounted on the front face of the box where it is accessible for checking and testing of the equipment when the box is installed in the spacecraft.

E1-4 Thermal Interface Considerations

Thermal path for the modules of the box shown in Figure E1-1 will be through the box structure to the rear panel. Operation of the rotary latch mechanism on the front panel applies the pressure needed to provide the required thermal interface between the rear panel of the box and the spacecraft mounted heat sink.

E1-5 Alignment Guides

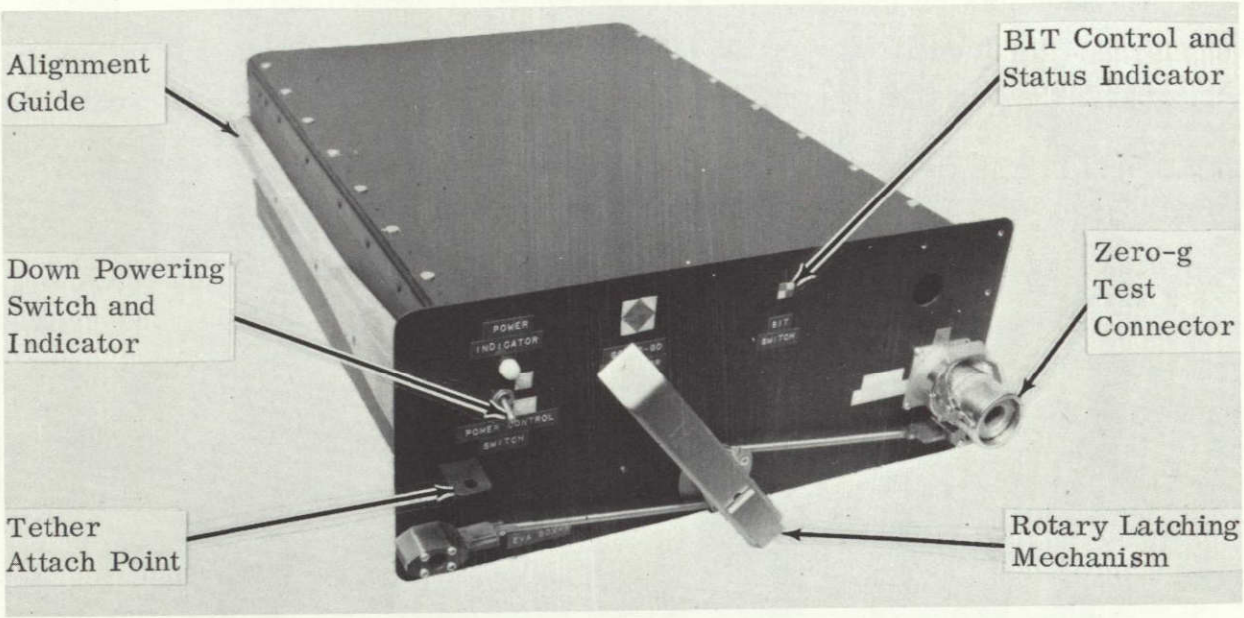
In order to reduce astronaut EVA work effort, it will be necessary to provide visual targeting aids and coarse alignment guides to align the box into the final guides associated with the structural shear pins. Box guides may take many forms, one of which is shown in Figure E1-1.

E1-6 Cover Design

A cover is usually required for EVA boxes. Where a cover is required, it must be secured to the box by means of one of the approved captive fasteners. The type fastener will be determined by the length of time the EVA box can be allowed to be out of service and whether onboard maintenance will be accomplished below the black box level.

E1-7 Tether Provisions

Provisions must be made to tether the box to the spacecraft and/or astronaut. Since the tether must be attached as one of the early steps of the remove and replace procedure, location of the box attach point should be such that it will offer a minimum of interference in removal and replacement of the box.



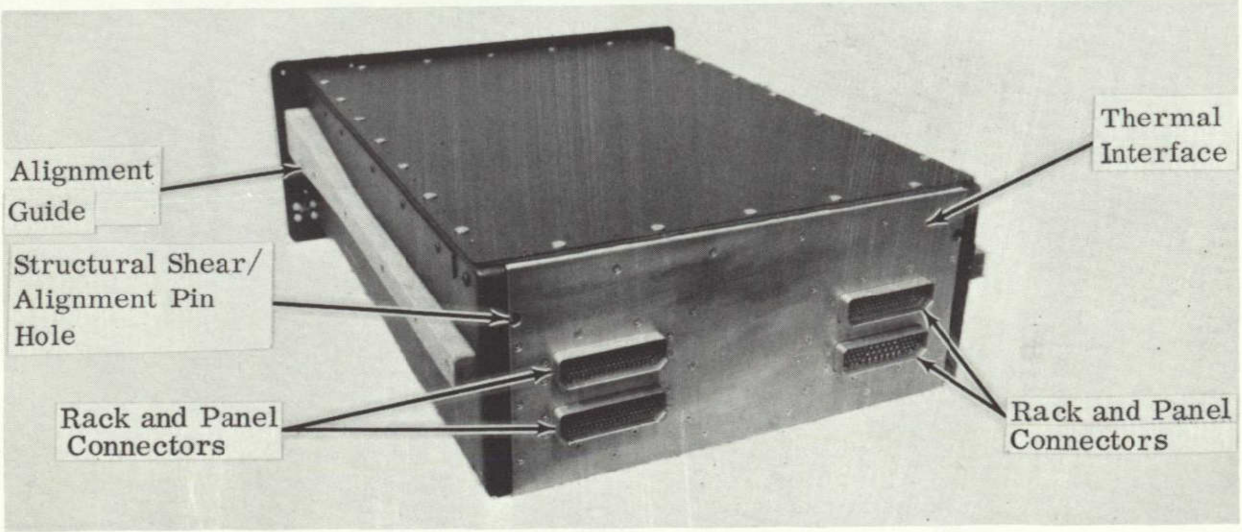


Figure E1-1. Large EVA Box With One Hand Lock-Up

EXAMPLE NO. 2

PRESSURE SUIT EVA APPLICATION

MEDIUM SIZE BOX WITH HEAT TRANSFER AT FRONT FLANGE

ONE-HANDED LOCK-UP

E2-1 General

This example illustrates a housing design for a medium sized EVA box which has the following characteristics:

- Simultaneous engagement of structural and thermal interfaces with one hand, in one motion
- Size and weight which requires structural attachment at front flange of box
- Thermal loads which require a medium sized contact area of the box with a spacecraft mounted heat sink
- Electrical interface is by other than rack and panel connectors.

Primary considerations which have the greatest impact on maintenance performed in an EVA environment, are given in the following paragraphs.

E2-2 Structural Interface Considerations

In Figure E2-1, a lever type quick release latching mechanism is used to secure the EVA box to the structure. Raising the handle allows a wedge at the sides on the front of the box to engage a roller on a structural shear pin. These shear pins transfer structural loads from the box to the spacecraft structure and are also used for alignment of the box.

The latch mechanisms in the illustrations were designed to provide a total lock-up force of up to 1500 pounds to properly mate the thermal and structural interfaces of this medium size black box.

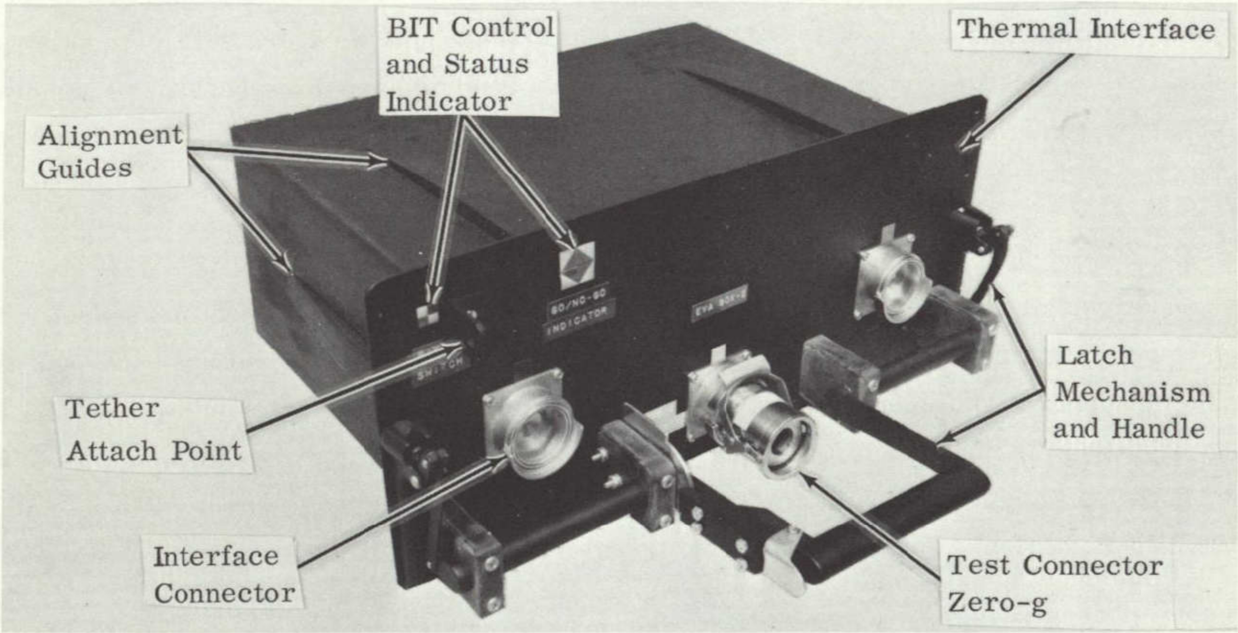


Figure E2-1. Medium Size Box-Heat Transfer Front Flange One Hand Lock-Up

E2-3 Electrical Interface Considerations

When rack and panel connectors cannot be used, NASA approved quick release connectors, capable of being operated under Zero-g conditions by one hand must be utilized.

- Sufficient space must be made available on the front panel to accommodate the interface and test connectors with sufficient glove clearance to engage/disengage the connectors. For glove clearance refer to Chapter 6-3.
- The time required for the astronaut to hand mate the connectors and perform the removal and replacement of the box must not exceed the requirements of Paragraph 4-1.

Figure E2-1 shows Zero-g type connectors for both interface and test mounted on the face of typical black box.

E2-4 Thermal Interface Considerations

The thermal path for the modules of the box shown in Figure E2-1 will be through the box structure to the flanges at the front face. Operation of the lever type latching mechanism on the front panel applies the pressure needed to provide a thermal joint between the front face of the box and the spacecraft flange heat sinks.

E2-5 Alignment Guides

In order to reduce astronaut EVA work effort, it will be necessary to provide visual targeting aids and coarse alignment guides to align the box into the final guides associated with the structural shear pins used in the latching mechanism. Box guides may take many forms, one of which is shown in Figure E2-1.

E2-6 Cover Design

A cover is usually required for EVA boxes. Where a cover is required, it must be secured to the box by means of one of the approved captive fasteners. The type fastener will be determined by the length of time the EVA box can be allowed to be out of service and whether onboard maintenance will be accomplished below the black box level.

E2-7 Tether Provisions

Provisions must be made to tether the box to the spacecraft and/or astronaut. Since the tether will have to be attached as one of the early steps of the remove-and-replace procedure, location of the box attach point should be such that it will offer a minimum of interference in removal and replacement of the box.

EXAMPLE NO. 3
EVA APPLICATION
SMALL SIZE BOX WITH HEAT TRANSFER AT REAR FLANGE
ONE-HANDED LOCK-UP

E3-1 General

This example illustrates a housing design for a small EVA box which has the following characteristics:

- Simultaneous engagement of structural and thermal interfaces with one hand
- Size and weight which allows structural attachment at rear flange of box
- Thermal loads which require a small contact area at the rear of the box
- Elecrrical interface can be made through one connector

Primary considerations which have the greatest impact on maintenance performed in an EVA environment, are given in the following paragraphs.

E3-2 Structural Interface Considerations

In Figure E3-1, the box is secured to the spacecraft structure through a multi-threaded fastener which has been combined with an alignment guide for the box. The fastener is attached through a shaft to a large knob which allows operation by a gloved hand.

The alignment guide also acts to take out any shear forces between the box and the structure allowing the threaded fastener to apply the necessary lock up tension forces. The mechanism in the illustration was designed to provide 800 pounds of force to properly mate the thermal and structural interfaces of this small size black box.

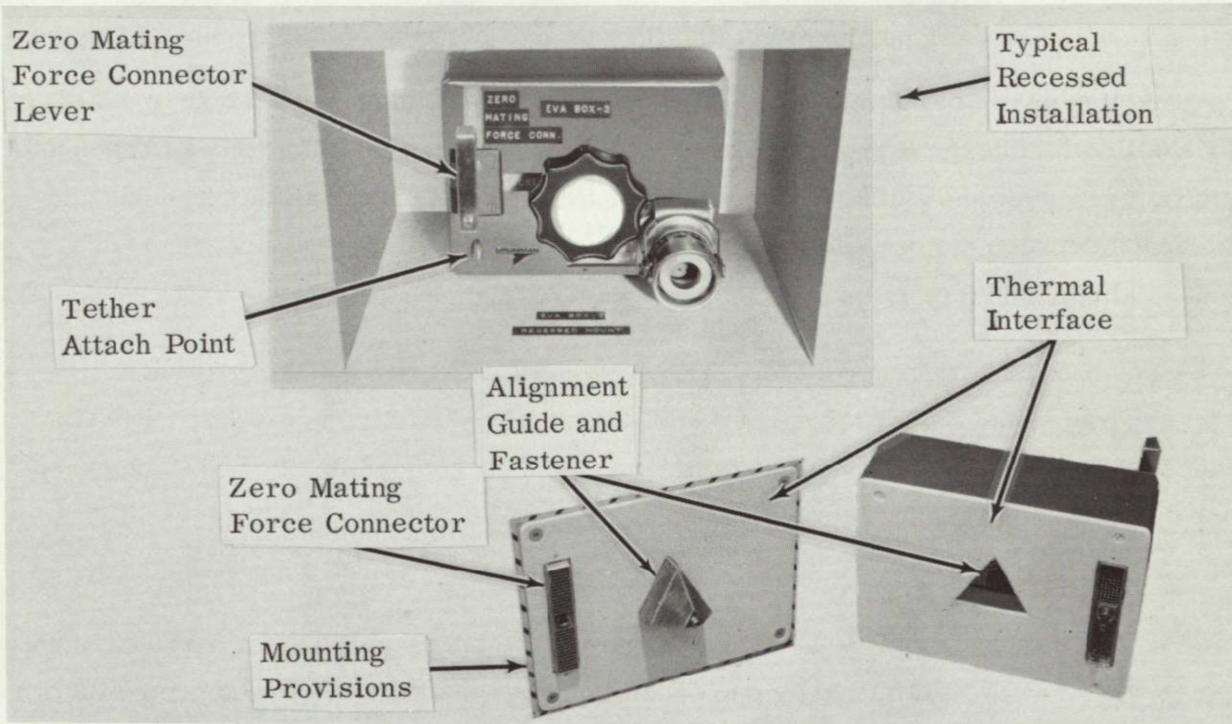


Figure E3-1. Small Size Box with Heat Transfer at Rear Flange One-Hand Lock-Up

E3-3 Electrical Interface Considerations

The zero mating force connector at the rear of the box has its shell aligned during the installation procedure and the pins are mated/demated by rotating the lever on the front face of the box approximately 90 degrees.

The connector on the front face of the box is a test connector, used during fault isolation tests to ascertain which box is defective in the event that BIT and OBC are incapable of isolating the items.

E3-4 Thermal Interface Considerations

The thermal path for the modules of the box shown in Figure E3-1 through the box structure to the rear panel. Operation of the knurled knob on the front panel applies the pressure needed to provide a thermal joint between the rear panel of the box, and the spacecraft mounted heat sink.

E3-5 Alignment Guides

In order to reduce astronaut EVA work effort, it will be necessary to provide visual targeting aids and an easy means of guiding the box into position on the spacecraft structure.

The combination alignment guide and fastening device along with the rear panel connector shell on this box will provide the necessary easy alignment of the box and connector pins. The alignment guide also serves as the structural fastener to transmit shear and tension loads between the box and the structure.

E3-6 Cover Design

A cover is usually required for EVA boxes. Where a cover is required it must be secured to the box by means of one of the approved captive fasteners. The type fastener will be determined by the length of time the EVA box can be allowed to be out of service and requirements for lower level onboard maintenance.

E3-7 Tether Provisions

Provisions must be made to tether the box to the spacecraft and/or astronauts since the tether will have to be attached as one of the early steps of the remove and replace procedure, location of the box attach point should be such that it will offer a minimum of interference in removal and replacement of the box.

EXAMPLE NO. 4

IVA APPLICATION

HORIZONTAL DRAWER

E4-1 General

This example illustrates a housing design for horizontal drawers in equipment cabinets having the following characteristics:

- Pull out drawer design for maintenance and troubleshooting
- Modules (not drawer) removed and replaced to correct discrepancies
- Heat sink in the drawer assembly is liquid cooled from spacecraft.

Primary considerations which have the greatest impact on maintenance performed in an IVA environment, are given in the following paragraphs.

E4-2 Structural Interface Considerations

In figure E4-1, the drawer in the normal or closed position is secured to the spacecraft structure through a slide at the sides of the drawer and a heavy duty latch at each handle. The latches have a lever mechanism to provide a tensile force (up to 1200 lbs.) needed to retain the drawer in the closed and locked position.

The drawer in the open or servicing position has stops on the slides to prevent inadvertent complete removal. A latch on the slides retains the drawer in the fully open position for accomplishing maintenance.

Modules can be mounted in the drawer in various arrangements to suit the equipment requirements. Common design housings and standard module mounting arrangements can be used to full advantage in this installation. In addition, odd shaped or larger sized modules can also be accommodated.

E4-3 Electrical Interface Considerations

The drawer remains connected to the spacecraft system when the drawer is extended, through a service loop in the cable. Since the drawer is not disconnected or removed for onboard system repair there are no electrical interface problems at this level.

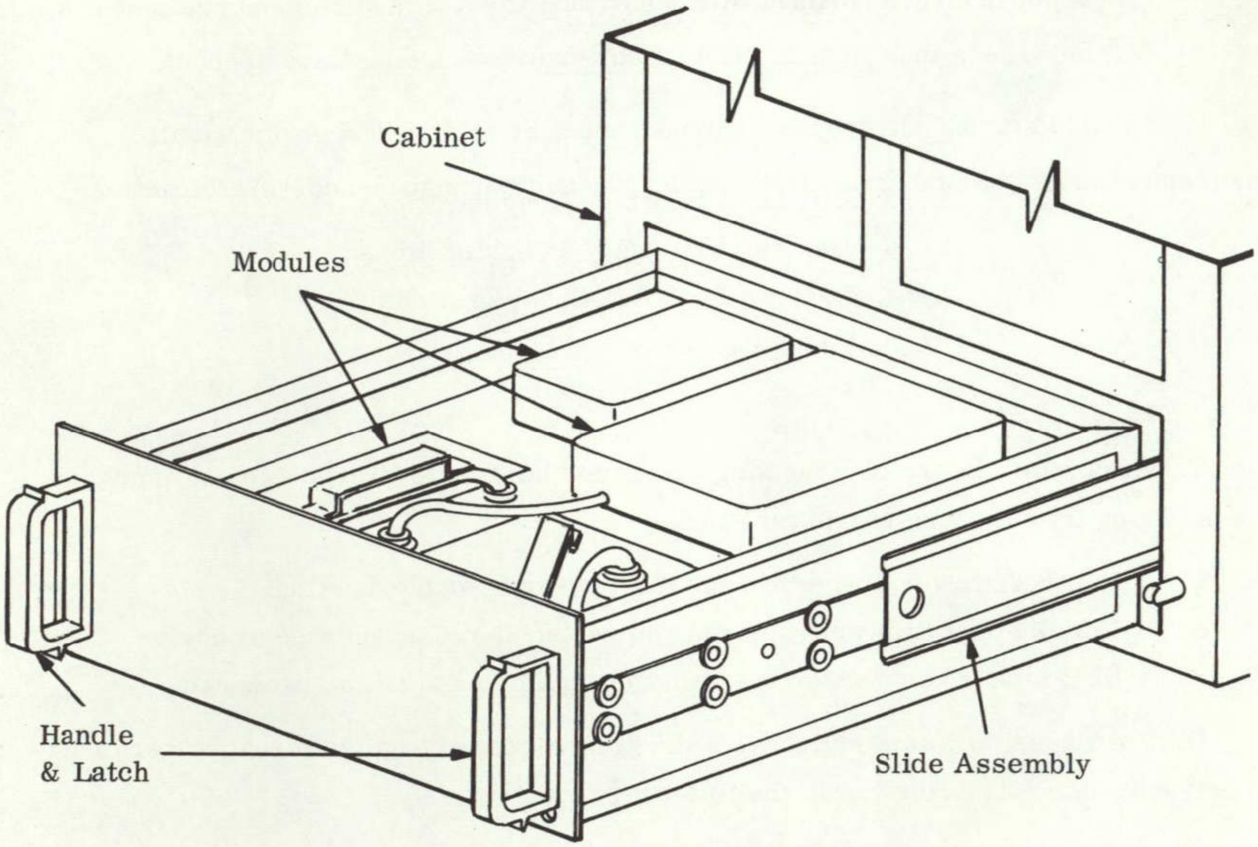


Figure E4-1. Horizontal Drawer

E4-4 Thermal Interface Considerations

The heat sink for the drawer is liquid cooled and remains connected to the spacecraft system when the drawer is extended, through a service loop in the coolant lines. Since the drawer is not removed from the cabinet for onboard maintenance there are no thermal interface problems at this level.

E4-5 Alignment Guides

The slide assemblies and the latches on the handles serve as a means of aligning the front panel to the spacecraft structure.

EXAMPLE NO. 5
IVA APPLICATION
VERTICAL DRAWER

E5-1 General

This example illustrates a housing design for a vertical drawer or wall rack installation having the following characteristics:

- Pull out drawer design for maintenance and troubleshooting
- Modules (not drawer) removed and replaced to correct discrepancies.
- Heat sink in the drawer or wall rack is liquid cooled from spacecraft.
- Drawer in full open and locked position represents a wall rack installation.

Primary considerations which have the greatest impact on maintenance performed in an IVA environment, are given in the following paragraphs.

E5-2 Structural Interface Considerations

In Figure E5-1, the drawer in the normal or closed position is secured to the spacecraft structure through a slide at the top and bottom and a heavy duty latch at each handle. The latches have a lever mechanism to provide a tensile force (up to 1200 lbs.) needed to retain the drawer in the latched or closed position.

The drawer in the open or servicing position has stops on the slides to prevent inadvertent complete removal. A latch on the slides retains the drawer in the fully open position for accomplishing maintenance.

In the fully opened and locked position, the illustrated vertical drawer provides a good representation of a wall rack installation for modules. Common design housings and standard module mounting arrangements can be used to full advantage in either the pull out drawer or wall rack installation.

E5-3 Electrical Interface Considerations

The drawer remains connected to the spacecraft system when extended through a service loop in the cable. Since the drawer is not disconnected or removed for onboard system repair there are no electrical interface problems at this level.

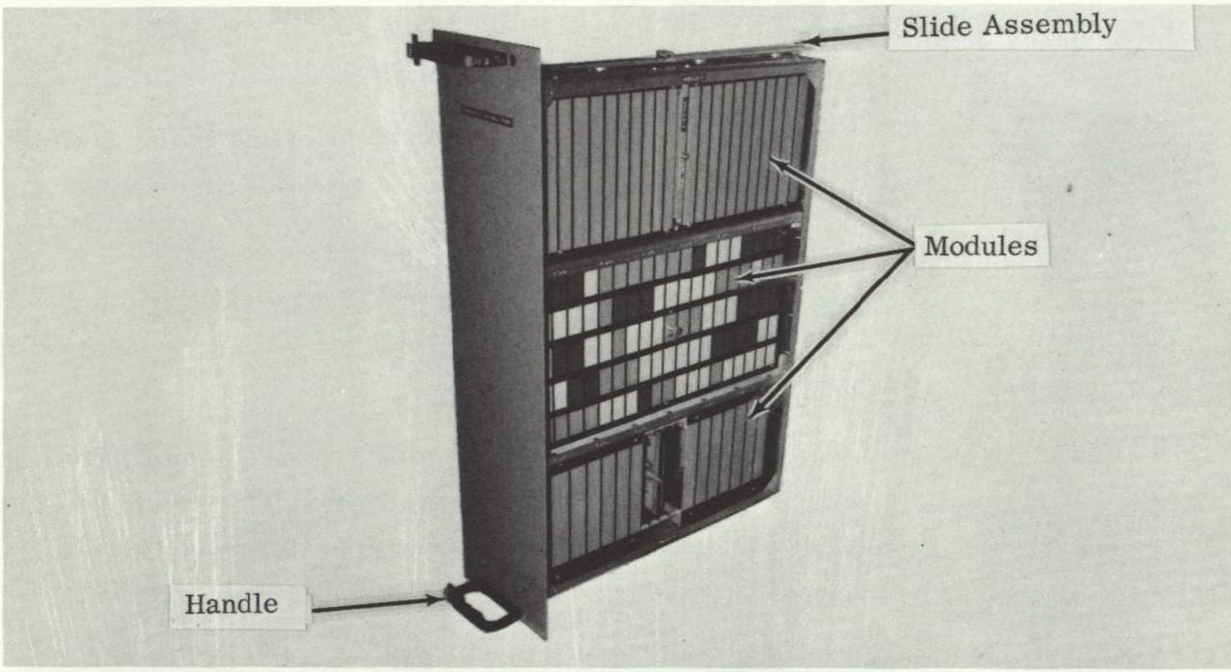


Figure E5-1. Vertical Drawer

E5-4 <u>Thermal Interface Considerations</u>

The heat sink for the drawer is liquid-cooled and remains connected to the spacecraft system when the drawer is extended, through a service loop in the coolant lines. Since the drawer is not removed from the cabinet for onboard maintenance there are no thermal interface problems at this level.

E5-5 <u>Alignment Guides</u>

The slide assemblies and the latches on the handles serve as a means of aligning the front panel to the spacecraft structure.

EXAMPLE NO. 6

IVA APPLICATION

HINGED FRONT PANEL

E6-1 General

E6-2 Structural Interface Considerations

E6-3 Electrical Interface Considerations

E6-4 Thermal Interface Considerations

E6-5 Alignment Guides

E6-1 General

This example illustrates a housing design for a maintainable installation that involves a control panel and a hinged front access with the following characteristics:

- Fastest access required to area behind panel
- Interior Modules (not panel) removed and replaced to correct discrepancies
- Control panel hinged for maintenance access
- Low thermal requirements for panel units
- Control panel elements modularized for rear plug-in insertions.

Primary considerations which have the greatest impact on maintenance performed in an IVA environment, are given in the following paragraphs.

E6-2 Structural Interface Considerations

In Figure E6-1, the panel in the closed position is secured to the spacecraft structure by two hinges at one side and a combination handle/latch on the opposite side. The hinge has a spring loaded mechanical lock to retain the panel in the open position for maintenance. The handle has a latching mechanism to retain the panel in the closed position that is capable of providing up to 600 pounds of lock-up force to satisfy the structural interface requirements.

E6-3 Electrical Interface Considerations

The panel remains connected to the spacecraft structure as does the electrical wiring through a service loop in the cable. Since the panel is not removed there are no electrical interface problems at this level. Modularized panel elements can be designed to plug in to the rear side of this hinged panel for quick repair.

E6-4 Thermal Interface Considerations

The hinged panel can be provided with either a service loop connection or a separable heat sink arrangement in the flange if equipment cooling becomes necessary. Otherwise, a thermal interface may not be required if the control panel contains only passive devices with extremely low thermal dissipation.

E6-5 <u>Alignment Guides</u>

Since the hinged panel remains connected to the spacecraft and is not removed during maintenance, no alignment guides are required at this level of disassembly for maintenance. It should be noted however, that locks are provided in the full open and closed positions of this panel to prevent inadvertant movement in the wrong direction.

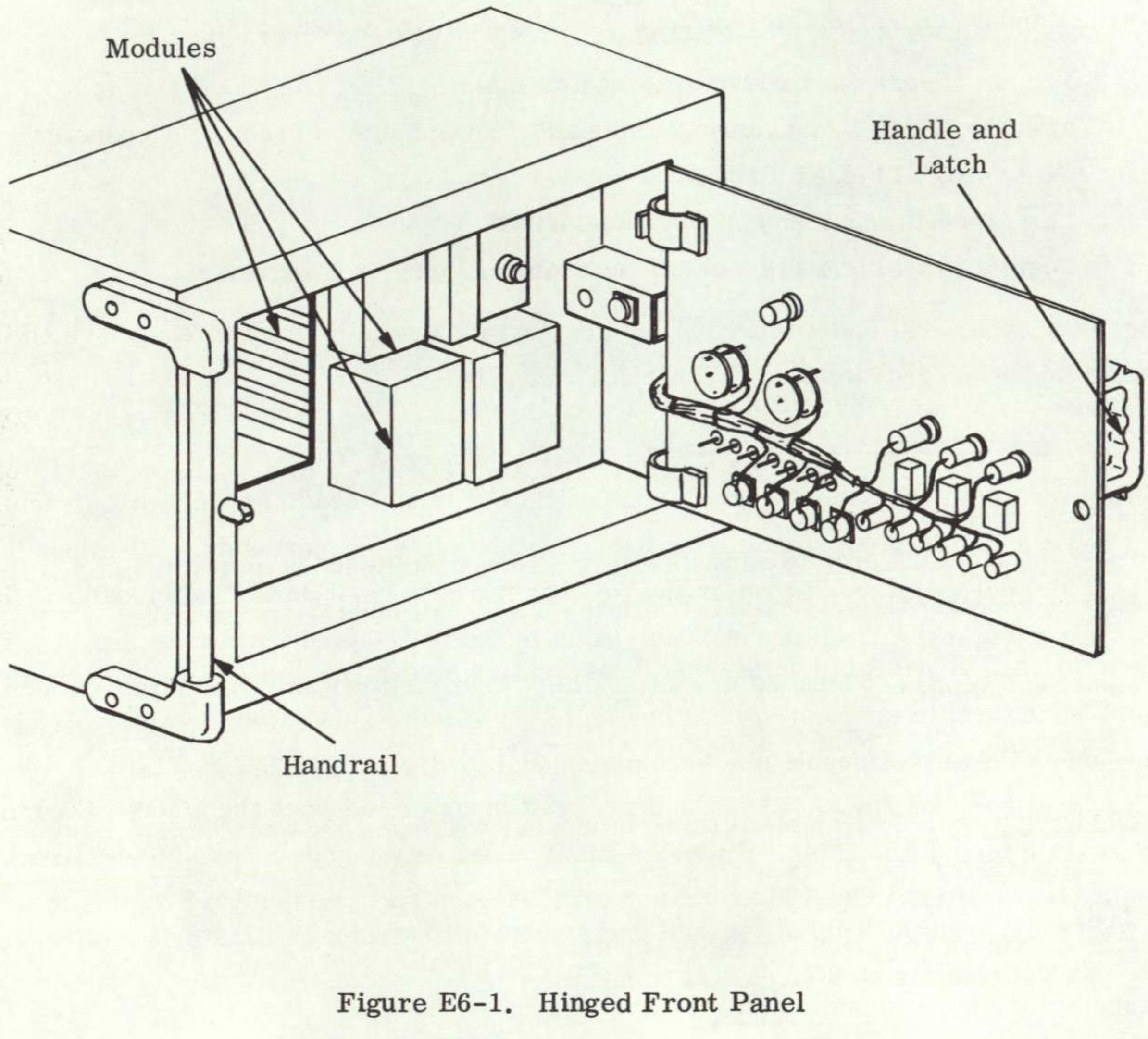


Figure E6-1. Hinged Front Panel

EXAMPLE NO. 7

IVA APPLICATION

MODULES WITH HEAT TRANSFER AT REAR SURFACE

E7-1 General

This example illustrates housing designs for three large IVA modules as shown in Figure E7-1, which have the following characteristics:

- Size and weight which allows structural attachment at rear flange of module.
- Thermal loads which require a large sized contact area of the module with a box mounted heat sink.
- Electrical interface -
  - High density, through rack and panel connector (design A)
  - Hand mated connector on drop cable (design B)
  - Hand mated connector on front face (design C)
- Mounting and lock up through two quick release fasteners.

Primary considerations which have the greatest impact on maintenance performed in an IVA environment, are given in the following paragraphs.

E7-2 Structural Interface Considerations

Each module is secured in the same manner. Multi-threaded captive fasteners are mounted in opposite corners of the modules.

Structural shear pins are located in the remaining corners of the module. These shear pins are also used for alignment of the module and structural fasteners. On module design A, the electrical connector is also coarsely aligned by the shear pins but has its own multi lead jack screw independent of the basic module mounting bolts.

The important feature of these mounting and alignment arrangements is prevention of incorrect installation through mechanical keying that is different for each unit.

E7-3 Electrical Interface Considerations

The major differences in the 3 module designs shown in Figure E7-1 is in the method of electrical interface.

Module Design A uses a rack and panel connector for the following considerations:

- It illustrates an installation where space available on the front panel is insufficient to mount the electrical connectors required
- Time required for removal and replacement of module otherwise exceeds that allowed by Paragraph 4-1.

Module Design B uses a drop cable for the following considerations:

- It illustrates an installation where space available on the front or rear panel is insufficient to mount the electrical connectors required.

Module Design C uses a hand mated connector for the following considerations:

- Space is available on the front panel to mount the electrical connectors required
- Time required for removal and replacement of module is within that allowed by Paragraph 4-1.

E7-4 Thermal Interface Considerations

The thermal path is the same for the three modules, through the rear panel to the heat sink in the box, rack, or drawer structure. The mounting bolts apply the pressure needed to provide the thermal interface bond.

E7-5 Alignment Guides

Alignment for the three module designs is provided by:

- Visual targeting aids which are used to orient the module prior to engagement of the alignment guides
- Alignment guides or pins in two corners of each module which provide the final close alignment required to engage the module fasteners. Unsymmetrical location of these guides prevents improper installation of the module.

Module A incorporates two unique combination locating/fastening devices which align the module prior to engagement of the rack and panel connector. Tethering attachments must also be provided.

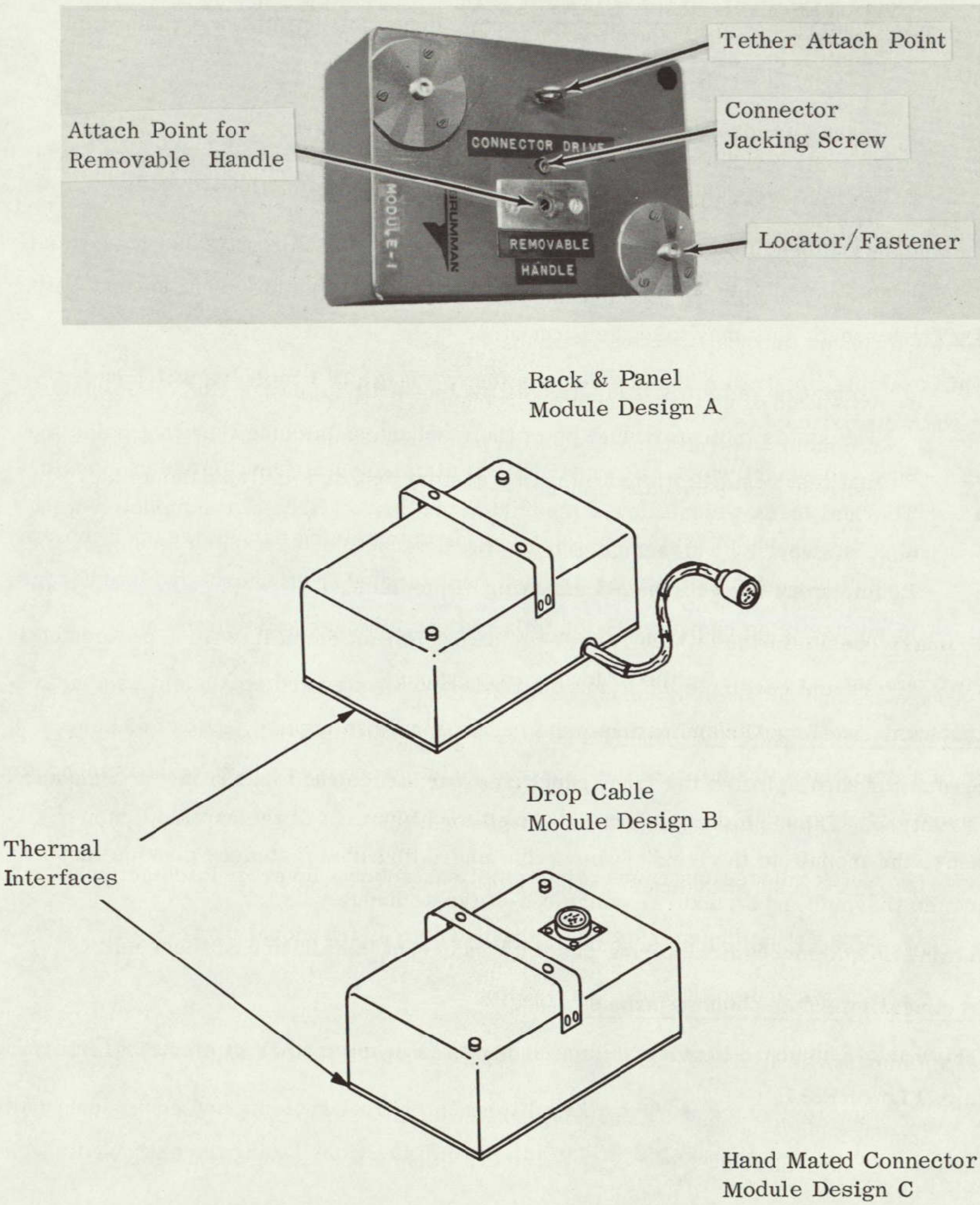


Figure E7-1. Enclosed Modules

EXAMPLE NO. 8

IVA APPLICATION

MODULES WITH HEAT TRANSFER AT FRONT FLANGE

E8-1 General

This example illustrates housing designs for two large IVA modules which have the following characteristics:

- Size and weight which allows structural attachment at front flange of module
- Thermal loads which allow a medium sized contact area of the module with a box, drawer, or wall mounted heat sink
- Requirement for submerged mounting of modules.

Primary considerations which have the greatest impact on maintenance performed in an IVA environment, are given in the following paragraphs.

E8-2 Structural Interface Considerations

Structural shear pins on the front panel transfer structural loads from each module to the box structure. These shear pins are also used for alignment of the captive fasteners which secure the module to the box. Two captive multi-threaded fasteners provide fast lock-up of the thermal and structural interfaces of these modules.

Again, unique mechanical keying prevents incorrect installation of these units.

E8-3 Electrical Interface Considerations

The major difference between the two modules is in the method of electrical interface as shown in Figure E8-1.

Module A uses a drop cable to illustrate an installation where space available on the front panel is insufficient to mount the electrical connectors required.

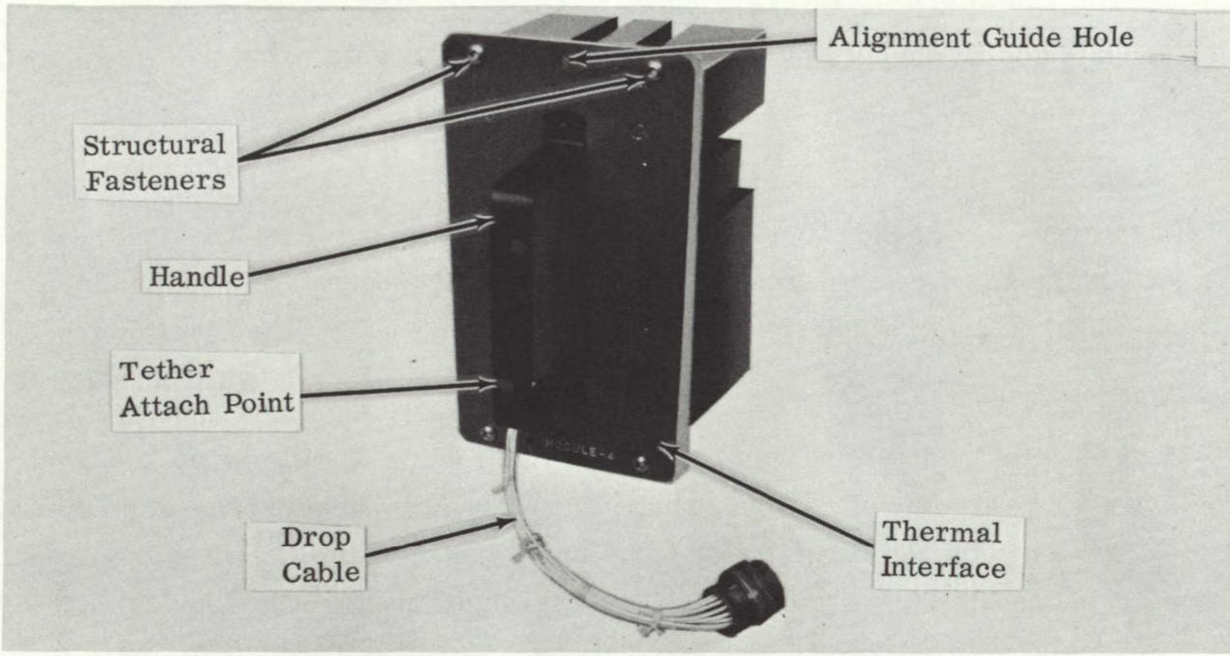
Module B uses a hand mated connector on the front panel to illustrate an installation where adequate space is available on the front panel to mount the quantity of electrical connectors required and the time required for removal and replacement of this module will be within that given in Paragraph 4-1.

E8-4 Thermal Interface Considerations

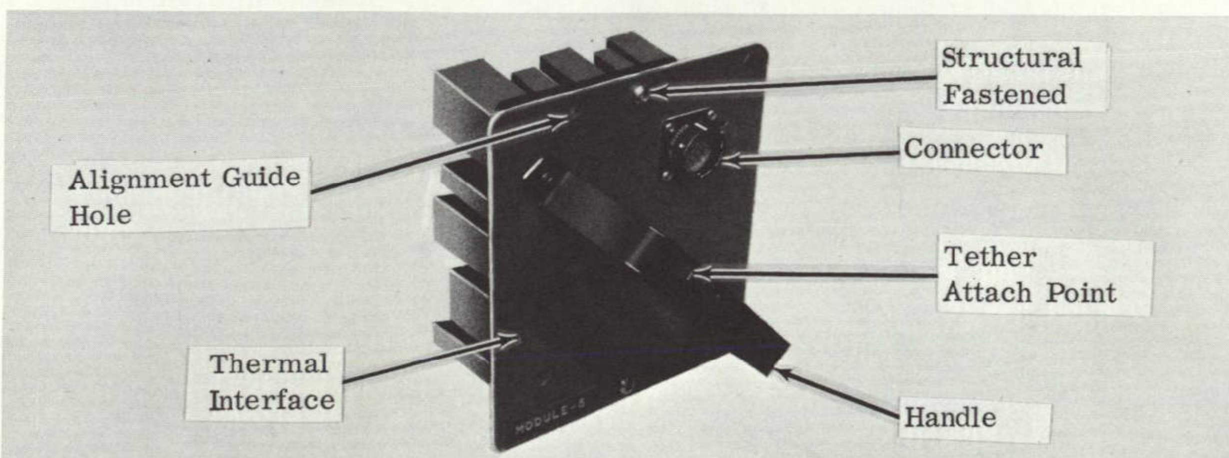
The thermal path is the same for both modules, through the front flange to the heat sink on the box, rack, or drawer structure. The mounting fasteners apply the pressure needed to provide the thermal interface bond.

E8-5 Alignment Guides

The alignment guides or pins on the sides of the front panel will provide the easy and positive alignment required for the mounting fasteners and will also function as structural shear pins. Visual targeting aids can also be used to provide a ready frame of reference for orienting the module prior to insertion. Tethering attachments must also be provided.



Drop Cable
Module Design A



Hand Mated Connector
Module Design B

Figure E8-1. Front Flange Mounted Modules

EXAMPLE NO. 9

IVA APPLICATION

ENCLOSED MODULE WITH HEAT TRANSFER AT REAR OF ENCLOSURE

E9-1 General

This example illustrates a housing design for a medium-sized module which has the following characteristics:

- Thermal loads, Electromagnetic interference, or structural requirements which require enclosing the module in a casting
- The casting along with the module to be removed and replaced to correct discrepancies.

Primary considerations which have the greatest impact on maintenance performed in an IVA environment, are given in the following paragraphs.

E9-2 Structural Interface Considerations

In Figure E9-1, the front panel or cover of the module assembly is secured to the casting by quick release captive fasteners. The casting is secured to the structure by two multi-threaded captive fasteners in opposite corners that provide the lock-up force for both the thermal and structural interface. Combination shear/alignment pins provide for the transfer of structural shear loads from the casting to the structure.

E9-3 Electrical Interface Considerations

A lack of space on the front panel and above the module for the electrical connectors required precluded the use of front mounted connectors. Drop cables take the least amount of front panel space. They are not as desirable as rack and panel connectors but this example illustrates an installation where rack and panel connectors cannot be installed for any one of a number of practical reasons faced by designers such as: cost, lack of space, lack of structural strength in the area, high density electronic interface, RF or other special wiring problems, etc.

E9-4 Thermal Interface Considerations

The thermal path is from the rear flange of the casting to the heat sink in the structure. The captive fasteners apply the pressure needed to provide a thermal bond between the casting and the heat sink on the structure.

E9-5 Alignment Guides

Combination shear/alignment pins are located in opposite corners of the casting to provide the easy and positive alignment required when the module is replaced in the spacecraft structure. Visual targeting aids can also be used to provide a ready frame of reference for orienting the module prior to insertion. Tether provisions must also be provided.

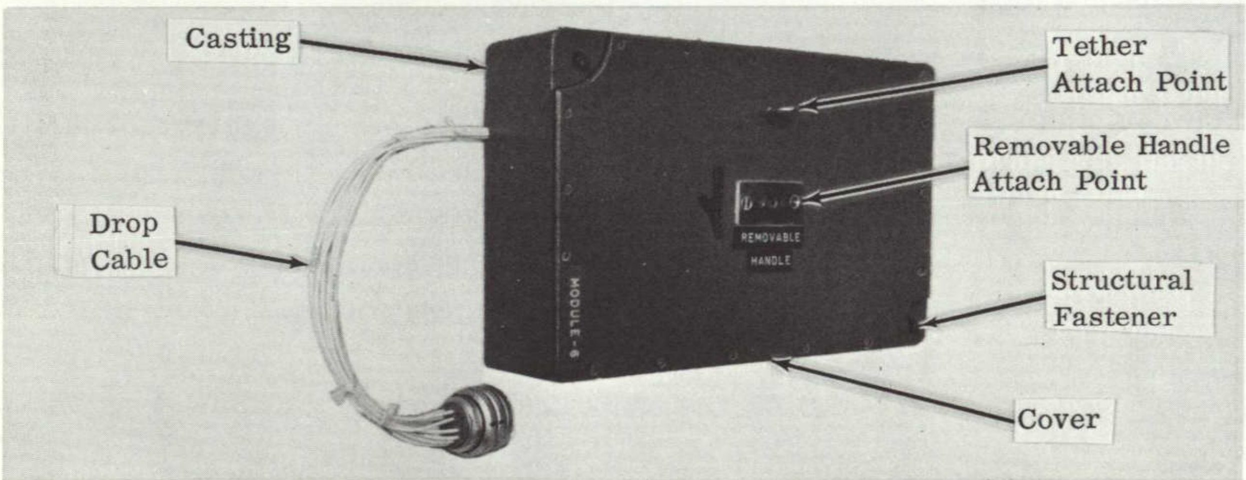


Figure E9-1. Module Enclosed by Casting

EXAMPLE NO. 10
IVA APPLICATION
PRINTED CIRCUIT CARDS

E10-1 General

This example illustrates typical application of printed circuit cards with the following characteristics:

- Size and weight of components allow mounting on printed circuit board.
- Plug in connector required to meet the time requirements of Paragraph 4-1.

Three types of printed circuit cards are depicted in Figure E10-1 as follows:

Module Design A

- Multilayer type construction
- High thermal load
- Connector pins mated/demated by captive fast acting fastener

Module Design B

- Low thermal load
- Levers used for demating
- Retained by cover or device common to all cards

Module Design C

- Single circuit board construction
- Medium thermal load
- Connector pins mated/demated by captive fast acting fastener

Primary considerations which have the greatest impact on maintenance performed in an IVA environment, are given in the following paragraphs.

E10-2 Structural Interface Considerations

Each of these modules is retained in the box, rack, or drawer installation through the printed circuit connector at the base and a guide in the box on two ends of the card. Modules A and C are fastened structurally to the box through a multi-threaded captive fastener which also mates/demates the connector, the head of which is accessible from the top of the card. Module B is structurally held in position by a bracket on the cover which applies pressure on the top of the card.

E10-3 Electrical Interface Considerations

Each of the printed circuit cards interfaces with the box through a printed circuit connector. The method of mating/demating the electrical contacts on Modules A and C is through the structural bolt. Module B is demated by applying pressure to the clips on the top of the card at each corner. These lever devices lift the card out of the electrical interface connector but are not satisfactory for jacking or unjacking high density connectors.

E10-4 Thermal Interface Considerations

The thermal path for the modules shown in figure E10-1 to the box, rack or drawer installation is as follows:

Module Design A

The printed circuit card has a high heat load and uses metal edges on the sides and on that portion of the bottom of the card not needed by the connector to transfer the load. The primary heat path is through the bottom of the card to the heat sink in the box. A secondary heat path is through the metal edge on the sides of the card to a mating guide in the box. The fit of the card on the sides is snug but not tight, allowing easy hand removal and replacement of the card. The structural multi-threaded fastener provides the pressure required to assure a good thermal path through the base.

Module Design B

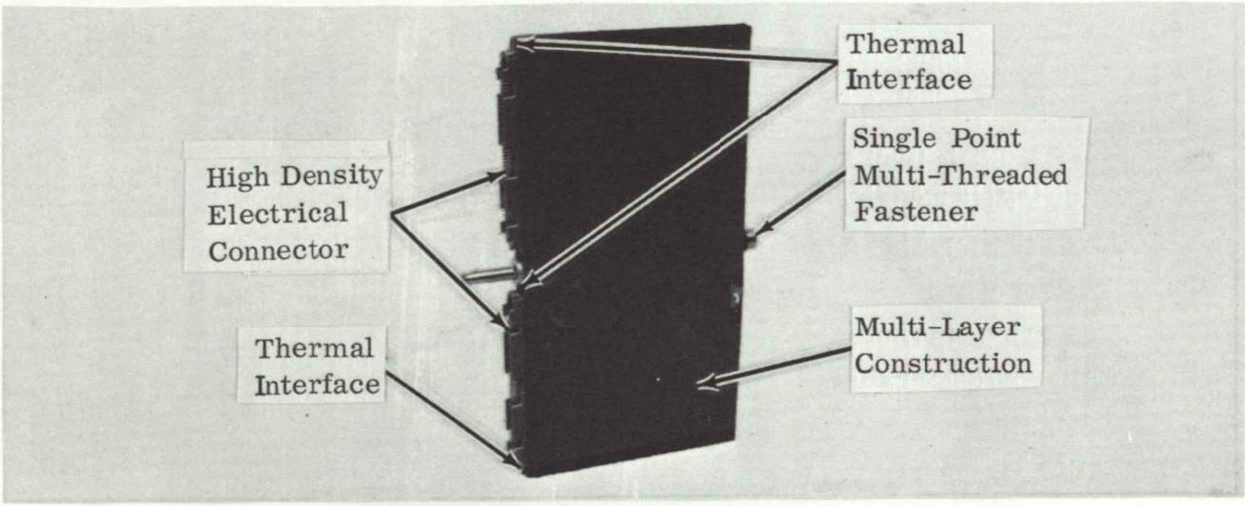
The heat loads for this type of printed circuit card are low enough to negate the need for any special requirements other than the normal transfer of heat to the guides at the sides of the card and through the connector at the base.

Module Design C

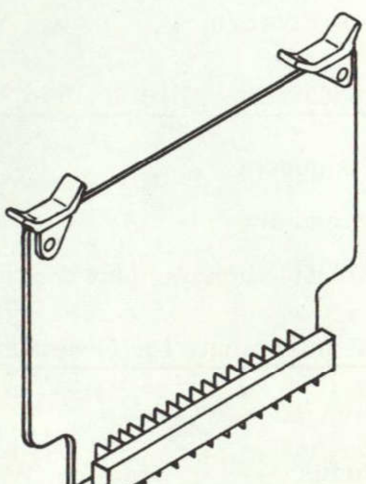
This printed circuit card has a high heat load and uses a metal edge on the top and sides to provide a thermal path to the guides in the rack retaining the card in the box. The guides in the rack are spring loaded to provide positive contact between the card and the rack to assure a good thermal path.

E10-5 Alignment Guides

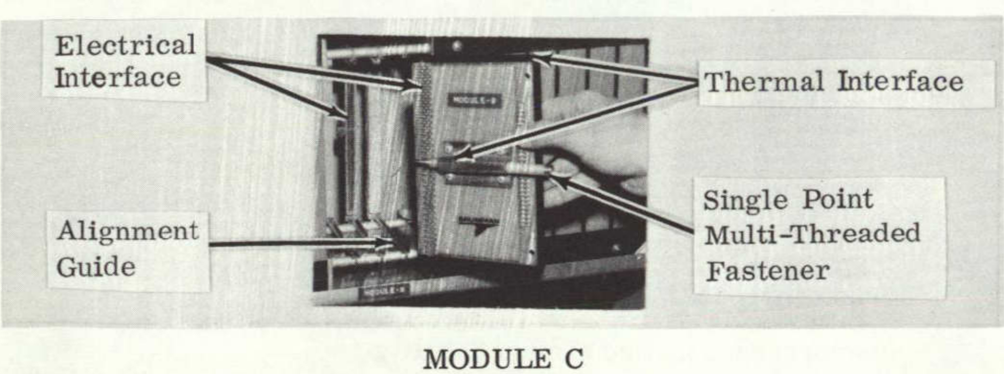
Each of the printed circuit cards is guided into the connectors at the base by full length alignment guides in the box or rack structure which fix the position of these cards. The guides also prealign the position of the structural fastener once the cards are inserted. There will be a problem associated with one handed insertion of PCB's into their guides under zero g conditions, unless the guides are designed to facilitate this action through wider or funnel shaped entrances to help the astronaut.



MODULE A



MODULE B



MODULE C

Figure E10-1. Printed Circuit Cards

EXAMPLE NO. 11

IVA APPLICATION, SMALL MODULE

E11-1 General

This example illustrates a housing design for small modules which have the following characteristics:

- Size restricted to that of a package of cigarettes, with weight corresponding to the size
- Typical cordwood module construction
- Very low thermal requirements
- Small quantity of pins required for electrical interface as for an IC
- No tools required to remove and replace.

The design could take many forms, one of which is shown in Figure E11-1. Primary considerations which have the greatest impact on maintenance performed in an IVA environment, are given in the following paragraphs.

E11-2 Structural Interface Considerations

In Figure E11-1, the module is secured to the box through a multi-threaded, captive, and self locking fastener attached to the knob on top of the module. This fastener provides all of the force necessary to mate and denote the thermal, electrical, and structural interfaces. An alternate method of driving the fastener, where tools are permitted, would be with the universal hex drive tool.

E11-3 Electrical Interface Considerations

The electrical pins are located at the bottom of the module along with the guide pins. Operation of the structural fastener applies the force necessary to mate/demate the electrical contacts. A module of this small size will not necessarily have a connector installed. Instead, a typical IC socket and pin arrangement can be used provided that proper orientation and alignment is maintained and the male pins on the module are recessed for protection. Keying for proper insertion of the electrical contacts is provided by the guide pins and structural keying arrangement.

E11-4 Thermal Interface Considerations

The thermal path for this module is a metal land surrounding the structural fastener. Operation of the knurled knob applies the pressure needed to provide a thermal bond between the module and the box heat sink.

E11-5 Alignment Guides

A mechanical alignment guide will be necessary to align the module properly before insertion of the electrical contacts. The alignment guide also serves as a means of keying the entire module to prevent incorrect insertion. This can take the form of a shaped shield around the entire module as shown in the illustration.

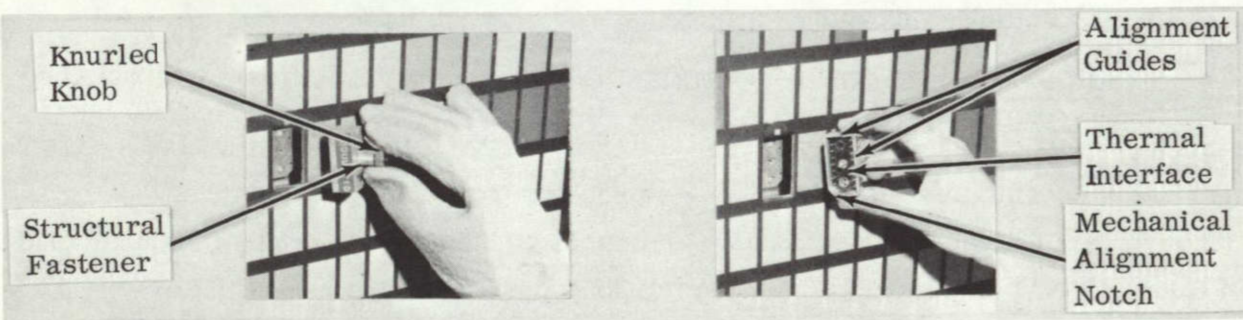


Figure E11-1. Small Module

GLOSSARY

BLACK BOX	An assembly or any combination of parts and modules, usually a plug-in unit, which is replaceable as a whole to correct a malfunction in a subsystem.
CHASSIS	A physical structure which retains and electrically interconnects a group of modules which perform higher level functions.
DEAD-FACING	Deactivation or removal of all signals from all leads in both halves of a connector prior to separation of the connector.
DOWN-POWERING	Deactivation of an entire replaceable unit, subsystem, or system to remove all electrical potential from all leads of all connectors prior to removal of a unit during a maintenance action.
INTERCHANGE	The removal and replacement of equipment.
LEVEL OF MAINTENANCE	The level of assembly, e.g., Black Box, module or piece part, at which the system or equipment is normally maintained.
MAINTAINABILITY	A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources.
MAINTAINABILITY CONCEPT	A comprehensive statement of the elements and/or extent of maintenance to be performed and their application to the program/equipment.
MAINTENANCE ACTION	An act of maintenance (repair or service) performed on a unit, system, or vehicle to return it to a specified condition.

GLOSSARY (Continued)

MODULE	An assembly forming part of a larger assemblage, both of which may be designed for complete replacement as units. It can be a subassembly within a black box or the system replaceable item in IVA for maintenance repair.
REMOVAL AND REPLACEMENT TASK	The task of physically interchanging the malfunctioning equipment with serviceable equipment and does not include preparation tasks such as gaining access to the equipment, obtaining spare parts, fault isolation, etc.
REPAIR	The process of returning a system/equipment to a specified condition by repair including preparation, fault detection, fault isolation, access, removal and replacement of defective equipment, verification tests, close out and secure action.

ABBREVIATIONS

BIT	Built In Test
EVA	Extra Vehicular Activity
g	Gravity
IC	Integrated Circuit
IVA	Intra Vehicular Activity
MMH/OH	Maintenance Man Hours per Operating Hour
MTTR	Mean Time To Repair
OBC	Onboard Checkout
PCB	Printed Circuit Board
R&R	Remove and Replace

APPENDIX C

RECOMMENDED MOCK-UP DEMONSTRATION PLAN

APPENDIX C

RECOMMENDED DEMONSTRATION PLAN FOR THE GRUMMAN SPACE MAINTAINABILITY ELECTRONIC PACKAGING MOCKUP CONTRACT #NAS-8-24690

I. DESCRIPTION OF MOCK-UP

The mock-up shown in Figure 3-1 of the basic report basically consists of two enclosures (A and C) of file-cabinet size and one smaller enclosure (B) mounted on a stand suitable for both storage and One-g demonstration. The three EVA type boxes and ten IVA type modules, all removable for maintainability demonstration, are contained within these enclosures. In addition, there are two slide-out equipment drawers and a typical control/display panel assembly, all of which have replaceable modules mounted within.

II. EQUIPMENT REQUIRED FOR DRY ZERO-g DEMONSTRATION

The following equipment will be required for the demonstration of maintainability in a dry Zero-g condition:

	Item	To be Supplied by: Grumman	NASA
(1)	Mock-up Enclosure C (wgt≈95# without boxes)	x	
(2)	Mock-up Enclosure B (wgt≈32#)	x	
(3)	Mock-up Enclosure A (wgt≈138#)	x	
(4)	Earth Orbital Simulator (Air bearing Parallelogram) with Lunar gravity attachment		x
(5)	Astronaut (Zero-g) Simulator (5 or 6 Degree of freedom		x
(6)	NASA EVA Pressure Suit		x
(7)	Three Helium Balloons and lines*		x
(8)	Movie camera, operator, and lights		x
(9)	Technician Demonstrator		x
(10)	C Hook Balancing Tool	x	
(11)	Universal Tool, Bits, Handle	x	
(12)	Twenty-four inch Hatch Simulator	x	
(13)	PCB Card Extractor	x	
(14)	Three Black Boxes	x	
(15)	Two Drawer Assemblies	x	
(16)	One Panel Assembly	x	
(17)	Ten Module Assemblies	x	
(18)	Equipment Tethering Hooks & Lines	x	
(19)	Astronaut Tethering Line and Snap		x
(20)	Elapsed Time Recorder		x
(21)	Zero-g Body Restraints		x
(22)	Velcro Foot Restraints		x
(23)	Helium Supply Tank		x
(24)	Handrails - four supporting pieces, two short rails for Enclosure B and two long rails for Enclosure A or C.	x	

*Note: The balloons are needed to counterbalance the weight of the three black boxes:

#1 ≈25#
#2 ≈12#
#3 ≈ 4#

III. DEMONSTRATION PROCEDURE

The demonstration will consist of four separate set-ups, three involving the mou ing of one of the three enclosures on the Zero-g, the fourth being performed in a one-g environment. The Zero-g set-ups will require:

- The balancing of the parallelogram for the mounted enclosure
- The balancing of the astronaut in the simulator with required equipment attached
- An exercise of the remove/replace actions with the equipment contained i each of the enclosures.

The EVA boxes shall be balanced for neutral buoyancy one box at a time (as show in Figure 8-12 of the basic report by:

1. Remove bracket from box on which it is fastened and secure bracket to uppe right-hand corner of the front panel on the box to be balanced.
2. Suspend C Hook Balancing Tool with a line from overhead at micarta block. Secure tube to bracket on the box by placing bolt in appropriate hole designat for the box. (Note -- use hole nearest astronaut for Box 1, next nearest hole for Box 3 and last hole for Box 2).
3. Move micarta block along tube to balance the box in both directions, then tighten fasteners to secure the micarta block.
4. Remove rope suspending assembly at micarta block and attach helium filled balloon of the proper buoyancy to suspend the assembly motionless.

A. SET-UP #1 - EVA REMOVE AND REPLACE ACTION

Run #1 (One-Hand Simultaneous Lock-up, No Foot Constraints) (Box #1)

(1) Fasten handrail (Long rails) to each side of Enclosure "C", then mount Enclosure "C" on earth orbital simulator (parallelogram) without lunar gravity attachment.

(2) Balance parallelogram without the three black boxes.

(3) Attach balloon and adaptor to Box #1, inflate and balance for neutral buoyancy. Place Box #1 into position in Enclosure and latch in place. Arm auto power disconnect circuit.

(4) Assemble suited astronaut in (Zero-g) Simulator, equipped with attached tethering hooks and lines.

(5) Activate air bearing blowers on both simulator and parallelogram. (Snap astronaut tether to parallelogram, if used.)

(6) Start camera and timer.

(7) Permit astronaut to grasp handrail with one hand.

(8) Astronaut demonstrates manual power-down by turning "off" the Power Disconnect switch. Light out indicates power off. Astronaut then turns switch "on" to arm the auto power disconnect circuit.

(9) Astronaut snaps on equipment tether, releases latch on handle, rotates handle to open position, withdraws Box #1 completely from the recess with one hand.

(10) Place box at 3/4 arms length from enclosure and take hand off box.

(11) Astronaut retrieves box, aligns and guides Box #1 into its recess, seats it, and locks it via handle motion. Equipment tether is removed.

Note: Power-on light should indicate power connected.

(12) Stop timer, camera, air blowers.

Run #2 (One-Hand Lock-up with Manual Connector; No Foot Constraints) (Box #2)

(1) Attach balloon and adaptor to Box #2, inflate and balance for neutral buoyancy. Place Box #2 into position in enclosure and latch in place.

(2) Start air blowers and snap astronaut tether to parallelogram, if used. Start camera and timer.

(3) Permit astronaut to grasp handrail with one hand.

(4) Snap equipment tether in place on box.

(5) Astronaut then removes Box #2 by disconnecting and stowing the two connectors then unlatching the mechanism and withdrawing the box completely from the enclosure with one hand.

(6) Place box at 3/4-arm's length from enclosure and take hand off box.

(7) Retrieve box, align and guide Box #2 into its recess. Seat it, release latch an lock box via handle motion.

(8) Astronaut retrieves two Zero-g system connectors from the stowed position ar installs these connectors in receptacles on Box #2.

(9) Equipment tether is removed from box.

(10) Stop timer, camera, air blowers.

Run #3 (One-Hand Simultaneous Lock-up, Small Box, No Constraints) (Box #3)

(1) Attach balloon and adaptor to Box #3, inflate and balance for neutral buoyancy. Place Box #3 into position in enclosure and latch in place.

(2) Start air blowers and snap astronaut tether to parallelogram if used. Start camera and timer.

(3) Permit astronaut to grasp handrail with one hand.

(4) Snap equipment tether in place on box.

(5) Astronaut then removes Box #3 by unlocking the connector, and then unscrewing the mount handle until the box is free.

(6) Place box at 3/4-arm's length from enclosure and take hand off box.

(7) Retrieve box, align and guide Box #3 into its recess. Seat it, and lock it with knob action.

(8) Astronaut proceeds to lock up the "Zero Mating Force" connector by rotating the connector drive handle 1/4 turn to the locked position.

(9) Equipment tether is removed.

(10) Stop timer, camera, air blowers. (Note: Zero-g test connector could be removed during this run to simulate manual connector action.)

B. SET-UP #2 - IVA REMOVE AND REPLACE ACTION (USING TOOLS AND FOOT CONSTRAINTS)

Note: Earth orbital simulator with lunar gravity attachment having foot (Velcro) constraints shall restrain movement of astronaut relative to enclosure.

Run #1 (R and R of Wall and Panel Units)

(1) Remove handrails from Enclosure "C," fasten handrails (short rails) to each side of Enclosure B then mount Enclosure "B" on parallelogram, Modules 2, 3, and 8 to be installed and latched in position.

(2) Balance parallelogram. Note: Compensate for movement of panel in the open and closed positions.

(3) Assemble "shirt-sleeve" astronaut in Zero-g Simulator equipped with tethering hooks, lines, tools and foot constraints.

(4) Activate air bearing blowers on both simulator and parallelogram.

(5) Start camera and timer.

(6) Permit astronaut to grasp handrail if desired

(7) Astronaut opens hinged panel by releasing catch, pulls to full open position.

(8) Astronaut attaches tether then removes system connector from Module #2 and unscrews the unit using hex drive tool. Tool is then stowed.

(9) Astronaut retracts both hands, one containing Module #2, other empty.

(10) Astronaut reinstalls Module #2 by aligning and guiding unit into place, tightens mounting screws, stows the tool, reinstalls system connector and removes tethers.

(11) Astronaut releases hinge latch, closes the panel, and fastens the handle latch.

(12) Stop timer, camera and air blowers.

Run #2 (R and R of Wall and Panel Units)

(1) Start air blowers, camera and timer.

(2) Permit astronaut to grasp handrail if desired.

(3) Astronaut opens hinged panel by releasing catch. Pulls to full open position.

(4) Astronaut attaches tether hook to Module #3.

(5) Astronaut removes system connector from Module #3 and unscrews the unit using hex drive tool. Tool is then stowed.

(6) Astronaut retracts both hands, one containing Module #3, other empty.

(7) Astronaut reinstalls Module #3 by aligning and guiding unit into place, tightens mounting screws, stows the tool, and reinstalls system connector.

(8) Astronaut removes the tether.

(9) Astronaut releases the hinge latch, closes the panel and fastens the handle latch.

(10) Stop timer, camera, and air blowers.

Run #3 (R and R of Wall and Panel Units)

(1) Start air blowers, camera and timer.

(2) Permit astronaut to grasp handrail if desired.

(3) Astronaut opens hinged panel by releasing catch. Pulls to full open position.

(4) Astronaut removes the PCB Module #8 using the PCB extractor tool. Tool is then stowed.

(5) Astronaut retracts both hands, one containing PCB Module #8, other empty.

(6) Astronaut reinstalls PCB Module #8 in its slot without tools. (Here is where we determine if current PCB mount designs are suitable for Zero-g)

(7) Astronaut releases hinge latch, closes the panel, and fastens the handle latch.

(8) Stop timer, camera, air blowers.

C. SET-UP #3 - IVA REMOVE AND REPLACE ACTION (USING TOOLS AND FOOT CONSTRAINTS)

Note: Earth orbital simulator with lunar gravity attachment having foot (Velcro) constraints shall restrain movement of astronaut relative to enclosure.

Run #1 (R and R of Vertical Rack Units)

(1) Remove handrails from Enclosure "B", fasten handrails (long rails) to each side of Enclosure "A" then mount Enclosure "A" on parallelogram, Modules 1, 4, 5, 6, 7, 9 and 10 to be installed and latched into position.

(2) Balance parallelogram. Note: Compensate for pull-out drawers.

(3) Assemble "shirt-sleeve" astronaut in Zero-g Simulator equipped with tethering hooks, lines, tools and foot constraints.

(4) Activate air bearings on simulator and parallelogram.

(5) Start camera and timer.

(6) Permit astronaut to grasp handrail, if desired.

(7) Astronaut unlatches and pulls out the vertical drawer to the stops.

(8) Astronaut unjacks Module #7 (typical computer card) using hex drive tool. Tool is then stowed.

(9) Removable handle is inserted in its socket and module is removed via use of this handle.

(10) Astronaut retracts both hands, one containing Module #7, other empty.

(11) Astronaut reinstalls Module #7 in the proper slot, removes handle, stows handle, seats and locks unit using the hex drive tool. Tool is then stowed.

(12) Astronaut releases catch and slides vertical drawer into place, then latches both handles.

(13) Stop timer, camera and air blowers.

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Run #2 (R and R of Vertical Rack Units)

(1) Start air blowers, camera and timer.

(2) Permit astronaut to grasp handrail, if desired.

(3) Astronaut unlatches and pulls out vertical drawer to the stops.

(4) Astronaut attaches tether hook to Module #9.

(5) Astronaut unjacks and removes Module #9 (typical aerospace PCB) using hex drive tool. Tool is then stowed.

(6) Astronaut retracts both hands, one containing Module #9, other empty.

(7) Astronaut reinstalls Module #9 in the proper slot, seats and locks unit using the hex drive tool. Tool is then stowed.

(8) Astronaut releases catch and slides vertical drawer into place, then latches both handles.

(9) Stop timer, camera, and air blowers.

Run #3 (R and R of Vertical Rack Units)

(1) Start air blowers, camera and timer.

(2) Permit astronaut to grasp handrail, if desired.

(3) Astronaut unlatches and pulls out vertical drawer to the stops.

(4) Astronaut acquires hex drive tool and removes panel over Module #10 by unscrewing quick release fasteners. Tool and panel are stowed.

(5) Astronaut removes smallest Module #10 by turning the knurled handle attached to the Module counter-clockwise to perform the release action.

(6) Astronaut retracts both hands, one containing Module #10, other empty.

(7) Astronaut reinstalls Module #10 in its mount and locks down by turning knurled knob clockwise until tight.

(8) Astronaut reinstalls cover panel using hex drive tool. Tool is then stowed.

(9) Astronaut releases catch and slides vertical drawer into place, then latches both handles.

(10) Stop timer, camera, and air blowers.

<u>Run #4 (R and R of Horizontal Drawer Units)</u>

(1) Start air blowers, camera and timer.

(2) Permit astronaut to grasp handrail, if desir

(3) Astronaut unlatches and pulls out horizontal drawer to the stops.

(4) Astronaut attaches tether hook to Module #1.

(5) Astronaut prepares for removal of Module #1 by first unscrewing the two self centering fasteners in the corners with hex drive tool, then unscrewing the fastener in the center of the Module with the same tool to unjack the rack and panel connector. The tool is then stowed.

(6) Removable handle is inserted and locked in its socket on the Module. Module is then removed via the use of this handle.

(7) Astronaut retracts both hands, one containing Module #1, other empty.

(8) Astronaut reinstalls Module #1 by inserting unit on alignment guides, disconnecting removable handle, stowing handle, jacking the connector fastener in the center of the Module with the hex drive tool, then tightening the fasteners in the corners with the same tool to secure the Module. Stow the tool.

(9) Remove tether from Module #1.

(10) Astronaut releases catches and slides horizontal drawer into place, then latche both handles.

(11) Stop timer, camera and air blowers.

<u>Run #5 (R and R of Horizontal Drawer Units)</u>

(1) Start air blowers, camera and timer.

(2) Permit astronaut to grasp handrail if desired.

(3) Astronaut unlatches and pulls out horizontal drawer to stops.

(4) Astronaut attaches tether hook to Module #4.

(5) Astronaut removes Module #4 by removing the system electrical connector, unscrewing fasteners with hex drive tool, and stowing tool.

(6) Astronaut retracts both hands, one containing Module #4, other empty.

(7) Astronaut reinstalls Module #4 by inserting unit on alignment guides, tightening fasteners with the hex drive tool, stowing the tool, then reinstalling and locking the hand mated system electrical connector.

(8) Remove tether from Module #4.

(9) Astronaut releases catches and slides horizontal drawer into place, then latches both handles.

(10) Stop timer, camera and air blowers.

<u>Run #6 (R and R of Horizontal Drawer Units)</u>

(1) Start air blowers, camera and timer.

(2) Permit astronaut to grasp handrail if desired.

(3) Astronaut unlatches and pulls out horizontal drawer to stops.

(4) Astronaut attaches tether hook to Module #5.

(5) Astronaut removes Module #5 by removing the system electrical connector, unscrewing fasteners with hex drive tool and stowing tool.

(6) Astronaut retracts both hands, one containing Module #5, other empty.

(7) Astronaut reinstalls Module #5 by inserting unit on alignment guides, tightening fasteners with hex drive tool, stowing the tool, then reinstalling and locking the hand mated electrical connector.

(8) Remove tether from Module #5.

(9) Astronaut releases catches and slides horizontal drawer into place, then latches both handles.

(10) Stop timer, camera and air blowers.

Run #7 (R and R of Horizontal Drawer Units)

(1) Start air blowers, camera and timer.

(2) Permit astronaut to grasp handrail, if desire

(3) Astronaut unlatches and pulls out horizontal drawer to stops.

(4) Astronaut attaches tether hook to Module #6.

(5) Astronaut prepares for removal of Module #6 by: Removing system electrical connector, unscrewing fasteners with hex drive tool and stowing tool.

(6) Insert removable handle in socket on Module #6, withdrawing Module using handle.

(7) Astronaut retracts both hands, one containing Module #6, other empty.

(8) Astronaut reinstalls Module #6 by: Inserting unit on alignment guides, disconnecting and stowing handle, tightening fasteners with hex drive tool, stowing the tool, then reinstalling and locking the hand mated electrical connector.

(9) Remove tether from Module #6.

(10) Astronaut releases catches and slides horizontal drawer into place, then latches both handles.

(11) Stop timer, camera and air blowers.

D. SET-UP #4 - ONE-g DEMONSTRATION OF ADDITIONAL FEATURES (THIS DEMONSTRATION SHALL BE PERFORMED WITHOUT NEED FOR ANY ZERO-g SIMULATION)

(1) Place Box #1 in position in Enclosure "C" and pull out Box #1 until front panel of the box clears the handrails. Caution should be exercised to prevent box falling from enclosure.

(2) Obtain the hatch simulation ring from beneath Enclosure "B" on the back panel of the mock-up and pass the ring over Box #1 to demonstrate passage of Box #1 through the hatch.

(3) Reinstall or remove Box #1 from enclosure.

(4) Place Box #2 on floor resting on rear face (front panel with handle at the top).

(5) Pass the hatch simulator ring over Box #2 to demonstrate passage of Box #2 through the hatch.

(6) With astronaut wearing a pressure suit glove, demonstrate grasp of the recommended 2-1/2" by 4" minimum size black box cross section for EVA.

(7) With astronaut wearing a pressure suit glove, demonstrate that smallest module can be handled.

(8) With astronaut wearing a pressure suit glove, demonstrate that the hex drive universal tool and removable handle concept is feasible.

IV. POSSIBLE PROBLEM AREAS

(1) The balance of units that slide out after being mounted on parallelogram may be upset by the additional movement arm in the extended position. Such units as the slide out drawers and hinged panel will require supplemental weights to prevent parallelogram motion when they are extended.

(2) Enclosures "A" and "B" are initially balanced on the parallelogram with all Modules installed and no neutral buoyancy provisions. Removal of modules will require that counterbalancing be applied and removed to prevent gross motion of the parallelogram at the instant of removal and reinstallation.

(3) Sufficient lighting must be present to permit a good visual contact with all areas where the maintenance operations are to be performed.

(4) The "universal" tool and removable handle must be stowed by the astronau during the maintenance operations. This could be done via a belt loop on t man or through simulation of retrieval from a tool box.

(5) The cover plate in the vertical drawer must also be stowed.

(6) Flashlight batteries are mounted inside Box #1, these should be removed for long-term storage.

(7) A suited astronaut may require help to operate the "Off-the-Shelf" tethering hook supplied with the mock-up.

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714