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A HUMAN FACTORS STUDY OF SHUTTLE/SPACE STATION CARGO HANDLING TECHNIQUES

Contract NAS8-26349

Final Report

by

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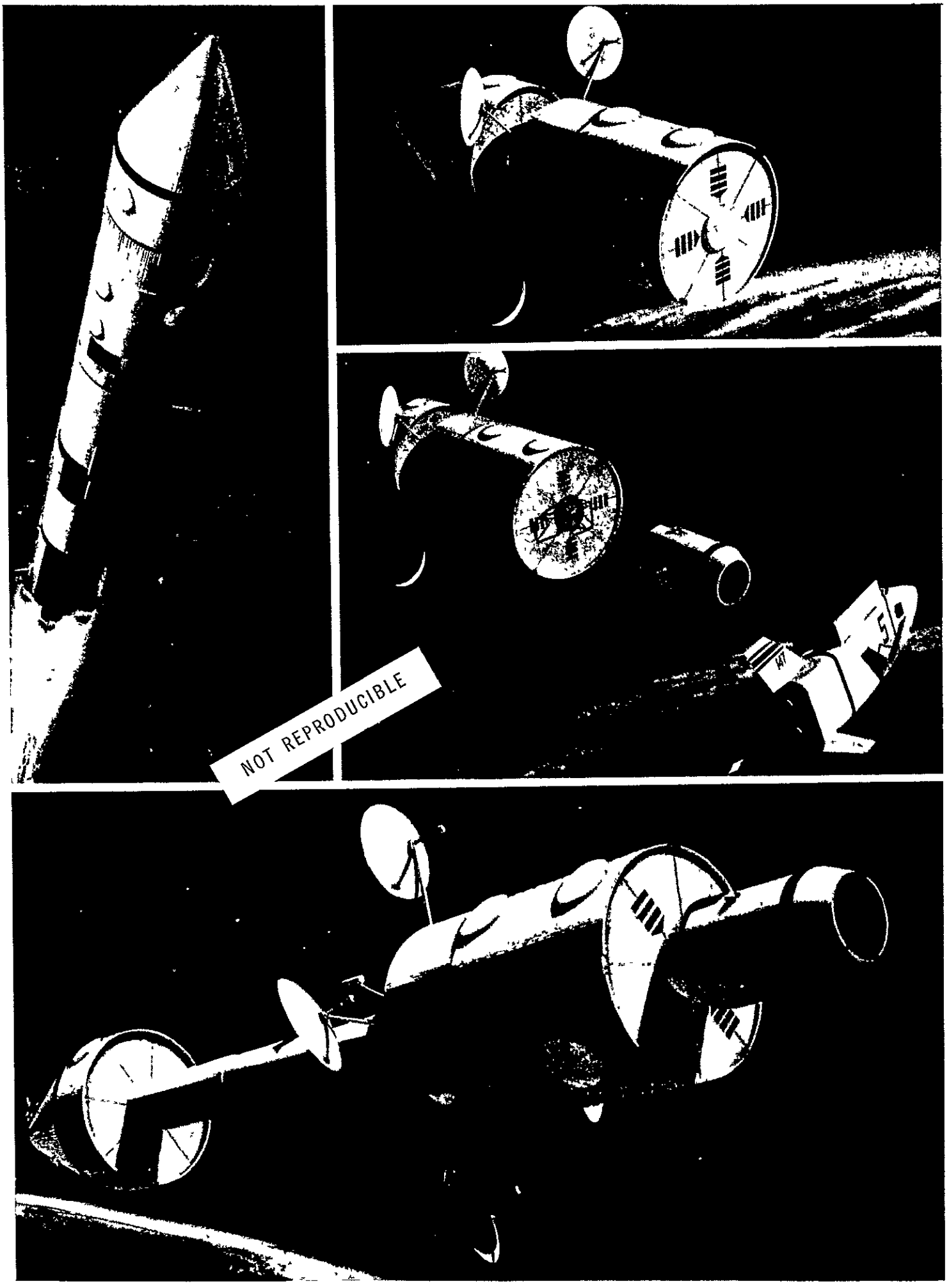
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EXECUTIVE SUMMARY

The study herein reported for the Marshall Space Flight Center represents the first independent human factors-oriented examination of in-space cargo transfer problems associated with the Shuttle-Space Station resupply mission.

The purpose of this study was to determine how much human involvement in cargo transfer should be expected vs the alternate potential of automated transfer systems. A final, end product of the study was intended to be a set of recommendations for additional research, including zero-g simulation studies.

Although the original study was to have been somewhat broader in scope, the final program included an investigation of in-space cargo handling between an attached crew cargo module (C/CM) and the Space Station (SS). The study also assumed that the Space Station would be in a zero-gravity operating mode, i.e., without artificial gravity.

The study consisted of an analysis of mission/vehicle/cargo parameters to provide a general model around which to study various transfer system concepts, examination and trade-off analysis of various transfer concepts (in order to select those that appeared to provide maximum utility and cost-effectiveness for further consideration), and the definition of problem areas and research requirements for developing information needed to select and design an ultimate in-space cargo transfer system.

Although it had been assumed at the beginning of this study, by both NASA and the Contractor, that sufficient information would be available on various transfer systems for effective design trade-off analysis, this did not prove to be the case. One of the first things this study has brought into focus, therefore, is the fact that too little effort has been devoted to specific design of the cargo transfer system; everything so far is in terms of generalities. There seem to be no specific transfer hardware concepts sufficiently well thought out for analysts to make consistent and meaningful tradeoff studies of system parameters such as weight, power requirements, space requirements, flexibility, reliability or cost-effectiveness.

Accordingly, in the present study, tradeoff criteria of a general operational and human factors-oriented nature had to be devised. Despite this problem, significant conclusions have been reached, and a number of important recommendations provided. These include a series of suggested research studies and experimental simulations believed necessary to provide urgently needed information prior to final conceptualization and design of a cargo transfer system between the C/CM and the SS.

A major conclusion of the present study is that the entire cargo transfer problem has received far too little attention. The result is that, at current levels of emphasis, transfer subsystem hardware and procedural requirements will have no impact on overall Shuttle-Space Station Mission concept development or hardware design. Experiment designers, for example, who should be receiving -- right now -- information regarding the size, shape, mass limit, center of mass location, etc. of the experiment packages they are designing, are having to be content with the vague hope that a way will be found, ultimately, to transfer these packages successfully between the C/CM and the SS. Accordingly, the NASA is strongly urged to place greater emphasis on the study of cargo handling at the earliest possible moment since it is the authors' conviction that success of the basic mission is dependent upon the use of an integrated cargo transfer (rather than an add-on) approach. This report includes a number of specific suggestions for experimental research and developmental work in this area.

Suggested areas for further research include the development of basic information on human capabilities in the typical zero-g cargo handling situations (including in situ reach and mobility envelopes, ability to manage various package sizes, shapes and masses in conjunction with individual restraint, workspace and transfer equipment interface constraints), integrated man/system simulations in which total procedural/task timeline information is developed, additional analysis of detailed cargo-handling task sequences for each living and work area of the SS in order to determine the best method for programming cargo, analysis of artificial-g operating modes on current conclusions and recommendations and, finally, an analysis of the overall human factors aspects of a total ground-to-space (round-trip) logistics plan.

1.0 INTRODUCTION

This document reports a study of in-space cargo handling as it relates to the NASA Shuttle Program. It deals primarily with the matter of astronaut participation in manual and semi-automatic cargo handling tasks in a zero-g, shirtsleeve environment (internal vehicle activity - IVA). This study was performed by Man Factors, Inc. for the Marshall Space Flight Center in Huntsville, Alabama under NASA Contract NAS8-26349.

1.1 Background

Although elements of in-space cargo handling have been examined at various times over the past several years, the direct commitment on the part of NASA for developing a Personnel/Cargo Shuttle System to support a long-duration, earth-orbiting Space Station provides an urgent need for detailed information with regard to how much crew participation can be expected in the cargo transfer process. Such information is critical to the proper design and development of specific hardware systems to handle cargo. Coincidental is the fact that such cargo handling hardware systems need to be tested before final design commitments are made.

The EVA (extra-vehicular activity) handling of cargo has been examined more extensively than IVA in terms of isolating functional problems and developing potential design and/or procedural solutions. Similarly, a number of simulated zero-g experimental programs have been performed to determine what a man can do with himself and tools when earth gravity is not available to secure him to a surface or help him to maintain an up-down orientation. Most of these experiments have been conducted with subjects in some form of space suit. Few simulation experiments have been conducted which specifically examined cargo handling tasks or related hardware problems using non-space suited subjects.

Characteristic of most of the above efforts is the invariable lack of generalizable output or data. That this is so is due to the hardware-system dependance of the test or experiment, the very limited scope of the subject task, the uniqueness of the garments worn, or the fact that most of the simulation "tests" were not really tests at all but were, in fact, merely demonstrations.

With the advent of Skylab development, increased emphasis has been placed on in-space movement of equipment packages, particularly items such as cameras and film cassettes. Once again, however, the studies relating to Skylab have dealt with EVA rather than IVA. Skylab, unlike the Shuttle Resupply Mission, will not face the problem of moving great numbers of packages, frequently, over great distances, and into a great variety of compartmental configurations. Skylab equipment or cargo movement studies have not had to deal with the tremendous variety of package sizes, shapes and weights anticipated for the Shuttle mission.

1.2 Purpose of the Present Study

Against this background of meager although somewhat related technical data, the present study goals were formulated. The purpose of this study was to analyze systematically the Shuttle Resupply Mission's cargo handling problems and to establish some current guidelines and research requirements for developing the information needed to conceptualize and design an effective Shuttle/Space Station cargo handling system.

Although the present study initially sought to examine both EVA and IVA problems, including the interactions between the Shuttle vehicle and the Space Station, it was later limited to include only IVA tasks associated with the transfer of cargo between a docked C/CM and a non-rotating Space Station.

1.3 Study Objectives

The study objectives were as follows:

a. Develop a general description of crew task requirements relative to in-space cargo transfer, as influenced by mission, equipment, and environmental constraints.

b. Examine and summarize state-of-the-art cargo transfer systems.

c. Isolate problem areas associated with human participation in cargo handling.

d. Recommend specific research and/or simulation studies required to develop information for making system concept and design decisions.

e. Prepare a series of simulation test plans for consideration and implementation by the NASA MSFC.

1.4 Program Scope

As already stated, the scope of this study was narrowed to consider only the IVA aspects of transferring cargo between a docked Crew Cargo Module (C/CM) and the Space Station (SS). In addition, the C/CM-SS configuration was assumed to operate only in the zero-g mode (i.e., no artificial-g).

Since current SS predesign efforts have not yet resulted in any one preferred configuration, it was not possible to study all SS workspaces in detail (in terms of cargo handling). In fact, since there still are a number of alternate versions of station design (see Vol I, NASA "Blue Book")[114], one of the first tasks in the present study was to select what might be called a "general SS Model configuration" in order that a common frame of reference could be maintained when considering alternate methods for cargo transfer. The SS "model" is similar to the current Integral Space Station concept described later in Section 2.3.3. The C/CM, also being analyzed in its various versions, likewise required the selection of a general CM model (described in Section 2.3.2).

The present study, then, examines the handling of cargo (see Fig. 1.4-1) as it would be acquired from the C/CM stowage spaces (Area I), transferred through the SS hatch (Area 2), transported within the central SS tunnel (Area 3), to a point where it would be received at a particular SS deck (Area 4) for interim stowage and, finally, as it returns to the C/CM. In the first case, cargo is referred to as UP CARGO; in the second, DOWN CARGO.

With respect to specific types of cargo this study was limited to "hard" equipment and/or package transfer rather than to liquid or fuel transfer via hose or other means.

The foregoing limits were placed on the present study in order to help differentiate it from other currently sponsored NASA studies. These latter are summarized in Table 1.4-1 for information purposes.

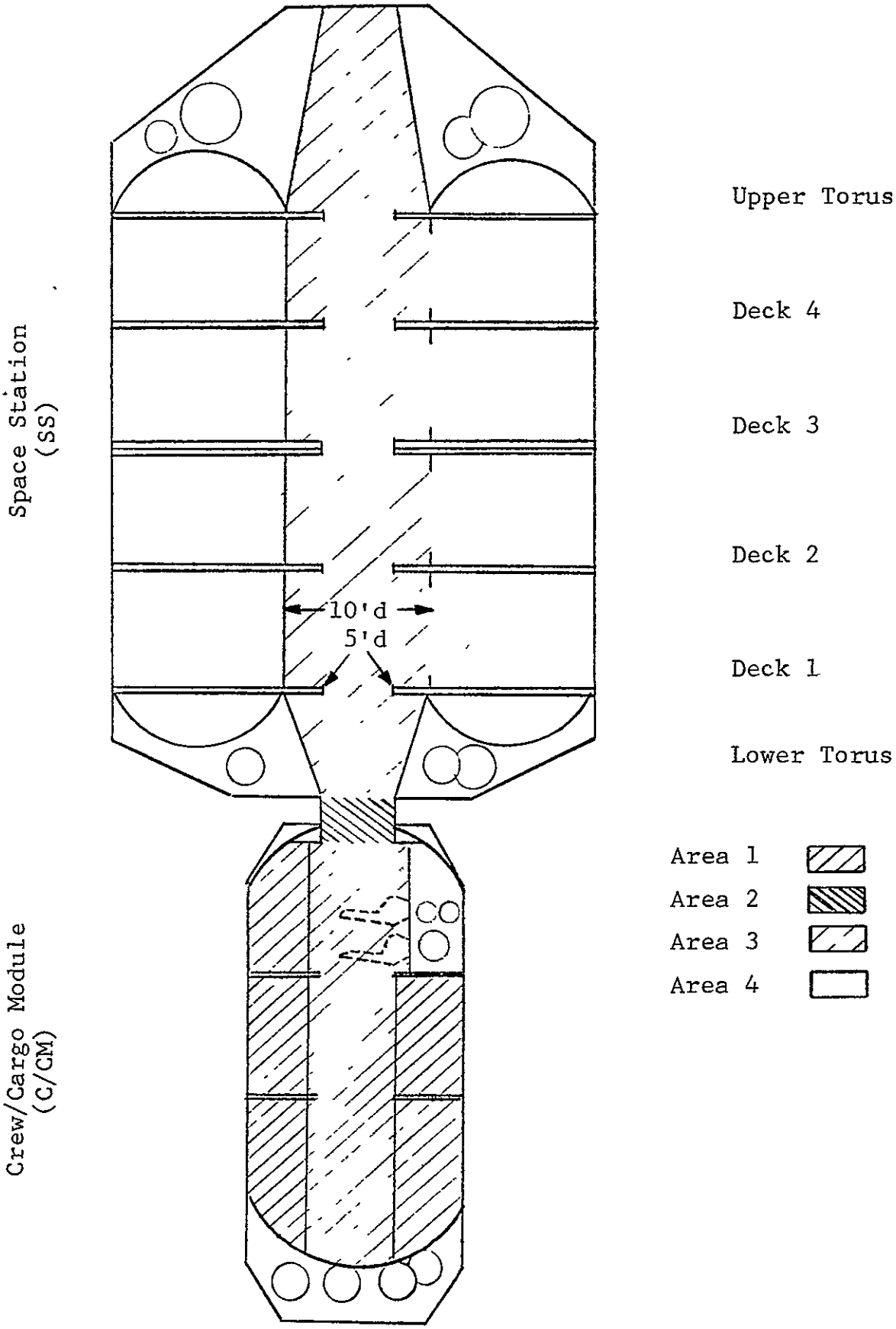

Figure 1.4-1 - C/CM-SS Areas Definition for Cargo Transfer Concepts

Table 1.4-1 - Comparison of Concurrent Space Cargo Handling Studies

WORK AREA	Sponsoring NASA Center		
	MSFC	KSC	LaRC
° Ground Support Operations and Equipment Requirements	No	Yes	No
° In-Space Cargo Handling Requirements (General)	No	Yes	Yes
° Logistics Resupply Mission Cargo Handling Requirements	Yes	No	No
° Cargo Handling System Human Factors Design Criteria	Yes	No	No
° Cargo Packaging Requirements (General)	Yes	Yes	Yes
° Human Factors Requirement for Cargo Packaging	Yes	No	No
° Storage Requirements	No	Yes	No
° Establishment of Cargo Data Bank	No	Yes	No
° Specification of Problem Areas in Cargo Handling	Yes	Yes*	No
° Preparation of Simulation Plans for Zero-g Cargo Handling	Yes	No	Yes**
° Conduct of Zero-g Cargo Handling Simulation	Yes	No	Yes
° C/CM Design	No	No	No
° Liquid Transfer (0_2, Propellants)	No	No	Yes
° Design of C/CM to Space Station Transfer Device	No	No	No
° Study of Artificial "G" Limitations on Cargo Handling	No	Yes*	No

*Limited to superficial analysis
**Level of detail unknown

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2.0 STUDY APPROACH

2.1 General

Four basic tasks were performed during the study. These are summarized briefly in Figure 2.1-1. Within these four general task areas, analyses were made of missions, systems, transfer techniques and concepts, crew tasks and problem areas. Each of these analyses is discussed briefly in the following paragraphs, with emphasis on the analytic approach taken, methods used, and a discussion of some of the problems inherent in the analysis itself.

Implicit in the several tasks was the necessity for a comprehensive review of available reports and other documentation bearing on space system studies, human performance in zero-g, and cargo handling system design. A brief summary of this literature review is provided in Appendix A as a supplement to the following discussion.

2.2 Mission Analysis

A complete review was made of the several mission descriptions that have been developed by Shuttle System study contractors for the NASA (See Appendix A). Inherent in all these descriptions is evidence of the tremendous magnitude of the projected resupply mission in terms of quantities of cargo, variety of cargo, and the difficulties forseen in maintaining a reasonable schedule. Included in the descriptions of cargo are such expendables as food and fuel, system components and spares, experiment supplies and new equipment, crew equipment, and supplies for station-keeping. It is not unreasonable to anticipate that the space station envisioned by NASA for the 1976-85 time period will require on the order of from 10 to 25 thousand pounds of cargo per resupply flight. The resupply operation, including packaging, orbiting, transferring and distributing of this quantity of cargo, normally will occur at approximately 3-month intervals. Recent studies also have considered resupply on a monthly basis.

In order to establish an overall picture of the resupply mission, several previous analyses were reviewed and summarized in a general top-level functional flow diagram model as shown in Figure 2.2-1. A simplified pictorial illustration (Figure 2.2-2) emphasizes the key elements in the cargo operations

TASK A	TASK B	TASK C	TASK D
Identify Cargo Handling Functional Requirements	Identify Describe and Analyze Candidate Cargo Transfer Systems	Specify Applicable Design Criteria & Define Problem Areas	Specify Analytic & Simulation Test Requirement & Methodology
Examine projected cargo handling concepts in terms of mission, functions, and operational constraints; prepare a basic, analytic description or task model against which candidate systems can be evaluated and compared.	Perform a man-machine predesign tradeoff study of candidate systems and prepare a summary, matrix analysis to demonstrate functional cost-effectiveness relationships among candidate systems.	Develop HF Design Criteria for the manual & man/machine function of cargo handling as available & specific problem areas both procedural & design which will require further study.	Develop a description of the analyses & simulation studies required to resolve the identified problem areas, preparing a list of simulation requirements and preliminary test plans in a form readily adaptable to timely test operations. Submit final report.

Figure 2.1-1 - General Outline of Study of Shuttle/Space Station Cargo Handling Techniques

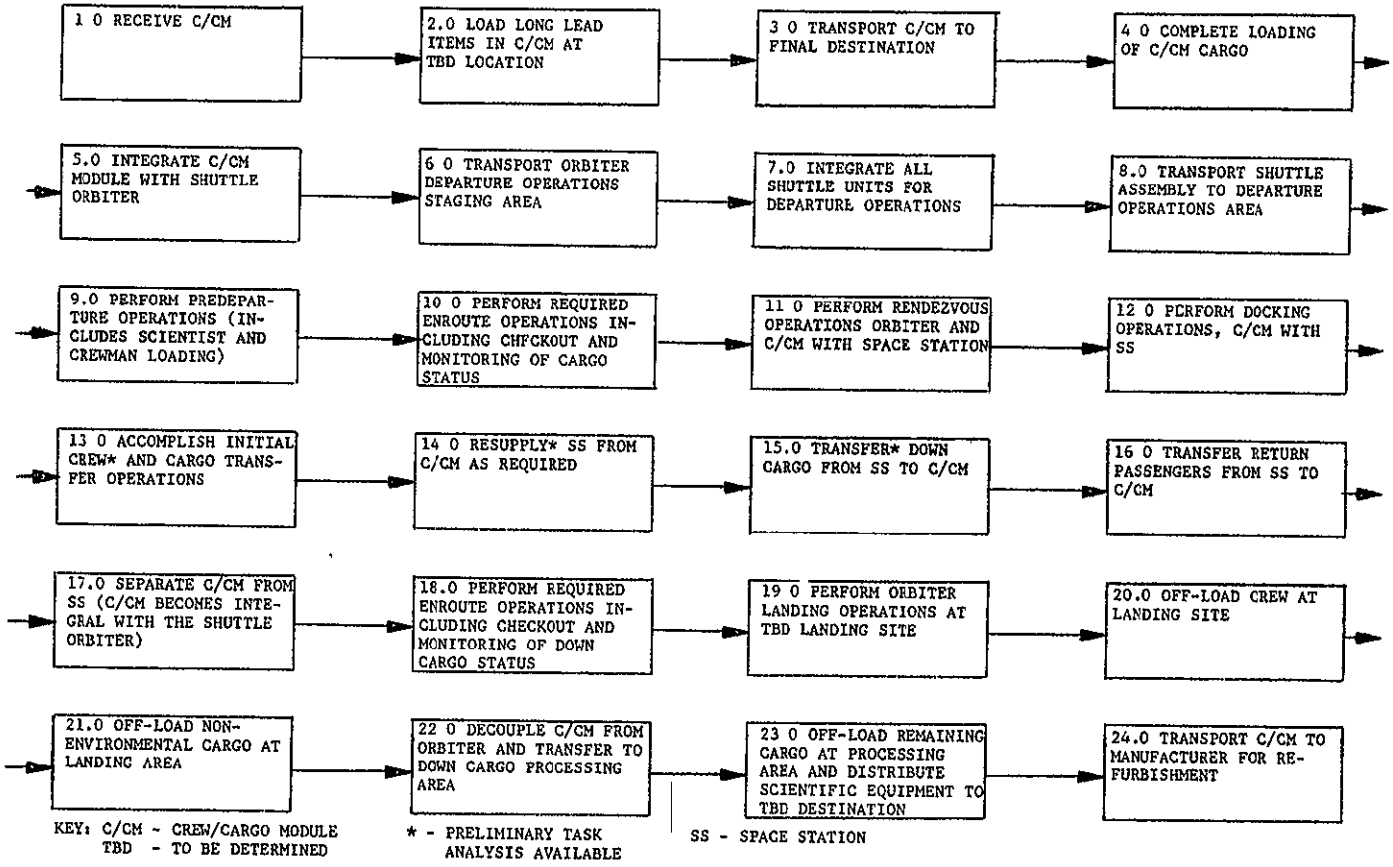


Figure 2.2-1 - Typical Crew/Cargo Sequence For Shuttle/Space Station Resupply Mission Top Function Level

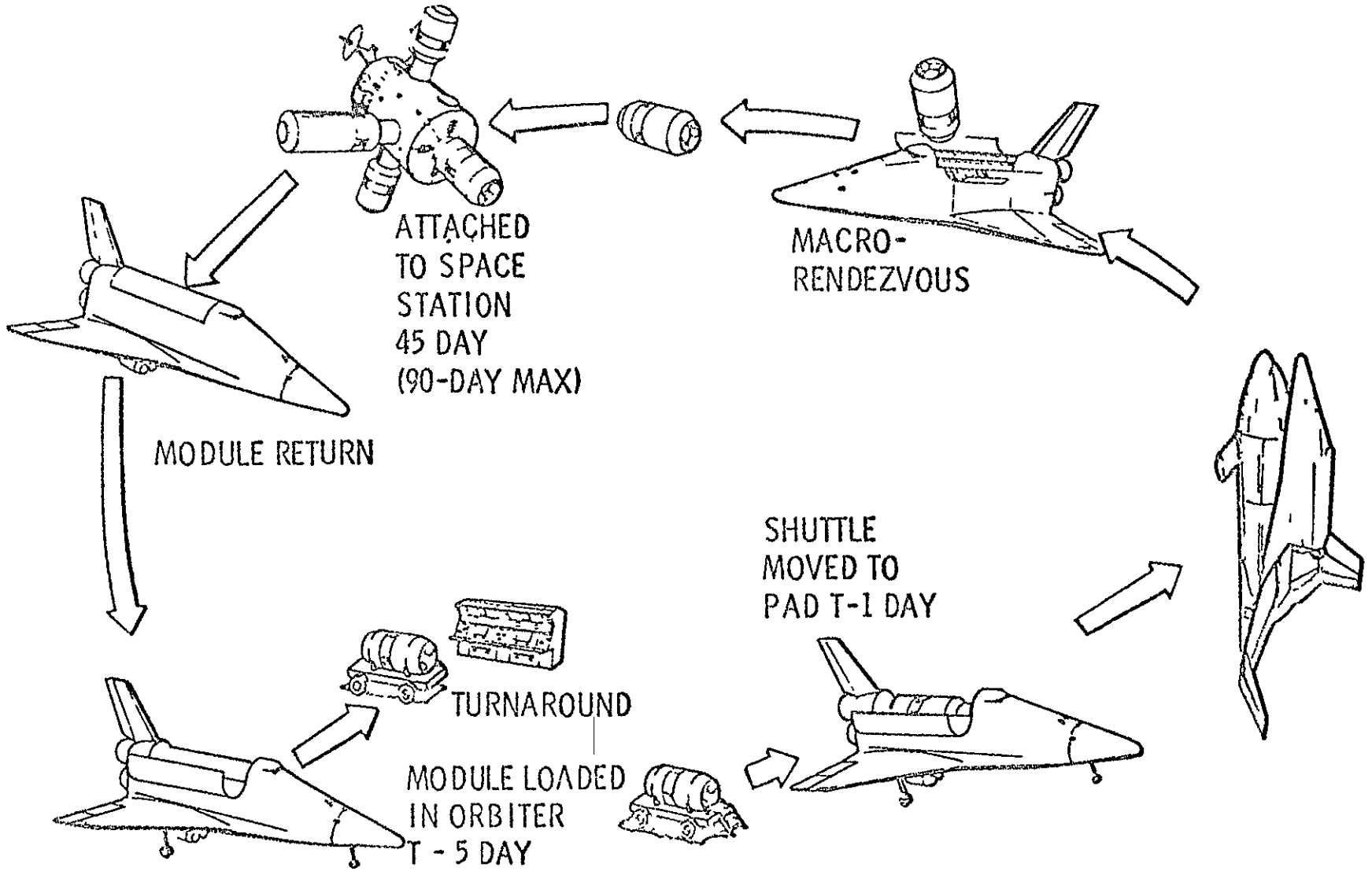


Figure 2.2-2 - Typical Operations Cycle for Resupply Mission

cycle. A preliminary mission schedule (Figure 2.2-3) provides a general idea of the major milestones conceived for the projected Space Shuttle Program. It should be noted that this is only one of many projected schedules and is presented here only as a general frame of reference.

2.3 Systems Descriptions

The systems described briefly in the following paragraphs are based on a careful analysis of current NASA study programs and in-house planning information regarding Shuttle/Space Station logistic concepts (Ref. NASA Blue Book NHB 7150.1[114] McDonnell Douglas Phase B Definition Study Reports).[79-84] These descriptions are generalized for the purpose of providing study models against which candidate transfer subsystem concepts can be evaluated. Although there are many alternate versions of the various systems, the present models provide a reasonable compromise which has allowed the authors to exercise their tradeoff criteria and to evaluate several feasible cargo transfer subsystem concepts in considerable detail. The systems considered in this section include the Space Shuttle, the Crew/Cargo Module (C/CM), and the Space Station (SS). The Shuttle is not analyzed in detail, however, since the study was limited to cargo transfer between C/CM and SS. The final system models reflect most of the MSFC baseline concepts as of November, 1970.

In addition to the above, general concept descriptions were developed for the cargo itself as well as for Cargo Transfer Subsystems (CTS).

2.3.1 Space Shuttle

The Space Shuttle is a recoverable two-stage vehicle system being designed to support several future space missions. These may include:

a. Space Station/Space Base logistic support

b. Placement and retrieval of satellites

c. Delivery of propulsive stages and payloads for high energy missions

SPACE STATION-SHUTTLE MISSION SUPPORT SCHEDULE

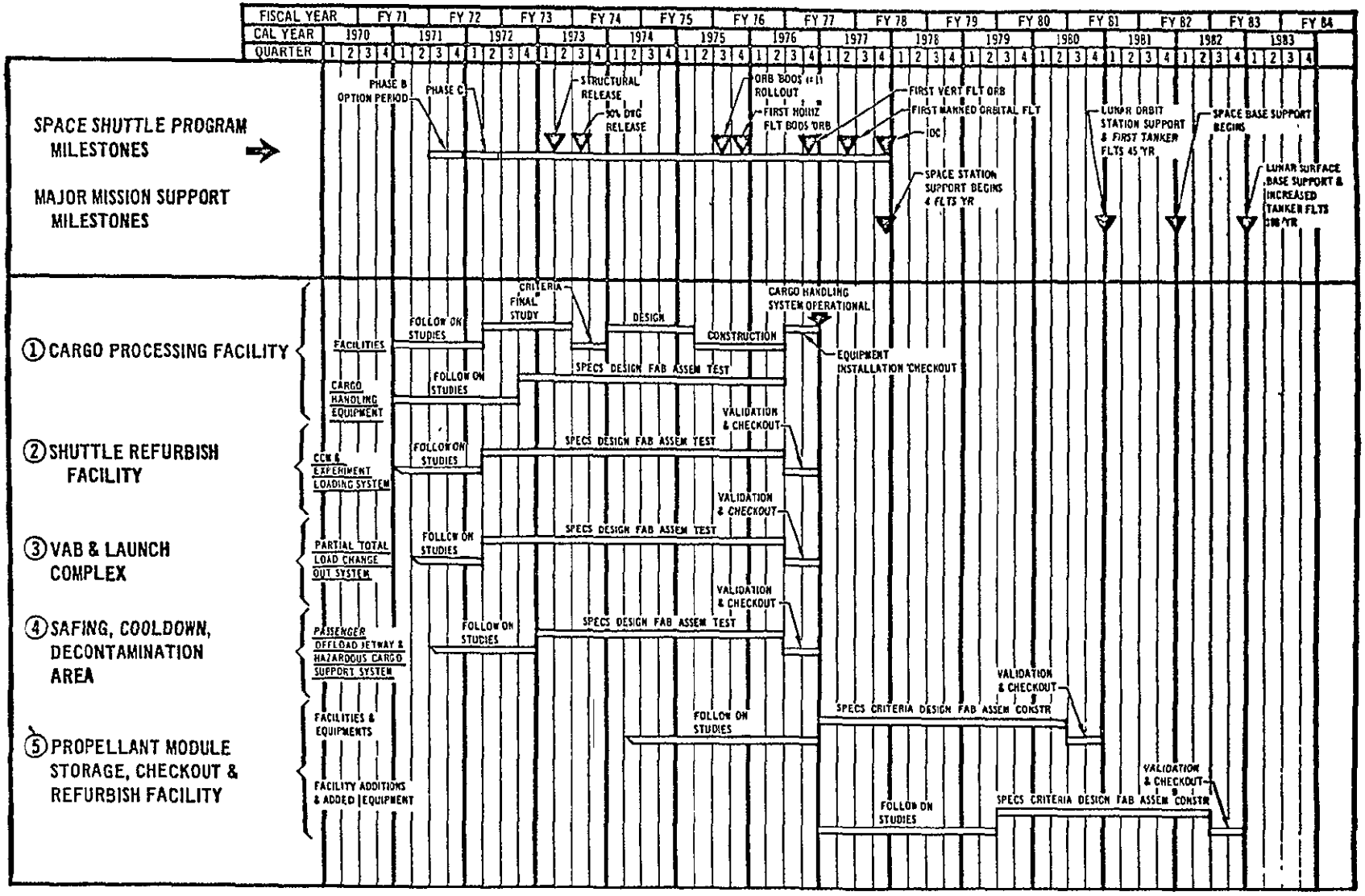


Figure 2.2-3 - Typical Shuttle Support Mission Schedule & Program Milestones

d. Delivery of propellants for reusable Space Tug or Nuclear Ferry

e. Satellite servicing and maintenance

f. Short duration orbital reconnaissance missions

A two-stage, reusable vehicle currently is envisioned (see Figure 2.3.1-1). A summary of the Shuttle's mission characteristics is provided in Table 2.3.1-1.

The orbiter element of the Shuttle System (Figure 2.3.1-2) has the following characteristics which ultimately may be pertinent to cargo transfer questions. Although these have not been examined in detail during this study, they are presented to complete the system description picture:

a. A 2-man flight crew, but flyable by a single crewman

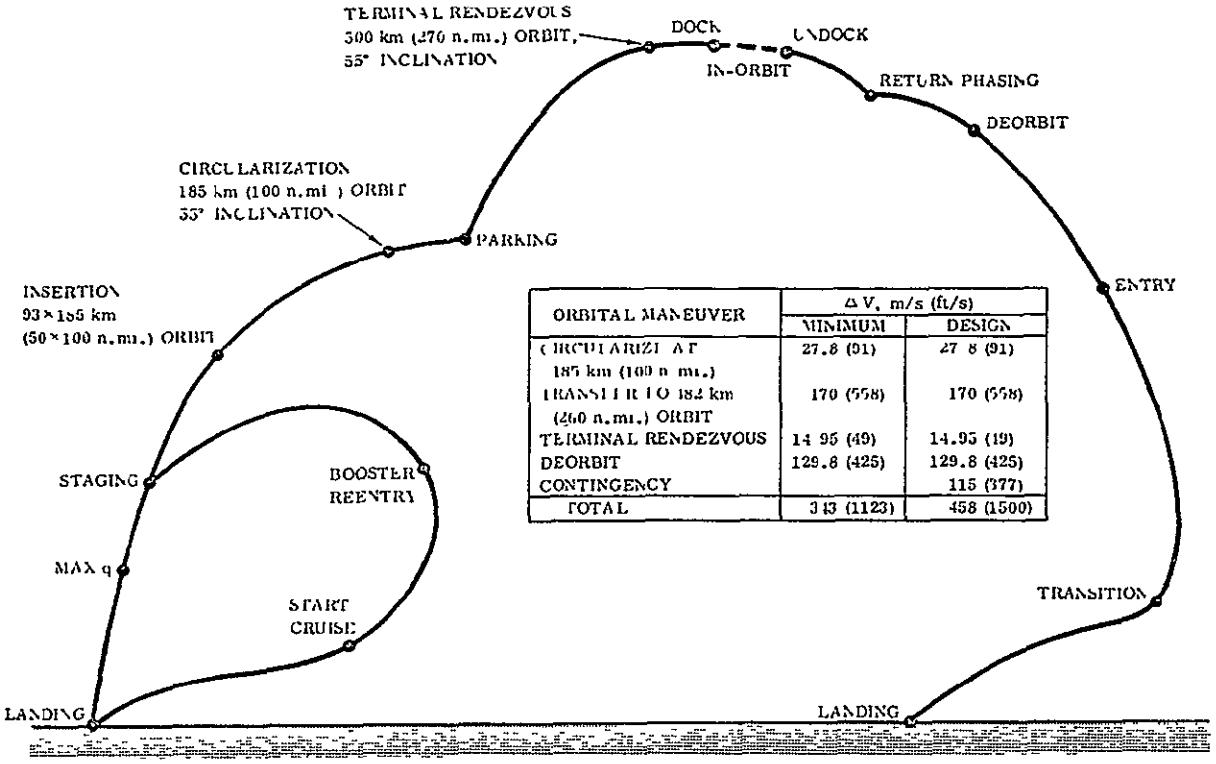
b. The ability to carry and deploy a 15-foot diameter by 60-foot long crew/cargo module.

c. An orbiter crew compartment utilizing an oxygen/nitrogen environment at a nominal pressure of 14 psi, permitting shirtsleeve operation. (Passenger compartment life support system in the C/CM is independent of the orbiter crew compartment, but also shirtsleeve.)

d. An orbiter trajectory design load of 4-g, with a 3-g anticipated capability for passenger-carrying missions.

e. Operational procedures anticipate the Orbiter and its C/CM payload will dock at the Space Station via the C/CM to accommodate personnel and cargo transfer (Figure 2.3.1-3). Normal procedure implies crew intra-vehicular activity (IVA) only, however, emergency EVA cargo transfer modes are a distinct possibility. EVA transfer is not covered in this study.

It might be noted at this point that although Shuttle vehicles were not examined in detail, a number of critical human factors problems appear to be unresolved in terms of the design concepts reviewed. Crew control-display interfaces in the cockpit and the C/CM passenger/crew compartment accommodations are the most significant areas of concern. And



ORBITAL MANEUVER	ΔV, m/s (ft/s)	
	MINIMUM	DESIGN
CIRCULARIZE AT 185 km (100 n. mi.)	27.8 (91)	27.8 (91)
TRANSFER TO 482 km (260 n.mi.) ORBIT	170 (558)	170 (558)
TERMINAL RENDEZVOUS	14.95 (49)	14.95 (49)
DEORBIT	129.8 (425)	129.8 (425)
CONTINGENCY		115 (377)
TOTAL	343 (1123)	458 (1500)

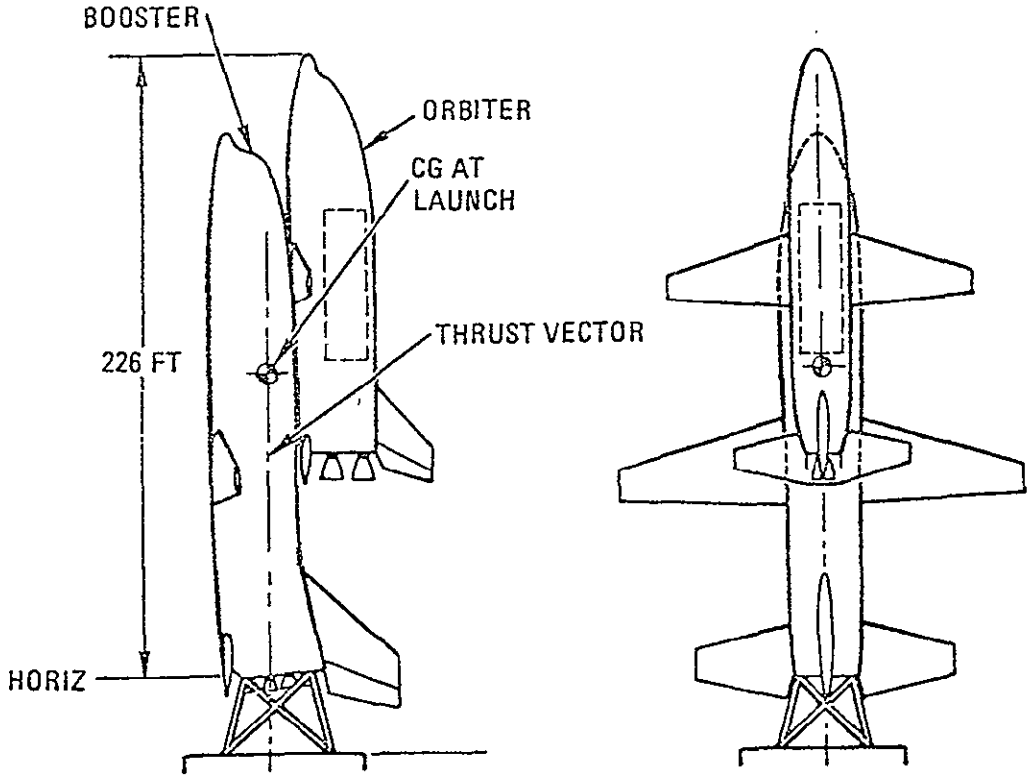


Figure 2.3.1-1 - Two-Stage Shuttle System and Operations Sequence

Table 2.3.1-1 - Preliminary Mission Characteristics (Adapted from NASA/MSFC Tech. Reqmts Document MICS-PD-PP-70-1, April 12, 1970)

	Space Sta. Base Logistics Support	Placement & Retrieval of Satellites	Delivery of Propulsive Stages and Payload	Delivery of Propellants	Satellite Service & Maintenance	Short Duration Orbital Mission
Orbital Characteristics						
Altitude (n.mi.)	TBD	100-800	100-200	100-300	100-800	100-300
Inclination (deg)	28.5-90	28.5-Sun syn	28.5-55	28.5-55	18.5-Sun syn	28.5-90
On-Orbit Stay Time (days)	3	7	7	7	7-15	7-30
Shuttle Personnel						
Crew	2	2	2	2	2	2
Passengers (min)	Rotate 50 men/Qtr	2	2	2	4	10
Ascent Payload						
Weight (1000-lb)	70/Qtr	10-50	25-50	50	5-15	25-50
Volume (ft^3)	TBD	5-10	10	10	5-10	4-6
Return Payload						
Weight (1000-lb)	45/Qtr	10-50	TBD	TBD	15	50
Volume (ft^3)	TBD	5-10	TBD	TBD	5-10	4-6

TBD - To Be Determined (still under study or requires further research)

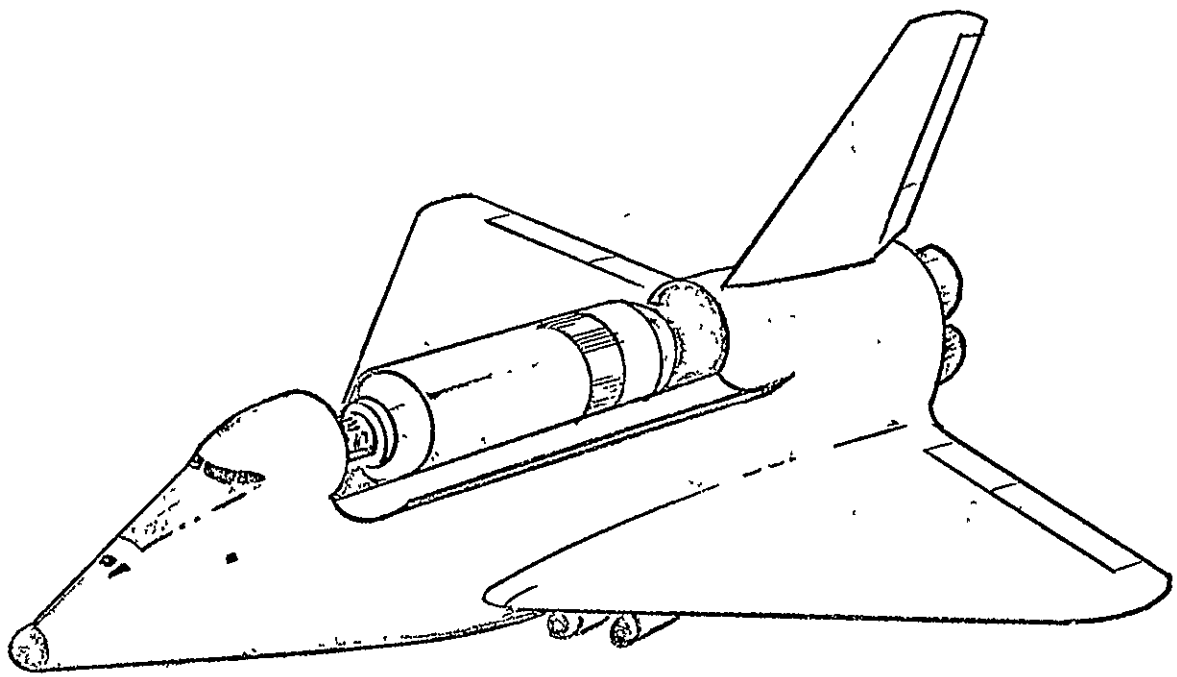
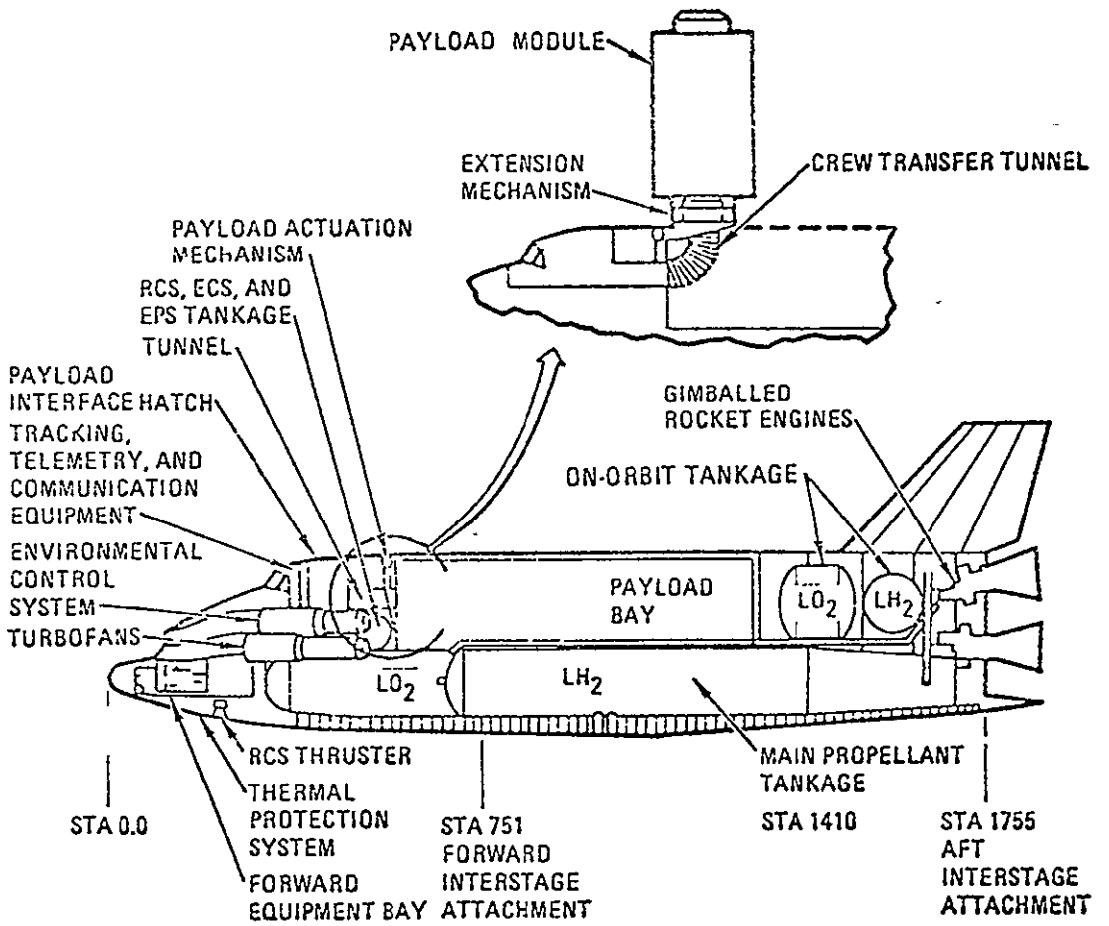


Figure 2.3.1-2 - Shuttle Vehicle: Orbiter Stage



Space Shuttle Orbiter Inboard Profile

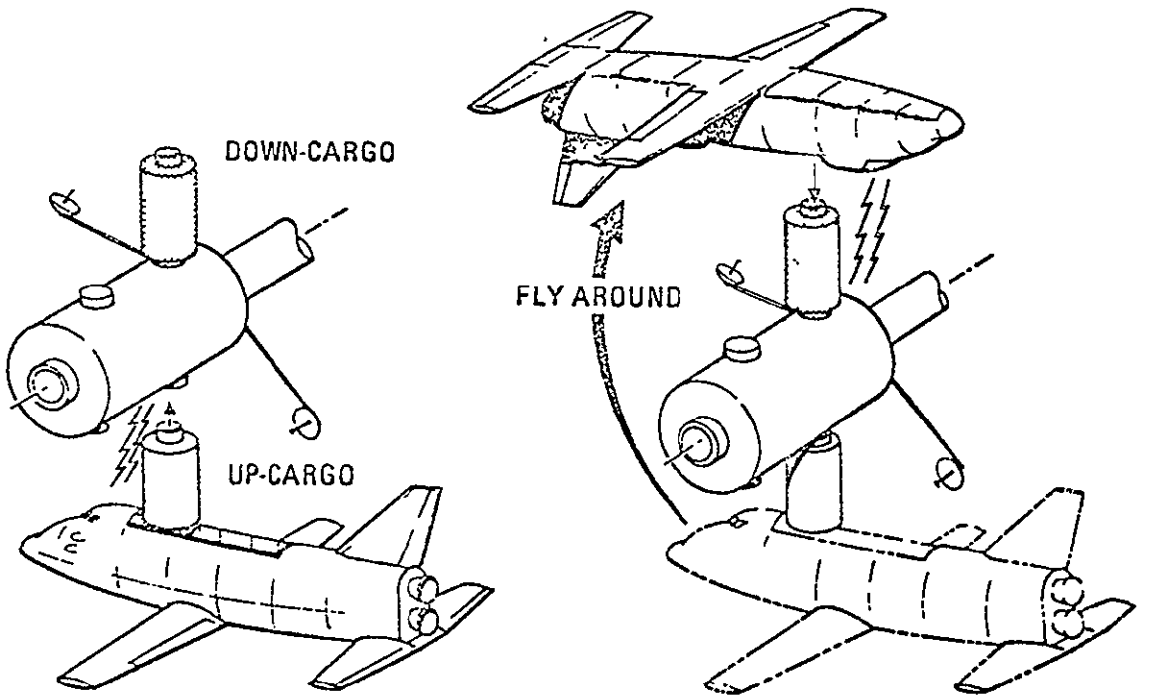


Figure 2.3.1-3 -Cargo Module Operational Mode

although they are not discussed in this report, their importance should not be overlooked by the NASA. Currently it appears that these questions have been assumed not to call for any new techniques and that the crews and their interface supports can be much the same as they would be for contemporary aircraft. This is not true, however, since the Shuttle vehicle traverses both an atmospheric and a space environment. The critical problem of re-entry appears to have been overlooked by the current Phase B predesigners, as indicated by the inadequate positioning of C/CM passengers for re-entry g-forces.

2.3.2 Crew/Cargo Module

The crew cargo module is essentially a self-sustaining, low cost system capable of transporting a mixture of crew and cargo varying from twelve men plus cargo to a version of cargo only (approximately 12,500 lbs). Although studies have examined various crew-cargo mixes (see Table 2.3.2-1), the preferred baseline -- and the one utilized during this study -- is a six-man-plus-cargo version. Figure 2.3.2-1 shows one typical design concept, indicating the general arrangement of internal elements. The C/CM is designed to provide means for rotating twelve men every 90 days during the ten year duration of the space station mission operation, and will deliver during that period of time approximately 850,000 lbs of cargo.

For purposes of the present study, the following assumptions were made concerning C/CM operation:

a. A 45-day, average launch frequency.

b. The C/CM would operate as a "lifeboat" (e.g., when attached to the SS, the CM would be self-supporting and also capable of receiving from, and/or supporting, certain subsystems of the space station).

c. The C/CM was assumed to be in a "pantry mode" when attached to the SS (i.e., although some supplies would be transferred immédiately upon docking, the major portion of the cargo would remain in the C/CM until re-quired, i.e., it would be "on-call.")

A major problem was created during the study because of the myraid of storage schemes suggested, none of which provided much detail. This made it extremely difficult to determine

Table 2.3.2-1 - Crew-Cargo Mix Comparison

Requirements:

- Rotate 12 men every 90 days
- Deliver 850,000 lb cargo over 10 years

Option	C/CM Configuration	Cargo/Flight (lb)	Flight Frequency (days)	Number of Flights	Total Delivered Cargo (lb)
A	12 Men + Cargo	7,200	90	41	846,000
	Cargo Only	12,500	90	44	
B	6 Men + Cargo	9,900	45	85	847,000
C	4 Men + Cargo	10,900	30	123	1,338,000

Option B Selected: (Preferred on basis of McDonnell-Douglas analysis)

- Staggered Crew Rotation Provides Skill and Duty Cycle Flexibility
- Single C/CM Configuration
- One Less Docking Port

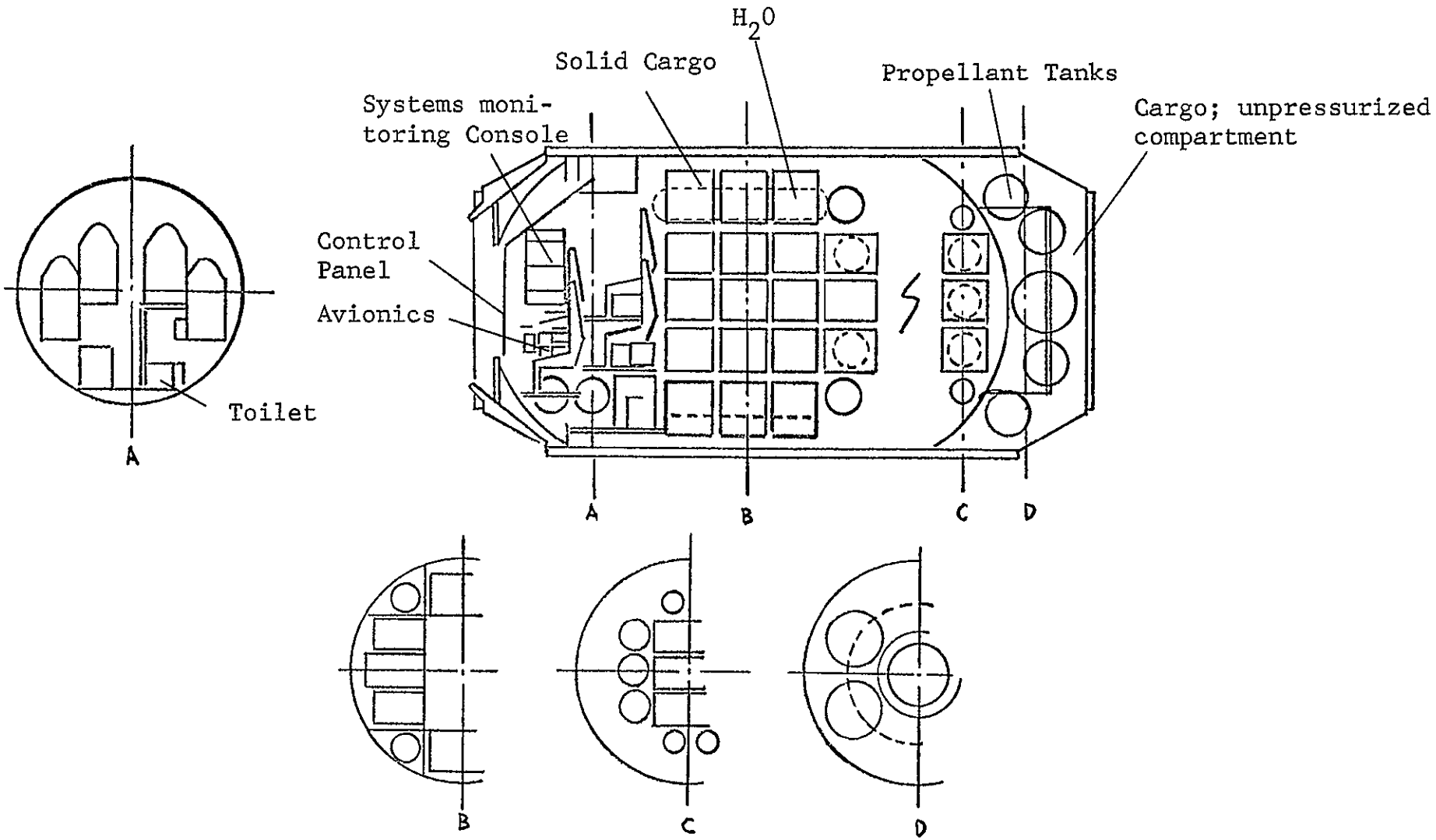


Figure 2.3.2-1 - Typical C/CM Design Concept

what the inherent man-machine interface problems might be. Typical concepts are illustrated in Figure 2.3.2-2 indicating the level of detail usually available.

In addition, several schemes were, and still are, under study relative to the C/CM-SS docking modes, i.e., end vs side docking. In order to provide a reasonable study baseline, MFI chose an end-dock configuration as the primary mode (with side dock at the 1st deck as an alternate) and assumed that the cargo of primary interest would be stowed only in the pressurized areas of the C/CM in an arrangement similar to that shown in Figure 2.3.2-2 (b). The general dimensional assumptions for the baseline C/CM included an interior diameter of approximately 14 feet, a 5-foot diameter docking port and a distance between the docking port and the farthest cargo of not more then 30 feet. It should be noted that in spite of this general C/CM model, consideration has been given to problems inherent in the side-dock mode and their impact on candidate cargo handling concept comparisons. The selected C/CM "stowage" model was chosen because it represents the highest density stowage capability. It has been referred to as the "Ice House" concept (see Figure 2.3.2-3).

Although the general C/CM study model assumptions discussed above provide a point of departure, it is apparent that a number of other questions relating to cargo handling should be defined. These include questions such as: How much working space must be provided in the area enclosed by the cargo stowage rack so that crewmen can remove and replace packages? MFI analysts have assumed that this space should be minimal (e.g., just enough to allow the man to work successfully) so that as little stowage volume as possible is lost. Such an assumption requires more knowledge about package size and shape and how packages will be stowed, as well as what type of hardware may be necessary to gain access to certain packages. There appears to be no such detail at this time, although several ideas can be generated to demonstrate the feasibility of high density packaging and minimum maneuvering space (see Figures 2.3.2-4 and 5). The minimum required "clear working space" defined for this study is an envelope of approximately 76 by 40 inches.

2.3.3 Space Station

The Space Station (SS) is a key element in the overall

CCM CARGO STOWAGE CONCEPTS

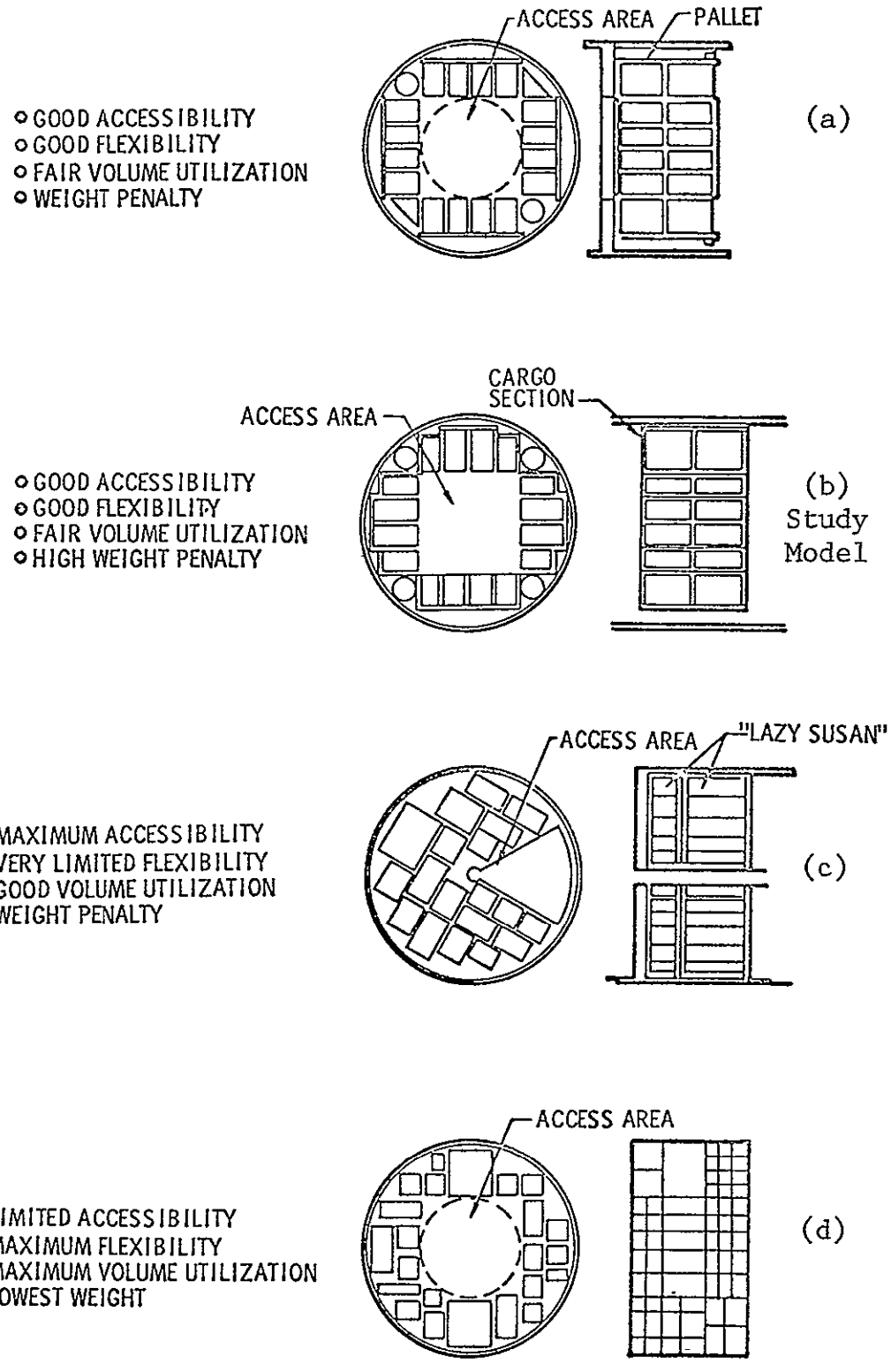


Figure 2.3.2-2 - Several Stowage Concepts for C/CM

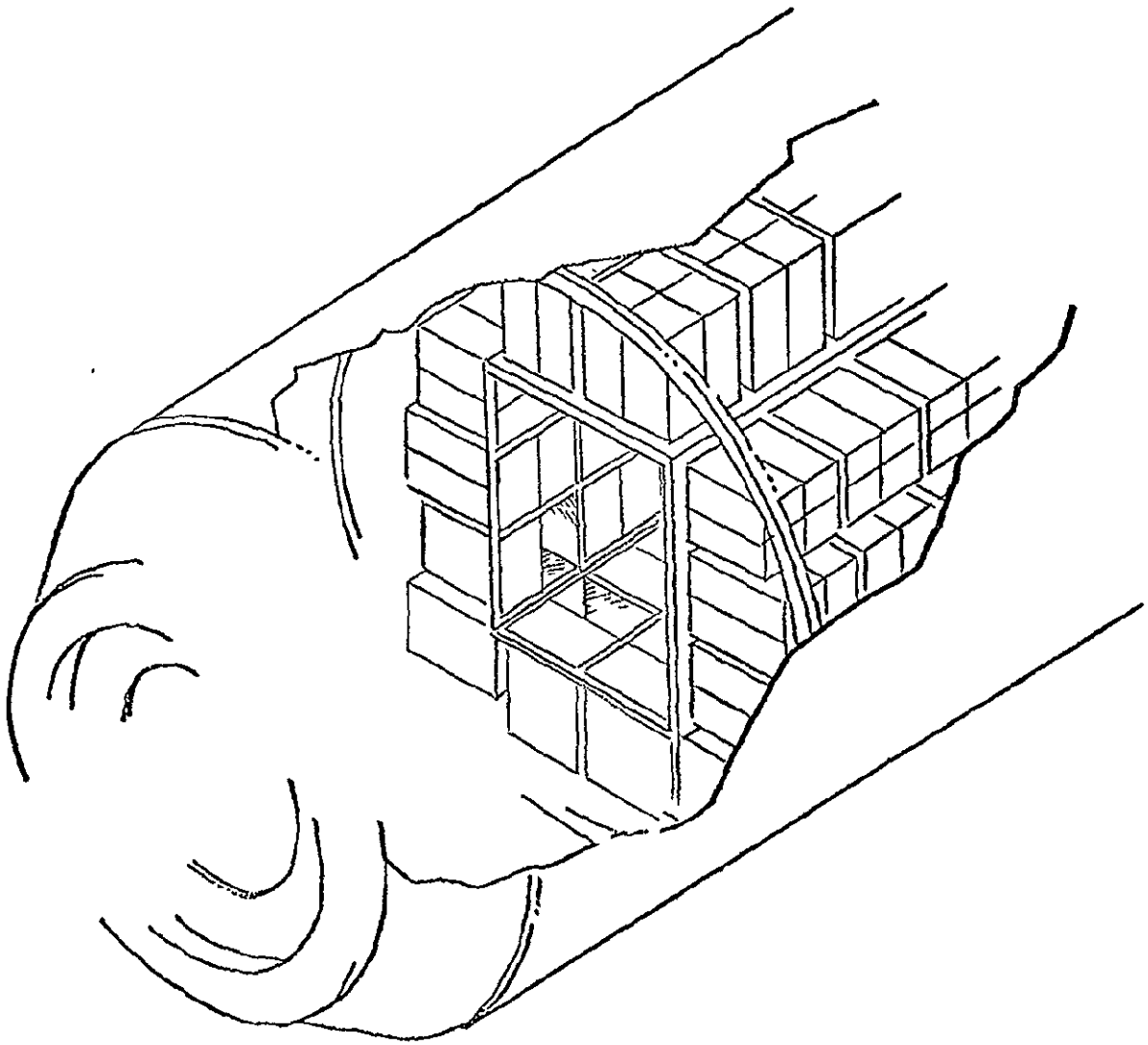


Figure 2.3.2-3 - "Ice House" Stowage Concept for Maximum C/CM Space Utilization

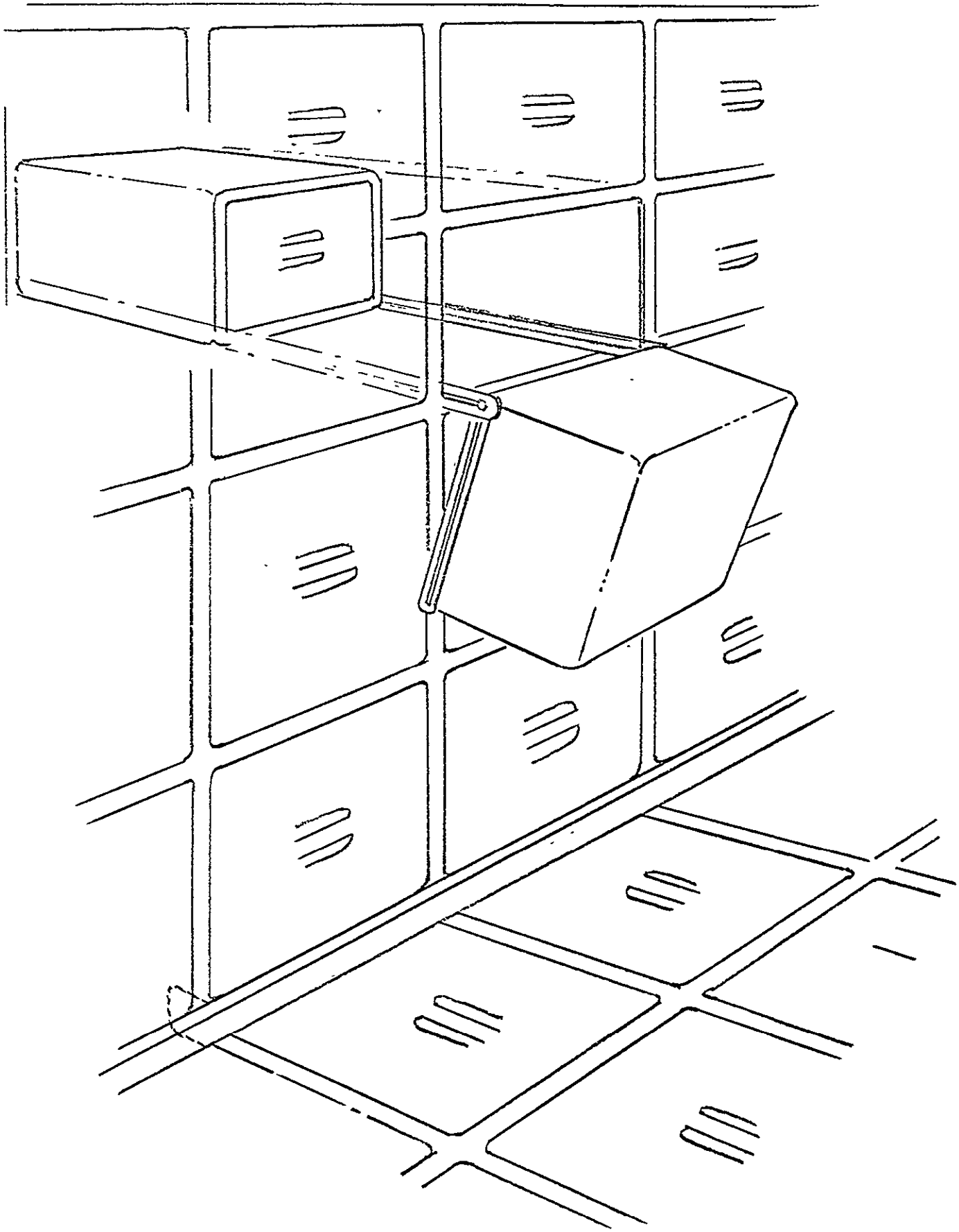


Figure 2.3.2-4 - Modules Stacked in Depth to Reduce Necessity to Reach Deep Into Rack Recesses

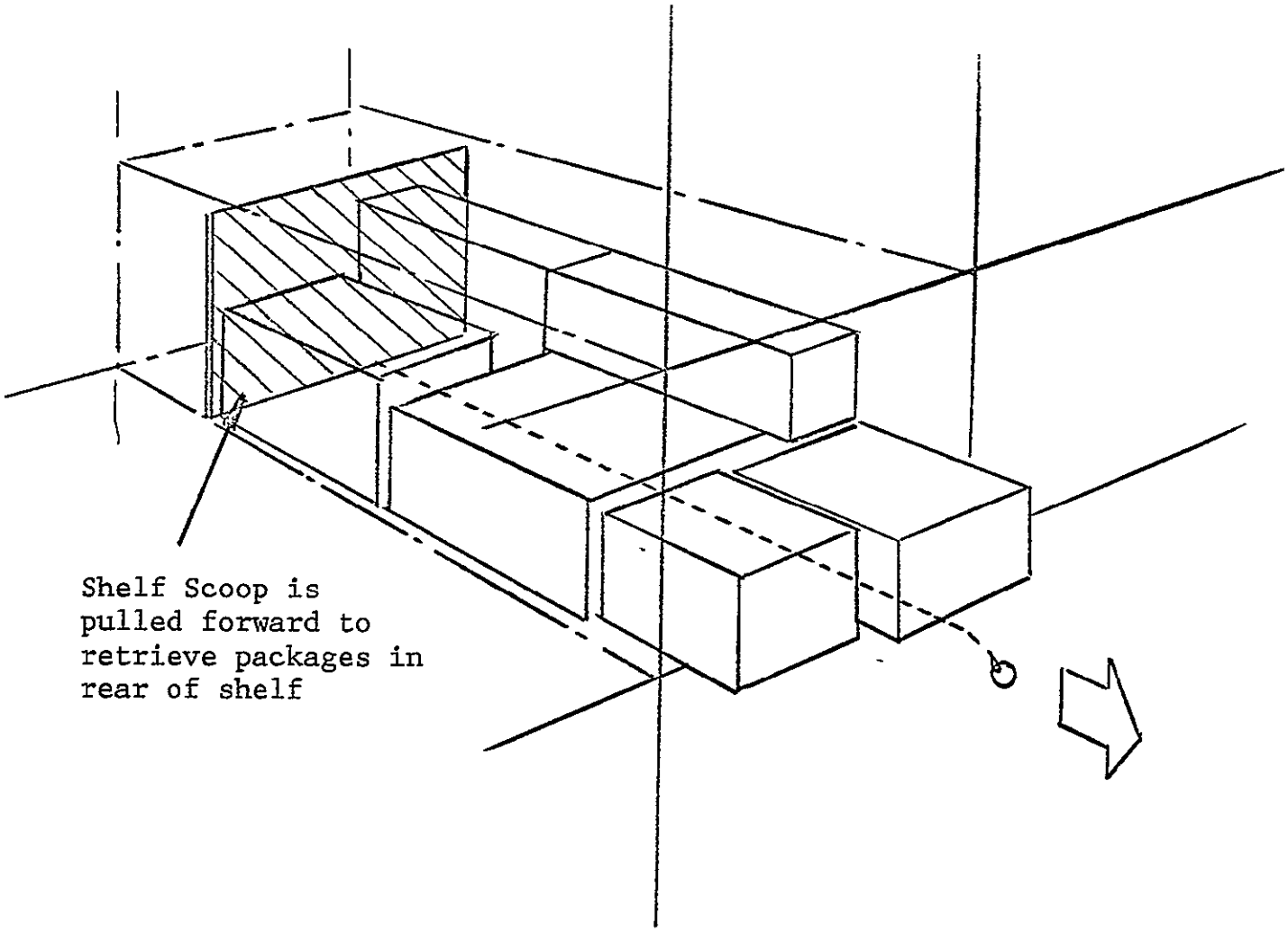


Figure 2.3.2-5 - Shelf Scoop Provides Simple Method for Bringing Packages Forward in Deep Racks

Shuttle resupply mission, imposing both cargo handling requirements as well as design constraints on an eventual cargo handling system concept.

Since there is a great variety of SS concepts under consideration by the NASA and its Phase B Contractors, it has been difficult to establish a reasonable configuration baseline for cargo requirements analysis. However, after reviewing most of these concepts in considerable detail MFI has developed a generalized model which is similar to what is referred to as an Integral Station concept, since this appears to represent the most nearly typical cargo handling requirements and implementation problems.

This model (shown in Figure 2.3.3-1) is a multi-storied, cylindrical structure 33 feet in diameter and approximately 60 feet long. It consists of 4 decks with a torus compartment at either end. A central tunnel (10 feet in diameter) connects all station compartments with a primary docking port at one end of the tunnel, by means of 5-foot hatches at each deck within the tunnel. The tunnel can be pressurized as an emergency shelter in the event of catastrophic failure on any one of the decks. Pressure hatches are located at each deck between the tunnel and the deck compartment. This hatch has been defined arbitrarily as an opening 30 by 60 inches, representing a typical, minimum-pressure hatch for personnel passage.

Unlike the tunnel area, individual compartment areas on each of the decks cannot be defined so clearly since there seems to be little agreement at this point in time as to what will be located on each deck or how it will be arranged. Because of this MFI has not tried to define the workplace areas in terms of a study model. Instead, it has been assumed (for the time being) that cargo transfer in these areas will be of the manual variety. This decision is considered defensible on the basis of the limited graphic descriptions (mainly artist sketches such as those shown in Figure 2.3.3-2) wherein it can be seen that very short transfer distances are involved. Even in the case of a circular hallway it appears unlikely that a semi-automatic, mechanical transfer device could be allowed to usurp part of the limited hall width as a tradeoff for the questionable advantages of moving a few packages the full length of the hallway.

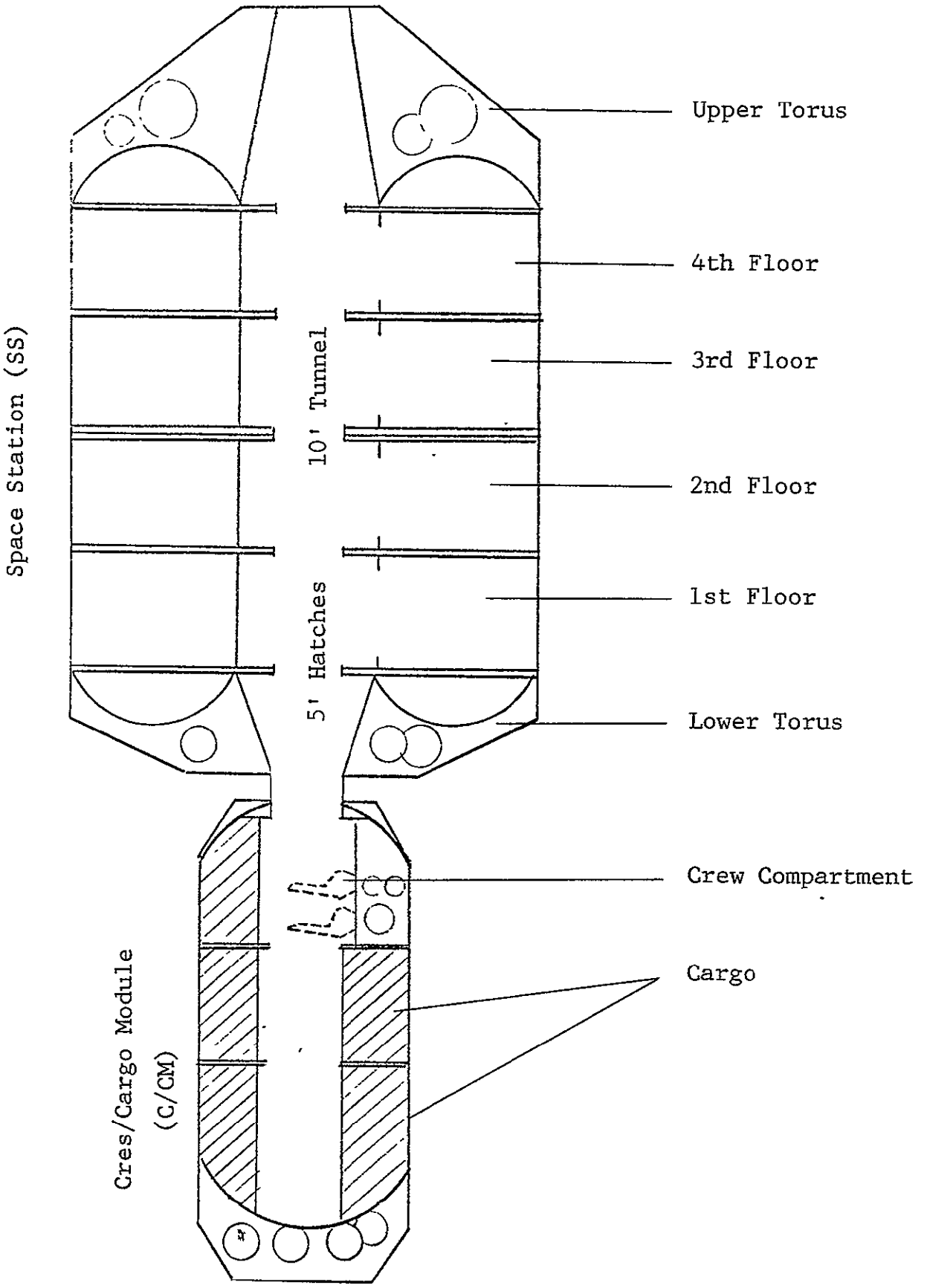
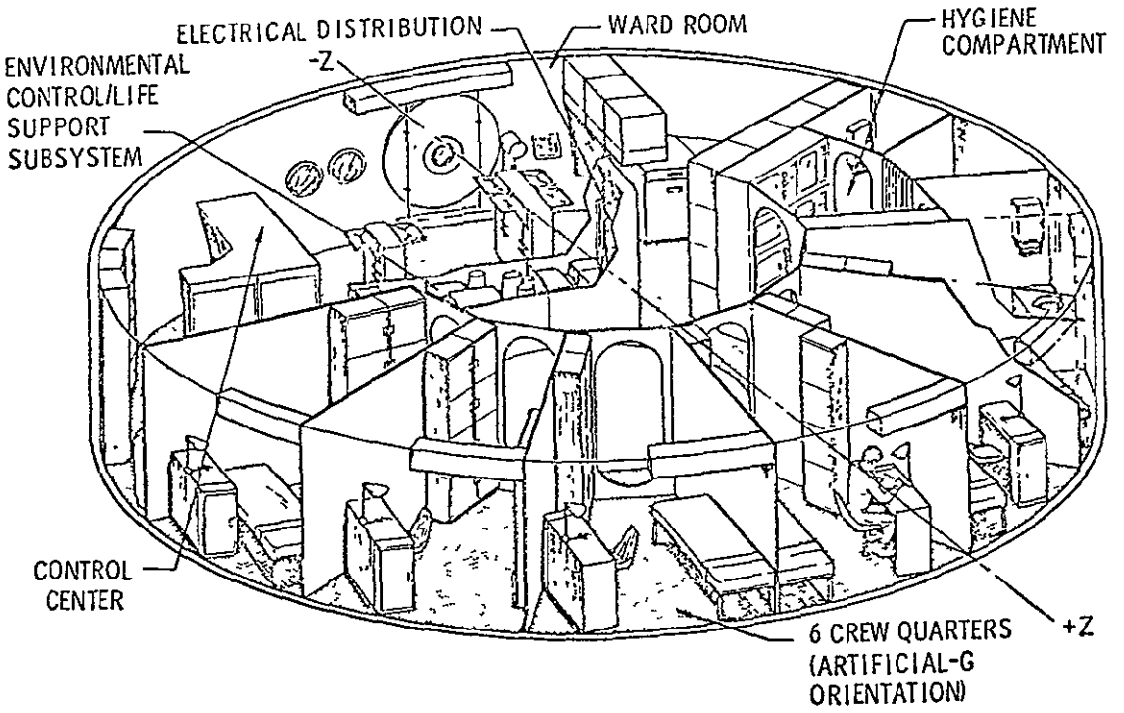


Figure 2.3.3-1 - Generalized Space Station-Cargo Module Study Model

CREW FACILITIES AND OPERATIONS
DECK 1 AND 3



EXPERIMENTS DECK 2

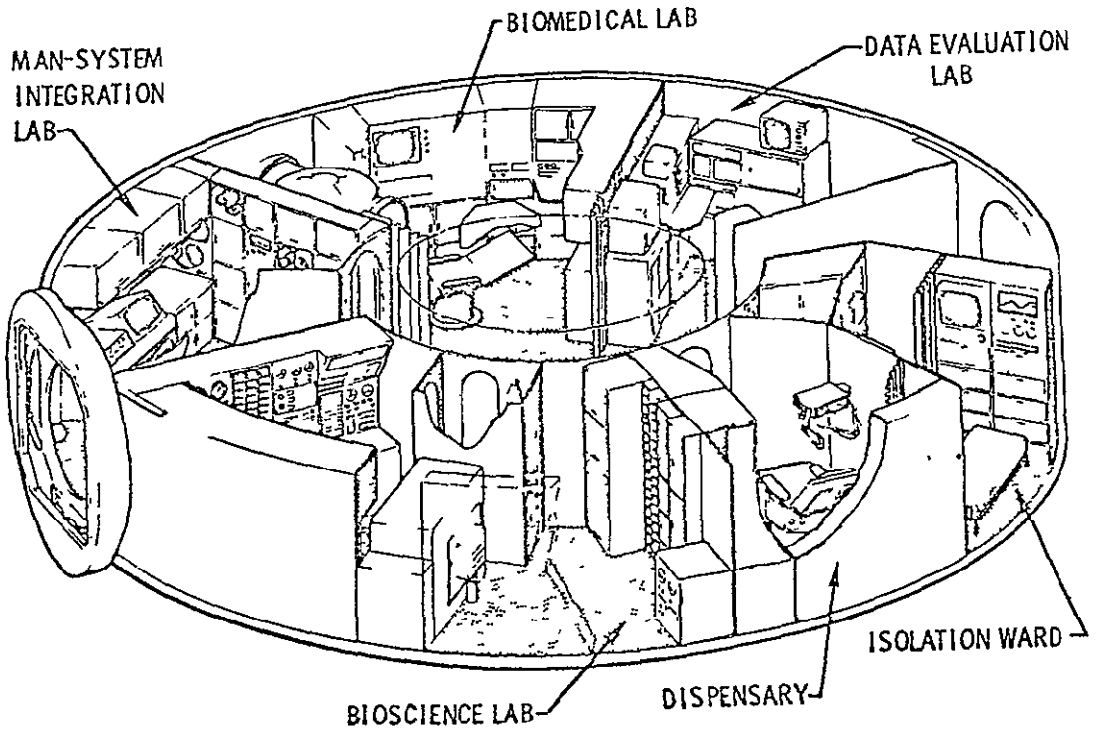


Figure 2.3.3-2 - Typical Space Station Compartment Assignment and Arrangement Concepts

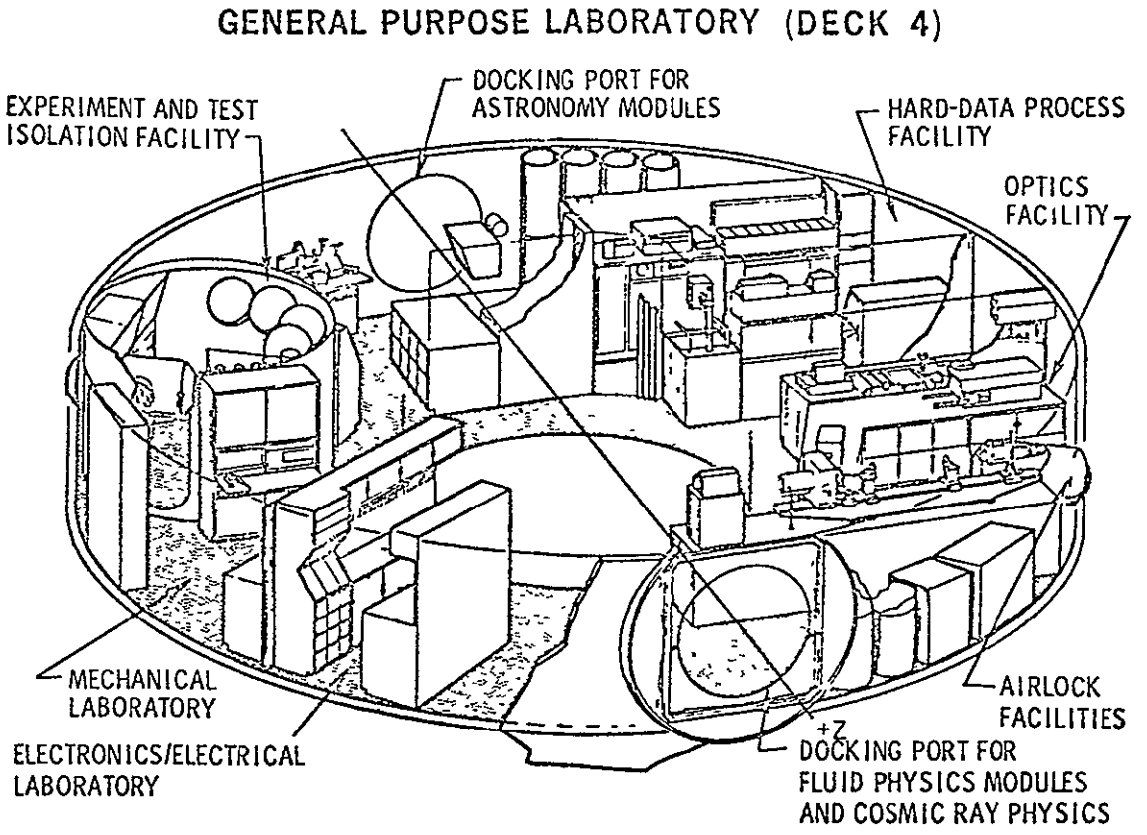


Figure 2.3.3-2 - Typical Space Station Compartment Assignment and Arrangement Concepts (Cont'd)

2.3.4 Cargo

In analyzing all of the available information developed to date regarding cargo characteristics and quantities for the Shuttle-Space Station mission, it immediately becomes apparent that a description of the cargo in simple terms is extremely difficult and perhaps premature. General estimates of total cargo requirements are shown in Figures 2.3.4-1 and 2, and Table 2.3.4-1. It also becomes obvious, in reviewing such cargo analyses as that performed by McDonnell-Douglas [82], that individual cargo items can vary from the smallest equipment, part or food package to very large and irregularly-shaped experiment equipments. It seems equally clear that handling many very small items on an individual basis is not efficient. Therefore, the question becomes one of estimating what the probable collective package characteristics will be, whether they are collected within modular containers or as larger individual equipment items.

The largest single item volume requirement has been estimated by other analysts as approximately 70 ft^3 and weighing approximately 150 earth-pounds. Extrapolations by others from zero-g simulated package handling experiments indicates that a package weighing more than 80 lbs is inconvenient for one man, and a 150-lb package requires two men to handle it efficiently.[115]

Other estimates indicate that about 60 percent of the resupply package handling will deal mostly with packages within the above limits. Although a number of suggestions have been made about how best to handle small items in several sizes of modular containers, little experimental evidence can be found to support the validity of these recommendations. MFI has developed a container-sizing concept that provides four sizes of containers designed to nest within one another for empty storing. This set is, of course, arbitrary and utilized the simple criterion that the smallest size merely represents a manageable package for one man to handle; the largest represents the 70-ft^3 maximum volume that appears to satisfy the largest single item defined by other analysts.

Although this four-package modular concept appears reasonable in most respects, it is recognized that the largest package is not compatible with the 5-foot diameter docking hatch or the 5-foot access opening in the SS tunnel area. Similarly,

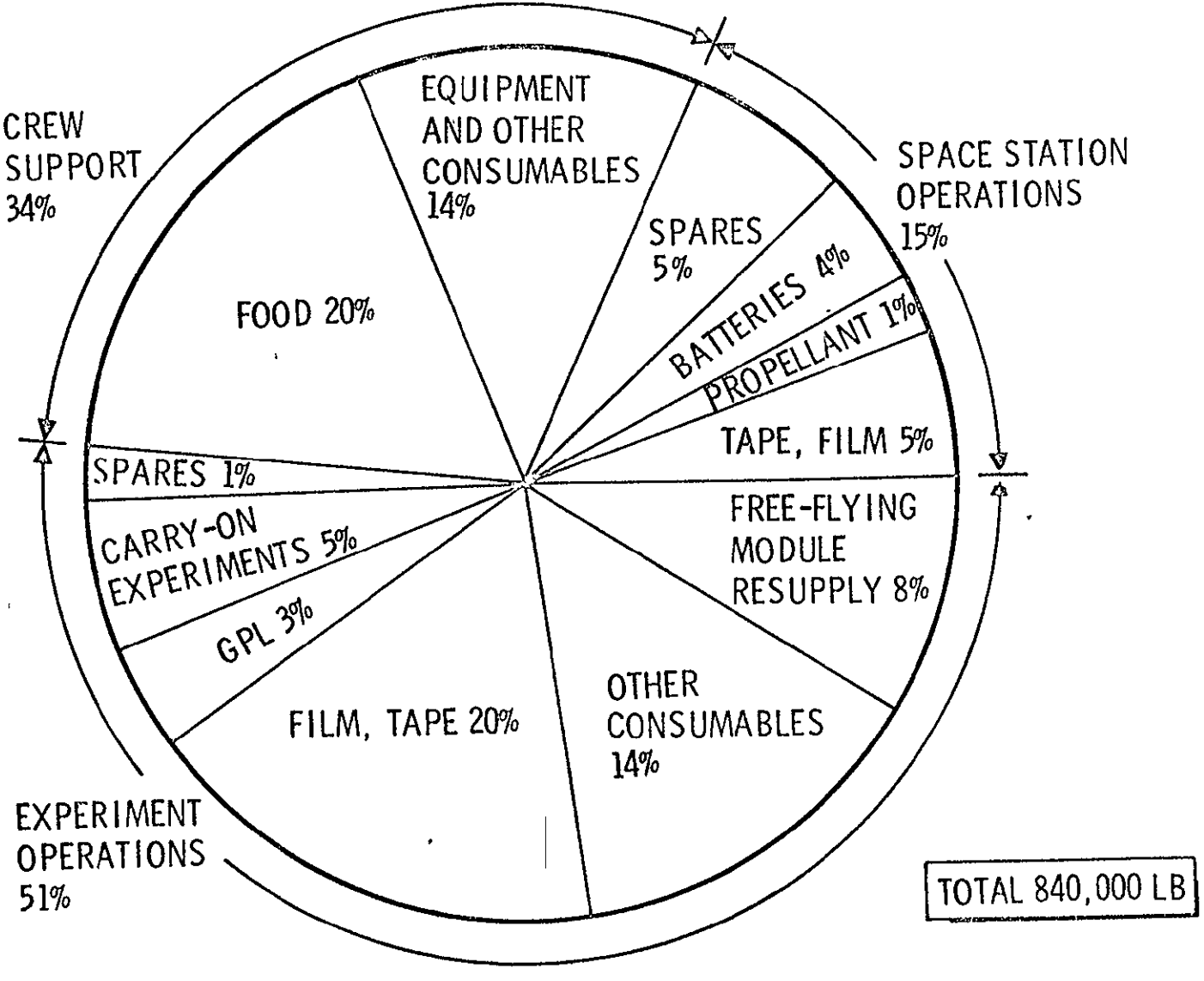


Figure 2.3.4-1 - Cargo Requirements 10-Year Space Station Operation By Weight

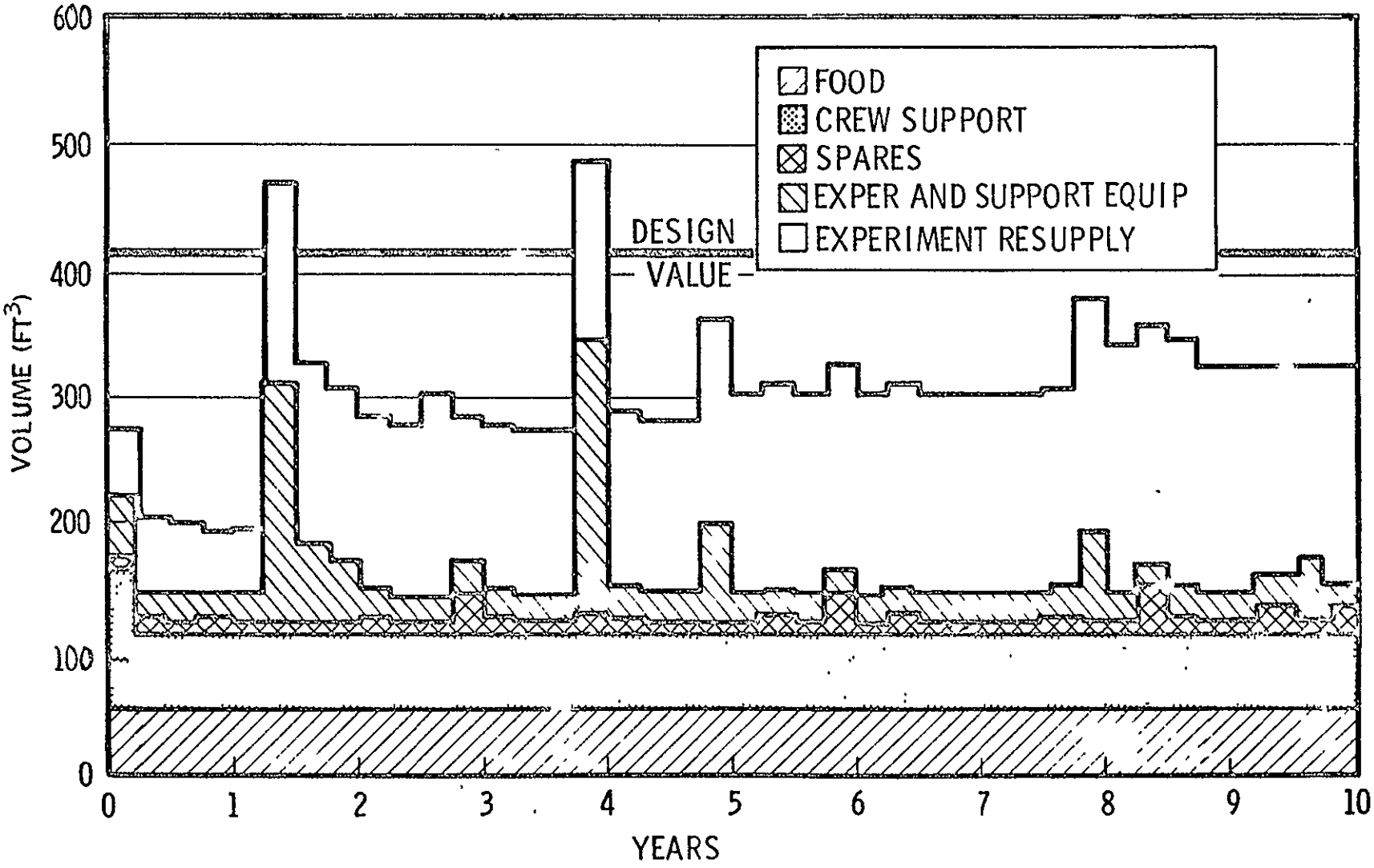


Figure 2.3.4-2 - Space Station Solid Cargo Volume Requirements

45 Day Periods

Table 2.3.4-1 - Cargo Characteristics

RESUPPLY ° STANDARD CONTAINER MODULES (2 X 2 X 2 FT) AND SUBMODULES FOR 95% OF SOLID ITEMS ° STANDARD MODULES AND SUBMODULES WEIGH LESS THAN 150 LBS ° SPECIAL STOWAGE FOR REMAINING 5% (5-FT DIA; 350-LB) ° SEVEN TYPES LIQUID AND GASEOUS CARGO IDENTIFIED IN VARIOUS MIXES ° SIGNIFICANT QUANTITY OF LH_2
RETURN ° 75% OF SOLID CARGO WEIGHT RETURNED ° TRASH AND WASTE COMPACTED AND TREATED TO 30 LB UNITS (TOTAL OF 1500 LBS/FLIGHT) ° WASTE UNITS STORED IN STANDARD CONTAINERS ° EXPERIMENT DATA, SPECIMENS AND REPLACED HARDWARE ITEMS RETURNED IN STANDARD CONTAINERS

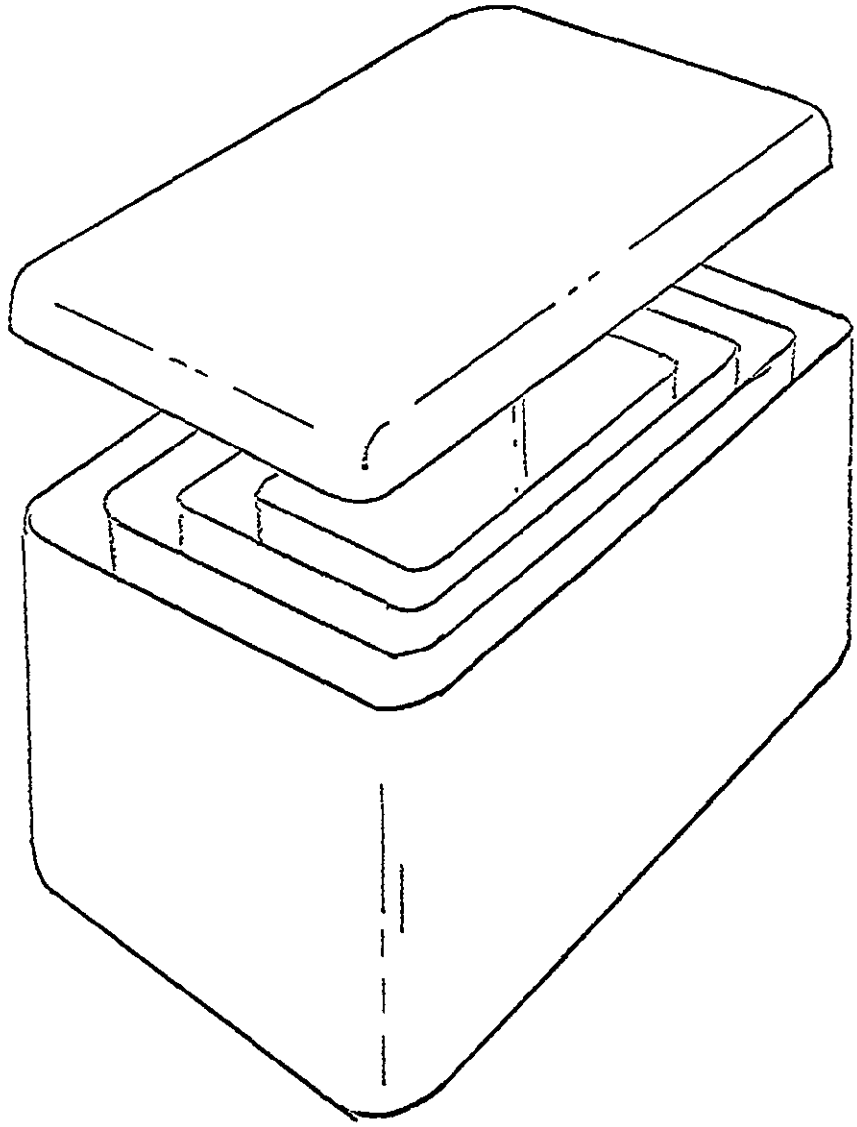
the arbitrary compartment hatch defined earlier (30 by 60 inches) eliminates the larger package altogether unless one of two things is done, viz. the compartment hatch size is modified, or the largest package is modified so that lateral dimensions are reduced, thereby causing the length to be increased to the point where the modular nesting concept no longer is valid.

For purposes of later evaluation of candidate in-space cargo transfer systems it became necessary to consider cargo only in very general terms. First, it has been assumed that primary concern in evaluating transfer systems must relate to cargo items which are moved most often and in the greatest quantity, i.e., those that support crew provisioning and experiments. These appear to be small enough to be compatible with the foregoing four-container module concept. Although the largest container will not fit through the model hatch criteria, it can be moved as far as the compartment hatch where the contents can be removed, one by one, into the compartment.

Very large, unique cargo items such as special experimental equipments will have to be moved into a compartment through a side hatch at least 5 feet in diameter. Figure 2.3.4-3 illustrates the 4-module container set used to establish the general range of container packages considered in evaluating transfer systems. Figure 2.3.4-4 illustrates the limitations of hatches, together with several alternative sizes of packages that could be moved through each. This latter model is provided because it seems likely that some common packages will not fit into the four modular containers and will have to be packaged independently. These shapes are, therefore, limited to the extent shown and influence the manner in which a transfer system must provide accommodation for them.

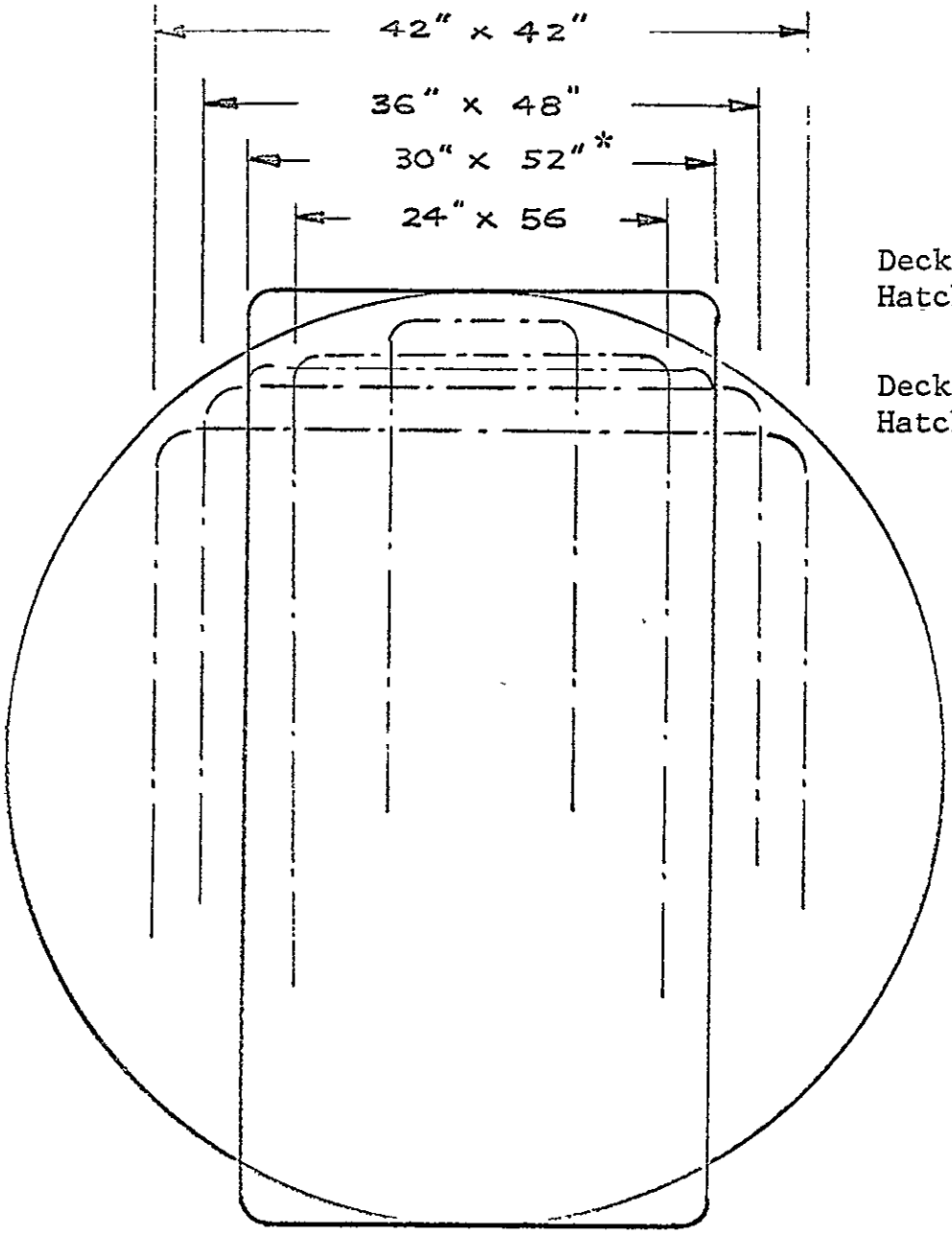
2.3.5 Cargo Transfer Systems (CTS)

For purposes of the present study cargo transfer systems have been divided into three classifications: (a) Semi-Automatic, (b) Manual-Aided and (c) Manual. Although a purely automatic system is possible, no such system appears to have been devised or proposed as yet. In fact all of the systems described and discussed in the following pages were prepared as generalizable combinations of known component hardware which would be amenable to a transfer system configuration. It might be pointed out that at the outset of this study it was assumed



Size A - 1½ ft^3, 1½ x 1 x 1 feet
Size B - 4½ ft^3, 2 x 1½ x 1½ feet
Size C - 18-3/4 ft^3, 3 x 2½ x 2½ feet
Size D - 70 ft^3, 5 x 4 x 3½ feet

Figure 2.3.4-3 - A Container Assortment Which Accommodates Estimated Cargo Content Requirements



* 30"x52" Package Approaches Limit of Deck Compartment Hatch Limit

Figure 2.3.4-4 - Possible Container Size Combinations Which Are Compatible with SS Tunnel Deck Openings and Compartment (Minimum) Hatch Criteria

that specific hardware systems would be available in sufficient detail to permit the analysis of the unique man-machine interface problems associated with each. Unfortunately this has not been the case. Except for rather preliminary information on the STEM concept and vendor brochures on the Telelift system, no other CTS has been developed beyond artist sketches or mock-ups, and none has sufficient detail upon which to base an evaluation of operator interface problems.

With this limitation in mind, the following system classification definitions were developed:

a. SEMI-AUTOMATIC SYSTEMS: Such systems will be electrical, pneumatic, hydraulic, or otherwise non-human powered and maneuvered.

   Cargo items may be located by a manual information retrieval system or by computer and may be obtained manually or through push-button control of automatically rotated shelves. The cargo is moved by electrical power under control of an operator. Loading and unloading will, however, be accomplished manually by a crewman. Generally speaking, in the Semi-Automatic system the crewman will not move with the packages.

b. MANUAL-AIDED: Such systems will be tracked, belted, pulleyed for guidance, but will be dependent upon human energy for their locomotion, starting and stopping, and end-point manipulation or guidance. Some systems will not require the crewman to move with the package, others will. Manual aids such as handholds and handrails will be used by the crewman to move himself and the packages and to guide and capture the package.

c. MANUAL: These system concepts rely entirely upon manpower for locomotion, package capture and guidance.

   Manual transfer represents a baseline point of departure since it usually will be the backup system when other categories fail. Table 2.3.5-1 identifies the basic factors or constraints of manual transfer.

In examining each of these system categories it is important to recognize and evaluate each of the following

Table 2.3.5-1 - Manual Cargo Transfer Constraints

1. Man has to propel and control both himself and the package.
2. He must be able to see what he is doing and where he is going.
3. He has to get hold of the package and maintain that hold.
4. He has to unlatch and re-latch package fasteners with one hand.
5. Any package which has to be carried without suitable handle increases the man/package imbalance situation.
6. Any latching manipulation should allow man to close the force loop within himself rather depending upon closure through the package or other structure.
7. Package mass should never be more than ½ the man's mass; package mass should be equally distributed whenever possible.
8. Package should never be so large that man cannot see over or around it when it is being transported.
9. Package handle diameters should not be so large that the man's longest finger cannot close with the fist or so small that the shortest finger has to press into the fist to maintain adequate grip on the handle.
10. Whenever possible, package shapes should be regular and flat-sided, with sides at right angles to each other.
11. Handles should be shaped, located and oriented so that they are compatible with all steps in manipulation and transport, and must consider the problems of handoff between crew members.
12. Package release and attachment to racks should be accomplished by a single-step manipulation.

functional requirements: package acquisition, package movement, package positioning, package release and package securing. A series of general transfer systems is classified by functional characteristics and requirements in Table 2.3.5-2. Additional descriptions also may be found in Appendix B.

2.4 Analytic Methods

The initial study work statement called for the use of a special analytic methodology developed during a previous study entitled, "The Study of Man vs Manipulator Functions" (NAS8-24384)[73]. This methodology, called Performance Effectiveness Evaluation Scheme (PEEVS), involved a four-step procedure for identifying "free space activity systems" (FSAS) that could be used in a specific mission. The steps included: (1) identification of extravehicular activity functions in the mission, (2) identification of highly developed FSAS's which appeared capable of performing the designated functions, (3) selection of system performance effectiveness and cost measures important to the mission, and (4) identification of an FSAS with the required capabilities and minimum cost. A fifth, optional step was the testing of the sensitivity of the system selection to assumptions and missing data.

Although a modified version of this methodology was used during the present study, other techniques also were applied in order to provide an effective approach to the analysis and identification of effective cargo handling systems. Three general analyses were performed: a functional/task analysis, a design evaluation, and a systems tradeoff analysis. These are described briefly in the following subsections.

2.4.1 Function/Task Analysis

Since task analyses really are meaningful only in terms of operator interface with well-defined -- preferably, existing -- hardware, any attempt to derive specific task requirements based on an essentially undefined and non-existing system necessarily implies the use of certain assumptions. Even so it tends to represent, essentially, a functional analysis combined with a simulated task analysis. This type of analysis can, of course, take many forms and is nearly always an iterative process, expanding and refining as more insight into mission and hardware parameters is gained.

Table 2.3.5-2 - Semi-Automatic CTS's: Package Handling
Functional Characteristics & Requirements

SYSTEM	ACQUISITION	MOVEMENT	POSITIONING	RELEASE AND SECURE METHOD
1. Dumbwaiter (A)	Computer or manual cargo location. Manual loading on movement subsystem	Electrically powered, the Dumbwaiter moves on dual rails from the C/CM loading area the length of the SS tunnel. A control panel is located in the C/CM or SS with Start, Stop, Rate & Distance controls. Movement rails are connective on docking. CTS launched with the SS.	Manual removal from clasps or Velcro.	Clasps or Velcro.
	NOTE: Cannot be used efficiently with side docking. Would require a right angle transfer at the Space Station.			
2. Dumbwaiter (B)	Same	Same, except crew moves on the system, control panel is located on the device (much larger motors required for Start & Stop operations).	Same	Same

Table 2.3.5-2 - Semi-Automatic CTS's: Package Handling
Functional Characteristics & Requirements (Cont'd)

SYSTEM	ACQUISITION	MOVEMENT	POSITIONING	RELEASE AND SECURE METHOD
3. Trolley (A)	Computer or manual cargo location. Manual loading on movement subsystem.	Electric motor, single-rail movement. Control panel located in SS or C/CM with Start, Stop, Rate and Distance controls and others (see Position in Subsystem). Rail is connected on docking; CTS is launched; possibly two trolleys used simultaneously.	Rail switch-off to compartment is possible. This permits two trolleys to be used.	Clasps, straps, other.
4. Trolley (B)	Same	Same, except crew moves on trolley with control panel located on mechanism.	Same	Same
5. Conveyor belt	Computer or manual cargo location;	Electrically powered, the conveyor belt will use standard pulleys. Control panel will be located in the C/CM or SS. Belt will extend into C/CM after docking. Mechanism will be launched with SS. Handholds may be located on conveyor belt to transfer Astronauts.	Manual off-loading.	Clasps, attach rings, bungee cords.

Table 2.3.5-2 - Semi-Automatic CTS;s: Package Handling
Functional Characteristics & Requirements (Cont'd)

SYSTEM	ACQUISITION	MOVEMENT	POSITIONING	RELEASE AND SECURE METHOD
6. Extendable Boom (STEM)	Computer or manual cargo locations. Manual securing with suction hooks, clasps, etc.	Electric motor, rate and travel controlled from LOS. STEM monitored in SS & controlled by operator in SS. (Not space-qualified, but same design as Skylab Boom).	Manual or additional Booms located in SS compartments.	Clasps, etc. as required.
7. Automatic Rail Trolley (Telelift)	Computer or manual cargo location. Manual loading on movement SS.	Electric motor, single or double rail layout. Control panels located in C/CM and all feasible destination points in SS or in system. Programmed for one rate. Destinations can be preprogrammed for automatic dispersal. Rail is connected on docking.	Rail switch-off to compartment is possible.	Captive rail; module removable only at terminals

Table 2.3.5-2 - Manual Aided CTS's: Package Handling Functional Characteristics & Requirements (Cont'd)

SYSTEM	ACQUISITION	MOVEMENT	POSITIONING	RELEASE AND SECURE METHOD
1. Mechanical Dumbwaiter	Same as S/A (1.)	Hand or foot ratchet hand-crank, foot-crank or bicycle pedals power the system. The dumbwaiter moves on dual rails from the C/CM loading area. Start, Stop, Rate and Distance control depend on line of sight. Movement rails are connected on docking; CTS launched with the SS.	Same as S/S (1.)	Same as S/A (1.)
2. Clothes-line	Cargo is attached to clothesline after being located by information retrieval system, either manual or computer.	Hand-over-hand power; clothes-line is attached to pulleys located approximately 1-ft apart on both the C/CM & the SS. One hook is all that can be used on the lower clothes-line. Mass limit approximately 3-5 slugs based on Environ-mental Sciences data from their simulator. Design sim-ilar to lunar off-loading clothesline.	Manual or other clothesline mechan-ism.	Attaching rings, attach cords.

Table 2.3.5-2 - Manual Aided CTS's: Package Handling Functional Characteristics & Requirements (Cont'd)

SYSTEM	ACQUISITION	MOVEMENT	POSITIONING	RELEASE AND SECURE METHOD
3. Roller Type Conveyor	Same as M/A (1)	Conveyor carried up on SS and extended into C/CM after docking. Power is by crewman (either push-release-and-catch at compartments, or push maintaining contact with cargo).	Side conveyors can be used to position cargo from the SS tunnel to the decks.	Clamps, straps, other.
4. Rails and Diaphragm	Same as M/A (1)	Rails & transfer dolly carried up on SS & extended into C/CM after docking. Semi-permeable diaphragms are located at each compartment hatch, controllable by SS crewmen. Cargo is placed on dolly and pushed along the rails, with deceleration controlled by destination compartment diaphragm.	Strictly manual, although rails and switching mechanism may aid.	Clamps, straps, other.

Table 2.3.5-2 - Manual (Unaided) CTS's: Package Handling
Functional Characteristics & Requirements (Cont'd)

SYSTEM	ACQUISITION	MOVEMENT	POSITIONING	RELEASE AND SECURE METHOD
1. Rail	Manual information retrieval system for location; manual acquisition of cargo.	Rail system is used for guidance & tethering of package. Rails extend into C/CM. Cargo is attached to rails & propelled by crewman using tethers & handholds.	Extension of rails into compartment or manual control of cargo. (Switching track possible).	Tethers and/or slide fasteners.
2. Fireman Pole	Manual information retrieval system for location; manual acquisition of cargo.	Fireman pole is similar to Skylab with cargo tethered to crewman. Fireman pole used to stabilize crew translation, not cargo.	Manual only.	Tethers.
3. Pitch & catch net	Manual information retrieval system for location; manual acquisition of cargo.	Packages tossed by hand. System practical only for small packages over a maximum distance of 10 ft. Net may be used to capture cargo at a compartment or deck.	Manual only.	N/A
4. Bucket Brigade	Manual information retrieval system for location; manual acquisition of cargo.	Cargo is free, passed from crewman to crewman. Requires all 12 crewmen to cover distances from C/CM handling area to SS compartment or Deck #4.	Manual only.	N/A

Table 2.3.5-2 - Manual (Unaided) CTS's: Package Handling
Functional Characteristics & Requirements (Cont'd)

SYSTEM	ACQUISITION	MOVEMENT	POSITIONING	RELEASE AND SECURE METHOD
5. Manual Restraint & Transfer	Manual information retrieval system for location; manual acquisition of cargo.	Each man carries cargo to desired location using hand-holds & handrails to stabilize self. Cargo may be tethered to crewman.	Manual only.	Tethers.

The principal purpose in introducing the task analysis approach into the present study was the expectation that it would assist the system tradeoff effort. It was hoped that analysis of the tasks involved in exercising each of the candidate CTS's would furnish insight into the relative operational merits of the several systems.

Accordingly, a rather broad functional analysis was performed (see Figure 2.4.1-1) to provide a basis for the task analysis effort. Thus each functional step in the cargo handling process was examined for task implications deriving from semi-automatic, manually-assisted, and/or purely manual modes of operation, without any attempt to define the related equipment in any detail. Although this approach did not produce sufficiently detailed task data for critical evaluation of potential man-machine interfaces, the generalizations did assist the design tradeoff analysis by serving to isolate general human factors problem areas. More importantly, the function/task model provided a reference for the analytic efforts that followed.

From the general model it appeared that the following assumptions could be made: (1) movement of cargo from the stowage area of the C/CM to its docking port hatch, and from a given SS tunnel/compartment hatch to a given compartment work or storage area would be performed manually or with manual-aided systems, because of the short distances involved; (2) the most appropriate use of a semi-automatic or manual-aided CTS would be along the major axis of the SS tunnel (and possibly the aisle of the C/CM); (3) movement of personnel simultaneously with cargo packages within the SS tunnel is not time-energy effective; and, (4) it is not necessary that a single CTS service the total route of cargo transfer. Shirt-sleeve operation was, of course, a specified constraint for this study.

Based on the functional analysis and the above tentative assumptions, a rather generalized task analysis was attempted wherein the operational characteristics, requirements, constraints, failure modes and effects, and personnel hazards of each of the major modes of operation were compared.

It quickly became apparent, however, that instead of contributing meaningful inputs to the tradeoff study, this

FUNCTION REQUIREMENTS ANALYSIS: C/CM-65 CARGO TRANSFER SYSTEM

ASSUMPTIONS: (a) Crew Members Shirtsleeve (b) Zero-g Condition

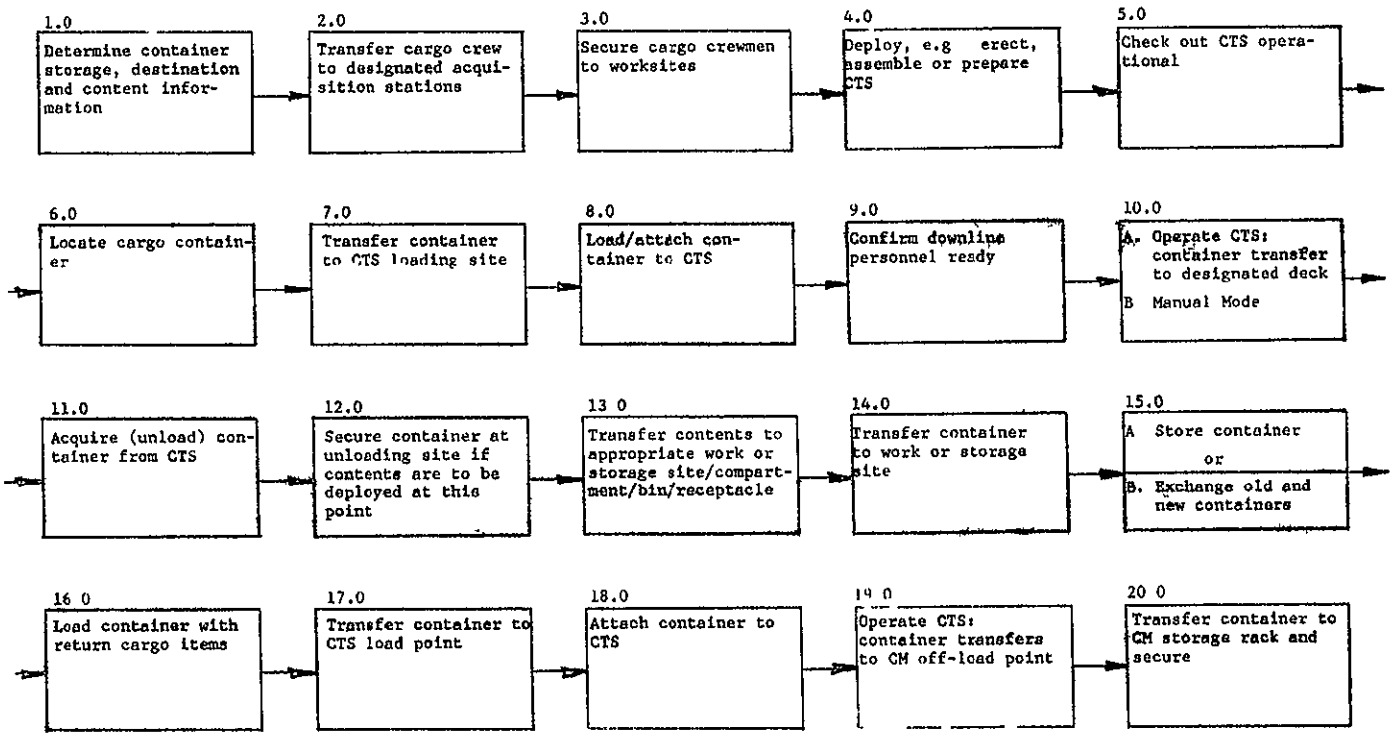


Figure 2.4.1-1 - General Function/Task Descriptive Model For In-Space Cargo Transfer

kind of comparative task analysis simply raised a great many questions relative to the unique hardware variables implicit in the various CTS's. Since it was evident that this kind of task analysis, based as it was on generalities, was not going to contribute anything useful to the tradeoff effort, it was decided to delay further task analysis until the design concept tradeoffs were completed and the field of candidate systems narrowed. At this point individual systems could then be examined and the results fed back into the tradeoff study on an iterative basis, thereby supplying some useful inputs.

This plan was followed, with the result that the preferred systems (from the tradeoff study) were exercised via the task analysis method and the detailed information gleaned used to refine the conclusions of the systems tradeoff.

An example of one such task analysis is shown in Figure 2.4.1-2, which presents an analysis of a simple cable-pulley system permanently erected in the tunnel area of the SS. It should be explained that the selection of this particular example as representative of the type of cargo transfer system that appears promising, occurred after a number of preliminary CTS analyses and several iterations of the task analysis. Use of this model is not meant to imply that it is the only suitable system for the tunnel area or that another system would not apply to other areas along the transfer route. As will be noted later in Section 3.0, rationale for the cable-pulley system in conjunction with a rail-trolley system can be developed reasonably well as long as a common function/task model is utilized in comparing the effectiveness of the various CTS's.

2.4.2 Design Evaluation

Prior to the application of PEEVS methodology in evaluating and comparing various CTS's, a general design evaluation was performed as a preliminary step in the overall tradeoff study. The principal purpose of this step was to identify the prime CTS candidates for further analysis and evaluation. In order to provide a common departure point for this initial design evaluation, a general set of assumptions was made, based on ideas and assumptions from similar study efforts, human factors design criteria and principles, and initial constraints or hazards driven out by the Master Task Analysis. These assumptions were as follows:

MASTER TASK ANALYSIS: CABLE CARGO TRANSFER SYSTEM (CTS)

ABBREVIATIONS: S/A = SEMI AUTOMATIC; M/A = MANUAL-ASSIST; M = MANUAL

ASSUMPTIONS: 1. SYSTEM INSTALLED, NO DEPLOYMENT ETC.; 2. SYSTEM USED IN TUNNEL ONLY; 3. CREW MEMBERS ARE SHIRTSLEEVE

FUNCTION REQUIREMENT	OPERATIONAL TASKS	OPERATIONAL REQUIREMENTS & CONSTRAINTS (ORIENTATION, STABILIZATION, VISUAL, AUDITORY)	FAILURE MODES & EFFECTS	FAILURE MODE OPERATION	PERSONNEL HAZARDS	CREW PERF. SKILL	TIME TO PERF. TASK (MINUTES)	
1.0 DETERMINE CONTAINER STORAGE DEST & CONTENT INFORMATION	QUERY INVENTORY INFO SOURCES	AN INVENTORY INFO RETRIEVAL SYSTEM WITH CONVENIENT OPERATOR ACCESS; ADEQUATE ILLUMINATION, GOOD LEGIBILITY	N/A	N/A	NONE	1		
2.0 TRANSFER CARGO CREW TO DESIGNATED ACQUISITION STATIONS	TRANSLATE MANUALLY TO STATIONS a. CTS/S INTERFACE b. DISPOSAL FLOOR	CREW MOVEMENT AIDS TO ASSIST TRANSLATION & POSITIONING (HANDHOLDS, RAILS, CTS CABLES); CLEAR VIEW OF TRANS AIDS & DESTINATION	BROKEN CTS CABLE	TRANSLATE VIA HANDHOLDS	LOSS CONTACT WITH TRANS AIDS, IMPACT STRUCTURE	3 a (2) b (1)		
3.0 SECURE CARGO CONTAINER TO WORKSITES	DEPLOY TETHERS (IF REQ'D), SECURE TO CARGO	CREWMAN STABILIZATION SYSTEM THAT ALLOWS UPPER TORSO & ARM FREEDOM, BODY MOTION; CLEAR VIEW OF CARGO STORAGE AREA &/OR RECEIVING STATION	BROKEN TETHERS, RESTRAINT SYSTEM	USE ALTERNATE ATTACH POINTS; REPLACE RESTRAINT HARNESS	NONE	3		
4.0 DEPLOY CTS	REMOVE HATCH COVERS AT EACH DESCRIPTION PLACE, COMPLETE OTHER NECESSARY STEPS	POSSIBLE TOOLS FOR REMOVING HATCH COVERS, SECURING CTS; STORAGE PROVISIONS FOR COVERS	COVERS FAIL TO RELEASE	SYSTEM INOPERABLE UNTIL COVER RESTRAINT FREED	SAME AS 3.0	R		
5.0 CHECK OUT CTS OPERATIONAL S/A MODE	OPERATE CTS MOTOR, OBSERVE NORMAL FUNCTIONING OF CABLE SYSTEM	START/STOP CTS MOTOR CONTROL, DECLUTCHING DEVICE, CLEAR VIEW OF CABLE SYSTEM, FULL LENGTH	MOTOR FAILS TO OPERATE; CLUTCH INOPERABLE; CTS UNUSABLE IN SEMI AUTO MODE	GO TO M/A OR M MODE	SAME AS 3.0	3		
5.1 CHECK OUT CTS OPERATIONAL M/A MODE	OPERATE CTS BY HAND CRANKING	HAND CRANK SYSTEM ON CTS FOR MANUAL POWER/OPERATION; CLUTCH OVERRIDE; RESTRAINT/STABILIZATION SYS TO PROVIDE ADEQUATE STABILITY, WITH FREEDOM FOR HAND-CRANKING CTS	CRANK FAILS, CABLES WON'T MOVE	LOCK CABLES; GO TO MANUAL MODE	SAME AS 3.0	1		
5.2 CHECK OUT CTS OPERATIONAL MANUAL MODE	LOCK CTS CABLE SYS	HAND-OPERATED LOCKING CONTROL ON CTS AT OPERATING POSITION, LOCKING FORCES NOT IN EXCESS OF ____ FT LBS	LOCKING DEVICE FAILS CABLE SYS CANNOT BE USED BY CREW FOR MANUAL TRANSPORTATION TRANSLATION AID	CTS INOPERABLE FOR CARGO TRANSPORTATION ID ANY MODE; USE HANDRAILS, HANDHOLDS TO ASSIST MANUAL TRANSLATION	SAME AS 3.0	1		
6.0 LOCATE CARGO CONTAINER IN CARGO MODULE	USING INVENTORY INFO DATA, PERFORM VISUAL SEARCH FOR CONTAINERS ACCORDING TO DELIVERY SEQUENCE (THOSE TO BE DELIVERED FIRST, ETC); OPERATE ANY SEARCH AIDS (CTS MOTOR CONTROLS, ETC)	CARGO LOCATION AIDS; LABELING/DOCKING SYSTEM IN C/M TO FACILITATE CONTAINER IDENTIFICATION; POSSIBLE CONTAINER MOVEMENT AIDS, GOOD ILLUMINATION IN C/M & LABEL LEGIBILITY TO ASSIST IDENTIFICATION	CONTAINER NOT LOCATED PROPERLY, SEARCH AID FAILS TO OPERATE, CONTAINER MOVER FAILS	PERFORM MANUAL SEARCH FOR CONTAINER	SAME AS 3.0	1		
7.0 TRANSFER CONTAINER TO CTS LOADING STATION	TRANSFER CONTAINERS FROM C/M TO LOADING STATION	TRANSFER MODE PRIMARILY MANUAL WITH POSSIBLE USE OF ASSIST DEVICE IF C/M CONFIGURATION SUCH AS TO PROVIDE CLEAR, STRAIGHT PASSAGEWAY THRU C/M & HATCH TO LOADING STATION, HANDHOLDS &/OR GUIDERAILS FOR C/M CREWMAN; POSSIBLE ATTACH PAD FOR STEM AT LOADING STATION TO MINIMIZE INTERFERENCE WITH LOADING TASK IF WORN BY CREWMAN/LOADER; CLEAR VIEW BETWEEN C/M AND LOADING STATION	HINGES, CAM DEVICES WITH TELETUBE, PISTON ENVELOPE FAIL TO RELEASE; ASSIST DEVICE FAILS TO OPERATE	FORWARD CABIN TRANSFER HANDRAILS (WITHOUT AID OF ASSIST DEVICE)	SAME AS 3.0	2		

Figure 2.4.1-2 - Master Task Analysis

MASTER TASK ANALYSIS CABLE CARGO TRANSFER SYSTEM
PAGE 2

FUNCTION REQUIREMENT	OPERATIONAL TASKS	OPERATIONAL REQUIREMENTS & CONSTRAINTS	FAILURE MODES & EFFECTS	FAILURE MODE OPERATION	PERSONNE HAZARDS	CREW PROFICIENCY REQ'D.	ESTIMATED TIME REQ'D. NORMAL	ESTIMATED TIME REQ'D. EMERG
8.0 LOAD/ATTACH CONTAINER TO CTS	ATTACH CONTAINER TO CABLES	CLAMPS OR OTHER MEANS OF FASTENING CONTAINER TO CTS CABLES; NORMAL VISIBILITY	CONTAINER ESCAPES BEFORE BEING FASTENED; ONE OR MORE ATTACH CLAMPS FAIL	RECAPTURE CONTAINER; REPLACE FAILED CLAMPS	LOOSE CONTAINER COULD BUMP CREW MEMBER	1		
9.0 CONFIRM DOWNLINE PERSONNEL READY	LOADER COMMUNICATES W/M RECEIVER, VERIFY HIS LOCATION AT CORRECT DECK AND READINESS TO RECEIVE CARGO	INTERCOM SYSTEM BETWEEN LOADING STATION & ALL RECEIVING STATIONS - EACH DECK; ADEQUATE ILLUMINATION FOR OPERATION OF INTERCOM	INTERCOM INOPERATIVE	DIRECT VOICE COMMUNICATION	SAME AS 8.0	2		
10.0 TRANSFER CONTAINER TO CORRECT DECK, CTS- S/A MODE	ACTUATE DRIVE MOTOR ON/OFF SWITCH; ENGAGE CTS CLUTCH; DISENGAGE CLUTCH ON (INTERCON) CONTROL FROM CREWMAN AT REC'G STATION	(SAME AS 5.0)	(SAME AS 5.0)	(SAME AS 5.0)	(SAME AS 3.0)	1		
10.1 TRANSFER CONTAINER CTS - M/A MODE	(SAME AS 5.1)	(SAME AS 5.1)	(SAME AS 5.1)	(SAME AS 5.1)	(SAME AS 3.1.0 NF)	1		
10.2 TRANSFER CONTAINER MANUAL MODE	LOCK CTS SYSTEM; ATTACH CONTAINER TO CTS CABLES BY SLIP-RINGS FOR GUIDANCE, ALSO ATTACH TO CREWMAN BY TETHER LINE; TRANSLATE TO RECVG STATION TOWING CONTAINER USING LOCKED CABLE TO ASSIST MOVEMENT	SEE 5.2, ALSO, CONTAINER-GUIDE SLIP-RINGS FOR STABILIZING CARGO MOVEMENT BETWEEN CABLES; TETHER TOW-LINE FOR ATTACHING CONTAINER TO CREWMAN	(SAME AS 5.2)	(SAME AS 5.2)	(SAME AS 3.0)	1		
11.0 ACQUIRE (UNLOAD) CONTAINER FROM CTS	USE INTERCOM TO DIRECT LOADER TO DECLUTCH CTS, STOP CABLE MOTION, WHEN CONTAINER AT CORRECT UNLOADING POS'N; DETACH CLAMPS, REMOVE CONTAINER, NOTIFY LOADER SYS CLEAR.	(SEE 3.0 & 9.0)	(SEE 3.0 & 9.0)	(SEE 3.0 & 9.0)	(SAME AS 3.0)	2		
12.0 SECURE CONTAINER AT UNLOADING SITE BY ATTACHING	ATTACH CONTAINER TO DECK PENDING TRANSFER OF CARGO TO WORK OR STORAGE SITE	VELCRO OR DECK-MOUNTED CLAMPS SUITABLE FOR QUICK SECURING OF CONTAINER	VELCRO/CLAMPS FAIL, CONTAINER DRIFTS AWAY	WORK STATION CREWMAN RECOVERS CONTAINER, SECURES SAME	POSSIBLE INJURY BETWEEN CREW & CONTAINER	2		
12.1 SECURE CONTAINER AT UNLOADING SITE BY TRANSFER TO WORK STATION CREWMAN	RECEIVER USES CONTAINER HANDLES TO TRANSFER TO WORK STATION CREWMAN FOR HIS DISPOSAL	RECESSED, CORNER HANDLES ON CONTAINER TO FACILITATE TRANSFER, STABILIZATION & CONTROL	ONE OR MORE HANDLES FAIL, CONTAINER DRIFTS AWAY	(SAME AS 12.0)	(SAME AS 12.0)	2		

Figure 2.4.1-2 - Master Task Analysis (Cont'd)

MASTER TASK ANALYSIS CABLE CARGO TRANSFER SYSTEM
PAGE 3

FUNCTION REQUIREMENT	OPERATIONAL TASKS	OPERATIONAL REQUIREMENTS & CONSTRAINTS	FAILURE MODES & EFFECTS	FAILURE MODE OPERATION	PERSONNEL HAZARDS	CREW PERS REQ'D	ESTD TIME REQ'D	
							WORK	ENDEX
13.0 TRANSFER CONTENTS TO WORK/STORAGE SITE/CONTNR/CH	WORK STATION CREWMAN TRANSFERS CONTAINER TO STORAGE OR WORK SITE, REMOVES CONTENTS, POSITIONS SAME IN FINAL USE OR STORAGE LOCATION	STABILIZATION SYSTEM FOR WORK STATION CREWMAN/TRANSLATION AIDS BETWEEN UNLOADING SITE & DECK STORAGE/WORK STATION AREAS, MEANS FOR STABILIZING CONTAINER WHILE REMOVING CONTENTS	CONTAINER STAB SYS FAILS, CONTAINER ESCAPES	(SAME AS 12.0)	(SAME AS 12.0)	1		
14.0 TRANSFER CONTAINER TO WORK OR STORAGE SITE	WORK STATION CREWMAN MOVES EMPTY CONTAINER FROM WORK SITE TO STORAGE SITE	TRANSLATION AIDS BETWEEN WORK STATION & DECK STORAGE AREA	CREWMAN LOSES HOLD ON CONTAINER, CONTAINER ESCAPES	(SAME AS 12.0)	(SAME AS 12.0)	1		
15.0 STORE CONTAINER	WORK STA CREWMAN FASTENS EMPTY CONTAINER IN LOCATION FOR STORAGE	TIE-DOWN SYSTEM FOR CONTAINERS IN DECK STORAGE AREA, METHOD FOR INDICATING EMPTY CONTAINERS, LOCATING/INDEXING SYSTEM	(SAME AS 14.0)	(SAME AS 14.0)	(SAME AS 14.0)	1		
15.1 EXCHANGE OLD & NEW CONTAINERS	WORK STA CREWMAN TRANSFERS EMPTY CONTAINER TO UNLOADING STA CREWMAN, ACCEPTS NEW, FULL CONTAINER	(ESSENTIALLY THE SAME AS 13.0)	(SAME AS 14.0)	(SAME AS 14.0)	(SAME AS 14.0)	2		
16.0 LOAD CONTAINER WITH RETURN CARGO ITEMS	WORK STA. CREWMAN LOADS EMPTY CONTAINER WITH RETURN CARGO ITEMS	METHOD OF SECURING CONTAINER WHILE LOADING IT WITH RETURN CARGO ITEMS	(SAME AS 13.1)	(SAME AS 12.0)	(SAME AS 12.0)	1		
17.0 TRANSFER CONTAINER TO CTS LOAD POINT	WORK STA. CREWMAN TRANSLATES TO CTS DECK UNLOADING POINT, CARRYING CONTAINER, TRANSFERS CONTAINER TO CARGO RECEIVER CREWMAN	TRANSLATION AIDS BETWEEN DECK STORAGE AREA & DECK CARGO RECEIVING/LOAD STATION	(SAME AS 13.0)	(SAME AS 12.07)	(SAME AS 12.0)	2		
18.0 ATTACH CONTAINER TO CTS	CARGO RECEIVER CREWMAN ATTACHES RECEIVED CONTAINER TO CTS CABLES	(SAME AS 8.0)	(SAME AS 8.0)	(SAME AS 8.0)	(SAME AS 12.0)	1		
19.0 OPERATE CTS1 TRANSFER CONTAINER TO CH OFF LOAD POINT	ACTUATE CTS MOTOR POWER REVERSE OPERATION TO RETURN CONTAINER TO CH OFF-LOAD POINT, ON COMMAND FROM LOADER	IN ADDITION TO ON-OFF SWITCH ON CTS MOTOR, REQUIRES REVERSE OPERATION MODE, USE OF INTERCOM	(SAME AS 5.0)	(SAME AS 5.0)	(SAME AS 3.0)	1		
20.0 TRANSFER CONTAINER TO CH STORAGE RACK & SECURE	CTS OPERATOR STOPS CTS LOADED CONTAINER IN POSN, DETACHES CABLE/PIG CLAMPS, TRANSFERS CONTAINER MANUALLY TO CH CREWMAN, WHO PLACES IT IN STORAGE RACK & SECURES	CTS CONTROLS + SAME AS 3.0	(SAME AS 8.0)	(SAME AS 3.0)	(SAME AS 8.0)	2		

Figure 2.4.1-2 - Master Task Analysis (Cont'd)

1. All cargo packages should be designed so that their inherent shape, size, mass and mass distribution characteristics are compatible with the anatomical limitations for manual handling.

2. Package manipulation aids should be so located and configured that they provide the operator with the best possible control over the package during all stages of handling.

3. Integrated package protection, transfer and storage systems should be used wherever feasible to reduce weight, space, procedural steps or permanent and non-flexible adjuncts to the space station and/or cargo module.

4. Any cargo transfer system involving the use of permanently installed aids should be designed so that an alternate manual transfer mode is easily and quickly available (in the event of malfunction) without undue delay due to the mechanical system or package in transit having to be removed.

5. No transfer concept should permit "free flight" of personnel and/or packages as a primary mode of operation.

6. Transfer aids should be simple and reliable to minimize steps in setup, package attachment and release, as well as in transit operations.

7. All mechanical/structural aspects of package and transfer system design should be free of potential hazards such as: sharp corners and edges; exposed moving elements which could snare, entrap, interfere or cause inadvertent release of an element under tension; and generators of high surface temperature or toxic conditions.

8. All transfer system concepts should be evaluated and compared on the basis of a set of common criteria which includes the following human factor considerations:

    a. Personnel hazards
    b. Equipment damage
    c. Transfer efficiency in terms of time and energy
    d. Probability of human error

e. Flexibility in terms of cargo variation, loading alternatives, mission adaptability
f. Maintenance
g. Simplicity of design and use

Based on these general assumptions and considerations, a broad examination of all known CTS's was made (see previous Table 2.3.5-2) within the context of the C/CM-SS configuration and function/task models. Although it had been anticipated that some CTS's would not be defined to the extent necessary to evaluate their applicability to the in-space cargo transfer problem, the almost utter lack of any detail at all was unexpected. Of the systems examined, only one had been designed to the extent that the manufacturer had proposed specific hardware for the space mission. No other systems appeared to have been developed at all. Except for artist sketches of generalized cargo handling conceptualizations, all CTS possibilities had to be generated from elemental hardware ideas. These are described in detail in Appendix B.

Figure 2.4.2-1 summarizes the transfer system candidates as they might be developed from typical hardware components. It should be noted that several of these could be designed to operate in more than one mode. The cable or clothesline concept could, in fact, even be designed for all three modes (a fact that is significant in later conclusions presented in Section 3.0). It should also be pointed out that, based on earlier decisions, MFI arbitrarily eliminated the roller conveyor, chute and propulsion systems from further consideration. The first two are not considered practical for zero-g operations, and AMU/propulsion systems were considered non-cost-effective or practical for the particular vehicular cargo-handling configurations involved.

2.4.3 Tradeoff Analyses

As indicated earlier, one of the objectives of the present study was to try to utilize the recently developed PEEVS methodology for evaluating cargo transfer system hardware concepts. It is not appropriate here to go into detail regarding the PEEVS methodology but, rather, to note the minor modifications that were necessary in order to use the technique.

CARGO TRANSFER SYSTEMS

	SEMI AUTOMATIC	MANUAL AIDED	MANUAL
Free flight			X
Pitch/catch		X	X
Bucket Brigade			X
Firepole - ladder		X	X
Trolley/rail	X	X	
Rail/tether		X	X
Cable/clothesline	X	X	X
Dumbwaiter/elevator	X	X	
STEM/Serpentuator	X	X	
Conveyor (belt)	X	X	
Conveyor (roller)	X	X	
Chute/tube	X		
AMU/Propulsion wand	X		

Figure 2.4.2-1 - Breakdown of Candidate CTS by Operational Categories

The first requirement was to select relevant criterion items from the large PEEVS list. This selection process was necessary because many of the criterion measures of the original list related to EVA rather than IVA. The mission and preliminary task analysis models were useful in making these selections.

Next, it was necessary to quantify rating scale limits and to assign function weights to each criterion measure. A forced-choice technique, using "expert" judges was used, with the results as shown in Table 2.4.3-1.

Finally, because of the previous modifications and unique questions relating only to cargo transfer in IVA, a simplified analysis worksheet had to be developed, as shown in Figure 2.4.3-1.

It became apparent early in the tradeoff analysis, using the modified PEEVS methodology, that this technique was not producing the definitive results anticipated due to a lack of sufficient CTS design data. As a result, a second analysis procedure was initiated using a simpler but more direct comparison of CTS's and based on more generalized, operationally-oriented criteria and simple ranking procedures using equal ratings. The criteria developed for this second analysis were generated by combining several of the original PEEVS criterion measures and rephrasing them in operational terms, as shown in Figure 2.4.3-2. It should be pointed out that this change in methodology in no way reflects on the adequacy of the PEEVS method but, rather, on the ability of the method to function properly when there is insufficient data on hardware system design.

Use of the task analysis approach explained in Section 2.4.1 served to identify critical aspects of CTS candidates and so support or modify tradeoff results arrived at by the method described above.

Table 2.4.3-1 - Tradeoff Study Criteria

(Adapted from NAS8-24384 Final Report)

MEASURE	DEFINITION	RATING SCALE	FUNCTION WEIGHTING
1. Visibility	The percentage of the required visual field which is obstructed by the CTS and associated hardware, including the cargo being transported.	1. Unrestricted 2. Partially restricting 3. Critically restricting	3
2. Deployed Volume	The space taken up by a CTS once it is deployed.	1. Negligible (no deterant to free manual translation) 2. Medium (some inpedance to free manual translation) 3. Great (free manual translation blocked by CTS)	3
3. Transport Velocity	The maximum rate with which cargo can be moved by the CTS* between the C/CM storage area and the SS deck destination.	1. High (over 1.5 fps) 2. Medium (0.5-1.5 fps) 3. Low (under 0.5 fps)	2
4. Cargo Mass Limit	The maximum cargo mass in slugs that can be transported by a CTS* between the C/CM storage area and the SS deck destination.	1. Heavy (10 slugs or less) 2. Medium (1-5 slugs) 3. Light (Less than 1 slug)	3
5. Cargo Size	The range of cargo volume that can be transported by a CTS* between the C/CM storage area and the SS deck destination.	1. Large (1-70 ft^3) 2. Medium (1-40 ft^3) 3. Small (1-20 ft^3)	3
6. CTS Mass	The mass of the CTS in slugs.	1. Light (1 slug or less) 2. Moderate (1-5 slugs) 3. Heavy (5 slugs or more)	2

*Defined as including the man, where applicable.

Table 2.4.3-1 - Tradeoff Study Criteria (Cont'd)

MEASURE	DEFINITION	RATING SCALE	FUNCTION WEIGHTING
7. Maintenance Time Requirements	The percentage of time in orbit when the CTS will be inoperative because of servicing, preventive maintenance or repair.	1. None 2. Infrequent (less than 10%) 3. Frequent (more than 10%)	5
8. CTS Stowed Volume	Amount of space in cu/ft occupied by the CTS while in a stowed configuration. (The man is not considered as part of the CTS for this purpose. It is also assumed to be a ground rule that the CTS in its stowed configuration cannot impede manual translation.)	1. Small (less than 10 cu/ft) 2. Medium (10-20 cu/ft) 3. Large (over 20 cu/ft)	1
9. Cargo Positioning Accuracy	The accuracy in lineal inches to which a CTS can position an item of cargo in the translation planes.	1. Excellent ($\pm$ 1 inch) 2. Fair ($\pm$ 5 inches) 3. Poor ($\pm$ 10 inches)	3
10. Cargo Orientation Accuracy	The accuracy in degrees to which a CTS can position an item of cargo in the rotational planes.	1. Excellent (5°) 2. Fair (5° 15°) 3. Poor (15°)	2
11. Emergency Provisions	Backup systems required to safely perform the CTS mission given a major sub-system failure.	1. None required 2. Integral to system 3. Required backup system	5
12. Operational Lifetime	The expected duration of system usefulness. The expenditure of irreplaceable consumables or the likelihood of failure in a critical subsystem or component usually defines the limit of this measure.	1. Long (over 5 years) 2. Medium (2-5 years) 3. Short (less than 2 years)	4

Table 2.4.3-1 - Tradeoff Study Criteria (Cont'd)

MEASURE	DEFINITION	RATING SCALE	FUNCTION WEIGHTING
13. Physical Energy Required to Operate CTS	The operator energy expenditure above normal space station systems monitoring operations required to utilize the CTS.	1. None 2. Minor 3. Much greater	5
14. Fuel and Power Expenditure	Battery power or fuel replenishment requirement for operation of the CTS.	1. None 2. Minimal (small electric motors, etc.) 3. Large (heavy power usage)	3
15. Range	The maximum distance from the C/CM cargo storage area which the CTS can transport cargo.	1. Unlimited (into any user area) 2. Limited (length of the space station tunnel only) 3. Close proximity (transports cargo less than the length of the space station tunnel)	5
16. Dependability	The confidence which may be placed in the CTS performing its assigned functions when called upon to do so.	1. No redundancy required 2. Redundancy required	5
17. Crew Requirements	The number of crewmen who must devote full time and attention to cargo yransfer operations with a given CTS.	1. One crewman required. 2. Two crewmen required. 3. Three or more crewmen required.	1

Table 2.4.3-1 - Tradeoff Study Criteria (Cont'd)

MEASURE	DEFINITION	RATING SCALE	FUNCTION WEIGHTING
18. Translation Rate Control	The precision with which the translation rate of a loaded CTS can be controlled after a 1 sec acceleration/ deceleration period.	1. High (± 0.01 ft/sec) 2. Medium (± 0.1 ft/sec) 3. Low (± 1 ft/sec)	1
19. Translation Stability	Average time required for a loaded CTS to return to a programmed attitude after being offset.	1. Stable (0.1 sec) 2. Moderate Stability (0.1-5.0 sec) 3. Unstable (5 sec)	4
20. Translation Maneuverability	Rate at which a CTS can change direction to avoid an obstacle, to select a different cargo location, or to follow a preprogrammed path.	1. High 2. Medium 3. Low	5
21. Deploy/Remove Time Requirements	The time needed to install and remove the CTS from SS tunnel or other transfer path areas.	1. Short (0-10 min) 2. Medium (10 min-30 min) 3. Long (30 min & greater)	2
22. CTS Deploy/Remove Physical Energy Expenditure Requirements	The crewmember energy expenditure above normal space station systems monitoring operations required to deploy/remove the CTS.	1. Slightly above 2. Moderately above 3. Greatly above	2

CARGO TRANSFER SYSTEM		MANUAL-AIDED							
		Mechanical Dumbwaiter		Clothesline		Mechanically Operated Conveyor		Rail & Diaphram	
MEASURES	WEIGHTING	R	T	R	T	R	T	R	T
Visibility									
Deployed Volume									
Transport Velocity									
Cargo Mass Limit									
Cargo Size									
CTS Mass									
Maintenance Time Rqmts									
CTS Stowed Volume									
Cargo Positioning Accuracy									
Cargo Orientation Accuracy									
Emergency Provisions									
Operational Lifetime									
Physical Energy Rqmts									
Fuel & Power Expenditure Rqmts									
Range									
Dependability									
Crew Rqmts									
Translation Rate Control									
Translation Stability									
Translation Maneuverability									
Deploy/Remove Time Rqmts									
Deploy/Remove Physical Energy Expenditure Rqmts									
TOTAL RANK									

Key: R - Rating
T - Total

Figure 2.4.3-1 - Sample CTS Tradeoff Worksheet

TRADEOFF STUDY OF CARGO TRANSFER SYSTEMS IN THE CREW CARGO MODULE AREA*

Generalized Measures	Cargo Transfer Systems			
Amount of preparation required for use & probable frequency of removal & replacement after launch				
Closeness of cargo delivery to Space Station docking tunnel				
Complexity, weight penalty				
Flexibility to move multiple cargo packages				
Intrusion/interference into free area				
Package handling shape, size & mass flexibility				
Power requirements				
Requires additional hardware for crew & cargo transfer				
Scheduled maintenance requirements				
RELATIVE OVERALL RANKING				

*Assume a maximum distance from storage area to Space Station docking hatch of 31 ft. with available envelope TBD but head room on the centerline of the transfer route not more than 10 ft.

Figure 2.4.3-2 - Simplified CTS Tradeoff Analysis Worksheet

3.0 CONCLUSIONS AND RECOMMENDATIONS

This Section presents the results of the several study tasks and provides summary discussion, general conclusions, suggestions and recommendations for future research and engineering activity in the area of cargo transfer system definition and design.

3.1 A Cargo Transfer System Concept

As the several analytic tasks were completed, the study team became aware that a general transfer concept had emerged which appeared to meet all the pre-established criteria. Although it is recognized that recommendation of a particular CTS at this time is somewhat premature, since the currently favored concept is based on a specific model of the many possible Shuttle-Space Station Systems, definition of a preferred CTS concept provides a useful baseline for determining the course of future research. Furthermore, by describing a baseline CTS at the beginning of this discussion, it is easier to relate the results and conclusions of various analyses and to show how the CTS concept occurred as an evolution rather than as the direct result of preconceived notions as to how an analytic technique such as PEEVS would "drive out" a preferred system. This evolutionary process received contributions not only from the initial mission, function, task and design trade-off analyses, but also from efforts to define future research requirements and specific experimental programs. This latter point is particularly important in that a key objective of the entire study has been to develop meaningful research needs and specific study plans.

Keeping in mind the basic C/CM-SS model discussed in earlier sections of this report, the baseline CTS concept to be described consists of distinct but interdependent sub-CTS's for the C/CM, SS tunnel and SS compartments (see Figure 3.1-1). A two-rail/trolley system (actually a basket, manually-powered) is used in the C/CM; a cable-pulley system is used in the SS tunnel area; and a direct manual system is proposed for the SS compartments and torus areas. Inherent in the first two systems is a broader concept referred to as the "Shopping Basket-Supermarket Concept."

To perceive the concept in simple terms, picture a housewife pushing her shopping cart around the supermarket, selecting

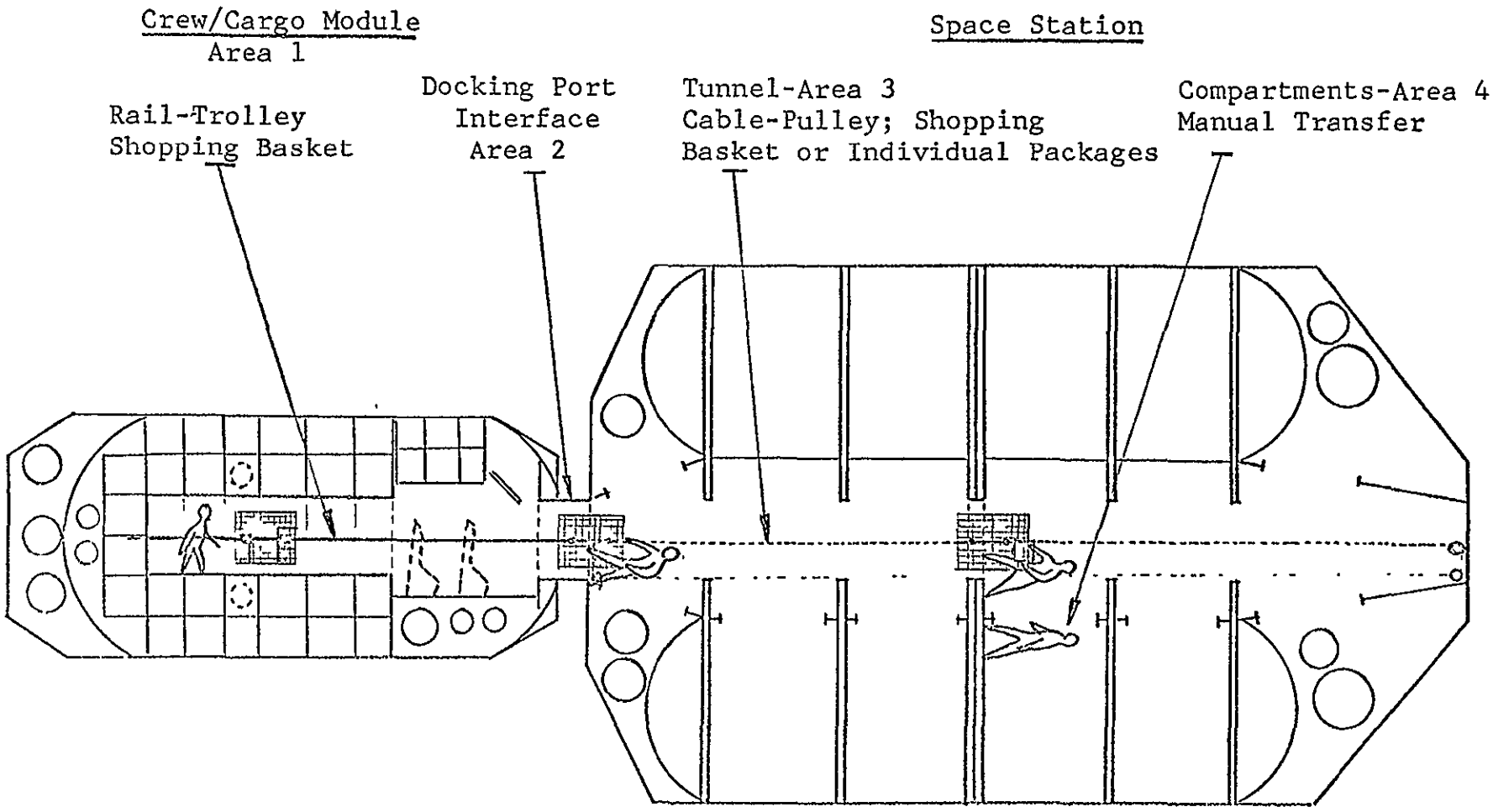


Figure 3.1-1 - Shopping Basket Concept Using Rail-Trolley/Cable-Pulley and Direct Manual CTS's

and picking up grocery items from various bins, shelves and counters, taking the basket to the checkout counter, to her automobile, and finally to her home where she deposits each item in its appropriate storage area. The C/CM may be thought of as the supermarket. A fixed, two-rail, manual-powered trolley system (actually a basket-like receptacle) is used to collect various cargo items from stowage compartments in the C/CM. The size of this basket is delimited by the size of the docking hatch (5-foot diameter) -- approximately 42" x 42" x TBD length. The basket has flexible closures at either end so that it is possible to close either end depending upon where the crewman is located. This also makes it possible for the crewman himself to translate through the basket (when it is empty) in order to get from one side to the other.

The crewman can move the basket along the rails to whatever stowage compartment is appropriate, selecting and placing cargo packages in the basket until it has been filled. At this point, he pushes the basket to the C/CM-SS hatch until the basket extends far enough into the SS tunnel area for a second man to gain access to and manipulate the basket. At this point a second type of CTS (e.g., a cable-pulley system) is available to transfer separate packages taken from the basket -- or the entire basket itself attached to the cable -- to the various decks in the SS. A third crewman stationed at each deck, retrieves packages from the basket as they arrive at the deck for which they are intended.

At this point the third crewman hands the packages to a fourth man within a deck compartment who then transfers the package either to an interim storage bin or directly to a work site by means of his own manual power and capabilities, aided by handrails or other assist devices. Figures 3.1-2 (a) and (b) illustrate the key concepts in the proposed system. The Rail-Trolley subsystem is powered manually since the distances and requirements for frequent short pauses make mechanical power undesirable. An electrical motor is used to drive the Cable-Pulley subsystem since the distances within the SS tunnel area are considerably longer and continuous.

Rails were selected for the C/CM area because a portion of these would have to be erected in zero-g (i.e., after the C/CM is docked and the crew seats removed). The cable system was selected for the SS tunnel area because it takes a minimum

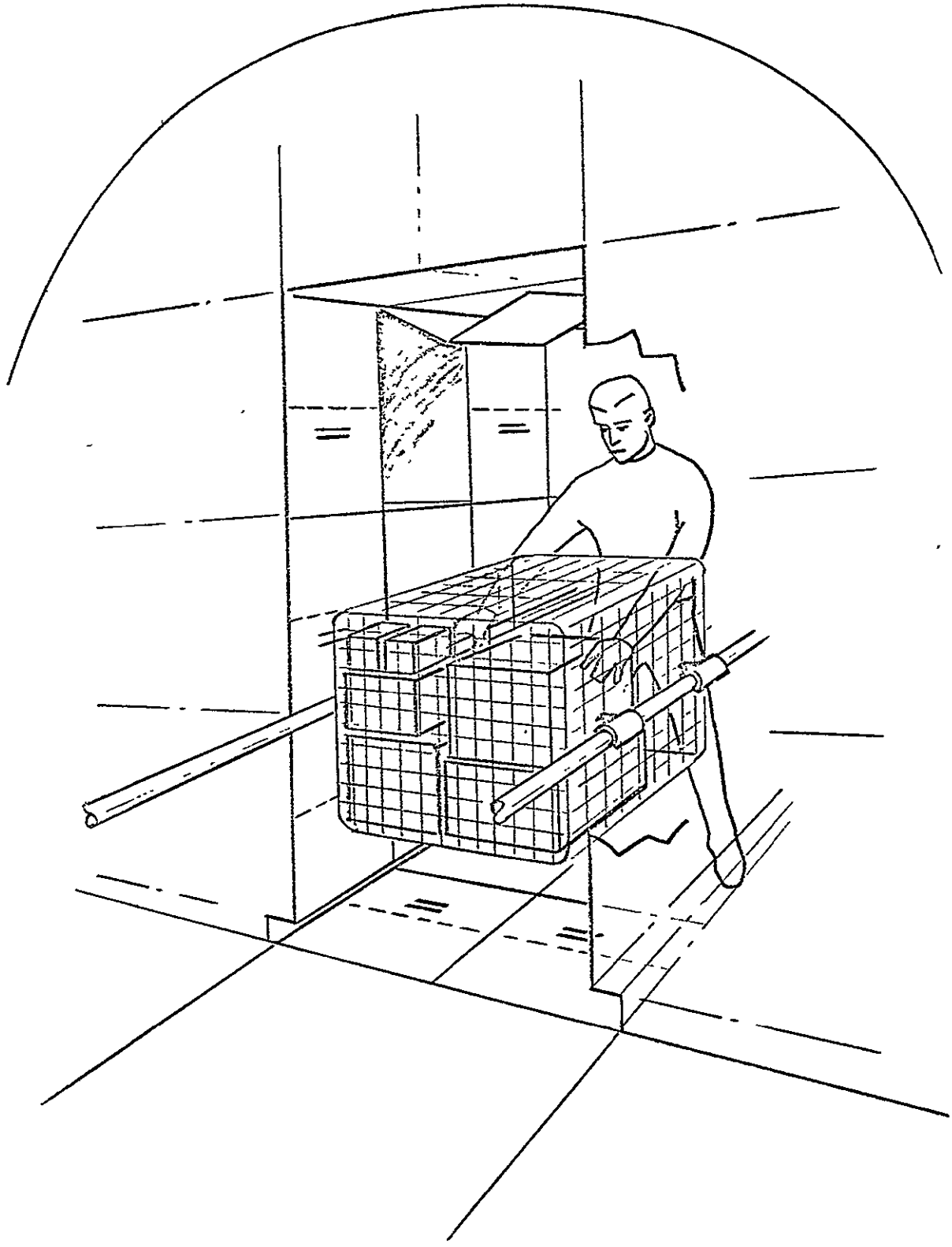


Figure 3.1-2 (a) - Artist Sketch of Shopping Basket-Rail Cargo Transfer Concept for C/CM Area

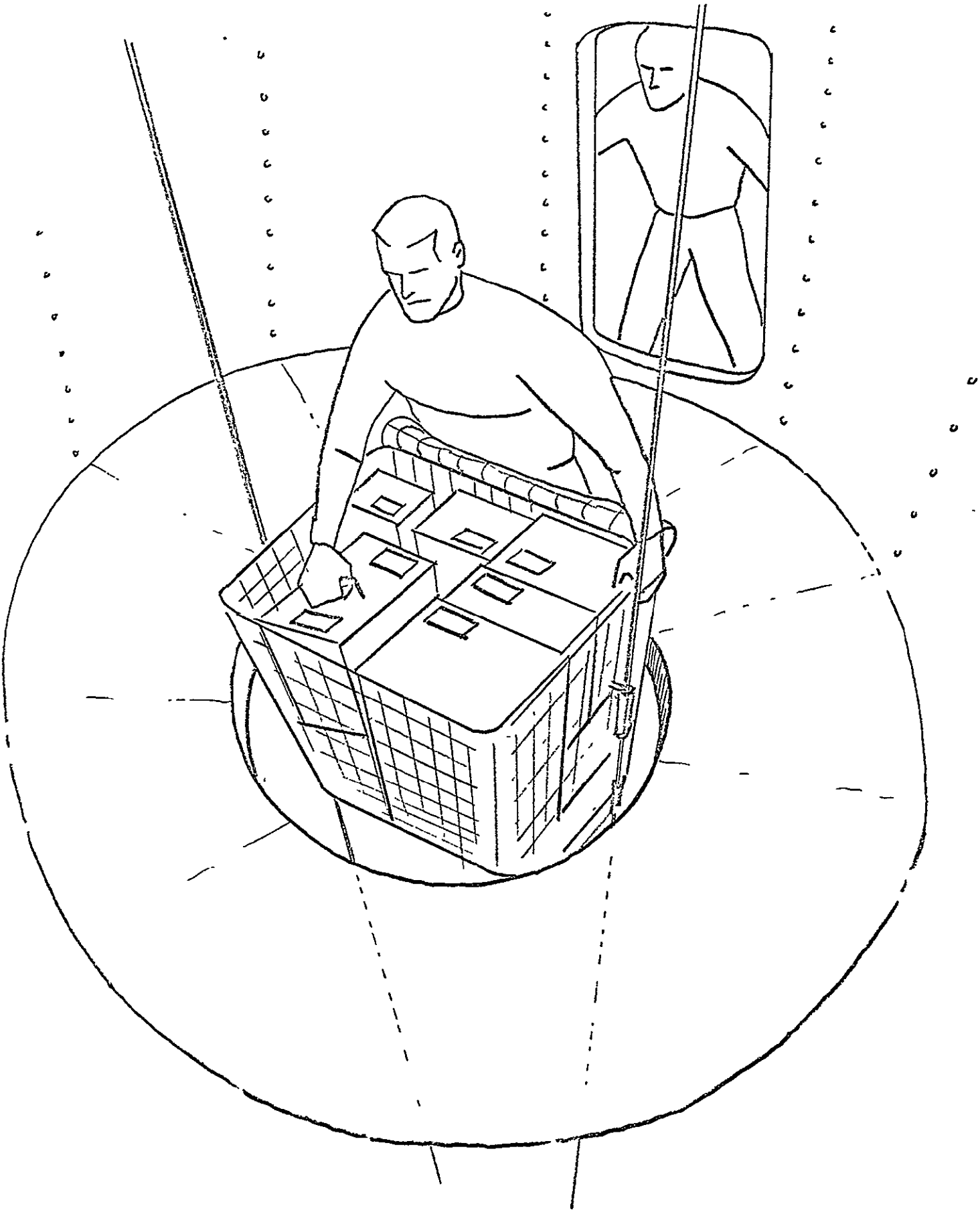


Figure 3.1-2 (b) - Shopping Basket System at Space Station Tunnel/Deck Offload Position

of space (intrudes into the tunnel least), provides the lightest and simplest means for applying electro-mechanical power, and accepts the greatest variety of package sizes and shapes. Both systems rate well in terms of simple backup in the event of failure, and both are easy to mate at the docking interface. The cable-pulley system normally would be a permanent installation since erection of loose cables in zero-g is not desirable.

The manual system was chosen for compartment cargo handling since the wide variety of needs, most of which involve short translation distance, do not warrant the complexity of manual-aided or semi-automatic CTS's.

Other considerations less well defined include such things as adaptability of the systems to ground handling (actually not a part of this study), and convenient failure mode operation. In the first case for example, the fixed, dual rail could be used in loading the C/CM assuming it is loaded in the horizontal position -- which is considered most likely. The SS, on the other hand, probably would be loaded in a vertical position, hence the cable-pulley system might provide an effective means for assisting in a portion of this operation.

In the event of failure of the electrical power for the cable system, manpower could easily take over by means of a hand crank to move cargo in the tunnel. In the event this failed (e.g., some lockout of the system occurred), the cables could be used as manual aids so that crewmen could translate themselves (and packages) and thus continue cargo transfer of small packages.

Finally, the cable system provides for movement of packages within the tunnel in both directions at the same time (limited, of course, by passing clearances).

3.1.1 Cargo Transfer System (CTS) Tradeoff Analysis Results and Final Concept Evolution

Following the initial identification and selection of potential or candidate CTS's, the PEEVS tradeoff analysis was performed. Rough artist sketches were created and gross CTS operating descriptions, capabilities and probable constraints were provided each analyst in order to minimize individual

confusion or misinterpretation of a candidate concept. Analysis worksheets were then completed by each analyst for each CTS, including a final rating of each CTS. Examples of these materials may be found in Appendix B. Results of the PEEVS CTS analysis is provided in Table 3.1.1-1.

As these worksheets indicate, ratings and total raw scores were generated for each CTS under the three separate categories of Semi-Automatic, Manual-Aided, and Manual systems. The final step in the PEEVS analysis was a ranking of CTS's for each category (shown in Table 3.1.1-2). In this final summary each CTS is given a rank based on its raw score (e.g., the Modified Telelift CTS had a low score under the Semi-Automatic Category and it is therefore ranked number 1 in that category). It should be noted that an arbitrary cut-off was applied, in that any raw score exceeding 120 was considered unacceptable for further evaluation. Crew participation was an integral factor in rating all CTS's although there is an inherent difference in the level of crew participation in a CTS, depending upon which category is being considered.

As noted in an earlier section of this report, it became apparent by the end of the PEEVS analysis that the method was not fulfilling its intended purpose. There was so little information available about any of the CTS's that analysts were placed in the difficult position of conjuring up personal assessments and estimates, based on extremely tenuous predictions of what these systems might be able to do and what constraints might be imposed by each system. It also became evident that even the slightest re-interpretation could change the rank of a given system. For example (see Table 3.1.1-2) the Modified Telelift appeared to rank first considering its overall convenience and ability to function (apparently) in zero-g. However, considered in terms of what might happen when it fails, there is little to go on in evaluating alternatives. Similarly, Trolley #1, which was ranked 2, could be considered in several alternate or emergency modes since it is a fairly simple system and amenable to gross conceptualization.

One further factor stood out in this approach, namely, that the arbitrary categorization of CTS's by the three levels of automaticity proved to imply something that has little meaning in comparing system effectiveness. Whereas these categories seemed to constrain comparisons, it became apparent that functional cargo handling requirements were going to be

Table 3.1.1-1 (a) - PEEVS CTS Analysis Worksheet

CARGO TRANSFER SYSTEM		SEMI-AUTOMATIC															
		Modified Telelift		Dumbwaiter (Cargo Only)		Dumbwaiter (Crew & Cargo)		Trolley (Cargo Only)		Trolley (Crew & Cargo)		Conveyor Belt		Bi-Stem (6 in. Diam)	
MEASURES	WEIGHTING	R	T	R	T	R	T	R	T	R	T	R	T	R	T
Visibility	3	2	6	2	6	3	9	2	6	3	9	3	9	1	3
Deployed Volume	3	2	6	2	6	2	6	1	3	2	6	2	6	1	3
Transport Velocity	2	1	2	1	2	2	4	1	2	2	4	1	2	2	4
Cargo Mass Limit	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
Cargo Size	2	1	3	1	3	1	3	1	3	1	3	1	3	2	6
CTS Mass	2	1	3	2	6	2	6	2	6	2	6	2	6	2	6
Maintenance Time Rqmts	5	2	10	2	10	2	10	2	10	2	10	2	10	2	10
CTS Stowed Volume	1	1	1	1	1	2	2	1	1	2	2	2	2	1	1
Cargo Positioning Accuracy	3	1	3	2	6	1	3	2	6	1	3	2	6	2	6
Cargo Orientation Accuracy	2	1	2	2	4	2	4	2	4	2	4	2	4	2	4
Emergency Provisions	5	3	15	2	10	2	10	2	10	2	10	2	10	3	15
Operational Lifetime	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4
Physical Energy Rqmts	5	1	5	2	10	2	10	2	10	2	10	2	10	2	10
Fuel & Power Expenditure Rqmts	3	3	9	3	9	3	9	3	9	3	9	3	9	3	9
Range	5	1	5	2	10	2	10	2	10	2	10	2	10	3	15
Dependability	5	2	10	2	10	2	10	2	10	2	10	2	10	2	10
Crew Rqmts	1	2	2	2	2	1	1	2	2	1	1	2	2	2	2
Translation Rate Control	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Translation Stability	4	1	4	1	4	1	4	1	4	1	4	1	4	2	8
Translation Maneuverability	5	1	5	2	10	2	10	2	10	2	10	2	10	2	10
Deploy/Remove Time Rqmts	2	2	4	2	4	2	4	2	4	2	4	2	4	1	2
Deploy/Remove Physical Energy Expenditure Rqmts	2	1	2	2	4	3	6	2	4	3	6	3	6	1	2
TOTAL RANK	69	33	106	39	126	41	130	38	123	41	130	42	132	40	135

Key: R - Rating
T - Total

Table 3.1.1-1 (b) - PEEVS CTS Analysis Worksheet

CARGO TRANSFER SYSTEM		MANUAL-AIDED							
		Mechanical Dumbwaiter		Clothesline		Mechanically Operated Conveyor		Rails & Diaphram	
MEASURES	WEIGHTING	R	T	R	T	R	T	R	T
Visibility	3	2	6	1	3	2	6	2	6
Deployed Volume	3	2	6	1	3	2	6	1	3
Transport Velocity	2	2	4	2	4	2	4	2	4
Cargo Mass Limit	3	1	3	2	6	1	3	1	3
Cargo Size	3	1	3	2	6	1	3	2	6
CTS Mass	2	3	6	1	2	3	6	2	4
Maintenance Time Rqmts	5	2	10	1	5	2	10	1	5
CTS Stowed Volume	1	2	2	1	1	2	2	1	1
Cargo Positioning Accuracy	3	2	6	3	9	2	6	2	6
Cargo Orientation Accuracy	2	2	4	1	2	2	4	1	2
Emergency Provisions	5	3	15	1	5	3	15	1	5
Operational Lifetime	4	1	4	1	4	1	4	1	4
Physical Energy Rqmts	5	3	15	3	15	3	15	3	15
Fuel & Power Expenditure Rqmts	3	1	3	1	3	1	3	1	3
Range	5	2	10	2	10	2	10	2	10
Dependability	5	2	10	1	5	2	10	2	10
Crew Rqmts	1	2	2	2	2	2	2	2	2
Translation Rate Control	1	2	2	3	3	2	2	3	3
Translation Stability	4	1	4	3	12	1	4	1	4
Translation Maneuverability	5	2	10	2	10	2	10	3	15
Deploy/Remove Time Rqmts	2	3	6	2	4	3	6	3	6
Deploy/Remove Physical Energy Expenditure Rqmts	2	3	6	2	4	3	6	2	4
TOTAL RANK	69	44	137	38	118	44	137	39	121

Key: R - Rating
T - Total

Table 3.1.1-1 (c) - PEEVS CTS Analysis Worksheet

CARGO TRANSFER SYSTEM		MANUAL									
		Rail System		Fireman's Pole		Pitch & Catch Net		Bucket Brigade with Fixed Restraint		Manual Restraint and Translation	
MEASURES	WEIGHTING	R	T	R	T	R	T	R	T	R	T
Visibility	3	1	3	2	6	2	6	1	3	1	3
Deployed Volume	3	1	3	1	3	2	6	1	3	1	3
Transport Velocity	2	3	6	3	6	2	4	2	4	3	6
Cargo Mass Limit	3	2	6	2	6	2	6	2	6	2	6
Cargo Size	3	2	6	2	6	2	6	2	6	2	6
CTS Mass	2	1	2	1	2	1	2	1	2	1	2
Maintenance Time Rqmts	5	1	5	1	5	1	5	1	5	1	5
CTS Stowed Volume	1	1	1	1	1	1	1	1	1	1	1
Cargo Positioning Accuracy	3	2	6	2	6	2	6	2	6	2	6
Cargo Orientation Accuracy	2	2	4	2	4	2	4	2	4	2	4
Emergency Provisions	5	1	5	1	5	1	5	1	5	1	5
Operational Lifetime	4	1	4	1	4	2	8	1	4	1	4
Physical Energy Rqmts	5	3	15	3	15	3	15	3	15	3	15
Fuel & Power Expenditure Rqmts	3	1	3	1	3	1	3	1	3	1	3
Range	5	2	10	2	10	3	15	1	5	1	5
Dependability	5	1	5	1	5	1	5	1	5	1	5
Crew Rqmts	1	1	1	1	1	2	2	3	3	1	1
Translation Rate Control	1	3	3	3	3	3	3	3	3	3	3
Translation Stability	4	3	12	3	12	3	12	2	8	2	8
Translation Maneuverability	5	3	15	3	15	3	15	2	10	3	15
Deploy/Remove Time Rqmts	2	1	2	1	2	1	2	1	2	1	2
Deploy/Remove Physical Energy Expenditure Rqmts	2	1	2	1	2	1	2	1	2	1	2
TOTAL RANK	69	37	119	38	122	41	133	35	105	35	110

Key: R - Rating
T - Total

Table 3.1.1-2 - PEEVS CTS Ranking Summary

Cargo Transfer Concepts		Raw Score	Rank	Status*
Semi-Automatic	Modified Telelift	106	1	A
	Dumbwaiter #1	126	3	N-A
	Dumbwaiter #2	130	4.5	N-A
	Trolley #1	123	2	N-A
	Trolley #2	130	4.5	N-A
	Conveyor Belt	132	6	N-A
	STEM**	135	7	N-A
Manual Aided	Dumbwaiter Mechanical	137	3.5	N-A
	Clothesline	118	1	A
	Mechanical Conveyor	137	3.5	N-A
	Rail & Diaphragm	121	2	N-A
Manual	Rails	119	3	A
	Firemans Pole	122	4	N-A
	Net	133	5	N-A
	Bucket Brigade	105	1	A
	Manual Restraint & Translation	110	2	A

*A Minimum raw score of 120 was required for acceptability

Key: A - Acceptable for further study.

N-A - Not acceptable for further study.

**Although other boom-type devices could be used, STEM was the only one considered for this analysis because of its size/weight advantages.

met by generalizable systems having inherent alternatives. For example, the concept of a trolley should be considered functionally rather than as semi-automatic, manual-aided or simply manual. The trolley becomes effective only when it can be designed with all of these capabilities. Similarly, the trolley and clothesline CTS's combine easily and, when appropriately designed, cross all three categories.

In view of the above considerations a second analysis was performed using a simple set of general criteria (discussed in an earlier section of this report). In this analysis a smaller number of CTS's were evaluated in terms of specific cargo handling operating areas, i.e., C/CM, SS Docking Tunnel, and SS Tunnel areas.

Table 3.1.1-3 presents the outcome of this analysis. It can be seen that an entirely new result appears to have occurred, and probably one which is more realistic from an operational point of view. The generalized measures created for this analysis obviously are less detailed than those devised for the PEEVS but probably are more appropriate, considering the lack of detailed design information available. Even the matter of number of crew members becomes somewhat academic at this point and, in fact, becomes a major issue in considering future research.

For example, it can be seen in Table 3.1.1-3 that for the C/CM and SS Docking Tunnel areas, the manual translation of packages appears to rate highest as the preferred CTS. However, simple logic tells us that the extra time and energy required for a single man to translate packages from the C/CM to some loading point in the SS tunnel is undesirable. It is for this reason that MFI has recommended the second choice, i.e., Rail-Trolley, as the preferred CTS.

The reason why many blank spaces appear in the foregoing summary tables is of course, because of the inappropriateness of comparing manual and semi-automatic systems. Other blanks occur because of our inability to assess the criterion measures at this time (e.g., task complexity and time required to erect a system after it is put into space is a relative matter depending upon the way in which the system is designed).

Reviewing the foregoing formal analyses one can see that the cargo transfer problem cannot be viewed as a whole-task

Table 3.1.1-3 (a) - Tradeoff Study of CTS for C/CM Area

	Cargo Transfer Systems						
	Tele-lift	STEM	Cable Pulley	Rail Trolley	Conveyor Belt	Manual Trans-lation	Bucket Brigade
Flexibility of package handling capability, e.g., size, shape, mass	6	7	1	2	3	4	5
Alternate use for emergency package transfer, personnel transfer, etc.	4	5	2	1	3	--	--
Complexity and time required to erect in-space.	6	4	5	3	7	1	2
Capability to move more than one package at once.	6	7	2	1	3	4	5
Capability to move packages in two directions at once, e.g., UP/DOWN cargo	6	5	1	4	7	2	3
Alternate use as ground loading system	6	7	3	1	2	5	4
Minimum intrusion or occupation of space, interference, etc.	6	5	3	4	7	1	2
Complexity, weight penalty	5	6	3	4	7	1	2
Power requirements	4	5	2	1	3	--	--
Scheduled maintenance requirement	5	4	2	1	3	--	--
RELATIVE RANKING .	6	7	4	2	5	1	3

Table 3.1.1-3 (b) - Tradeoff Study of CTS for SS Docking Tunnel Area

	Cargo Transfer Systems						
	Tele-lift	STEM	Cable Pulley	Rail Trolley	Conveyor Belt	Manual Trans-lation	Bucket Brigade
Flexibility of package handling capability, e.g., size, shape, mass	6	7	1	2	3	4	5
Alternate use for emergency package transfer, personnel transfer, etc.	4	5	2	1	3	--	--
Complexity and time required to erect in-space.	6	4	5	3	7	1	2
Capability to move more than one package at once.	6	7	2	1	3	4	5
Capability to move packages in two directions at once, e.g., UP/DOWN cargo	6	5	1	4	7	2	3
Alternate use as ground loading system	6	7	3	1	2	5	4
Minimum intrusion or occupation of space, interference, etc.	6	5	3	4	7	1	2
Complexity, weight penalty	5	6	3	4	7	1	2
Power requirements	4	5	2	1	3	--	--
Scheduled maintenance requirement	5	4	2	1	3	--	--
RELATIVE RANKING	6	7	4	2	5	1	3

Table 3.1.1-3 (c) - Tradeoff Study of CTS for SS Central Tunnel Area

	Cargo Transfer Systems						
	Tele-lift	STEM	Cable Pulley	Rail Trolley	Conveyor Belt	Manual Trans-lation	Bucket Brigade
Flexibility of package handling capability, e.g., size, shape, mass	3	5	1	2	4	--	--
Alternate use for emergency package transfer, personnel transfer, etc.	4	3	1	2	5	--	--
Complexity and time required to erect in-space.	--	--	--	--	--	--	--
Capability to move more than one package at once.	4	5	1	2	3	--	--
Capability to move packages in two directions at once, e.g., UP/DOWN cargo	3	2	1	4	5	--	--
Alternate use as ground loading system	3	5	4	2	1	--	--
Minimum intrusion or occupation of space, interference, etc.	4	2	1	3	5	--	--
Complexity, weight penalty	4	3	1	2	5	--	--
Power requirements	3	4	1	2	5	--	--
Scheduled maintenance requirement	5	4	2	1	3	--	--
RELATIVE RANKING	3	4	1	2	5	--	--

concept since each work area imposes different constraints -- which in turn suggest slightly different criterion measures. Similarly, almost any of the transfer systems can be upgraded arbitrarily by appropriate design sophistication, creating near equivalence among candidate systems (or so it seems).

The two-step analysis did however serve to order the problem parameters and provide analysts with a clearer perspective. For example, by examining only one work area at a time it was possible to consider that area without bias from other area-system constraints. A case in point is the evolutionary review of the C/CM transfer possibilities as shown in the artist sketches (Figures 3.1.1-1 through 4).

In the first figure, it becomes apparent that the highly ranked single crew translation mode would be time and energy consuming even though the distances are not great. From the second and third illustrations it becomes obvious that too many crewmen would be required for the bucket brigade (also highly ranked). Thus, point by point the rail-trolley system appears more acceptable and, as it is examined in terms of alternative uses, seems most cost-effective under all situations.

A similar evolution occurred during the examination of the SS tunnel area requirements and constraints. The extremely long distance involved as well as the unique problems associated with the tunnel-hatch geometry brought into focus the need to provide a system with minimum intrusion into the hatch openings as well as one that could provide backup personnel transfer aid without requiring additional hardware. Since the cable-pulley system emerged as first choice in the formal analysis, it became the prime candidate for further evolutionary study.

The chief problem of concern to analysts was the possibility of packages swinging or oscillating on the cable (especially if the packages were very large). Although it was not our role to "design," the problem had to be resolved before the cable-pulley arrangement could be accepted even tentatively as a candidate system. Accordingly, a simple design analysis and concept development was undertaken with the result as shown in Figure 3.1.1-5. As illustrated, a single cable is arranged over a series of pulleys so that two parallel lines proceed in the same direction at the same time. Such a system permits

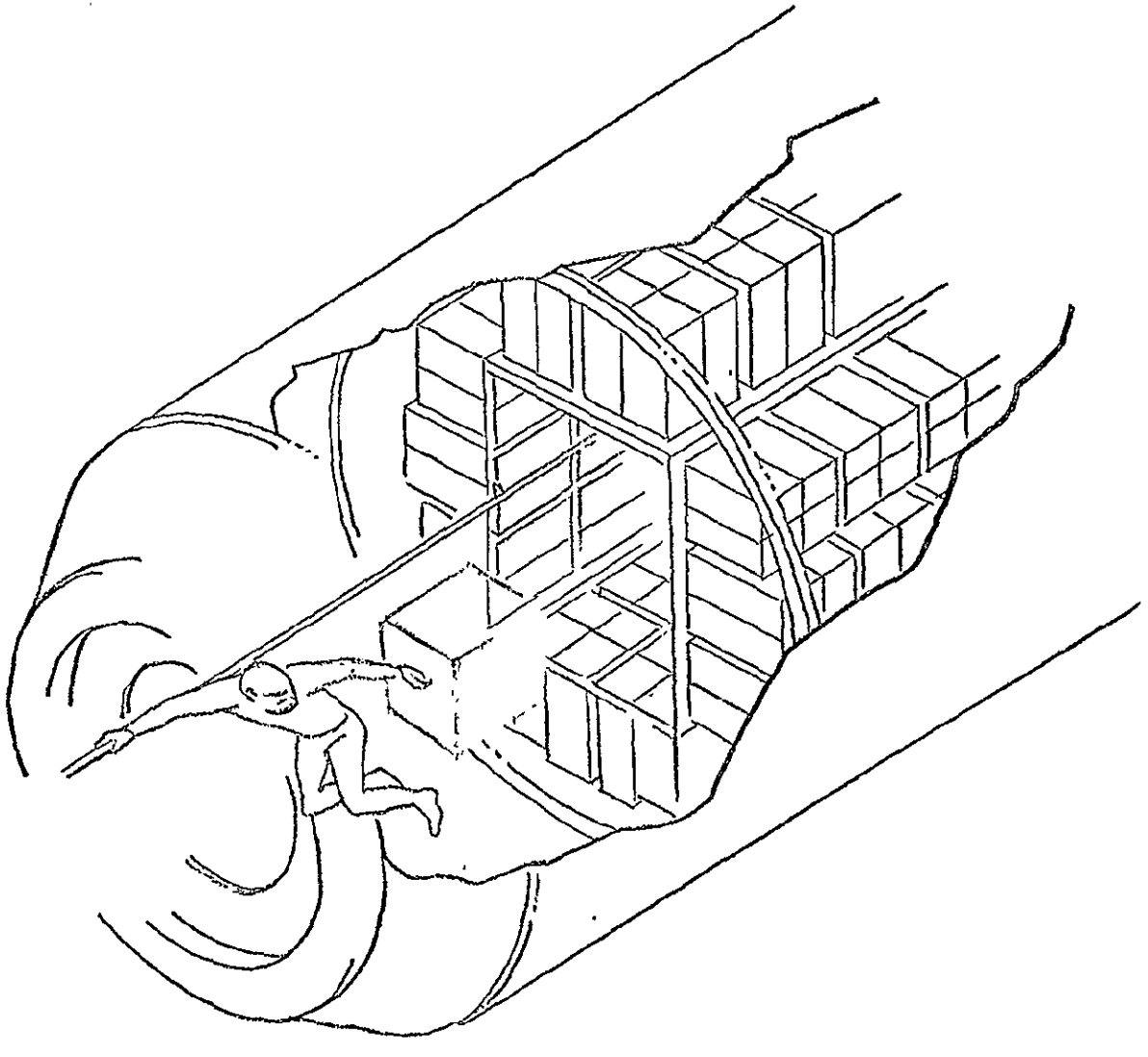


Figure 3.1.1-1 - Typical Manual Cargo Transfer Using Handrail For Comparison With "Shopping Cart"

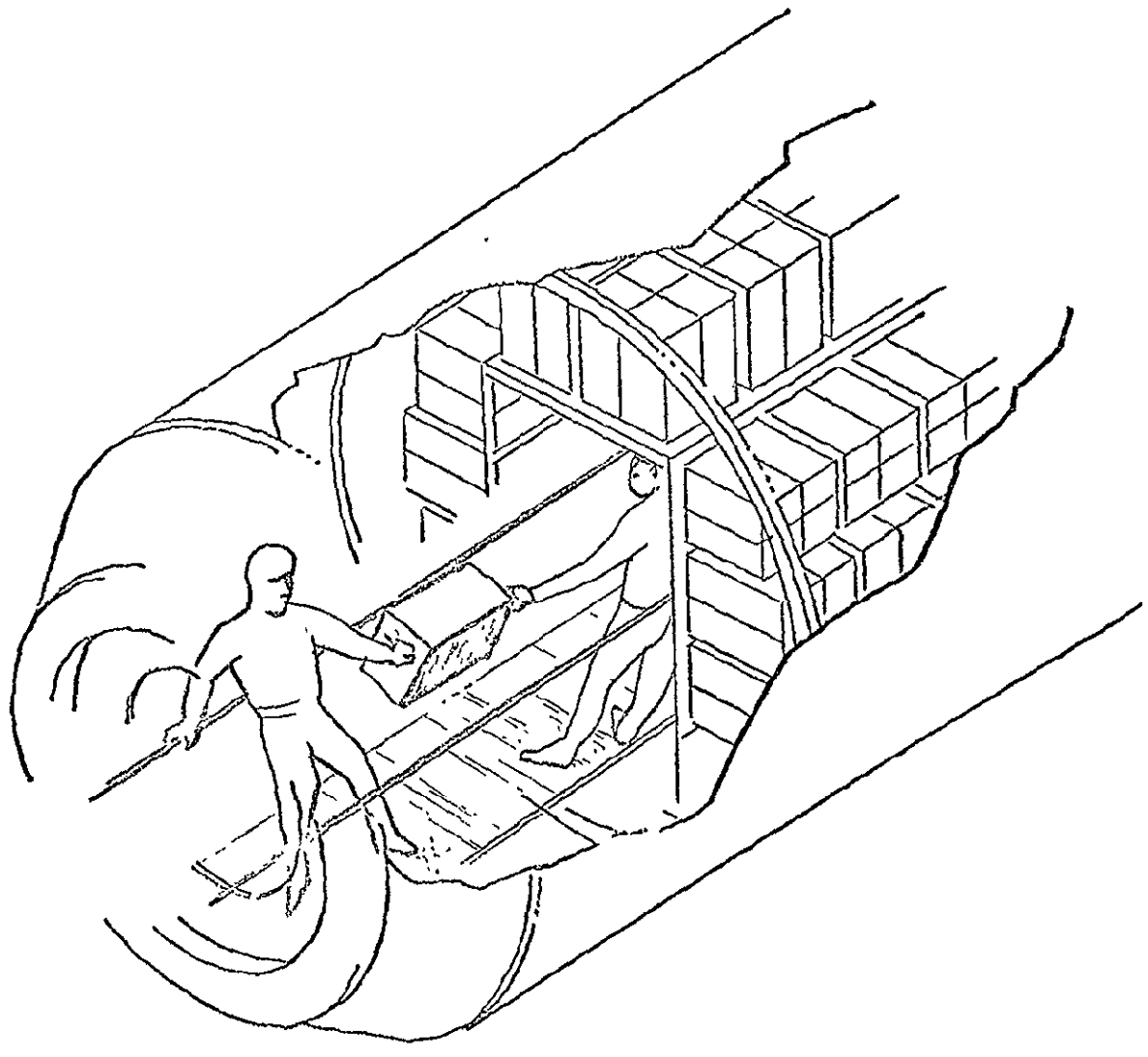


Figure 3.1.1-2 - Bucket-Brigade Technique for C/CM Cargo Handling

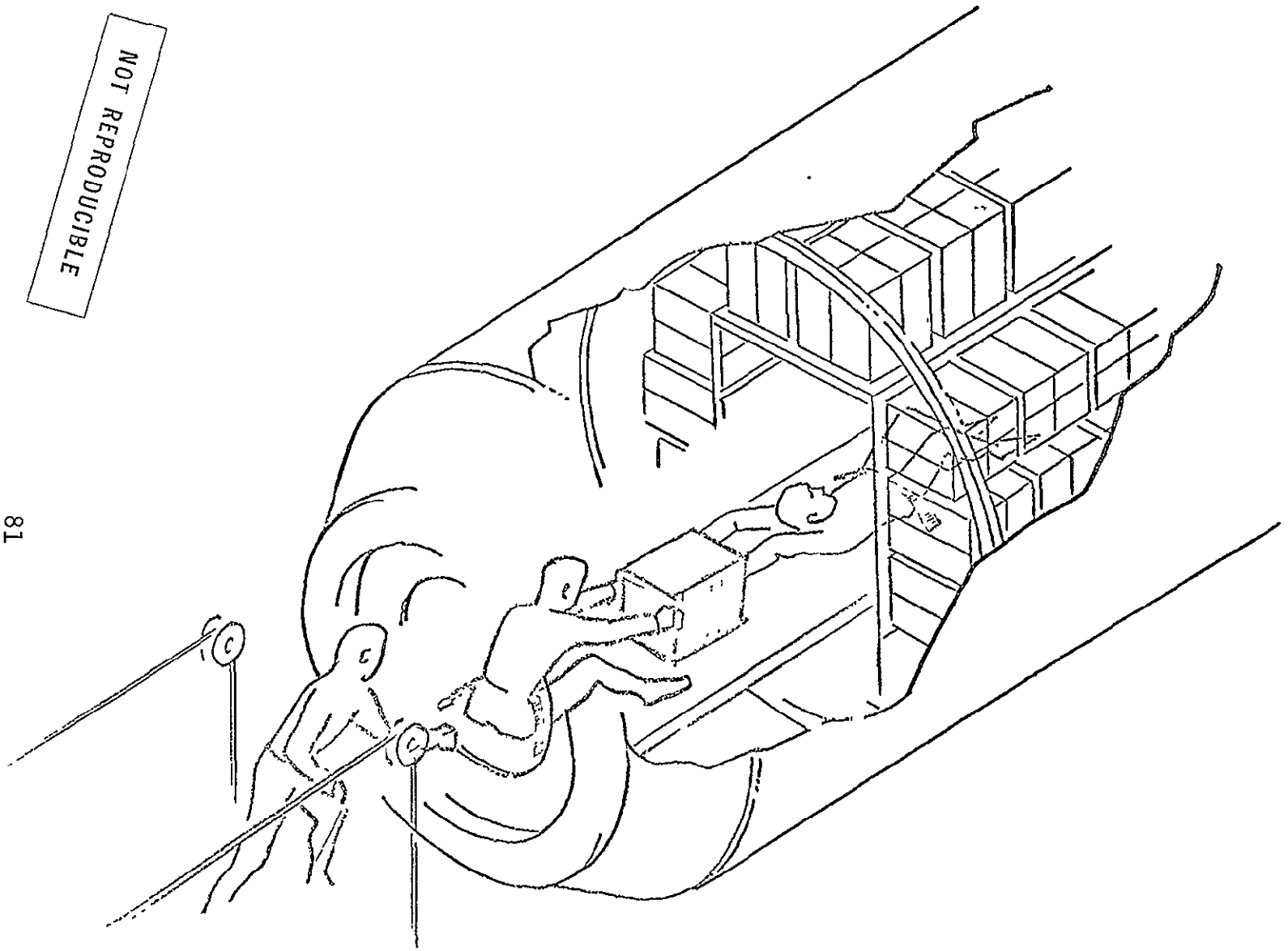


Figure 3.1.1-3 - Alternate End-Over-End Bucket Brigade Concept For Cargo Handling In C/CM to SS CTS Loading Point

Figure 3.1.1-4 - "Shopping Cart" Technique Using Combination of Permanent and Removable Rails in the C/CM

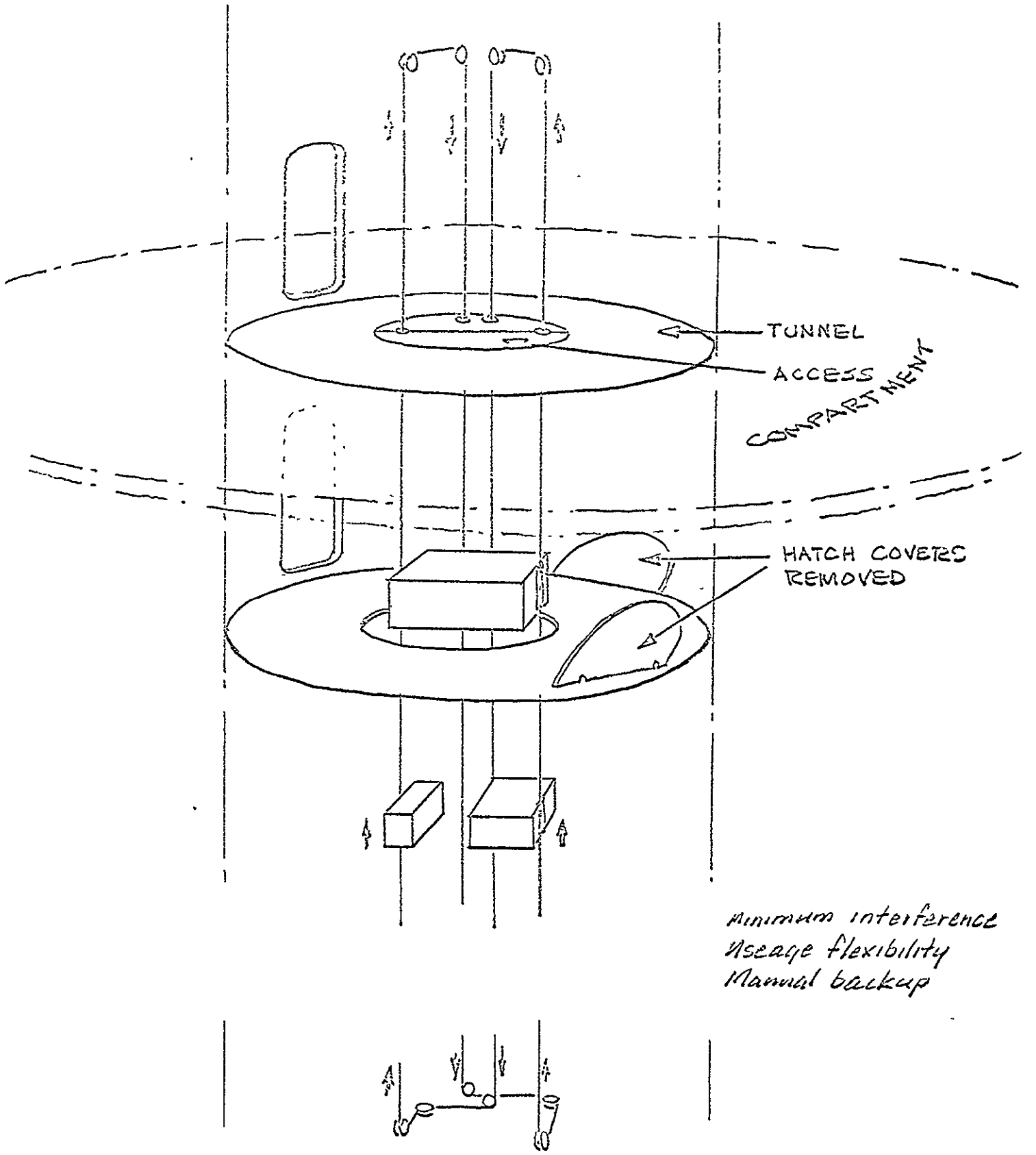


Figure 3.1.1-5 - Powered Cable/Pulley Transfer Concept

large packages to be kept under control and allows for the transfer of all shapes of packages. As noted earlier it also provides the unique capability of transferring UP and DOWN cargo at the same time. Another interesting result is that the rails emenating from the C/CM area mate naturally with the two-line cable configuration in the SS area.

Before concluding this discussion on the evolution of a recommended transfer system for the specified C/CM-SS model, some comment is in order regarding the possibilities of other CTS concepts -- particularly the TELELIFT by Mosler.[85] This system, designed especially for ground-based facilities such as hospitals, is an example of a somewhat more sophisticated, semi-automatic approach to package handling and transfer. Although it did not rate particularly high in the formal analysis completed during this study, in the opinion of the present investigators it has sufficiently acceptable characteristics to warrant further study.

The most important factor in favor of the TELELIFT concept is that it could serve as a single CTS for the entire C/CM-SS complex as shown in Figure 3.1.1-6. A detailed design analysis should be performed to determine the ultimate capabilities of such a system and what weight and power penalties might be expected.

3.2 Cargo Handling Problem Definition and Discussion

An assumption made at the outset of this study was that problems of cargo handling in space could be examined in terms of the satisfaction of the operational requirements (output) and the system energy costs (inputs). A problem area would, therefore, be one in which system output was not equal to input. It was also felt that problem area definition would be further complicated by requirements for communication and integration activities among cargo-handling crew members. In order to identify and define useful and meaningful problem areas, basic questions were formulated relative to the movement of crewmen and/or cargo in space. For example:

1. What is the largest mass/volume that can be handled by a single man?

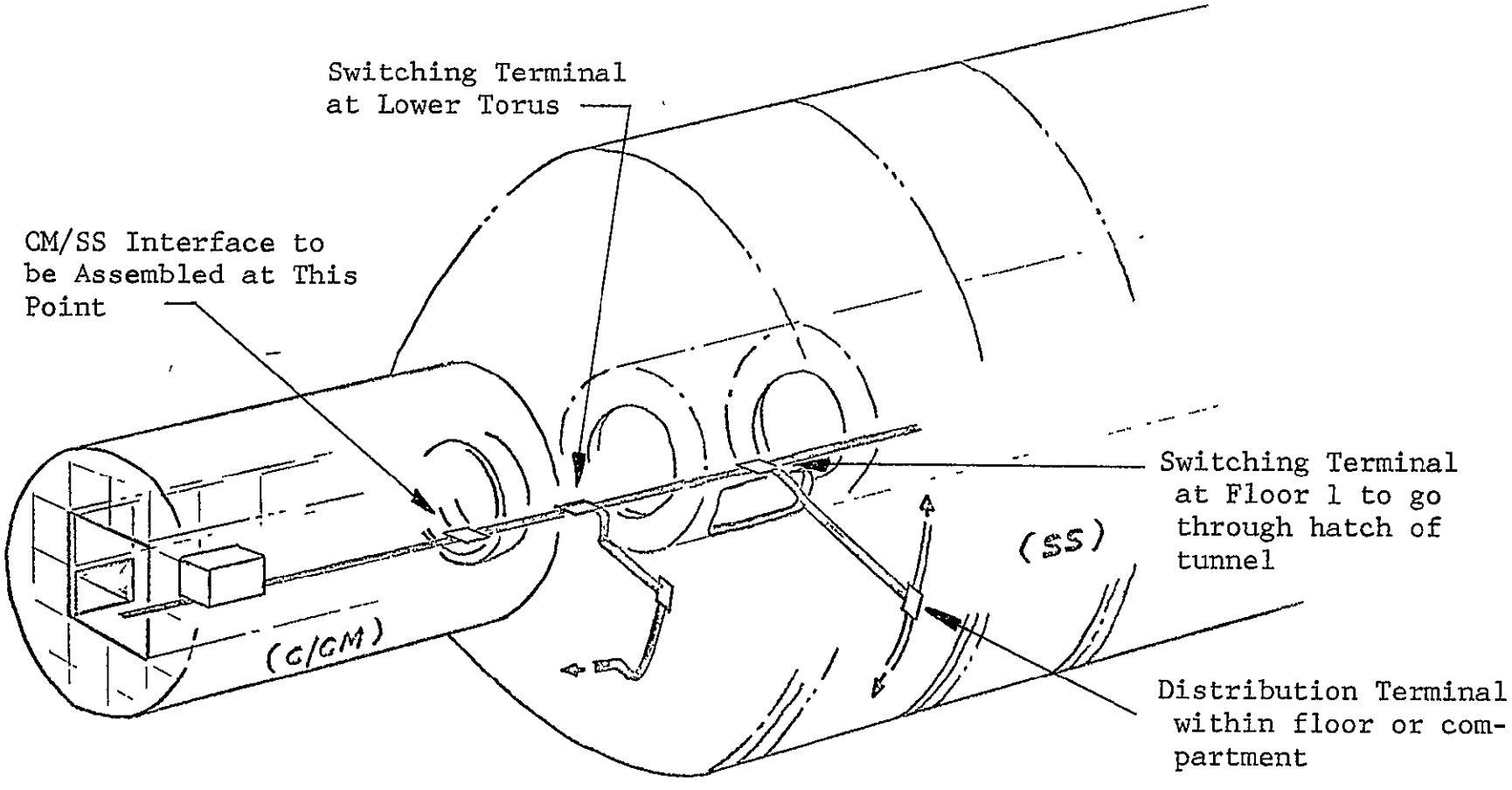


Figure 3.1.1.-6 - Telelift System Integrated Between C/CM and SS
For Totally Automatic Transfer

2. What is the accuracy with which objects of a given mass/volume can be steered/aligned?

3. How can a crewman properly control the deceleration of a given mass/volume?

4. How well can a single crewman control necessary rotation of a package in terms of pitch, roll, and yaw?

5. What is the maximum rate at which various mass/volume packages can be moved safely?

6. What propulsion, transfer, maneuvering, positioning and alignment modes are available to the crewmen, and what are their relative efficiencies?

A comprehensive literature search was conducted to answer as many of these questions in quantifiable terms as possible (see Appendix A). Very little quantitative information has been developed and many of the studies provide conflicting results. Therefore, although it is still desirable to try to quantify input/output imbalance as a method for problem area definition, lack of quantitative information makes it necessary (for the present at least) to return to the six (6) basic questions in order to derive any meaningful problem descriptions.

The problem areas to be discussed in the succeeding paragraphs are of a general operational type which result from both a general lack of basic information about man's cargo-handling capability limits in a zero gravity environment and also from the dearth of information about specific cargo handling systems.

An attempt has been made to organize problem descriptions -- some of which were uncovered by the task analysis and some by the literature search (see Appendix A) -- into three general categories. Category I includes design and procedural problems involved in manual and mechanically aided manual cargo handling operations; Category II includes problems associated with semi-automatic cargo handling; and Category III includes general procedural and design problem areas stemming from the unique Shuttle/Space Station configuration used as a study model.

3.2.1 Category I, Manual and Manual/Aided Cargo Handling Problem Areas

Inherent in all crewman cargo-handling operations are three distinct requirements: (1) crewman restraint and stabilization at a given position, (2) aids necessary to assist the crewman in translating and maintaining appropriate body orientation and control during movement from one place to another, and (3) devices and/or procedures (relative to container design) necessary to assist the crewman in holding onto and manipulating a container while it is being removed from a storage rack, being loaded onto a CTS, removed from a CTS, being transported manually from one place to another or handed to or "pitched" to another position, receiving astronaut or automatic, fixed receiving device and, finally, being placed into a workplace receptacle, rack or other assembly.

A number of restraint, translation and package handling devices have been devised and evaluated in the past. Very few of these have, however, undergone any extensive modification or further development following evaluation to eliminate problems, re-evaluate the devices, or to make comparisons among all devices. Such comparisons would allow generalizations and specific design tradeoffs to be made and to be applied to future systems, such as those required for transferring cargo in the present shuttle/space station resupply mission. These early restraint and translation concepts (covered briefly in Appendix A) set the stage for the discussion that follows.

Table 3.2.1-1 provides a list of Category I problem areas identified during this study and describes them in terms of what a cargo-handling crewman will have to do during a typical transfer sequence. Discussion of specific interface operations with a given cargo transfer system purposely has been avoided here, however, since these problems are covered in detail under Category II problem areas. The following discussion deals with typical restraint and translation subsystem design problems that must be resolved in order to remove or minimize the procedural difficulties discussed in Table 3.2.1-1.

Astronaut Restraint Systems

Several types of restraint devices and systems have been proposed in the past. Some have been fabricated and tested

Table 3.2.1-1 - Category I: Manual and Manual/Aided Cargo Handling Problem Areas

DESCRIPTION	REMARKS
1. Identification of and locating stored position of Up-Cargo package in C/CM	Coding and labeling is straight forward, however development of a Identifier-Locator System is needed in order to minimize time and energy requirements imposed on the crew, i.e., so a crewman can go directly to a desired package.
2. Getting the astronaut to the package within the C/CM	Different storage concepts impose varying space and mobility requirements. Articulated systems bring packages to the astronaut, however, typical fixed-rack systems require crew mobility aids - the most convenience vs cost in terms of weight and lost storage volume.
3. Getting hold of and releasing package from stored position, prior to transferring it to a particular CTS	Information is required regarding the convenience of package fastening devices. Each should be evaluated in a man-machine zero-g simulation environment to determine which devices are optimum from an error/time/energy standpoint.
4. Transferring package from its stored position in the C/CM to the CTS loading point	Astronaut mobility requirements are similar to those in 2 above except that he will be hindered by package. This requires test of various package-carrying techniques in a man-machine, zero-g simulation environment.

Table 3.2.1-1 - Category I: Manual and Manual/Aided Cargo Handling Problem Areas

DESCRIPTION	REMARKS
5. Transferring package from CTS off-loading point to working site or storage area	Astronaut mobility requirements and restrictions are similar to those described in 2 and 4, except that transfer distances may be greater. This activity will most likely be accomplished by SS deck personnel and thus will not impose new mobility aid requirements. However typical SS compartment configurations should be simulated and mobility requirements evaluated for the unique cargo transfer mission.
6. Install and secure package at worksite	This operation will be manual in most cases. Evaluation of several package-mounting concepts is required in terms of package positioning, slide and latch manipulation and associated astronaut mobility, dexterity and restraint.
7. Baseline manual manipulation of cargo packages of various sizes, shapes, masses using various handhold concepts and devices	Isolated zero-g evaluations of very specific package and transfer aid devices cannot be extrapolated directly to cargo handling. Alternate designs should be compared in terms of effectiveness in order to know which techniques are appropriate to which CTS concepts.
Note: All of the above problem areas need to be systematically investigated in order to define and resolve the overall question of "what is the appropriate level of astronaut involvement in cargo handling in space"? Although certain task elements can be examined using air cushion- and suspension-type simulators, these restrict mobility of the subjects to the extent that results are of limited value. Therefore, a neutral buoyancy technique appears to be the most desirable simulation medium. Its primary deficiency is in the fact that subject movement cannot be rapid. Parabolic flight simulations may be of considerable value for part-task tests wherein a task could be completed within the short, 30-second, zero-g exposure capability.	

in various zero-g simulation environments as well as in-space flights. These include:- (1) foot restraints (e.g., "Dutch Shoe" cups, Velcro interface shoe and deck pads, simple foot stirrups, bar-type rails under which the foot can be "hooked," extruded, continuous screens in which the foot can be inserted at almost any point, or cleated shoes which interface with an open-mesh surface, etc.); (2) knee restraints in which a seated operator can create a closed connection between himself, the seat and the knee restraint by pressing his knees against the knee restraint element, usually the lower part of a deck or console structure; (3) flexible body harness attached either at single or multiple points on the body and to some structure or rail; (4) a rigid rod device attached between the astronaut's body and some structure (in a similar manner to that used for the flexible straps); (5) Velcro body-limb interface pads that can be pressed against mating pads on structures; (6) simple handhold or rails that can be grasped with one hand while the astronaut uses the free hand to accomplish some other manipulation task; and (7) various combinations of the above in which advantage is taken of the best features of each to provide a three-point closed-loop system of restraint, but which also allows the astronaut maximum freedom to articulate his upper torso and arms.

An obvious objective both in the previous work and also in current goals is to find some simple system which can be used in all working areas, with all unique man-equipment interfaces, and with a minimum of preparation. Since, in the normal earth environment, gravity provides the primary means for helping the man to maintain a given position, it would be desirable to have a space system which is equally simple and flexible - in terms of not requiring something extra on the part of man's adapting to the system or preparing it for use. With this objective in mind, the following evaluations and discussions of design problems are presented for each known restraint technique:

a. Velcro - Velcro material consists of two specially designed surfaces one of which intertwines or "hooks" into the other by means of small fibres. Under reasonable direct pull loads, it is difficult to separate the two fibre surfaces from each other, i.e., a "peel" technique is required to separate the two materials. Tests have been conducted in which it was demonstrated that a man could (with practice) walk up a wall using Velcro pads on his shoes and Velcro on the surface of

the wall (i.e., neutral buoyancy simulation). The Astronauts have had an opportunity to use Velcro in actual space flights for the purpose of securing small objects to Command Module surfaces.

The Velcro system offers flexibility not unlike the earth-gravity situation in that the material could be placed on total deck areas, the complete length of a tunnel surface, in strategic surface areas of the C/CM, etc. Astronauts then would need only to wear shoes with Velcro pads in order to attach themselves almost anyplace they wanted, as long as the mating Velcro surface was available. It is not known however, what kinds of cargo handling activities might result in sufficient peeling force that the Velcro would not hold.

Previous experiments have shown that it is necessary to "stomp" in order to secure one's foot to a Velcro surface. In space this may be quite difficult because as the astronaut "stomps" he is also applying a reactive force that tends to push him away from the surface. Some subjects have learned to walk reasonably well using Velcro, but most such experiments were limited to walking only and did not include other tasks.

It is one hypothesis that Velcro, used appropriately as a restraint device while performing loading and manipulative tasks, might be useful even though it may not prove effective for walking. However, we do not know how effective Velcro restraints would be when an astronaut has to handle a large package of sizable mass -- whether the inertia generated would dislodge his feet from the Velcro surface. It is believed that a Velcro system may prove adequate for a relatively fixed, inactive (i.e., minimum body motion) position. In this case, the astronaut should have little difficulty in assuming a desired position and body orientation with his hands, arms and torso free for use in a natural manner.

Although it has never been explored, Velcro may offer possibilities for securing packages in zero-g storage (in space). The advantage here would be that rack hardware might be eliminated, saving space and weight. The astronauts might however, find it difficult to separate or move packages so closely packed. Velcro might also be used to assist manual grasp, i.e., Velcro gloves that interface with Velcro surfaces

on a package may prove a useful substitute for conventional handles.

All these possibilities are considered potentially valid and should be evaluated in the context of cargo handling.

b. Stirrups - Unlike Velcro systems, stirrups have been studied strictly as a fixed-position aid. A major share of this work has been done in connection with space-suited astronauts at workstations. The limiting factor in the use of stirrups is not that they are particularly difficult to use or that they do not work satisfactorily, but rather, that one must know exactly where to locate the stirrups (a great number may be required for a complex arrangement) plus the fact that there must be other aids to help the astronaut get into the stirrups.

Human body posture control normally is maintained (using the stirrup concept) by exerting foot and ankle deflection forces against the stirrups, with some developed systems. It is important that the separation of the feet be correct, otherwise the astronaut can easily upset himself. A limited amount of work has been done so far to explore all the problems of stirrup use, especially as it relates to the manipulation of packages of large size and mass. This work will have to be done before stirrups can be compared to other techniques with any degree of confidence.

An obvious problem associated with stirrups is the matter of size so that all astronauts could use them equally well. Another problem is that of interference, i.e., numerous stirrups permanently attached all over the space station might be in the way at times and could conceivably present some hazards. An alternative yet to be explored is foot-rails, which might eliminate some of the above problems.

c. Harnesses - Considerable work has been done to determine the best combination of harness necessary to provide an astronaut with reasonable orientation security and yet maintain torso and limb freedom. A three-point suspension system mounted near the waist for two of the points, the third being closed by another strap and by the subject's limbs, is the typical approach. Alternatives have been devised in which stiff but adjustable rods are used to replace the flexible harness, thus providing

more rigidity to the astronaut's body positioning. Similarly, crude waist cradles have been tried but found generally to be too restrictive. Most of the work performed with restraint systems such as these has been associated with the use of space tools which normally impart a reciprocal motion to the astronaut's body if he is not restrained. How well such systems will work for tasks such as pulling a package out of a storage rack, has not been fully explored at this point. Such restraints should be evaluated using previously generated results to modify restraints to fit cargo task work stations and/or activities.

Regardless of previous problems, the restraint harness has considerable potential for tethering an astronaut to a translating element so that he does not escape inadvertently from typical transfer devices such as the "fireman's pole," or for tieing a package to the astronaut to keep from "losing" it. Strategically located semi-rigid straps through which a man could put his arm temporarily for stabilization, or the use of various combinations of straps with other types of restraint devices also should be investigated.

d. Knee Restraint, Handrails, etc. - Individually these techniques do not appear to provide a complete solution to the problem of securing crew members at a fixed point for performing cargo handling tasks. In combination with other techniques, however, they may be useful. The most important disadvantage of the handrail is that it requires the use of at least one of the astronaut's hands, thus restricting his flexibility in performing many handling tasks. However, a handrail may be used alternately as a foot or hand restraint.

e. Other Possible Restraint Techniques - Many other restraint system possibilities exist that have never been fully explored nor, in most cases, fabricated or tested. (Note: Equipments such as as self-powered Astronaut Maneuvering Units purposely have been excluded.)

One such method is a "skate board" which is captured by and follows a permanent track system mounted in the deck. Another might be the use of magnetic or key-slot shoes used on appropriate metal workplace or walkway surfaces. Still another is a rigid shoulder bracket hung from the ceiling at a specified

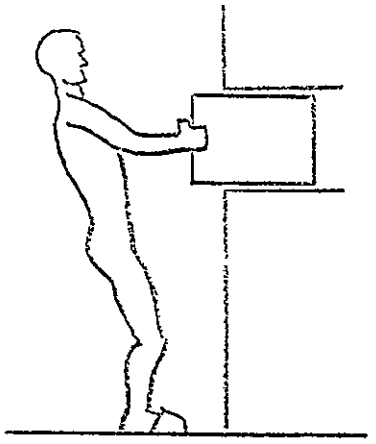
workplace to keep the crewman "compressed" to the deck. Even more important are the more simple "aids-of-opportunity" found in typical workspaces. These include use of compression techniques (e.g., bracing between deck and ceiling, walls, equipment, etc.), use of equipment or drawer handles or protruding or recessed elements of a console, rack or equipment.

Summarizing the above it appears that in spite of some previous investigations, quite a variety of restraint concepts should be studied systematically, specifically with relation to the unique requirements of cargo handling. Figure 3.2.1-1 provides a graphic summary of the state of knowledge regarding restraints for package remove-replace tasks.

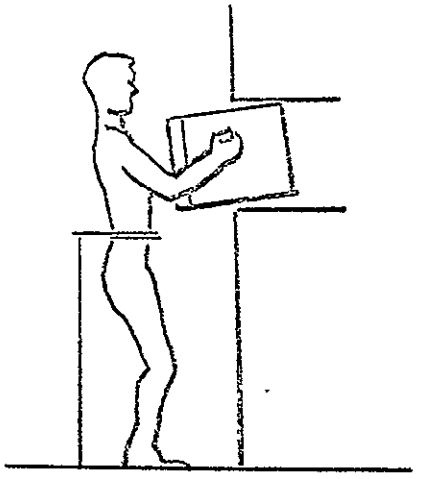
Astronaut Translation Systems

Many different techniques have been explored for astronaut movement or translation in the zero-g space environment. These include: empirical demonstrations and experiments of "free" movement in which the astronaut merely pushes off from a structure; translation using single and dual handrails and handholds; translation using ladders and firepoles; and translation using AMUs, "jet wands," "jet shoes" and Velcro surfaces. In addition, experiments have been conducted using jet and extruded metal screens similar to those used by military forces for climbing over the side of a ship. Most of these tests were limited to astronaut translation without serious encumbrance of cargo packages, therefore there is little information from which to extrapolate to the current problem, especially when it becomes necessary to compare all modes of astronaut translation.

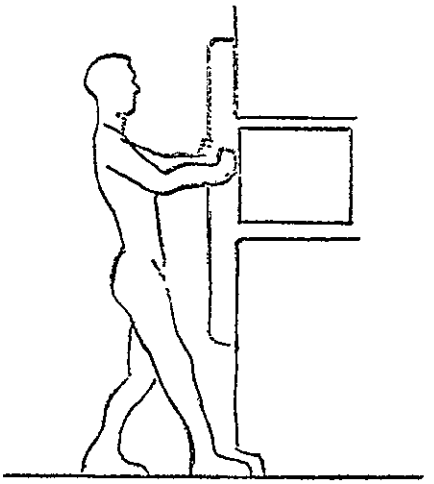
Although the jet powered devices noted above are interesting and potentially useful for future consideration, in the opinion of the authors they are too complex and of too questionable merit to warrant consideration in the present IVA analysis. On the other hand, it appears that the other translation methods and aids offer immediate promise of a very practical nature. However, they need to be explored in more detail in terms of cargo transfer objectives. The following paragraphs provide a preliminary evaluation and projection of capabilities and limitations of several personnel/cargo translation techniques as they appear relevant at this point in time.



Foot restraints mounted at the package manipulation station, foor stirrups, Dutch Shoes and other configurations have been designed and tested in limited degree. The package and rack detail in these experiments does not provide information regarding attendant problems of matching package with slides or slots, moving package to precise place in successive task context. Major issues include envelope of man-restraint constraint and its influence on package size, storage position.

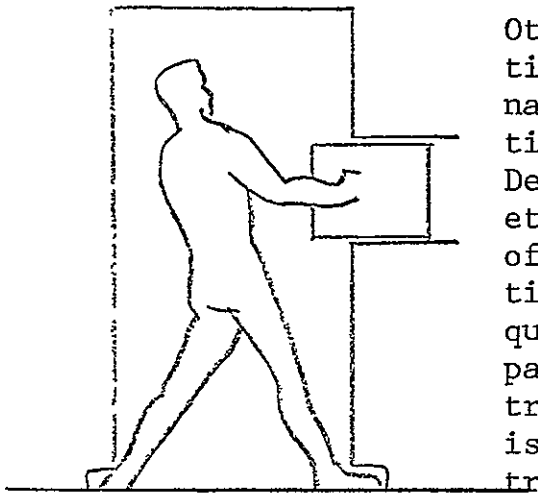


Waist restraints mounted at the package manipulation station; same comments as above except that the variety of waist restraint designs devised so far indicates less than adequate exploration of possibilities. Major issues much the same



Handhold restraints mounted at the package manipulation station; limited tests indicate it least effective, but designs and location variations lead one to believe capabilities not fully explored - especially use of handhold and all other types of aids.

Figure 3.2.1-1 - Astronaut Restraint, Operations Summary



Other restraints at package manipulation station include toe recesses in narrow passage (as shown in illustration), Velcro, Triangle Wedge Shoe-Deck device, Floating Waist Clamp, etc. Major issues concern efficiency of each device singly and in combination; crewman's position is also open question (i.e., in front or to side of package); various package shape extremes should be examined since there is interaction between work area geometry and package manipulation clearance requirements.

Summary of Package Removal and Replacement Techniques:

The above illustrations summarize the various possibilities for crew restraint while removing or replacing a package in various rack configurations. Similar pictorials could be developed for CTS loading stations. A relatively few unique or inventive schemes seem to have been proposed for restraining crewmen at a fixed work station as compared with translation schemes. What few systems have been fabricated and tested or demonstrated leave a poor impression, mainly because of the crudeness of the hardware. Little comparison can be made because of this lack of hardware variation and the poor design detail evidenced in the few items demonstrated. Most work has been done with pressure suited modes, therefore hardware is generally designed for this mode and merely adapted ("jury-rigged") to accommodate a shirtsleeve test or demonstration.

Figure 3.2.1-1 - Astronaut Restraint, Operations Summary (Cont'd)

a. Free Movement - This is perhaps the simplest translation mode for the astronaut and would (in a normal earth environment rather than zero-g) be considered the best and most natural. Unfortunately, in zero-g free movement is sometimes difficult, often complex, requires considerable training and can be hazardous. However, experience using this free movement translation technique both in ground simulations and in parabolic flights and/or actual space flight over the past several years has shown that astronauts can learn to accommodate to most zero-g problems. Most of this experience did not involve the coincident task of package handling, however, and except for a few experiments in which small equipment items were moved short distances and installed in typical, conventional equipment racks, no concentrated examination has been made of the total range of cargo transfer problems associated with types of cargo and/or transfer space geometries, mounting facilities, etc.

Key problem areas anticipated include such things as: the effect of package size, shape, mass and mass distribution on astronaut body motion, orientation and control; methods for astronaut-package attachment; visibility; movement rate and velocity; and potentiality for injury and equipment damage. Previous studies have not explored a wide enough variety of packages, equipments, space geometries, exposure time and procedural alternatives.

For example, a recent Skylab-related study performed in the KC-135 involved a subject pushing off from a baseline structure towards a typical equipment rack, pushing an experiment package that was to be inserted into an equipment rack. The subject, completely unaided at the start, was left to his own devices to get from point A to point B. Naturally, he experienced problems of tumbling and difficulty in stopping himself. Although practice improved his performance, the short exposure time allowed such practice to be accomplished only in spurts.

It became apparent to observers that some technique was required to assist the subject during the intermediate stopping sequence, prior to inserting the experiment package into the equipment rack. Accordingly, a separate jig was provided in front of the equipment rack to provide a capture point and simplify the equipment handling tasks prior to the final,

complex task of mating the package to the conventional rack apparatus. Although performance improvement was evident at once to an outsider (one not involved in the initial experiment) the immediate question raised was: "Why not just provide a second astronaut, stationed at the rack to aid in the problem of stopping and reorienting the package for insertion into the rack?" Although this seems a simple and obvious solution, it had not occurred to the system designer and it is noted here to point out that too many of the previous studies were not designed to explore sufficient alternatives. Consequently they do not provide for meaningful comparisons or effective design tradeoffs. The observation just cited also demonstrates how often and easy it is to add complexity and extra hardware for a questionable increase in performance efficiency.

Since the "free movement" mode of package transfer is simplest and imposes least on total system design, it should be explored more completely and systematically in order to establish baselines with which other package translation methods and techniques can be compared. For example, it should be determined what transfer time characteristics are for the free movement mode; what the limitations and requirements are relative to the surrounding structural geometry; what the package constraints are relative to size, shape and mass; what the implications are in terms of numbers of personnel required to accomplish package transfer for various package/space/physical geometry combinations; and, finally, what the human energy costs and hazards are. Once these baselines are established, other more automated modes and techniques can be evaluated in terms of performance improvement and system cost.

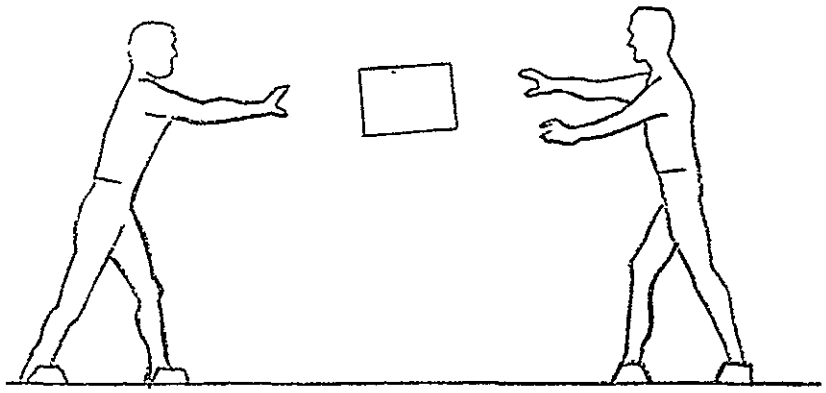
b. Manual Transfer (Mobility) Aids - Single handholds, handrails, firepoles, ladders, and Velcro surfaces which were discussed earlier under restraint systems all have potentially useful translation roles. From the numerous studies that have examined these techniques in the past it is clear that in zero-g, mobility aid design, location and use have to be appreciably different than they would be in the normal earth gravity environment. Early space station predesign concepts often made the mistake of assuming that one could "best guess," for example, the proper location for a handhold or handrail, or the spacing of ladder rungs. Neutral buoyancy tests demonstrated that body motions sometimes interfered with a subject's ability to use handholds effectively, since they had been designed or

located based strictly on earth-gravity experience. A few of these experiments examined package transfer problems, per se.[141] However, the current study has uncovered no complete inventory of information about package handling in zero-g that is sufficient for a meaningful tradeoff comparison of the several translation techniques.

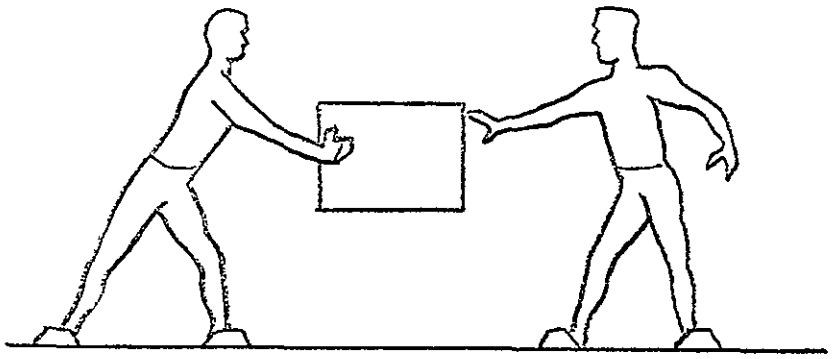
Typical of the problems that need systematic exploration are: (1) the effects and efficiencies of various astronaut-package interface modes (e.g., grasping a package directly vs attaching packages to the astronaut so that his hands are free for self translation); (1) the effects of package size, shape, mass and mass distribution on astronaut movement and body control; and (3) time and motion information and personnel requirements for different transfer techniques, particularly as these relate to preparations for, and following, the actual translation phase of transfer.

Relatively little comprehensive, detailed attention has been given to methods for interfacing cargo packages with the astronaut except for a few specific applications, such as those noted for Skylab. This is perhaps due to the questionable assumption that crew members can pick up and carry packages much the same as they do on earth, or that harness and attachment techniques for mounting a package on the back of an astronaut will be similar to earth methods.

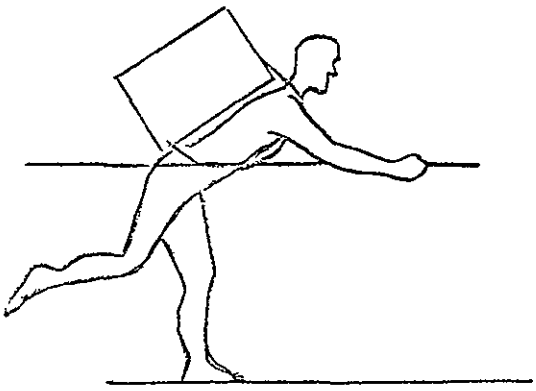
Even during the limited simulation studies that already have occurred it is apparent that time and motion estimates of manual transfer are distorted unless optimized procedures for interfacing the package with the astronaut are used.[60] Typical activities involved in acquiring and carrying a package or hoisting and mounting it on one's back on earth depend to a great extent on the advantages and/or disadvantage of gravity acting on the package and the subject. Since this condition does not exist in space, package and subject behavior change radically. It is not sufficient to assume that "he will learn to do it." There is a need to know what these problems are in terms of required compensating procedures, effects on performance time, etc., so that some yardstick is developed for comparing manual transfer with other modes. Figure 3.2.1-2 provides a graphic summary of the state of knowledge relative to package translation in zero-g.



Free-Toss system considered undesirable because of hazards involved; tried in qualitative manner, no hard data concerning package weight and size limitations.

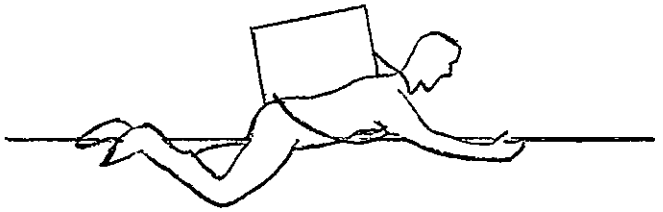


Bucket-Brigade system has not been examined in any detail; issues include package weight and size, best handles, procedures for handoff, best restraint and crew position.

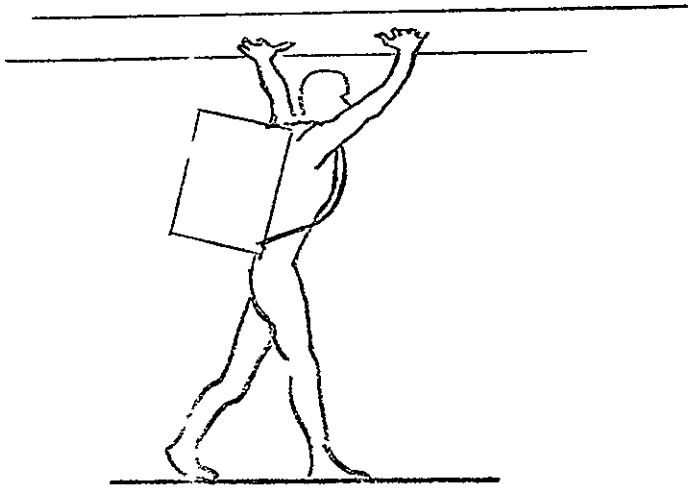


Back-Pack with handrail translation; some experience in space and limited simulation tests; major issues involve package weight and mass distribution effect; whether man can use deck as aid with handrail, also problem of donning and doffing the package alone.[115]

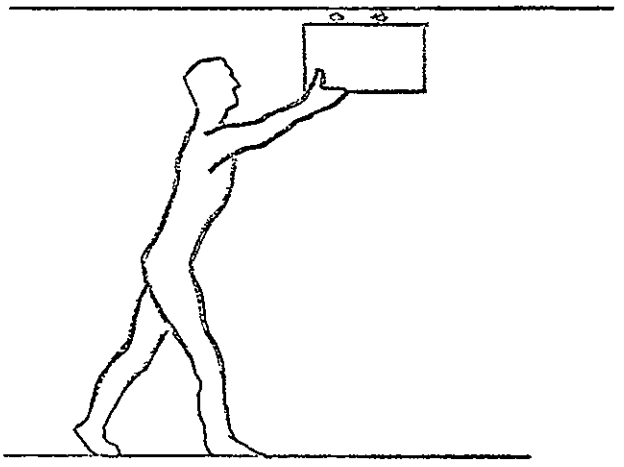
Figure 3.2.1-2 - Manual Cargo Handling: Package Translation



Back-Pack using both feet and hands on handrail - same comments as for system using a floor aid. One simulation study provides some data regarding limited number of packgaes and masses (no unbalanced configurations).

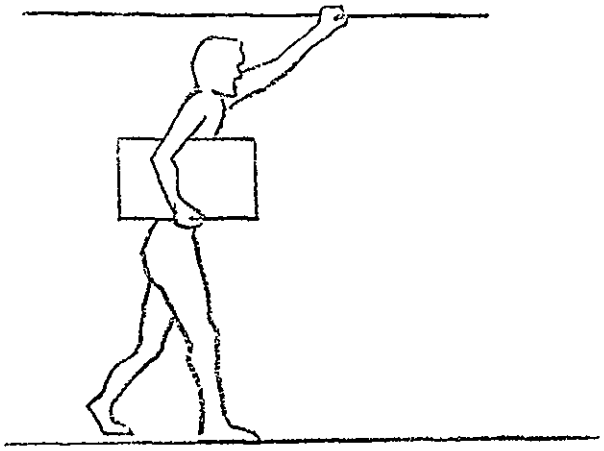


Back-Pack using floor-ceiling compression technique for translation; system untried as an experimental test; major questions involve package size weight and effect on crew mobility and ability to maintain surface contact. Additional translation aids such as Velcro could be introduced.

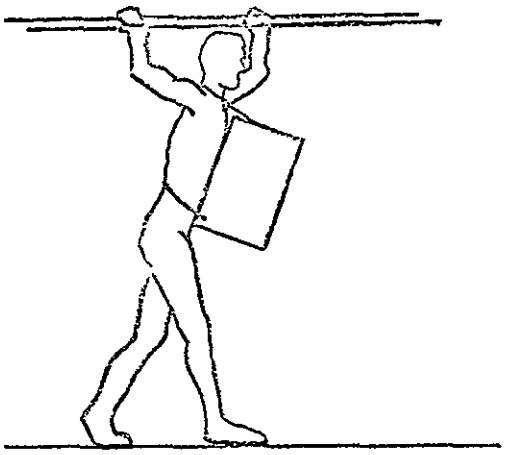


Overhead-Trolley system has not been tried; major questions are related to package size and weight, whether man can maintain surface contact with this procedure, what the optimum height has to be, whether Velcro or other floor aid is desirable

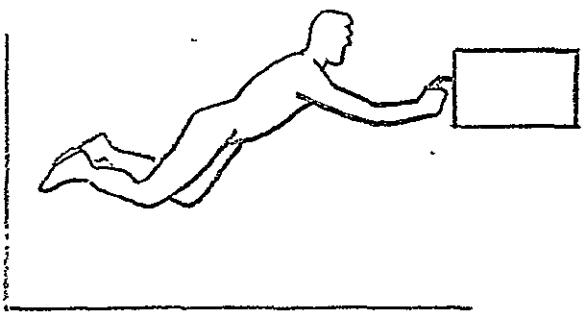
Figure 3.2.1-2 - Manual Cargo Handling: Package Translation (Cont'd)



Under-arm hand carry with rail-floor translation assist; some experimental work has been performed in simulated zero-g; limited information relative to variations in handrail positions, size and weight of packages or other aids such as floor. Major issues include package size, shape and weight, location of handrail, floor surface treatment.

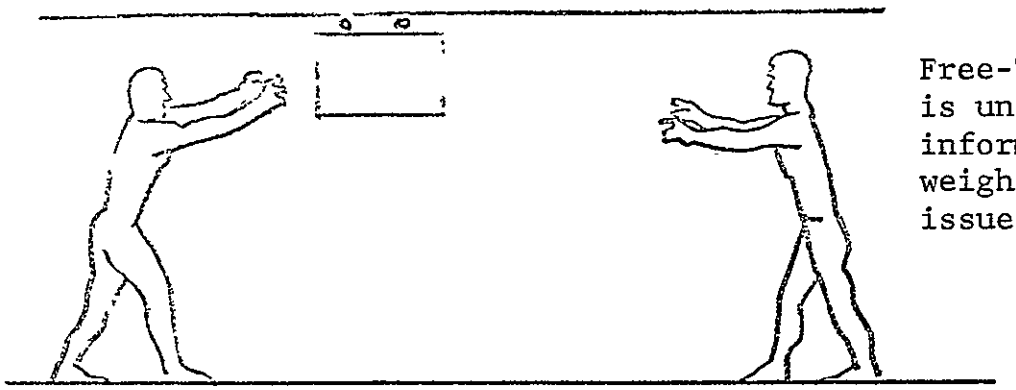


Double or single overhead handrail; both hands, with package back-mounted; working against floor (i.e., semi-compression translation); not tried as far as experimental test. Prime issues are location and spacing of rails from side to overhead, package size and location (back vs front), floor surface.

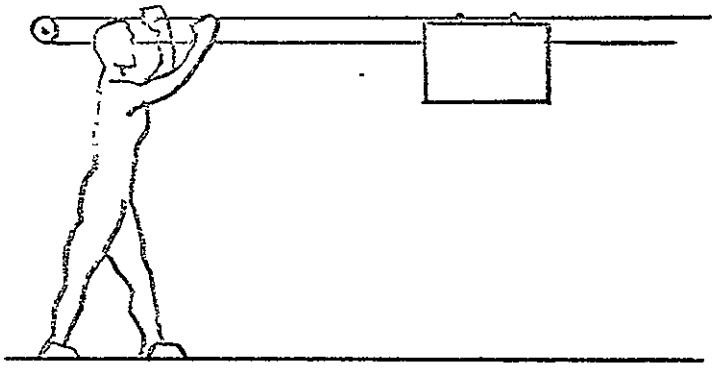


Shove-Off and free travel, pushing package in front; only demonstration trials noted, no experimental data. Major issues include package size, shape, weight and balance, handle shape and location.

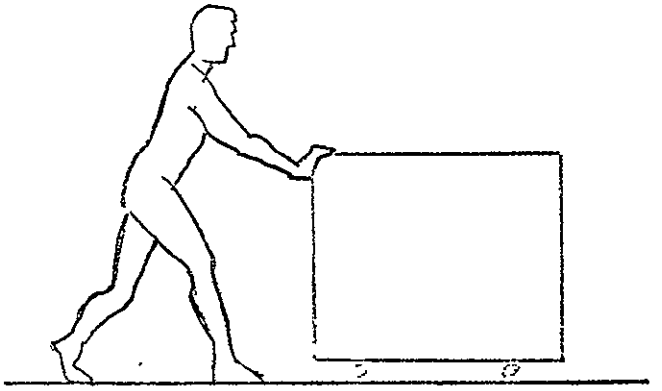
Figure 3.2.1-2 - Manual Cargo Handling: Package Translation (Cont'd)



Free-Trolley system is untried; no design information. Package weight limit is major issue.

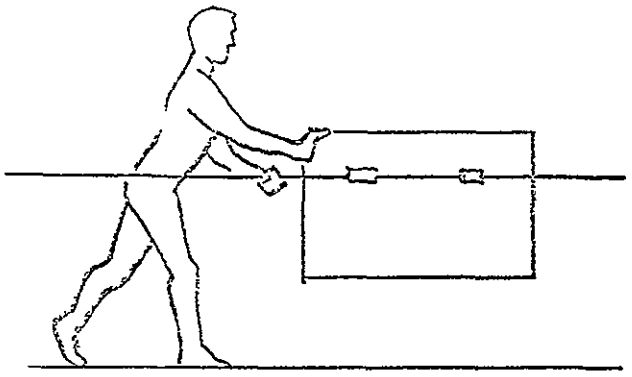


Cable-Pulley, man-powered; limited trial in 1/6th-g lunar environment. Package weight is major issue.



Deck-Trolley system; has not been tried. Major questions are package weight and whether man can maintain contact with floor by holding onto package; also question of floor surface.

Figure 3.2.1-2 - Manual Cargo Handling: Package Translation (Cont'd)



Shopping Basket-Rail system not tried to our knowledge. Major issues include package (basket) weight, rail location and spacing, floor surfacing and other translation aids (in conjunction with handrail)

Summary of Package Translation Techniques:

The above illustrations provide a brief summary of the various possibilities for manual transfer of cargo from one place to another. Obviously variations of each of these become apparent as one imagines the implementation of each technique. Many of the above ideas have not appeared in previous studies, have not been examined in a serious and complete series of related tests or experiments, thus there is no way to compare the several techniques at present.

Figure 3.2.1-2 - Manual Cargo Handling: Package Translation (Cont'd)

3.2.2 Category II: Semi-Automatic Cargo Handling Problem Areas

Cargo handling with semi-automatic systems presents many of the same problems that need to be solved for manual handling, particularly at the on- and off-loading points of the system. As discussed earlier, a combination of cargo transfer subsystems may be required to provide an effective overall system. The previous discussion will not be repeated except to point out three major manual problems specifically associated with semi-automatic cargo systems (see Table 3.2.2-1).

An obvious advantage of semi-automatic cargo handling, if any, will be in freeing crewmen for other more important tasks such as performing experiments, making scientific observation and analyzing data. Automation might also decrease the physical energy expenditures of participating crewmen and thus reduce drains on life support systems. The basic decision of whether to automate or not, or how much to automate, cannot be made until the relative advantages of various combinations of systems can be quantified more positively. This means that various kinds of semi-automatic cargo transfer systems should be mocked up and tested, emphasizing development of quantified performance information about each system's capabilities and limitations. Potential problems exist concerning the test and use of certain types of semi-automatic cargo transfer systems. Cable and trolley type systems, for example, present a potential problem in zero-g environments in that there is a possibility of the cargo package introducing uncontrollable oscillations into the system or the crewman.

It is important to anticipate such problems. Even if such systems should not be designed for astronaut-cargo translation, the capability remains and it should be anticipated that somebody will try to use the system as a dual purpose device. The extent of these problems should be determined so that it is possible to develop appropriate rules and warnings or modifications to the systems.

Currently very little detailed design work has been done, so that it is difficult to assess the nature or extent of dynamic motion or stress imposed on CTS's by various package characteristics. The present CTS concept developed by this

Table 3.2.2-1 - Category II: Semi-Automatic System Cargo Handling Problem Areas

DESCRIPTION	REMARKS
1. Loading packages of various shapes and sizes on typical cargo transfer systems	Each cargo transfer system may have slightly different loading constraints. Each should be evaluated in a man-machine, zero-g simulation environment. Major problems are astronaut mobility and restraint interaction with cargo transfer system constraints and package shape, size, and mass.
2. Operation of individual cargo transfer system concepts	Each cargo transfer system requires specific operating procedure (including manipulation of cranks, cable, pedals, push buttons and/or control knobs). Each should be evaluated in a man-machine, zero-g simulation environment. Major problems are astronaut restraint and mobility.
3. Off-loading packages from the cargo transfer system to an interim point or to another cargo transfer system	Should be similar to #1 above except that astronaut restraint and mobility problems may be different for off-load area geometry. Each cargo transfer system should be evaluated in a man-machine, zero-g simulation environment.

study provides at least one test configuration that should be designed, fabricated and evaluated in a simulated zero-g environment. Although this is only one of many possible systems, it provides a credible model (one that meets preliminary functional criteria), one that offers an opportunity to exercise several design alternatives (i.e., methods for on- and off-loading cargo, different package mountings, different package sizes, shapes and masses), and measuring time and energy requirements for each design and/or procedural alternative.

3.2.3 Category III: General Configuration Cargo Handling Problem Areas

Five important although somewhat unrelated man/system interface problems are summarized in Table 3.2.3-1. The first two problems deal with crewman/package maneuvering space requirements and/or workspace allocation. Problems 4 and 5 -- identified by the task analyses -- point out certain procedural requirements that have not been considered in current predesign efforts. Problem 3 is mentioned frequently in Phase B studies but no particular solutions have been proposed.

Astronaut-Package Maneuvering Space

That space is at a premium within the C/CM and Space Station is hardly debatable. Predesigners constantly want to know how much space to allow for "man." This question has always been hard to answer, even in the design of aircraft or other confined workspace vehicles. In the earth-bound situation gravity often does much to confine the man-activity volume since he is "anchored" by gravity forces and so can control unnecessary movement quite well. In zero-g, this is not true. Man tends to "wander" more, although unintentionally! Just how much space is required for typical cargo handling tasks is not known. In fact, there is little current information to indicate whether this requirement is greater or less than that for an earth environment. An answer to this question is important for making tradeoff comparisons among various cargo transfer systems. To date man maneuvering space envelope requirements generally have been established by subjective evaluations of preconceived design envelopes, i.e., a particular envelope represented by a compartment or passageway configuration has usually been dictated by other than man-related requirements. Previous studies reflect only a quasi-objective evaluation

Table 3.2.3-1 - Category III: General Configuration Problem Areas For Space Cargo Handling

DESCRIPTION	REMARKS
1. Crewman-package maneuvering space requirement	Dimensional information is required to define the limiting geometries for cargo package manipulation, including maximum and minimum values both to clear the man-package unit and to provide useful control restraints. This requires zero-g simulation since the boundaries will be considerably different than those for one-g conditions.
2. Cargo Transfer System space requirement	Each semi-automatic system will impose unique space requirements at loading and unloading points. Each should be studied to determine the best method for restraining the crewman as well as to specify clearance required to manipulate the array of packages anticipated. Zero-g simulation will be required since the optimum loading approaches will not necessarily be like those for an earth-gravity environment (e.g., the crewman may be upside down).
3. Compatability of packaging for both ground and space handling	It is desirable to have a packaging concept that is equally manageable in either zero- or one-g environments. Several designs probably will be proposed; each should be investigated experimentally in a simulation test series. Shape, size, handling aids, etc. are critical interface variables and should be tested in all transfer/manipulation modes.

Table 3.2.3-1 - Category III: General Configuration Problem Areas For Space Cargo Handling

DESCRIPTION	REMARKS
4. Interim stowage and handling of DOWN cargo on the Space Station	Preliminary estimates indicate that DOWN cargo activities will consume about 60% of the total transfer activity; local storage on each floor of the SS is considered a potentially desirable mode of operation. Further task analyses should be performed to establish the optimum locations and stowage configurations for this interim stowage of DOWN cargo.
5. Procedures for sequencing and handling of UP and DOWN cargo	Preliminary task analyses of cargo transfer using the "pantry concept" indicate that several alternate sequences might prove more cost effective. A total task-sequence, simulated operation should be performed to evaluate alternative sequences and to determine which provides the most cost-effective procedure in terms of time and energy.

of whether the space "seemed to be" adequate for the passage of an astronaut through or within the space, generally without encumbering cargo.[54,149] Unfortunately this type of evaluation provides no hard data upon which to project to other volumetric geometries.

It also should be noted that (in space) too much volume can sometimes be as much of a problem as too little volume insofar as it affects an astronaut's mobility and self-orientation efficiency. For example, it is (theoretically) conceivable that under certain conditions an astronaut inadvertently could become isolated from all surface contact and thus be unable to regain contact with any surface, without help. Although this is an extreme possibility it serves to point up the issue. An ideal volume/geometry on the other hand could perhaps provide the simplest and most cost-effective means for crewmen to control their body positions and translation merely by appropriate contact-use of structural surfaces that are within convenient reach. KC-135 experience demonstrates how quickly subjects learn to rely on a push here and there, a body-wedging procedure when proper structure is available, and so on. It is interesting to note that although this natural technique can be observed over and over in such tests, no one seems to have thought it important enough to capture objectively the principles involved and to interpret them in terms of criteria for design pruposes (although preliminary criteria were developed recently using rough estimating procedures [150]).

Interim Stowage and Cargo Handling Procedures

One of the major problems associated with cargo transfer is, of course, the sheer logistics of the cargo handling (i.e., number of items, sequencing and rates). Logistics in this case includes coordination of movement of both personnel and cargo. Logically, it would seem that the most efficient scheduling arrangement for the shuttle/space station resupply mission should provide for minimum crew time involvement with a maximum amount of cargo transfer. In this respect definition of how the C/CM "pantry" concept is to be used is extremely important. One method suggests that DOWN cargo replace UP cargo in the C/CM as new stores or provisions are required to maintain the SS and its crew. Cargo transfer from the C/CM to the appropriate SS deck might be scheduled once a day, to fill standard order for items such as food, personnel equipment,

and experiment supplies, supplemented by non-critical spares on an as-required basis. This is a straightforward concept for one-way transfer of cargo. However, if DOWN cargo is being taken back to the C/CM simultaneously with UP cargo transfer, confusion may result, increased handling time, crewmen interfering with each other, and crowding of already overloaded workspaces. On the other hand such problems might be avoided by another approach, namely, the use of interim stowage areas located on each deck for both UP and DOWN cargo. Space may not be at as much of a premium in these areas as in the C/CM, and reuse of packaging containers could be simplified.

A more detailed examination of in-space cargo handling schedule requirements than was possible in this study should be made soon. Reloading DOWN cargo also appears to have somewhat different task and schedule requirements than off-loading UP cargo. UP cargo can be scheduled and obtained as required on a fairly regular basis throughout the mission, whereas DOWN cargo may require special processing or have to be handled on an individual basis (e.g., packaging or repackaging before being returned to the C/CM). If DOWN cargo could be transferred from its deck-stowed areas to the C/CM at one time this might facilitate sequencing and loading of the C/CM with reference to control of cargo center of gravity. It also might eliminate some of the special C/CM environmental design requirements and make better use of the free time prior to the crew exahange period, when a maximum complement of personnel is available.

The following information needs to be developed in fairly good detail in order to establish an effective space logistics time table:

a. Inherent cargo constraints such as environmental storage requirements.

b. Onboard SS experiment procedural descriptions and timeline sequences.

c. Time sequences of cargo movement required to support (b).

d. Mission constraints that can influence cargo transfer schedules (e.g., launch schedules, station attitudes, etc.).

e. Definition of the most efficient sequence with rank order of alternatives.

f. Definition of cargo/CTS design factors that have a significant influence on system optimization.

Analysis of typical UP and DOWN cargo logistics theoretically is being accomplished by Phase B study contractors. This should produce preliminary mission, configuration, and system descriptions, and provide most of the information noted above. However, it is believed (from what has been reviewed) that these efforts may not provide specific cargo handling sequence detail and design recommendations for alternate procedures such as the interim stowage concept noted above. If not, this concept may not be given due consideration simply because design will be frozen before thorough cargo handling and transfer logistics studies are completed.

Ground/Space Handling-Packaging Compatability

Major emphasis elsewhere in this report has been specific to packaging and handling requirements for the in-space environment. In all of this discussion of packaging and package-handling system concepts designs for zero-g, it is important not to lose sight of the fact that all cargo used in space originates and has to be handled on earth.

Traditionally, a container is provided to encompass or cover a cargo/equipment item and so protect it from the rigors of the 1-g transportation environment. Such containers dictate the nature of the process for putting the cargo item into the container at one point and, normally, taking it out again at the receiving point (destination). In space operations, independent protective packaging creates a rather severe problem (weight, space) in terms of storing and/or disposing of containers.

As a result of the current study it has become apparent that protective packaging concepts should be re-examined together with the overall systems design so that a more efficient method of built-in protective packaging can be devised. Ways should be sought that minimize the necessity of putting containers on and removing them from as much of the anticipated cargo as possible.

A number of packaging ideas relative to ground/space, end-to-end packaging have developed during this study and are worthy of discussion. For example, personnel clothing and personal effects containers could be portable. Thus, instead of building permanent lockers aboard the cargo module and/or the space station, there could be nothing more than attachment hardware in these areas to which a crewman fastens his own portable locker which he carries aboard. When departing to be replaced by a new crewman, he would simply remove his locker, leaving the space open for the new crewman's locker.

Such a concept obviously could be extended to other cargo. This idea does not, however, seem to have appeared in any of the current station/module concepts studied. Instead, designers still think in terms of providing permanent cabinetry, racks, shelves, lockers and so on. Duplicative protective packaging for ground and space environments imposes a severe penalty which in turn is further aggrevated by on-board built-ins. These take additional space, add weight, and probably will not always be utilized to full capacity since it is inherently impossible to anticipate all the possible variations in future equipment storage requirements.

In summary, then, the major problem areas associated with developing a satisfactory cargo handling system for the Shuttle-Space Station Mission as defined by this study are two-fold. First, there is insufficient information at this point in system conceptualization to define crew participation because we cannot predict how well man can perform typical cargo handling tasks in zero-g. Second, not enough has been done in the way of hardware design on any of the potentially useful semi-automatic transfer systems to isolate specific human tasks.

To solve the first problem it will be necessary to institute a series of definitive human performance studies in simulated zero-g environments, designed to define the capabilities and limitations of an astronaut in terms of his control and manipulation of himself and the cargo packages he handles. Although some data already exist relative to package manipulation, in both a free and restrained condition, there is no complete catalog of information suitable for predicting performance across a broad spectrum of anticipated tasks. The most significant questions to be answered are:

a. What are the limits of the working envelope for passing packages from one man to another, removing and replacing packages from various positions for different stowage hardware configurations, and what are the clearance requirements for accommodating these envelopes?

b. What are the ergonometric limits of the human for controlling the motion of cargo packages when starting, stopping, or guiding maximum cargo masses?

c. What are the best translation and restraint aids for performing specific cargo handling tasks?

To solve the second problem more detailed design work must be done on the most promising semi-automatic transfer system concepts in order to provide human task specificity. Once this has been accomplished, a series of man-machine task simulations will be required to assess the time and energy implications of each system.

Finally, it is recommended that a more concentrated effort be mounted to develop and evaluate a total cargo transfer system concept, including the entire logistics problem of inventory management, ground handling, and specification of cargo characteristics, handling system hardware, personnel requirements and resupply support procedures.

To aid in the development of hardware concepts, a series of preliminary human engineering-type design criteria have been proposed. These are presented in Appendix D.

3.3 Recommended Research

The concluding task of the present study was to analyze the various problems uncovered and to determine which of these are sufficiently critical to warrant additional study. Of particular interest are the questions that deal with human performance efficiency and safety, and the matter of how much to use man in the cargo handling activities of the Space Station mission.

Analysis obviously can take one only part way in resolving certain questions. However, the present study has indicated

that certain analyses still are needed before all the problems are described in sufficient depth to suggest experimental work. As noted earlier in this report, two immediate areas are of special importance and greatly in need of additional analytic work. These center first around the question of an artificial-g mode of Space Station operation, and second around the need for developing a more detailed, descriptive model of the activities in each of the Space Station work areas, or decks. In the first case artificial-g may create an entirely new set of tradeoff parameters and thus prove that current recommendations for transfer systems are inadequate. In the second case, an improved task model is required before any firm assessment can be made regarding the optimum system for intra-deck cargo handling.

Other, equally important analytic study areas also are recommended. These are discussed briefly in the following paragraphs. No attempt has been made to prepare complete program outlines for these studies since it is believed that their merits are evident from the brief descriptions of purpose and approach given for each study. It also should be pointed out that a benefit may be realized by combining several of the studies in order to reduce some of the redundant efforts normally required to "get up to speed" in the general problem of cargo transfer.

3.3.1 Analytic Studies

The following studies are presented in the order of their anticipated importance and are described only in sufficient detail to clarify purpose and general approach.

Study No. 1: Investigate the Implications of an Artificial-G Operating Mode on the Selection of In-Space Cargo Handling Systems.

The purpose of this study would be to determine what effect an artificial-g (i.e., rotating) station operation will have on decisions regarding the design of cargo handling system hardware. Inherent in this study are, of course, the human factors implications as man participates in the cargo transfer process. An approach similar to that used in the present study should be followed.

Significant factors to consider are the several methods that are being considered for spinning the space station complex in order to determine the range of forces that may act upon cargo elements at different points in the transfer system. A mission sequence model should be developed to determine when cargo movement will occur in zero-g vs artificial-g and whether there is a way in which to schedule the major share of transfer activity when the station is not in motion. A second important aspect of the problem is that associated with the specific location of the center of rotation and its effect on alternative cargo transfer activity positions. Although it has been almost impossible to predict any kind of human performance capability for handling mass in the zero-g environment in the present study, it should be possible to develop fairly reasonable predictions for the artificial-g mode for different positions relative to the axis of rotation and distances from it.

The study could also include investigation of the disadvantages and advantages gained by working in partial-g fields. In some cases the transfer of objects from one point to another can be accomplished more efficiently by premeditated use of "involuntary constant contact" forces (moving belts, roller bearing races, etc.). Artificial-g could be used to locate transfer systems more conveniently (arm height on sidewalls for example) or even as the transfer energy source (e.g., centrifugal direction with systems of brakes and bumpers).

If the projected artificial-g structures are planned to be an outgrowth of more elementary zero-g structures, it might be advisable to examine the growth potential of zero-g systems and the effect of such phenomena as Coriolis forces on these systems.

Study No. 2: Analyze Current Space Station Work Area Designs and Develop a Set of Cargo Transfer System Design Criteria for These Areas.

The purpose of this study would be to gather as much information as possible about the proposed space station workplace layouts and develop a set of human engineering criteria for defining and designing cargo transfer system and manual handling aids for these areas.

Although it appears that considerable confusion exists regarding the layout and use of various compartments of the projected space station, there probably is enough information to establish a general work area task model. During the present study there was insufficient time -- as well as a lack of timely communication with Phase B contractors -- to define these work areas to the level of detail necessary for tradeoff analyses. Many layouts still are of the artist's-sketch type with very little hard engineering data developed.[80,116,150]

In addition to task and function descriptive analysis, this study should include some predesign effort to firm up hardware configurations. When this is completed a cargo handling system tradeoff similar to the one performed in this study can be accomplished for the areas in question. It should be pointed out that Phase B contractors, despite the efforts of their own crew systems personnel have, up to this time, predicated preliminary C/CM-SS design concepts on cargo storage and transfer systems that were selected in a somewhat arbitrary manner as functions of structures, weight, etc. Certain necessary information will be required from these contractors to perform the study proposed, but an equally valuable amount of information likewise will be made available to these contractors as a result of the information exchange process.

Study No. 3: Perform a Human Engineering Analysis of the Stowage System Requirements for the Crew/Cargo Module.

The purpose of this study would be to develop more detailed design information regarding the probable method to be used for stowing cargo aboard the C/CM. As pointed out in the present study, one of the most difficult questions to answer regarding cargo handling system design is one dealing with acquiring and returning packages in a storage system. Current predesign detail in this area is sadly lacking. The problem should be studied both from the ground- and space-loading points of view since one or the other may bias the system by default and thus compromise either or both operations.

The proposed approach to this study is to review each of the current C/CM configurations, specifically from an on-loading and an off-loading point of view. Current stowage

concepts should be carried further in terms of design detail, getting down to dimensional factors, hardware accessories for mounting, container sizes, modularizing possibilities, and prediction of how many standard packages vs unique packages can be accommodated for different stowage schemes. Finally, a tradeoff analysis should be performed to determine if the CTS proposed in the present study still is suitable for the C/CM cargo transfer requirement.

Study No. 4: Man-Machine System Analysis of the Total Resupply Mission to Identify Critical Interactions Between Cargo Handling in the Ground Environment and in the Space Environment.

The purpose of this study would be to begin a systematic review of the total cargo handling problem from ground to space and return. Based on experiences gained in the present study it is apparent that there is a lack of integration between engineers working on the ground logistic problem and those concerned with design of an in-space cargo handling system.

It is suggested that a human engineering analysis provides a unique motivation for bringing the two elements of this problem together, since man is essentially the center of both aspects of the mission. This study should be paced by Phase C contractor efforts since design detail is a prerequisite to establishing a functional model for assessing various concepts. EVA problems should be examined in considerable detail during this study since emergency backup requirements have not been investigated thoroughly.

Personnel requirements also should be examined during this study so that early predictions can be developed for manning the resupply mission logistics plan. Unlike current space missions where "tiger teams" have been the rule, NASA now will face a 10-year manning problem that will be fraught with most of the problems faced by military systems managers. The main difference is that non-military personnel can quit at the wrong times. Personnel planning must start by the beginning of Phase C or it will be too late, i.e., the system most likely will be delivered before trained personnel are ready to operate it.

Personnel requirements will fall into two unique categories,

ground and orbital. Ground personnel will have to be "space oriented" to the point that they can anticipate correctly the conditions under which their "airborne" counterparts will have to reverse their loading and stowage efforts. Despite the most rigidly controlled procedures plans, situations will occur where the ground crewman will have to make judgments or adjustments that should be accomplished with knowledgeable empathy for the task generated by his actions in the subsequent use of the equipment concerned. This is especially significant in dealing with cargo elements involved in emergency recovery operations.

Study No. 5: Investigate and Develop a Workable Cargo Identification, Location and Retrieval Concept for Cargo Loading and Management.

The purpose of this study would be to develop preliminary concepts for cargo management both on the ground and in orbit. A thorough review of cargo requirements over the ten-year mission span is essential. State-of-the-art techniques should be reviewed to determine which are feasible for the Space Station mission, and recommendations developed for a preferred cargo scheduling, loading and monitoring system. Information retrieval techniques already are available that probably could be used. However these have not been examined with respect to the requirements and constraints of the Space Station mission. Central to these systems are the man-machine interfaces and the limitations of personnel time and energy available to perform the many tasks that may be inherent in these systems.

Study No. 6: Compile and Analyze Fastening Concepts for Cargo Transfer Systems Design and Simulation.

The stowage, retrieval and movement of cargo elements in either zero-g or artificial gravity situations necessarily will involve methods of securing these elements (or their receptacles) to other spacecraft structures. For example, containers will require means of closure and methods to secure them to storage bins and transfer systems, doors and barricades will require latches, tie-down or hold-down devices will have to provide some means of positive connection, blind fasteners will have to be provided with alignment guides and some form of assurance that the retainer is performing as planned.

Too often a simulation test for some function of an orbital task is compromised by lack of definitive information regarding the design and use of secondary hardware. For instance, a test to examine the relative merits of a "trolley" system and a "clothesline" system cannot produce the desired information if the experiment gets bogged down over the question of how to fasten the test elements to the system. Simulations of stowage and retrieval systems cannot, on the other hand, be considered valid unless the test cargoes are subject to the securing hardware that will be required in the real situation.

The proposed study should begin with the assimilation of design details of all state-of-the-art fastening concepts including:

Adhesives and velcro-types

Jam cleats and spring detents

Pip pins and bayonet fasteners

Toggle bolts and over-center latches

Slide and hook fasteners

The next logical step might then be an analysis of the potential occurrence of fastening requirements with the cargo transfer system and a consequent tradeoff study of the applicability of each fastener type to each situation.

This study would provide test engineers and spacecraft designers with an information source for the development of more complete cargo transfer systems concepts.

3.3.2 Recommended Cargo Handling Prerequisite Simulations

The conceptualized NASA Shuttle-Space Station program will require the transfer of cargo by crewmen in a zero-g environment, a condition totally unfamiliar to most human operators. Information about crew performance in this environment and during required cargo handling tasks is of immediate importance to mission planners and engineering designers who will use criteria generated for cargo handling systems and work spaces.

Eventually a whole-task, full mission simulation of cargo-handling techniques, using some well-defined Shuttle-Space

Station system, will be designed and executed to verify hardware and procedural systems concepts. This future requirement will be outlined at the end of this section.

First, however, a number of prerequisite, basic research simulation studies of cargo handling in a zero-g environment will be necessary to determine which variables operationally affect that task. A large number of variables is involved and little is known of their effect on the cargo handling task. The variables of most immediate concern include: work space volume; work output; restraint systems; point of restraint; mass, size and shape of packages; non-restrained movement with packages; acquisition, transfer and positioning accuracy. Although a number of studies have investigated certain of these variables, all are deficient to some degree. Specific restraint systems were used, reach envelopes were described graphically -- but for a static rather than a dynamic work task -- and/or package transfer was investigated for a specific set of conditions or hardware, and generalization or extrapolation to other systems is not practical.

By analysis of completed studies and the requirements of the Shuttle-Space Station mission, six simulations have been identified that will provide the prerequisite information necessary to the design of operationally efficient cargo handling systems. These six simulation studies are described briefly below and discussed in detail in the remainder of this section.

Experiment 1. Body Movement Capabilities As A Function Of Class of Restraint

Although previous studies have described reach envelopes for crewman under zero-g conditions, results were obtained statically and described graphically.[150] The purpose of this study is to determine the operationally effective dynamic work envelope of a crewman, under simulated zero-g conditions, for acquiring, stowing, or handing off a package as a function of class of restraint, one- or two-hand manipulation, point of acquisition, point of release, and plane of movement. Results are expected to describe realistic workspace (i.e., ergonometric, volumetric) task requirements.

Experiment 2. Stability Limitations and Force Capability as a Function of Class of Restraint

While some past studies have described static reach envelopes and others have investigated dynamic tasks such as tool operation or package handling related to specific hardware, no study has investigated the basic effect of the force-restraint combination upon body stability or movement. That is, there are no criteria generalizable to any hardware system for this particular aspect of zero-g task operations.

The purpose of this simulation study is to describe the force required and resultant body movement as a function of point of restraint and/or the interaction between force vectors and restraint points. Results are expected to have implications for the design and location of restraints for general as well as particular task requirements, in addition to obvious overlapping usefulness in estimating workspace volume and designing stowage configurations.

Experiment 3. Accuracy of Package Positioning as a Function of Class of Restraint

Although limited studies have been performed [27,60], no known experiment has been designed and executed to determine all of the effects on, or interactions between, restraint systems and positioning accuracy under zero-g conditions as these relate to the performance of a shirtsleeved crewman. The purpose of this simulation study is to investigate the ability of a crewman to position accurately, or stow, a package in zero-g as a function of restraint class and stowage location. Results are expected to have direct implications for the design and location of restraints, stowage configurations, package dimensions, and visibility requirements.

Experiment 4. Control of Package Movement as a Function of Mass and Class of Restraint

Although there are bits and pieces of information that can be extrapolated from isolated studies of manual package handling under simulated zero-g, there has been no systematic study of the interacting variables of package design within the widely varying operating conditions anticipated for the Shuttle-Space Station mission.

The purpose of this simulation study is to determine the effects of mass, in both magnitude and distribution, on the ability of a crewman to control movement. Expected results will provide quantative information that will permit the definition of critical package design characteristics, where these characteristics materially affect the ease and efficiency with which packages can be grasped, held or carried, for each package transfer operation in the zero-g environment.

Experiment 5. Accuracy of Package Positioning for a Non-Restrained Crewman as a Function of Workspace

To date most cargo handling studies have directed attention to the crewman performing with specific restraint systems or translation aids in a zero-g environment.

The purpose of this simulation study is to investigate package acquisition or removal and stowage performance by a non-restrained crewman in a zero-g environment as a function of available work space and/or handholds or restraints of opportunity. Results are expected to demonstrate minimum restraint and work space volume and ergonomic output requirements as well as the level of practicality of these particular task environments.

Experiment 6. Translation Aid Requirements for Manual Cargo Transfer

Over the long term, for Shuttle-Space Station missions now in planning, there will be many instances in which a crewman will find it more convenient to transfer a package manually over the longer distances without activating automatic or semi-automatic transfer systems.

The purpose of this simulation study is to investigate the requirements for efficient crewman translation while carrying a package. Results are expected to produce criteria useful in the design of operationally effective translation aids as well as modes or techniques for manually carrying a package.

It is emphasized that no single study described above and in the latter part of this section will solve the total cargo

handling system problem. However, careful integration of the information derived from each of them should provide the necessary design solutions. In addition, investigators should be alert to requirements for possible sub- or part-task studies generated during the execution of the experiments described below:

Finally, every effort should be made, within the constraints of available time and money, to correlate the various simulation techniques with actual zero-g conditions and thus derive some estimate of the level of validity of the simulation techniques.

3.3.3 General Design Requirements of Six Prerequisite Cargo Handling Simulation Tests

In the simulations described below certain variables remain constant for each design. Crewmen subjects will be drawn from populations reasonably similar to expected crew complements. Adequate illumination must be provided and all simulations will be limited to IVA tasks under anticipated zero-g environment with crewmen in shirtsleeve clothing. It is understood that all other routine, normal and standard experimental controls will be strictly adhered to during the execution of all simulation tests.

3.3.3.1 Experiment 1. Body Movement Capabilities as a Function of Class of Restraint

Problem and Objectives

At various times during the acquisition and loading or unloading of cargo packages in the zero-g environment, crewmen will be required to secure themselves to the structure or other permanent equipment elements in order to: (1) apply the necessary forces and maneuvers to manipulate packages in and out of storage racks, consoles or other holding devices; (2) place and fasten them onto or remove from semi-automatic cargo transfer devices; and/or (3) to hand packages to another crewman. Although certain restraint techniques have been examined in various ways, no comprehensive, systematic program has been developed to provide criteria for the design of specific restraints based on well defined tasks. Thus, it is not possible to make any kind of objective, quantitative comparison of the effectiveness of any restraint technique as it might apply to specific hardware system concepts proposed from time to time.

Volumetric work envelopes under zero-gravity conditions will differ significantly from those experienced previously by a man under 1-g conditions. The elimination of gravitational stabilization must be accomplished by some artificial means. Since zero-gravity conditions may, in fact, extend the limits of man's body movements, the primary restriction, or aid (as the case may be), will be the type of restraint or contrathrust platform system used.

Most previous studies of zero-g work envelopes, either in a pressure-suited or shirtsleeved condition, have been of static design. Several neutral buoyancy studies for NASA by the General Electric Company [27] were dynamic in design but lacked representative work tasks. Although anthropometric (reach) envelopes were graphically described, ergonometric (work) envelopes were not studied and thus knowledge of performance directly applicable to cargo handling was not obtained. If only reach envelopes are to be considered, then clearly foot restraint is superior from the standpoint of both envelope size and control of body movements. However, work envelopes in addition to other variables must consider the direction of the force required by the task. There may be a tradeoff between work envelope and work capacity. It is, therefore, necessary to obtain basic criteria so that these may be appropriately used by engineering designers dependent upon system operational task requirements.

The first four simulation studies described below involve restrained crewmen, hence much of the foregoing discussion is relevant to those four studies and will not be repeated. The last two studies deal with non-restrained crewmen.

The purpose of this study is to determine the operationally effective work envelope of a crewman in zero-gravity for acquiring, stowing or handing off a package as a function of class of restraint: one or two hand manipulation; point of acquisition; point of release; and plane of movement.

Experimental Design (see Figure 3.3.3.1-1)

Independent Variables

The four independent variables to be investigated in this

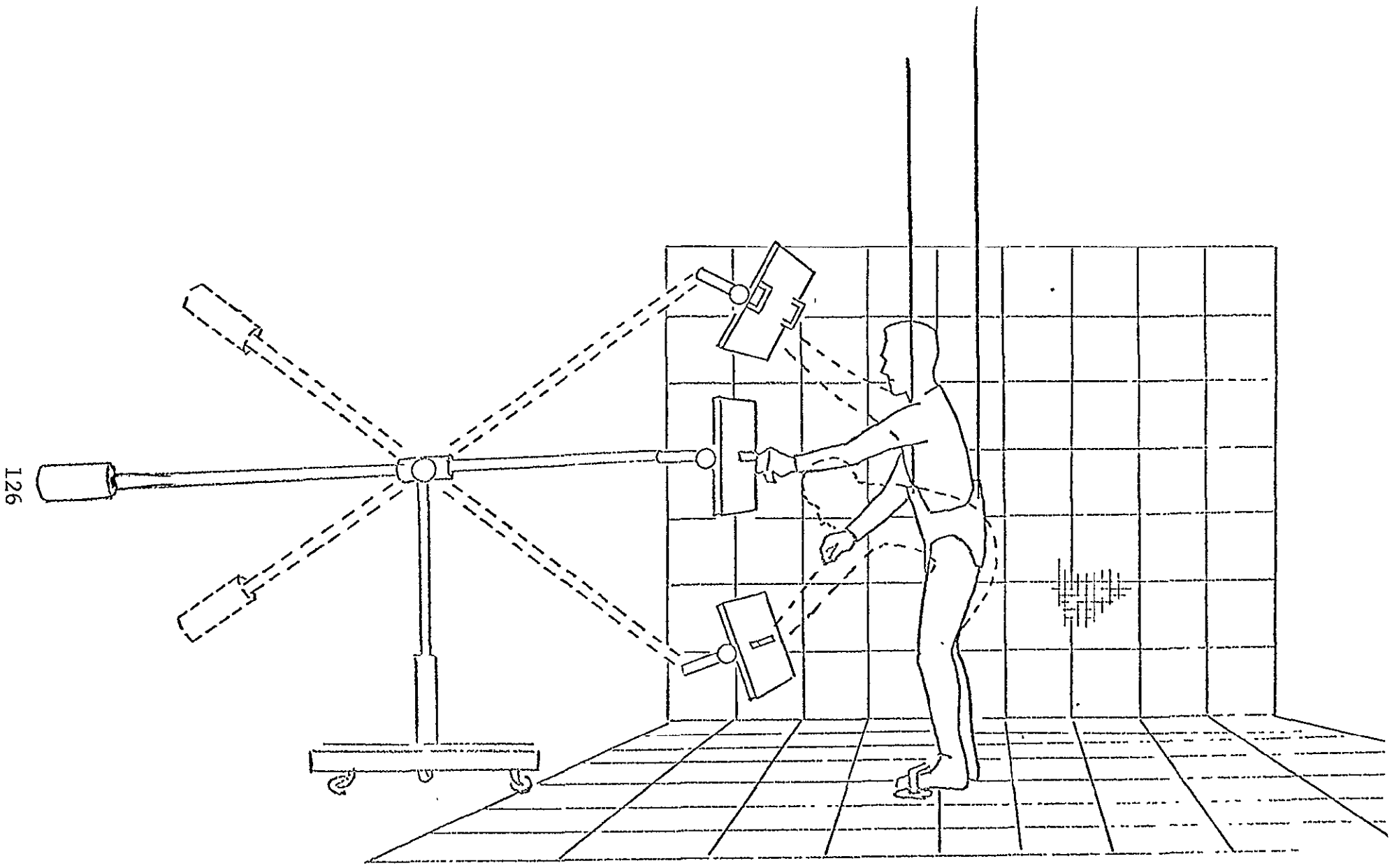


Figure 3.3.3.1-1 - Simulation No. 1: Defining Package Handling Envelope

experiment are: (1) point and/or type of restraint, (2) package dimension, (3) number of handholds, and (4) plane of movement.

1. Point and/or type of restraint. In view of the limited knowledge presently available, it is recommended that the following be included as a minimum:

(a) Foot restraint - While a variety of forms have been designed, these may be expected to have similar implications for work envelope although differing in other aspects. Use of a toe-bar in this experiment should yield data relevant to all forms of foot restraint (while eliminating the need for individual fitting), determination of separation, and other problems relevant to specific types. However, careful selection of footwear should be exercised, i.e., high top, stiff leather boots should be avoided.

(b) Waist restraint - Again, a number of options are available for waist restraints. Consideration both of probable conditions for a cargo handling area and of feasible experimental design suggests limiting this investigation to a relatively short, flexible tether. This would be expected to interfere minimally with body flexion while providing a high degree of stability, relative to other single-point restraints.

(c) Waist and foot combination - Full use of the increased reach envelope available with foot restraints may place energy requirements on the crewman which might be reduced by using a relatively long waist-tether in conjunction with the toe bar.

2. Package dimensions. For the purpose of determining work envelopes, two package sizes of minimum weight will be sufficient. The smallest reasonable dimensions will yield the maximum envelope dimensions, and the largest dimensions reasonable for handling by a single crewman will determine the minimum envelope. (These envelopes are defined as the space used by the man, excluding the extension of the package).

3. Handholds. The critical aspect of handholds for this experiment is the number used, either one or two. Maximum work envelopes will be obtained with use of one hand, and the envelope will decrease with the use of two hands, diminishing as the angle of separation increases. For this experiment one-hand manipulation would employ a single handhold in the center of the package face. Two-hand manipulation would require handholds placed on opposite edges of the face.

4. Plane of movement. The actual work envelope would be determined in terms of maximum points for acquisition and for release in several planes: left-right, up-down, fore-aft, and planes intermediate to the normal coordinates.

Dependent Variables

1. Work envelopes measured in centimeters from an arbitrary body reference point. To facilitate comparisons with previous neutral buoyancy reach data[27] the reference point should be the same, i.e., the intersection of a central longitudinal plane with a line drawn on the skin surface of the anterior thorax at nipple height. The envelopes will display distance to maximum acquisition points and release points for each combination of independent variables.

2. Supplementary data: (a) detailed written observations by the test conductor; (b) photographic records of the experimental sessions taken in one or more dimensions against a background grid; (c) subject's comments obtained after each session; (d) anthropometric data for each subject.

Test Equipment Requirements

1. Restraint systems. In accordance with the minimum requirements outlined above, the following must be provided:

(a) Toe-bar of sufficient length to permit each subject to adopt a comfortable foot separation

(b) Short waist-tether

(c) Long waist-tether for use in conjunction with toe-bar

2. Package models. Since this experiment is concerned with work envelopes rather than energy requirements, the packages should be light in weight to minimize fatigue over the course of an experimental session. According to information currently available the following are dimensions for small and large packages:

(a) 1' x 1' x 1'

(b) 3½' x 4' x 5' (TBD)

3. Handholds. Each package model provided with three handholds:

(a) one centered on face of package;

(b) two located in centers of opposite edges of package face.

4. Apparatus for positioning packages for acquisition. Must be capable of holding package:

(a) at varying but calibrated distances from subject reference point;

(b) at varying angles with regard to normal coordinates

5. Apparatus for acquiring package from subject. This could consist of a Velcro target, however, the subject should not be able to support himself fully against this target. An alternative would be manual transfer to a member of the support personnel with measurement obtained from grids or photographic records.

6. Background (vertical and floor) grids

7. Photographic equipment

8. Test protocols, data sheets, etc.

Facility Requirements

The NASA-MSFC Task Analysis Facility Multi-degree-of-freedom Simulator (Jump rig) would be the facility of choice.

Either Keplerian flight or neutral buoyancy could be used, but neither is required since package mass is not a consideration, and the large number of trials that will be required make the jump rig most economical in terms of time and money.

3.3.3.2 Experiment 2. Stability Limitations and Force Capability as a Function of Class of Restraint

Problem and Objectives

The stability and related performance capability of a crewman under zero-g conditions and various single point classes of restraint systems will vary depending upon the direction in which he is required to produce a force. Studies to date, while graphically describing possible points of initiation of force, have not established resultant contrathrust body movement, either for single restraint points or combinations of restraint systems and locations.

This information is intimately related to and required for eventual determination of workspace volume, package size and mass, and crewman ergonomic output. Since no data currently are available it is only possible to guess the effect of force and force vector on a crewman for even simple package manipulation. Attempts have been made to describe body movement mathematically based on best guess forces and force vectors as associated with location or a specific type of restraint. These analytic efforts cannot succeed because: (1) not only are actual force requirements unknown, but (2) the crewman's natural or learned physical response (i.e., his attempt to maintain a desired posture as required by the task) and the subsequent energy cost and/or task performance efficiency is unknown. Such data, in addition to obvious general usefulness, will have implications for the design and location of restraints for particular task requirements.

The purpose of this study is to determine force values and resultant body movement as a function of force vectors and restraint points and the interaction thereof.

Experimental Design (see Figure 3.3.3.2-1)

Independent Variables

1. Restraint systems. The choice of restraints to be

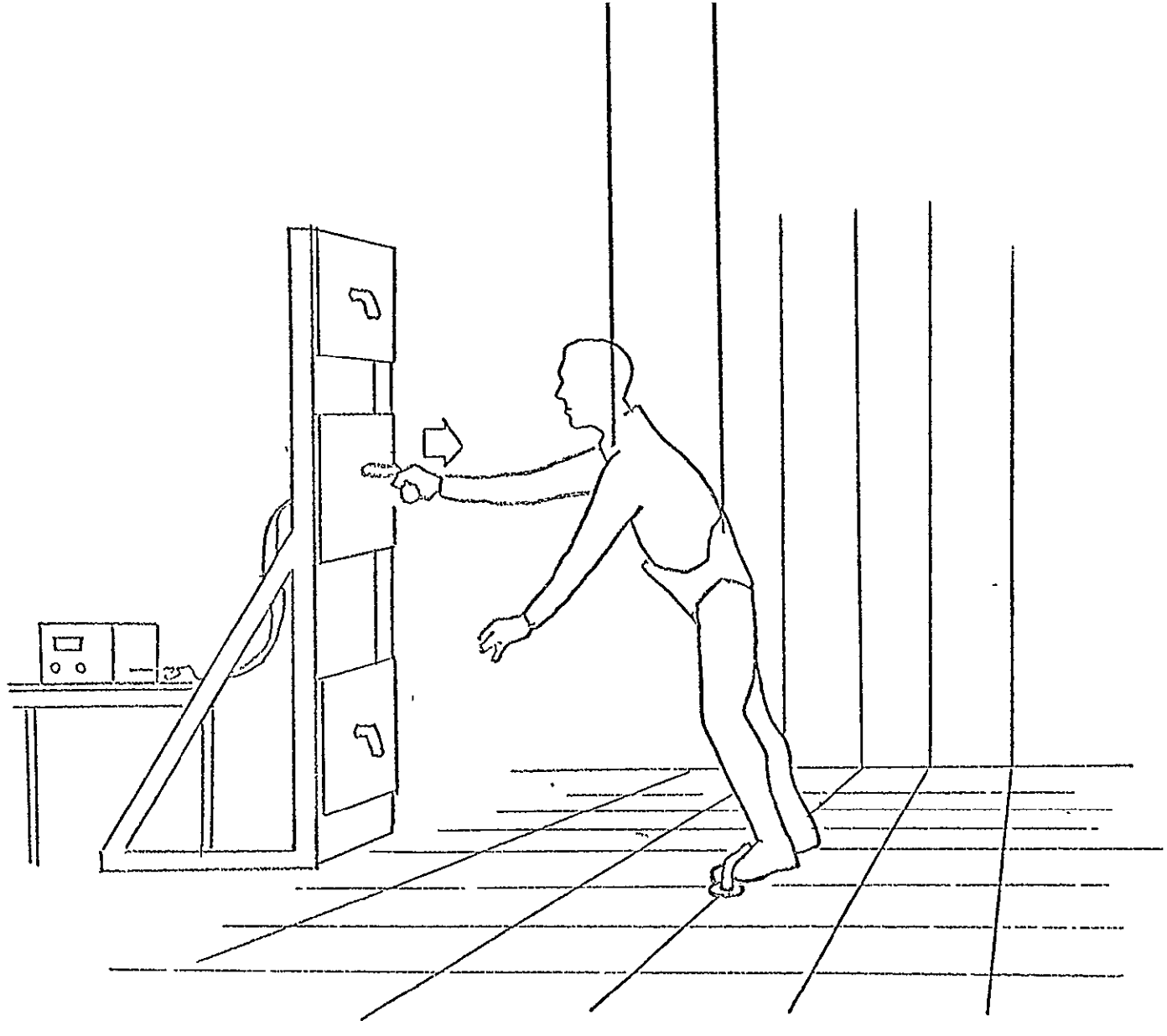


Figure 3.3.3.2-1 - Simulation No. 2: Defining Extraction Force Envelope

used is based on the considerations outlined in Experiment 1; in fact the two experiments can be conducted concurrently. If Experiment 1 is completed first, data obtained from that experiment may suggest modifications of the restraint systems used.

2. Force Vector. Linear and rotational force capability should be obtained at least for both directions on the three principal axes and for the intermediate directions using one and two hands.

Dependent Variables

1. Force capability. Since relative data are of primary concern here, this should not be interpreted as instantaneous force capability but rather, that force which can be maintained for some brief period, e.g., 3 seconds. Alternatively, a slow, steady increase in force could be applied away from the subject, with force capability defined in terms of onset of uncontrolled body movement (loss of stability). Force would be measured most conveniently in pounds and, if required for purposes of comparison, converted to poundals by multiplying by 32. These measurements should be obtained at or near the boundary of work envelopes as determined in Experiment 1.

2. Supplementary data:

(a) Photographic record against grid background

(b) Written notes of trained observers

(c) Reports of subjects

Test Equipment Requirements

1. Restraint systems as discussed above and in Experiment 1.

2. Force scale probably electronically derived with strain gauges and a digital printout.

3. Framework or support system for positioning force scale at required directions and distances from subject reference point.

4. Photographic equipment, including grid background

5. Test protocols, data sheets, etc.

Facility Requirements

Based on considerations similar to those outlined in Experiment 1, the Task Analysis Facility jump rig is the recommended simulation facility.

3.3.3.3 Experiment 3. Accuracy of Package Positioning as a Function of Class of Restraint

Problem and Objectives

The desired end result of acquisition and transfer of cargo by a restrained crewman is the accurate positioning, stowage or handing off of packages. The degree of efficiency for this task will vary as a function of restraint class, package mass and size, handholds, visibility and direction, location, and configuration of package destination. A recent study [27] investigated cargo placement as a function of package size and restraint system but this study used only a limited number of package locations, i.e., front, left and right positions relative to the restrained crewman. Also, no provisions were made for measuring the accuracy of placement of a package into a receptacle or for determining the most efficient receptacle-to-package size ratio. Thus, data are required that reflect performance over a more variable range of locations and placement accuracy.

The purpose of this simulation study is to investigate the ability of a shirtsleeved crewman to position accurately or stow a package in zero-g as a function of restraint class and stowage location and configuration.

Experimental Design (see Figure 3.3.3.3-1)

Independent Variables

1. Restraint systems. The choice of restraints to be used is based on the considerations outlined in Experiment 1, and in fact the two experiments can be conducted concurrently. If Experiment 1 is completed first data obtained from that

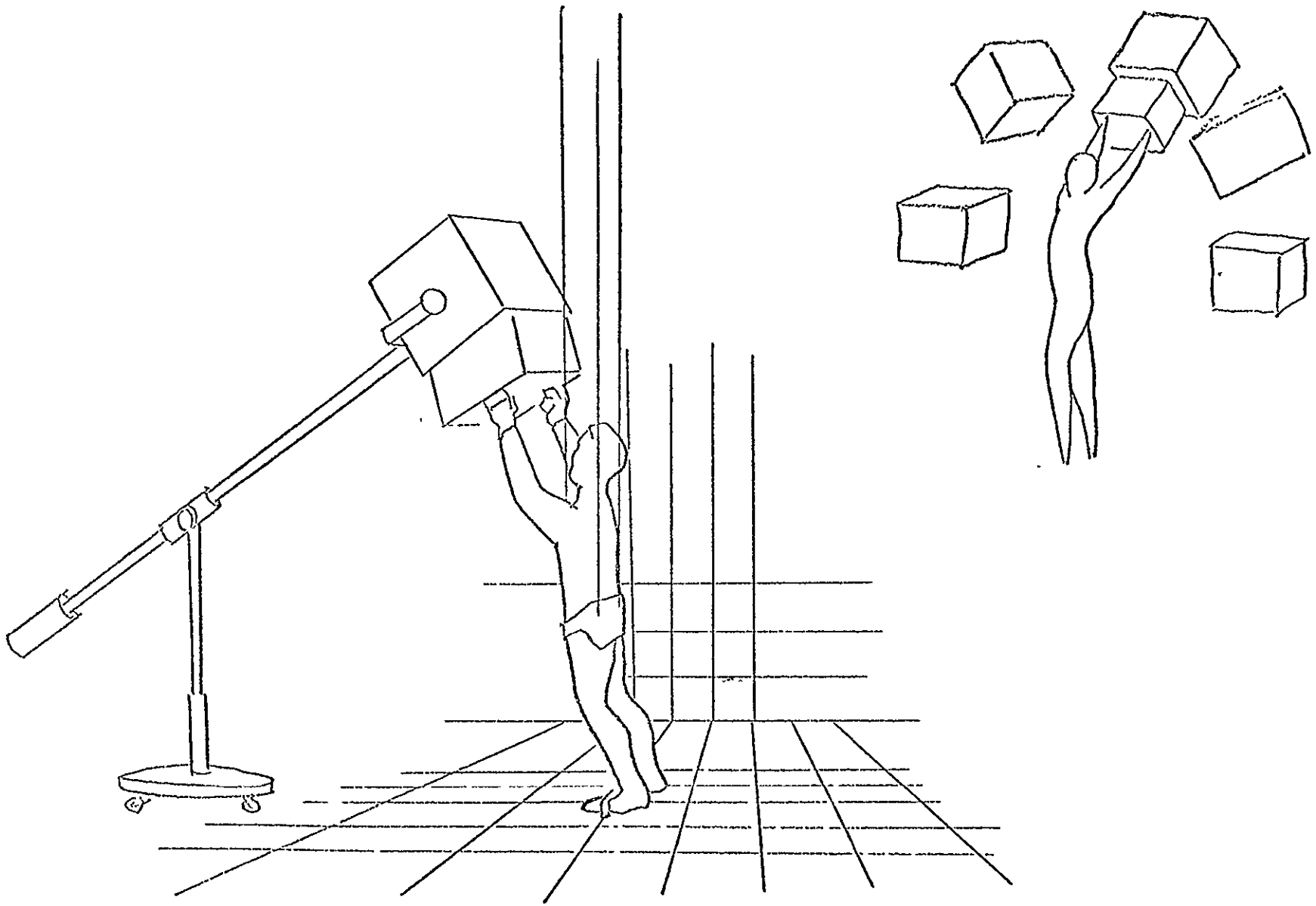


Figure 3.3.3.3-1 - Simulation No. 3: Defining Package-Rack Mating Accuracy Envelope

experiment may suggest modifications of the restraint systems used.

2. Package dimensions. Choice of package dimensions is discussed under Experiment 1. It should be noted here that there are certain conditions in the present experiment which overlap with those used in the previous research [27]. For purposes of comparison one of the packages used here should be 1 ft. x 1 ft. x 1 ft.

3. Handholds. These should be the same as described under Experiment 1, i.e., one center handhold and two edge handholds.

4. Angle and position of stowage compartment relative to subject reference point.

(a) Positions should be within the work envelope established in Experiment 1, and in each of 12 directions suggested in the previous experiments, i.e., on the normal and 45° axes.

(b) At each position, two angles of placement should be used: parallel to the fore-aft axis, and directly away from the subject reference point.

5. Other. Subject to time and other considerations, two other aspects may be either varied or controlled.

(a) Compartment clearance - two or more values may be chosen, e.g., 1 inch on each side and 3 inches on each side.

(b) Distance from subject reference point.

Dependent Variables

1. Time. The two components of task time, compartment location time and stowage time, should be obtained. Compartment location time is measured from onset of trial to insertion of package some small distance (e.g., 1 inch) into compartment, and stowage time from insertion to completion.

2. Accuracy. Two measures of accuracy may be obtained:

(a) Number of misses, where a miss is defined as contact with the face of the stowage mockup (or package).

(b) Number of contacts with the sides or top of the stowage compartment (or package).

3. Supplementary data

(a) Photographic record against grid background

(b) Written notes of trained observers

(c) Reports of subjects

Test Equipment Requirements

1. Restraint systems as discussed above and in Experiment 1.

2. Package Models. As discussed above in Experiment 1, these would include lightweight models with dimensions.

(a) 1' x 1' x 1'

(b) 3' x 4' x 2' (TBD)

3. Stowage Mockup. This could be a portable system of the form shown in accompanying sketches. It must be capable of varied positions as called for by experimental design and, as required, different compartment dimensions.

4. Timing and counting devices.

5. Photographic Equipment and Grid backgrounds.

6. Test Protocols, Data Sheets, etc.

Facility Requirements

Based on considerations similar to those outlined in Experiment 1, the Task Analysis Facility jump rig is the recommended simulation facility.

3.3.3.4 Experiment 4. Control of Package Movement as a Function of Mass and Class of Restraint

Problems and Objectives

Seemingly minor variation in the shape, size, weight (mass), mass distribution within a package, type and location of handles for cargo packages will cause significant differences in the ease with which such cargo can be handled in the zero-g environment. At the present state of development, cargo packaging has been examined from an exceedingly gross or rough level of detail. Designers may feel that there are more important things to worry about in development of overall hardware system concepts. However, poor package design can impose operational constraints on the cargo transfer portion of the mission that will limit the overall efficiency of the final in-space operation.

At the present time there are few useful guidelines for designing cargo containers for most efficient handling. Failure to provide such guidelines at an early date will mean that designers will begin to design containers to protect their individual items of supplies, equipment, etc. as they see fit, each container concept being different from that of other designers. Alternatively, unless guidelines are provided it also is possible that some group, given overall responsibility for the Shuttle-Space Station logistics problem, may impose some type of common packaging or container concept, based on goals or objectives that are not compatible with man-handling constraints.

Although certain pieces of information can be extrapolated from isolated studies of manual package handling, no consistent, thorough study ever has been made of all the interacting variables of package design within the widely varying operating conditions anticipated for the Shuttle-Space Station mission.

While many schemes can be generated for packaging various supplies and equipment merely by logical and systematic analysis, most designers are constrained by their lack of experience with the problems of zero-g environment. Evidence of this earth-bound bias appears over and over in many of the early cargo transfer study reports and presentations. Although astronauts

and others experienced in zero-g simulation research can look at and identify possible problems with these concepts, there is a lack of objective data to support the contention that an idea will or will not work in space. It is essential, therefore, that a systematic study of cargo packaging per se be conducted, in which a complete set of package possibilities is examined, first analytically, then tested experimentally in a simulated task setting. The final outcome of the proposed study should be a set of specific guidelines (including trade-off alternatives) which will be useful both to system designers and to mission cargo planners.

The overall objective of this study is to develop quantitative information that will allow for the definition of critical package design characteristics where these characteristics materially affect the ease and efficiency with which such packages can be grasped, held, carried, and manipulated for each of the package transfer operations, both in the 1-g and zero-g environments. This study will produce actual dimensional values or ranges of values within which packages should be constrained in order that handling problems be minimized.

It can be anticipated that compromises will be required to produce the most cost-effective package design concepts since consideration has to be given to variables such as storage density and maximum utilization of on-board space, earth loading and unloading as well as in-space loading and unloading, cargo protection against launch forces as well as other environments, flexibility for containing as many different types of cargo as possible, and weight. However, the package that accomplishes all of these, but which takes too many crew members, too much time, creates potential damage or injury hazards because personnel may make errors, is not optimized in terms of overall cost-effectiveness.

Experimental Design (see Figure 3.3.3.4-1)

Independent Variables

The selection of values for the independent variables will depend both on data obtained in previous experiments and on design concepts current at the time the experiment is conducted.

1. Restraint systems. These may include the same

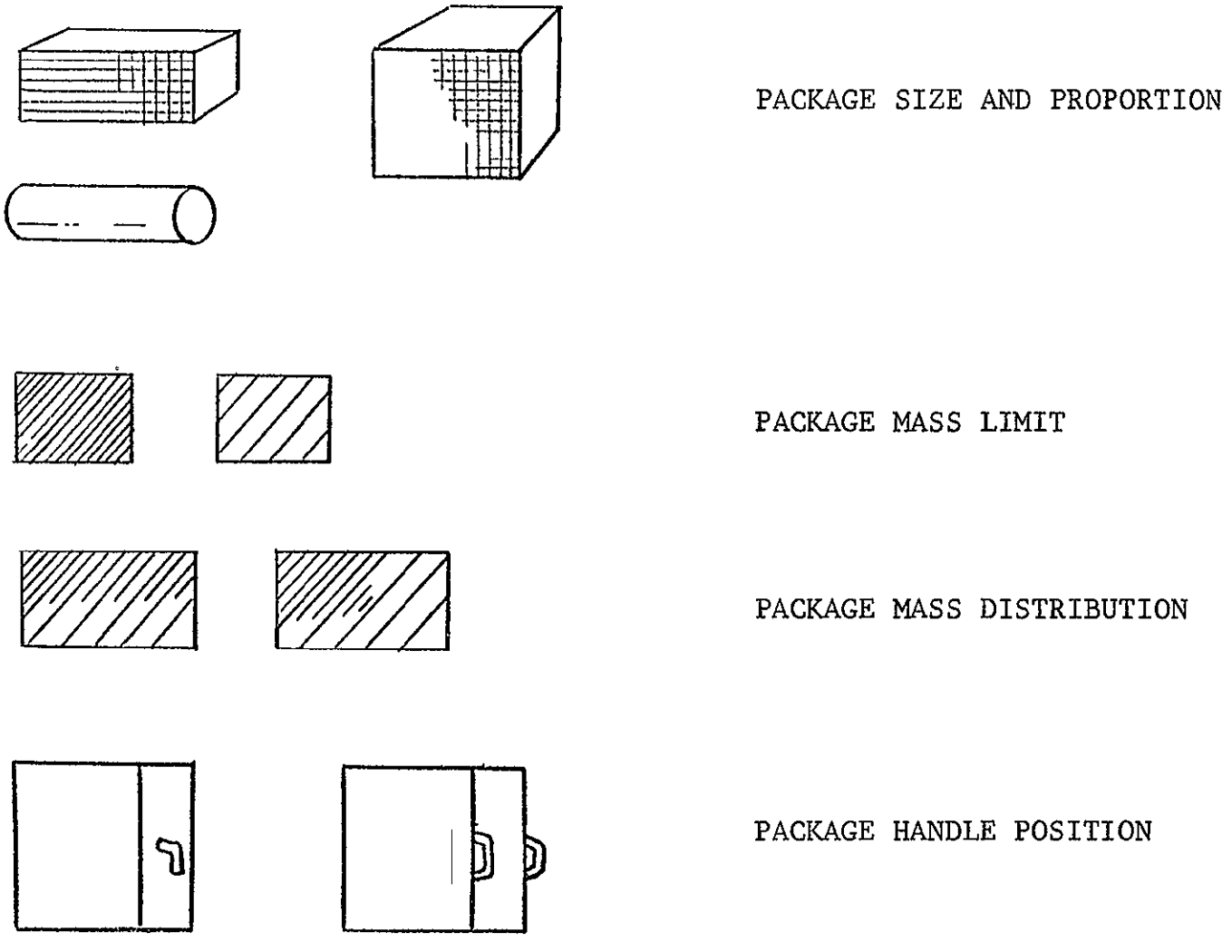


Figure 3.3.3.4-1 - Simulation No. 4: Definition of Package Characteristics Limits

restraints used in Experiment 1 or modifications of these based on the outcomes of the first 3 studies. It is also possible that one or more of these will have been shown to be infeasible, so that it is preferable to examine several forms of a single restraint class (e.g., Velcro, toe-bar, sandal strap, and Dutch-shoe foot restraints).

2. Packages. These should vary in several aspects:

(a) Volume - Three sizes should be used -- small, medium and large. Under present definitions these would be approximately 1-2, 10-15, and 30-40 cubic feet. (TBD)

(b) Shape - Two shapes -- roughly square, and long -- should be used.

(c) Mass - Three levels of mass should be used -- light, medium and heavy. These should be uncorrelated with package volume in order to ascertain the effects of conflicting visual and kinesthetic cues.

(d) Distribution of mass (moment of inertia) - The center of mass should be varied along the axis through the center handhold. For example, three points could be chosen, with the center of mass at the geometric center, nearer the handhold, and more distant from the handhold.

3. Handholds. These should be limited to one- and two-hand manipulation as described in the preceding experiments. Various handhold designs will have to be evaluated, however, this testing should be done after basic handling capabilities have been established.

4. Plane of movement. Control capability should be established for the planes described in the preceding experiments.

Dependent Variables

1. Time. Total trial time from acquisition to release of package should be obtained. A continuous rate measure should

be obtained in order to determine the ability to control package velocity.

2. Trajectory. Ability to control package movement is indexed by trajectory. Photographic records in three planes may be used, alone or in combination with precise measures of distance traveled compared with minimum (straight line).

3. Supplementary data.

(a) Photographic record against grid background

(b) Written notes of trained observers

(c) Reports of subjects

Test Equipment Requirements

1. Restraint systems as called for by experimental design.

2. Package models. Flow-through neutral buoyancy configuration models will be required in the shapes and sizes called for by experimental design. Weights will be provided and attached to achieve the mass and distribution requirements.

3. Time and rate measurement apparatus.

4. Mockup for positioning and receiving packages according to test protocol.

5. Photographic equipment and grid backgrounds.

6. Required neutral buoyancy equipment (Scuba, communications, etc.)

7. Test protocols, data sheets, etc.

Facility Requirements

Since both the man and the package must be in simulated zero-g, and because of the large number of data points to be obtained, the MSFC Neutral Buoyancy Tank would be the preferred facility. The space requirements of this experiment are not great, hence it probably could be conducted concurrently with other simulation studies.

3.3.3.5 Experiment 5. Accuracy of Package Positioning for a Non-Restrained Crewman as a Function of Workspace

Problem and Objectives

All of the conceptual cargo handling problems discussed thus far have involved a formally restrained crewman. Complete knowledge of cargo handling in zero-g must include the condition in which a non-restrained crewman may be required to acquire, stow or hand off a package. This condition signifies an absence of formal restraint systems, such as shoes or tethers, but does not exclude restraints of opportunity such as floors and ceiling, projecting equipment components, and handles on stowed packages. It is a situation that may be expected to arise frequently in the course of long-term missions during which crewmen may seek out single packages from the C/CM on an as-required basis. Under such conditions formal restraint systems may be a hindrance rather than a help unless it can be shown that efficient acquisition of a package otherwise is unsafe, impractical or impossible. In this operational situation too much work space may be as detrimental to efficient performance as too little space under formal restraint conditions.

The purpose of this simulation study is to investigate package acquisition, hand-off, and stowage performance by a non-restrained crewman in a zero-g environment as a function of available space and/or restraints of opportunity. The results of the experiment will be compared with the results of the other simulations described above. In addition to implications regarding work space and restraint placement, it will be interesting to compare crewman ergonomic output under the various study conditions.

Experimental Design (see Figure 3.3.3.5-1)

Independent Variables

1. Space

   (a) Minimum - may be determined during Experiment 1.

   (b) Maximum - determined by crewman body size. The

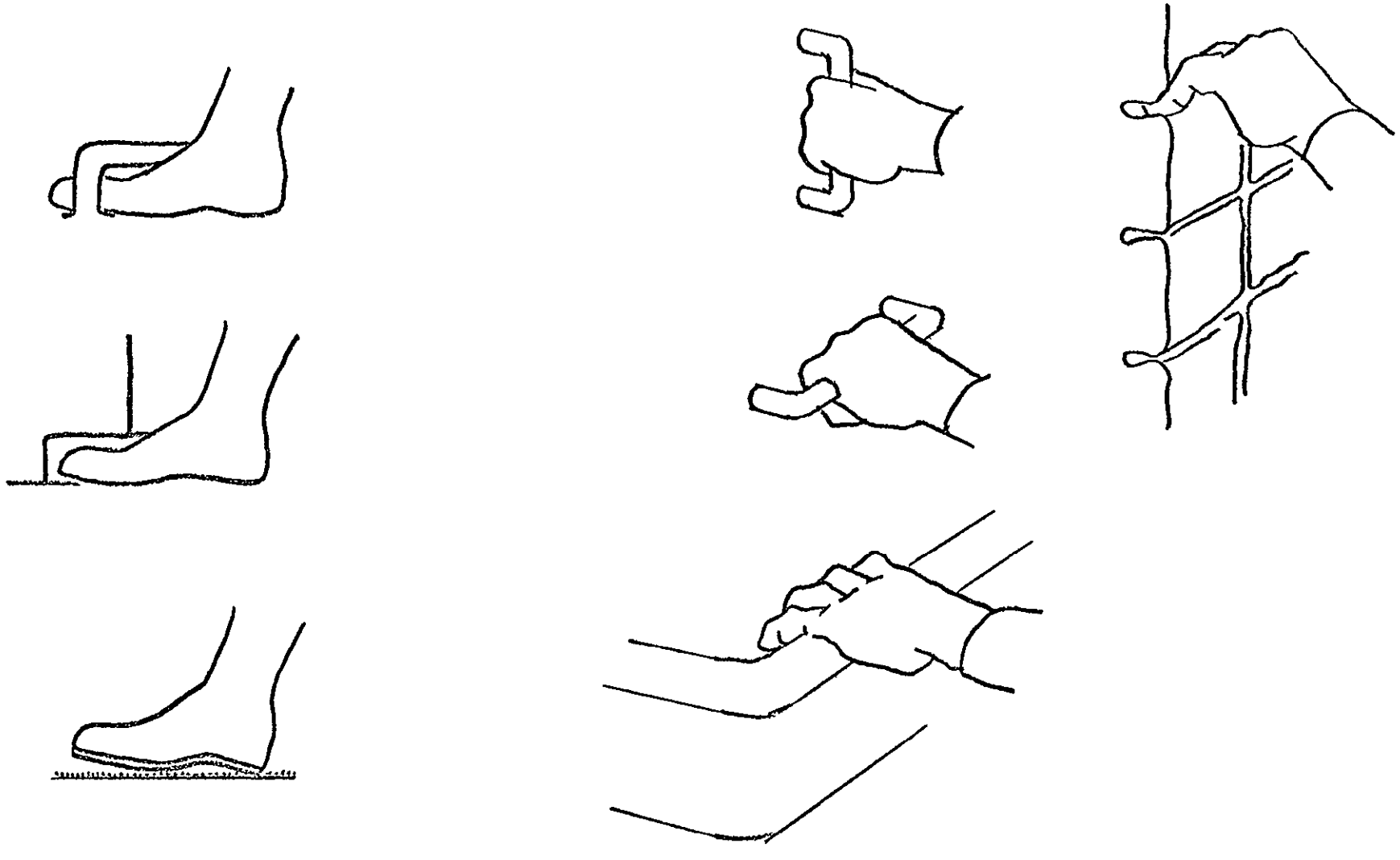


Figure 3.3.3.5-1 - Simulation No. 5: Utility of Common Restraints for Static Package Handling

dimensions must preclude bracing against the opposite wall.

(c) Intermediate value(s) - number TBD.

In all other respects the design of this experiment is similar to Experiment 3, except that angle and position of placement are not relevant and distance is measured from acquisition point.

2. Package Dimensions

(a) Small

(b) Large

3. Handholds

(a) One in center

(b) Two on edges

4. Other

(a) Compartment clearance

(b) Distance from acquisition point

Dependent Variables

1. Time. Compartment location-time and stowage time, as described in Experiment 3, should be obtained.

2. Accuracy. The two measures of accuracy described in Experiment 3 should be obtained.

3. Supplementary data

(a) Photographic record against grid background.

(b) Written notes of trained observers, with special attention to use of equipment for handholds - where how often, etc.

(c) Reports of subjects.

Test Equipment Requirements

1. Package models. Small and large packages as specified by the experimental design will be needed, with neutral buoyancy configuration.

2. Stowage mockup - A rack with compartments having the dimensions called for in the experimental design.

3. Timing and counting devices as described in Experiment 3.

4. Work space enclosure, variable in volume.

5. Photographic equipment and grid backgrounds.

6. Required neutral buoyancy equipment (Scuba, communications, etc.)

7. Test Protocols, data sheets, etc.

Facility Requirements

Since unrestricted movement capability is required the MSFC Neutral Buoyancy Tank should be used.

3.3.3.6 Experiment 6. Translation Aid Requirements for Manual Cargo Transfer

Problem and Objectives

Both long and short cargo transfer distances will be required in the planned Shuttle-Space Station mission. Operational transfer tasks will occur within the C/CM, Space Station tunnel and in the various work and living space compartments. There undoubtedly will be many instances when a crewman will choose to transfer a package or packages manually rather than activate an automatic or semi-automatic transfer system. In this case the crewman would not be formally restrained. However, many kinds of mobility aids may be required to assist him in propelling, controlling position, orientation, velocity and turning corners during the transit cycle.

Although apparently simple, a continuous manual transfer from C/CM to final cargo operation point may not prove cost

effective due to the amount of time and energy consumed. An important and currently unknown performance parameter is the technique by which a crewman carries or holds on to a package during manual transit. A package may be carried under an arm, held onto by a package handle, or attached somehow to the crewman, allowing him free use of both hands and arms. This study will help to determine if manual transfer is feasible or whether some combination of manual and automatic transfer is more practical.

The purpose of the study is, then, to investigate the requirements for efficient crewman manual translation with a package. Derived criteria should describe operationally effective translation aids as well as the techniques for carrying packages.

Experimental Design (see Figure 3.3.3.6-1)

Independent Variables

1. Work Space

   (a) Minimum - to accommodate crewman and/or package

   (b) Maximum - such that only translation aid and adjacent wall are within reach

   (c) Intermediate value(s)

2. Translation aids

   (a) Discrete (spatially separated) handholds

   (b) Continuous rail

   (c) Others might include rail plus tether, or rings that could be utilized either as handholds or toe-bars.

3. Packages. These should vary in several aspects:

   (a) Volume - Three sizes should be used, small, medium and large. Under present definitions these would be approximately 1-2, 10-15, and 30-40 cubic feet. (TBD)

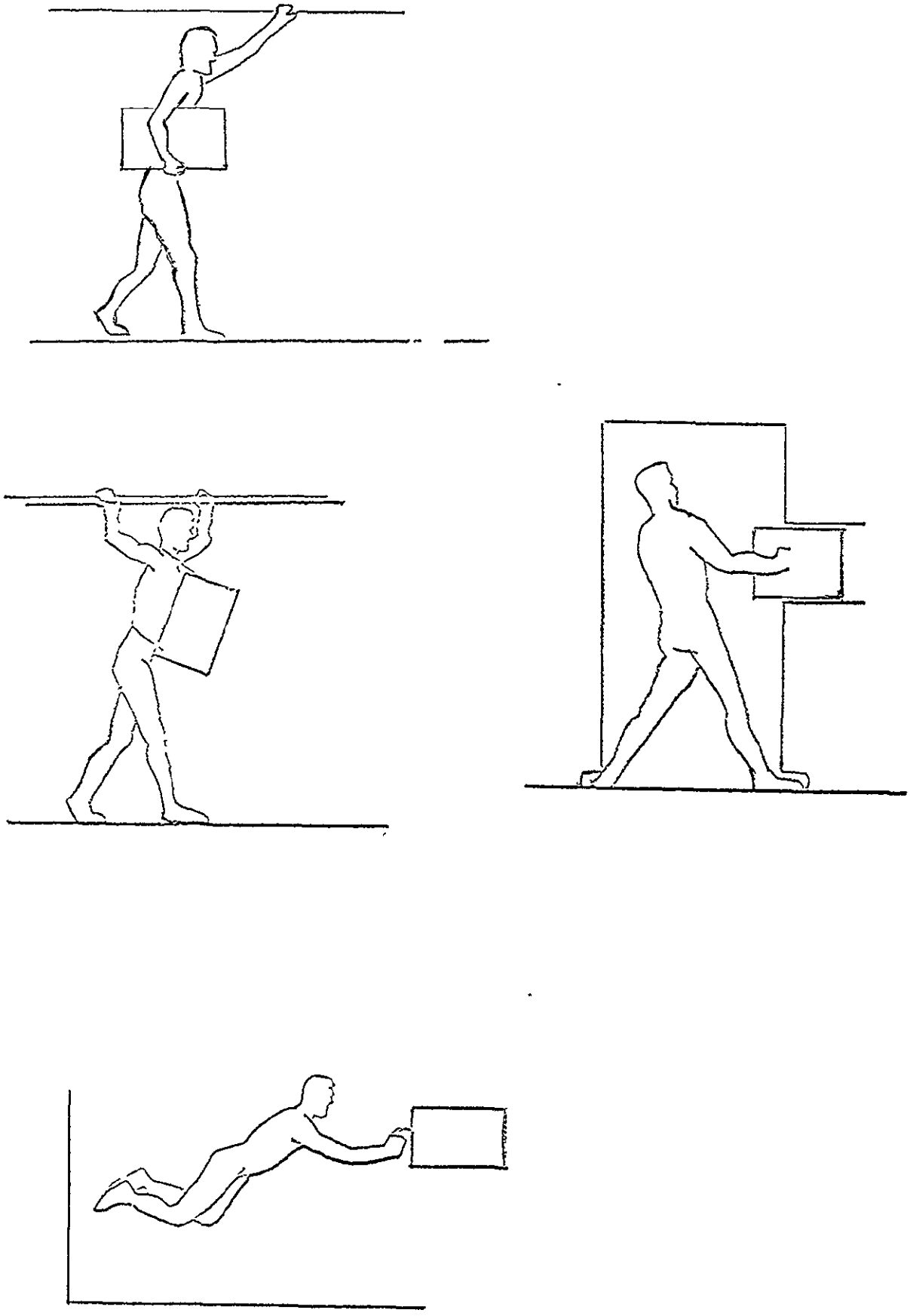


Figure 3.3.3.6-1 - Simulation No. 6: Package Handling Alternatives

(b) Shape - Two shapes -- roughly square, and long -- should be used.

(c) Mass - Three levels of mass should be used: light, medium and heavy. These should be uncorrelated with package volume in order to ascertain the effects of conflicting visual and kinesthetic cues.

(d) Distribution of mass (moment of inertia) - The center of mass should be varied along the axis through the center handhold. For example, three points could be chosen, with the center of mass at the geometric center, nearer the handhold, and more distant from the handhold.

4. Handholds

(a) One, centered

(b) Two edges

5. Mode of holding (e.g., pushing, dragging, underarm) could be varied systematically by instruction or could be left up to the individual subject and observed as a dependent variable.

Dependent Variables

1. Time to translate a fixed distance.

2. Observations as to tumbling and other lack of package control, use of handholds, etc.

3. Subjective reports.

4. Possibly bio-medical monitoring.

Test Equipment Requirements

1. Work space enclosure. A tunnel with variable cross section will be needed, constructed of a material that will minimize its functioning as a translation aid (e.g., plexiglass).

2. Translation aids as required by experimental design.

3. Package models. Flow-through, neutral buoyancy configuration models will be required in the shapes and sizes called for by experimental design. Weights will be provided and attached to achieve the mass and distribution requirements.

4. Photographic equipment and grid backgrounds.

5. Required neutral buoyancy equipment (Scuba, communications, etc.)

6. Test protocols, data sheets, etc.

All the simulation studies outlined in this section can be accomplished using the MSFC Neutral Buoyancy Facility. However, depending upon the availability of various simulation systems, other combinations are possible and should not seriously degrade results.

Experiments 1, 2, 3 and 4 could be executed using the reduced friction MSFC 5½°-of-freedom jump rig facility. Experiments 5 and 6 would have to be accomplished in the neutral buoyancy facility or in the KC-135 aircraft. Use of the latter for these experiments would restrict the number of possible data trials and variable combinations. The KC-135 aircraft, however, should be considered for final limited sample verification testing of all of the experiments described herein.

Developmental Systems Simulations

The present cargo handling study has shown that no conventional or off-the-shelf cargo transfer systems will suffice, as is, to accomplish predicted cargo handling tasks. Rather, a carefully designed combination of different devices and techniques will be necessary to satisfy the cargo handling task. Two conditions must be satisfied before full scale whole-task simulations can be considered. First, the prerequisite studies outlined herein must be completed and resulting data documented. Second, a hardware model based on mission system requirements must be reasonably well defined. With a detailed hardware system model available specific preliminary candidate cargo transfer systems can be designed.

Based upon the well-defined hardware-mission system,

standard task and functional analyses can be performed. The data from the three sources -- viz., the shuttle system model, the task and functional analyses, and (of particular importance) the prerequisite simulation studies -- can then be applied to the high fidelity mockup of candidate transfer systems. Subsequent static and dynamic simulation and testing will isolate problems and eventually produce a valid prototype system. Test-derived concepts may be investigated by part-task methods as they develop and design deficiencies thus corrected.

By this time enough hardware and simulation equipment should be available to configure and undertake whole-task simulation. Appropriately designed simulations and tests will be useful in any final modification of the system because of hardware design or procedural deficiencies.

The whole-task simulation apparatus should be maintained to investigate required engineering design changes. The simulation facility should be used to verify final system configuration, validate man-system compatibility and establish procedural timelines. Finally the simulation system can be used as a crew training facility.

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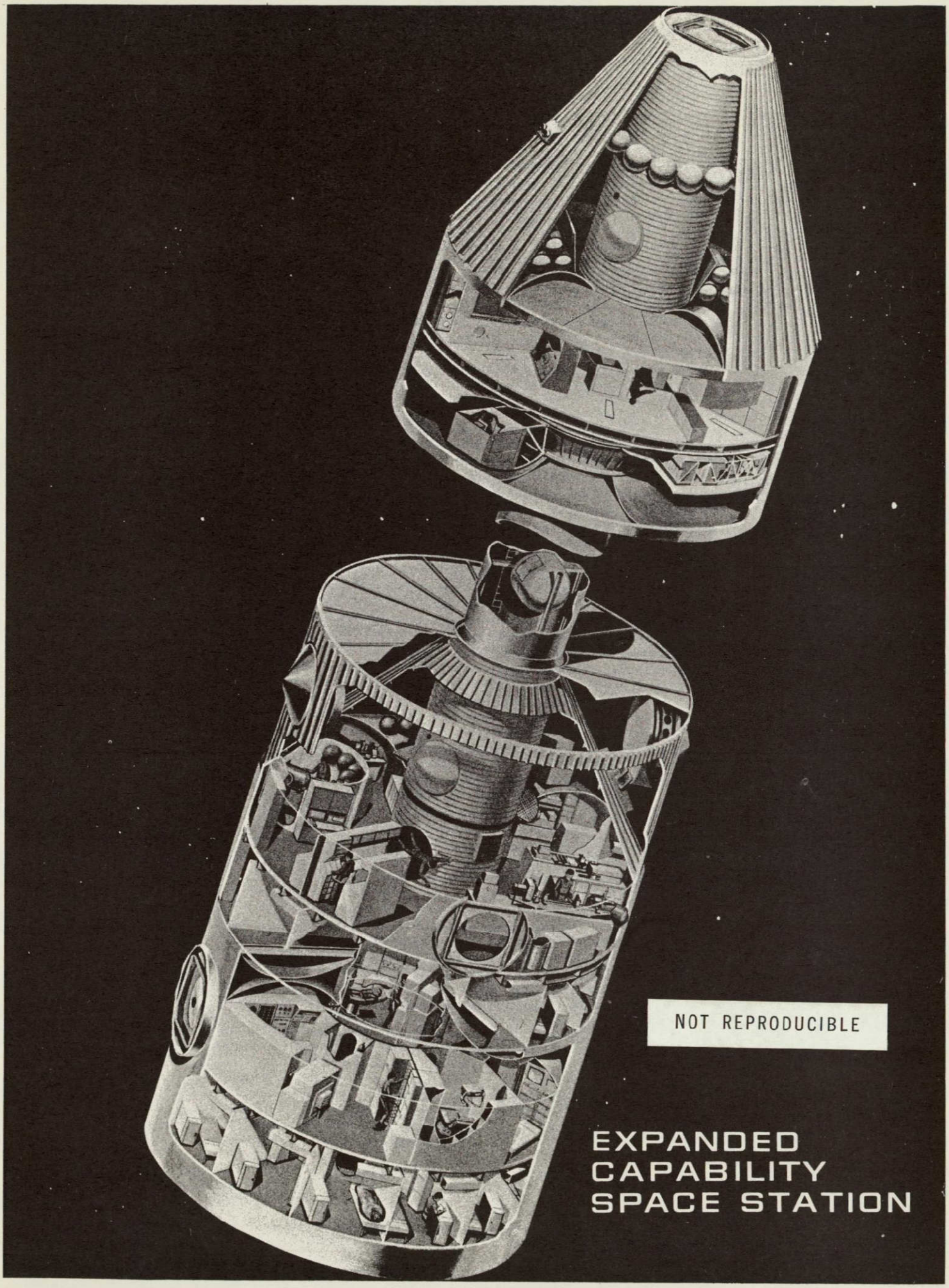

NOT REPRODUCIBLE
EXPANDED
CAPABILITY
SPACE STATION

APPENDIX A

LITERATURE REVIEW SUMMARY

Introduction

An initial task of the present study was to review the literature considered pertinent to in-space cargo handling as implied in the Space Shuttle Resupply Mission. Therefore, the review covered reports, memoranda and briefing documents dealing with missions, prime systems, transfer subsystems and crew performance in zero-g environments. Although a considerable amount of documentation was reviewed (see reference bibliography), only those documents considered directly applicable are summarized here.

Missions and Prime System Concepts

In spite of a great many secondary reports dealing with mission concepts and basic hardware systems design, the most useful and relevant documents (i.e., most representative of current NASA-Industry thinking) are the NASA "Blue Book" series [114] and the several Phase B Concept Definition Study reports and briefing documents prepared by the McDonnell-Douglas and North American-Rockwell companies. A major share of the illustrations in this section have been taken from one or more of these documents and do not represent newly-generated ideas.[79,80,81,82,83,84,114,116]

It is significant to note that the overall mission-systems concept is still under study, and alternate plans and concepts are being examined in terms of possible phasing into the final concept shown here. It should also be recognized that considerable speculation still exists regarding mission objectives since a certain amount of serendipity must be expected in long range research. Hence, as certain experiments are completed new requirements will be generated that may not have occurred to planners at this point in time.

Mission Concepts - An early-orbiting space station capable of remaining on station for a period of ten years is conceived to provide a base of operations for research by academic, commercial, and governmental organizations to further scientific

and commercial pursuits. These would include such fields as astronomy, space physics, aerospace medicine, space biology, materials sciences and manufacturing, earth observations, communications and navigation.

The Space Station would be supported by a Shuttle System that would permit the transfer of supplies and the return of data on a regular basis, making it possible to maintain a continuous, year-around operation. In order to accomplish this type of mission, the NASA has developed an overall system concept consisting of the elements shown in Figure A-1. Also shown are the general operational functions associated with management of such a system/mission. Relevant to the present study are the anticipated operations plans and the sequencing of elements of the station supply system. These are illustrated in Figure A-2. Within this mission concept, in-space cargo transfer primarily involves the Crew Cargo Module (C/CM) and the Space Station (SS) together with their specific problems of stowage and handling of cargo packages.

Obviously, the main purpose of the SS mission is to perform scientific investigations and engineering tests. It is apparent from the present review that there is an almost infinite number of these. It is also clear that there is considerable difference of opinion as to how some of the experiments and tests should be conducted, what equipment will be required, and what the nature of the data transfer and resupply requirements will be. Nevertheless, progress is being made in defining these experiments and equipment requirements. The NASA Blue Book series now covers at least the following scientific and engineering mission areas:

Astronomy

Physics

Earth Observations

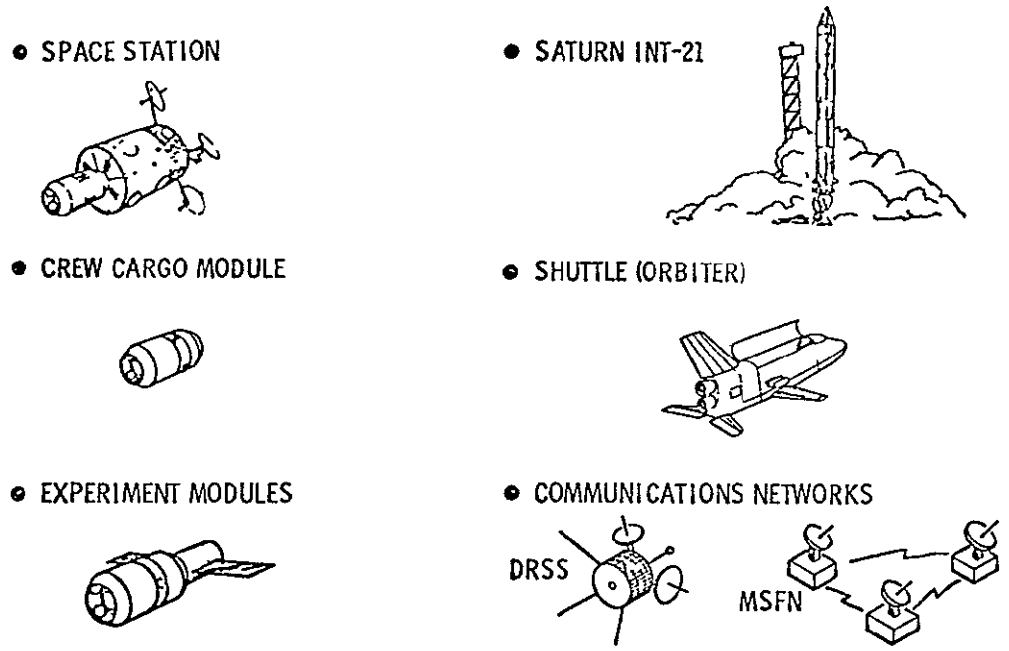
Communications/Navigation

Materials Science & Manufacturing

Technology

Life Sciences

SPACE STATION PROGRAM COMPOSITION
ELEMENTS/PROJECTS



SPACE STATION MISSION
MANAGEMENT OPERATIONAL FUNCTIONS

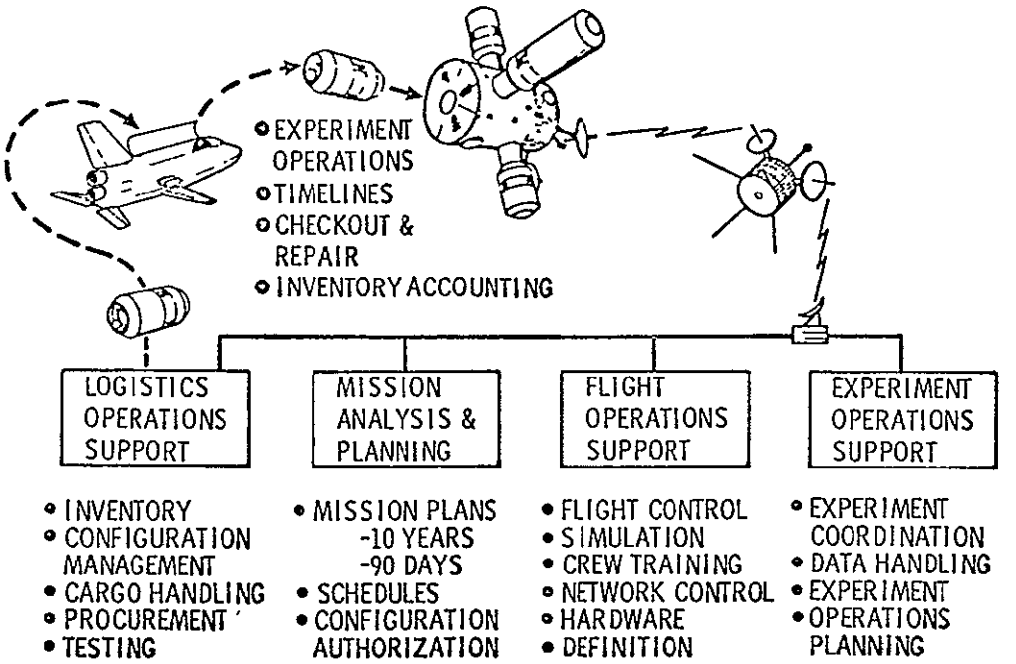


Figure A-1 - Space Station-Shuttle Mission Characteristics

90-DAY MISSION CYCLE
PRE-MISSION PLANNING FLOW

PROJECT DATA (INPUT)	INTEGRATED PLANNING	INTEGRATED ACTIVITIES
MISSION CYCLE PROJECT REQUIREMENTS • EXPERIMENTS • PROGRAM HARDWARE	EXPERIMENT OPS PLAN • EXPERIMENT DEFINITION • DATA HANDLING	FACILITY RECONFIGURATION • MOSC/PVM • DATA NETWORK
ON-GOING MISSION STATUS • INVENTORY • EXPERIMENTS	FLIGHT OPS PLAN • TRAINING • FLIGHT SUPPORT	PROCEDURAL • SCHEDULE COORDINATION • TIMELINES/PROCEDURES
SUPPORT PROJECT STATUS • CREW CARGO MODULE • LOGISTICS SHUTTLE • COMMUNICATIONS NETWORK	MISSION PLAN • CONFIGURATION AUTHORIZATION • SCHEDULES	TRAINING • GROUND AND FLIGHT CREW • SIMULATIONS
	LOGISTICS OPS PLAN • CONFIGURATION/INVENTORY • MAINTENANCE/TEST	INVENTORY CONTROL • PROCUREMENT • CARGO PACKAGING/ LOADING

CCM OPERATIONS CYCLE

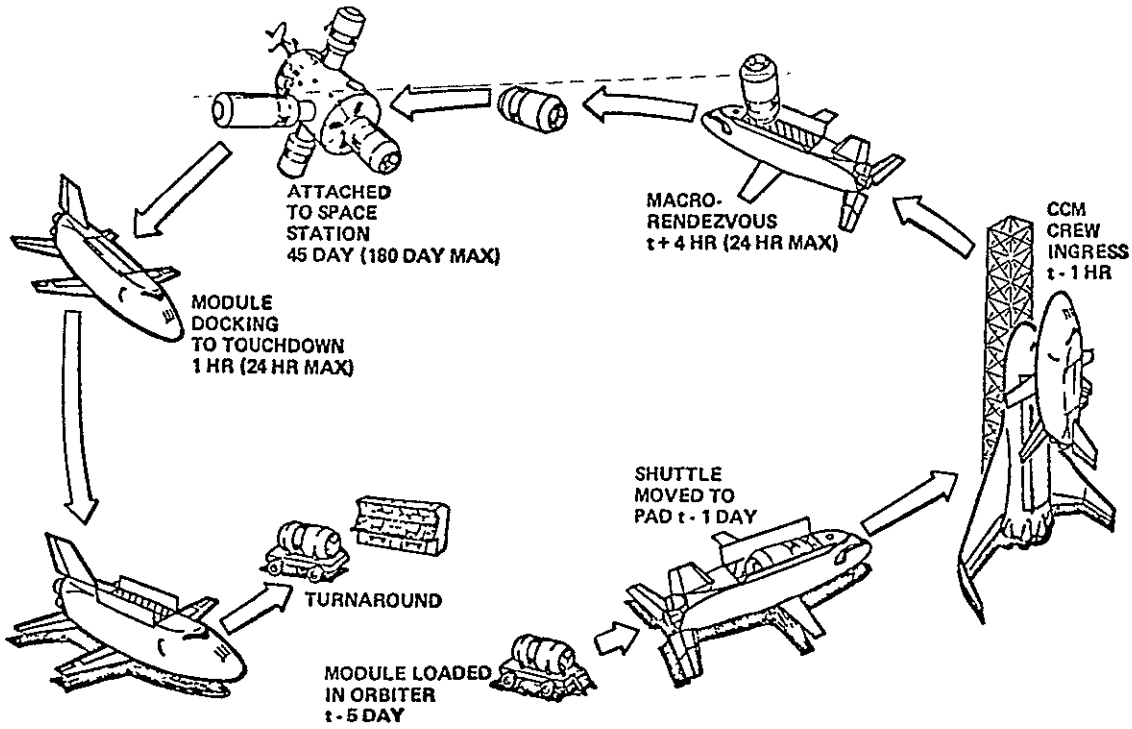


Figure A-2 - Mission Operation Concept

Support for these missions in terms of the actual supplies that influence cargo handling concept decisions still is somewhat unclear from our review. However, the one significant attempt to get at this problem has been the development of an "expendables data bank"[51,52,53] . Although the authors admit to the tentative nature of this information, it furnishes the only basis for considering in-space package handling systems. The present review centers on the mission interfaces between the C/CM and the SS. These are identified within the larger mission sequence in Figure A-3.

Crew Cargo Module Concepts - Phase B concept studies include many versions of the C/CM, as illustrated in Figures A-4 through 6 and Table A-I. It is significant that the design detail leaves much to the imagination regarding the specifics of package-stowage interface. The one common thread appears to be the 15-foot CM diameter and the 5-foot docking hatch diameter. However, there is considerable confusion regarding the probable packaging characteristics. Figure A-7 presents a typical estimate of package characteristics requirements.[84] It does not represent a recommendation for standardization of package size and shape, however. Other such recommendations vary considerably, depending upon whether the analyst is concerned with manual handling, accessibility through hatches, or convenience for racking and stowage. Although many of the criteria identified by these analysts are valid, the one that seems to have the most practical consequence for this study is that of accessibility through hatches.

Cargo stowage aboard the C/CM obviously is an important consideration. Typical stowage concepts are shown in Figure A-8. Unfortunately, little detail design has been found regarding the package-rack interface hardware for any of these concepts. Similarly, very little concrete design detail has come to light regarding packaging. General philosophies about packaging -- such as unit vs intermediate vs modular container vs cabinet or bins -- have been examined in a cursory fashion.[81] Gross conceptualization exercises have come up with broad package design criteria (i.e., convencience and safety factors), and rough estimates have been made as to the mass-handling limits of cargo handlers in the zero-g environment.[54] However, little integrated information is available at this time to help establish the parameters that will constrain design of the stowage system, a package handling system, or a cargo inventory/location system.

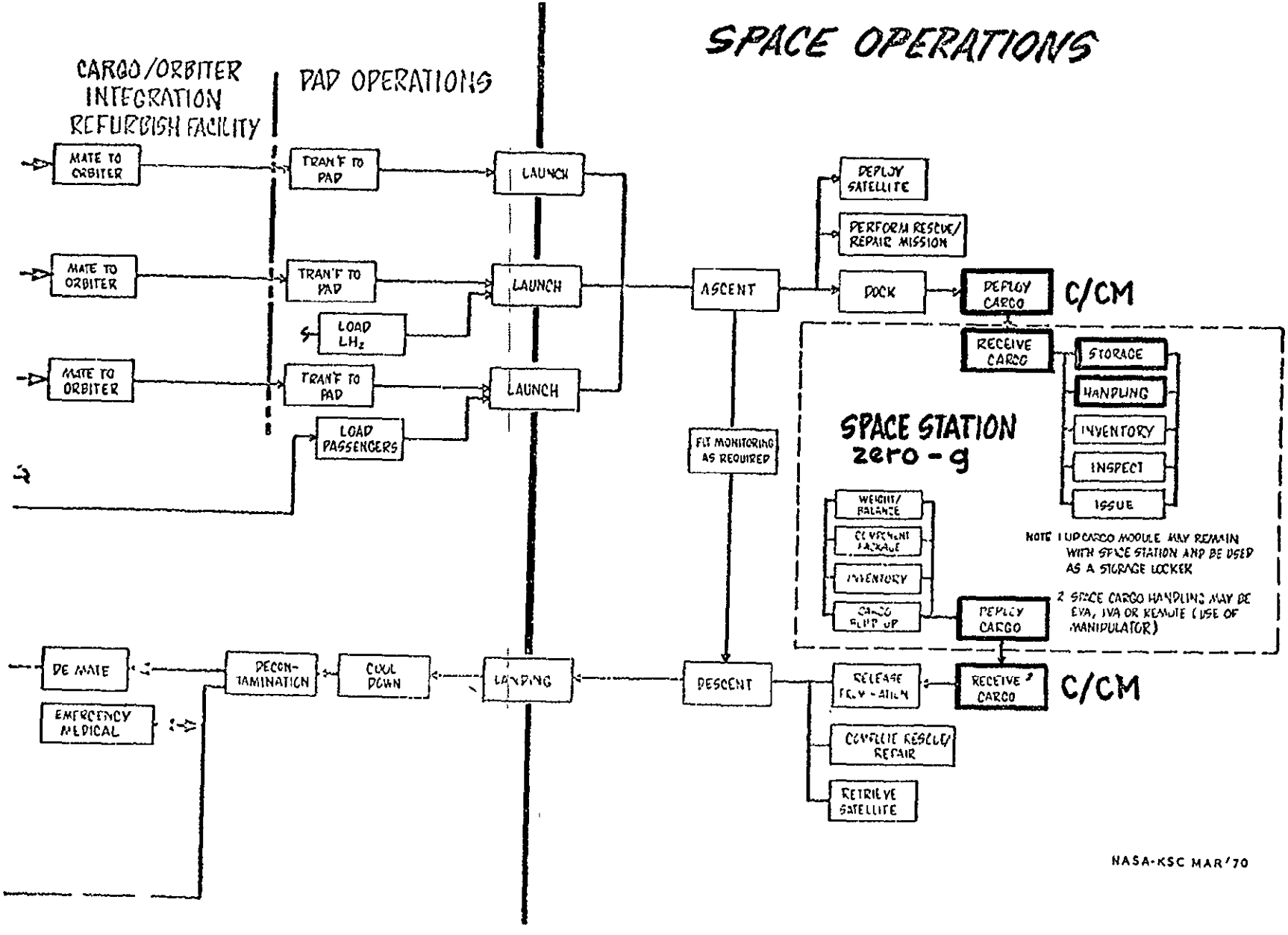


Figure A-3 - Typical Resupply Mission

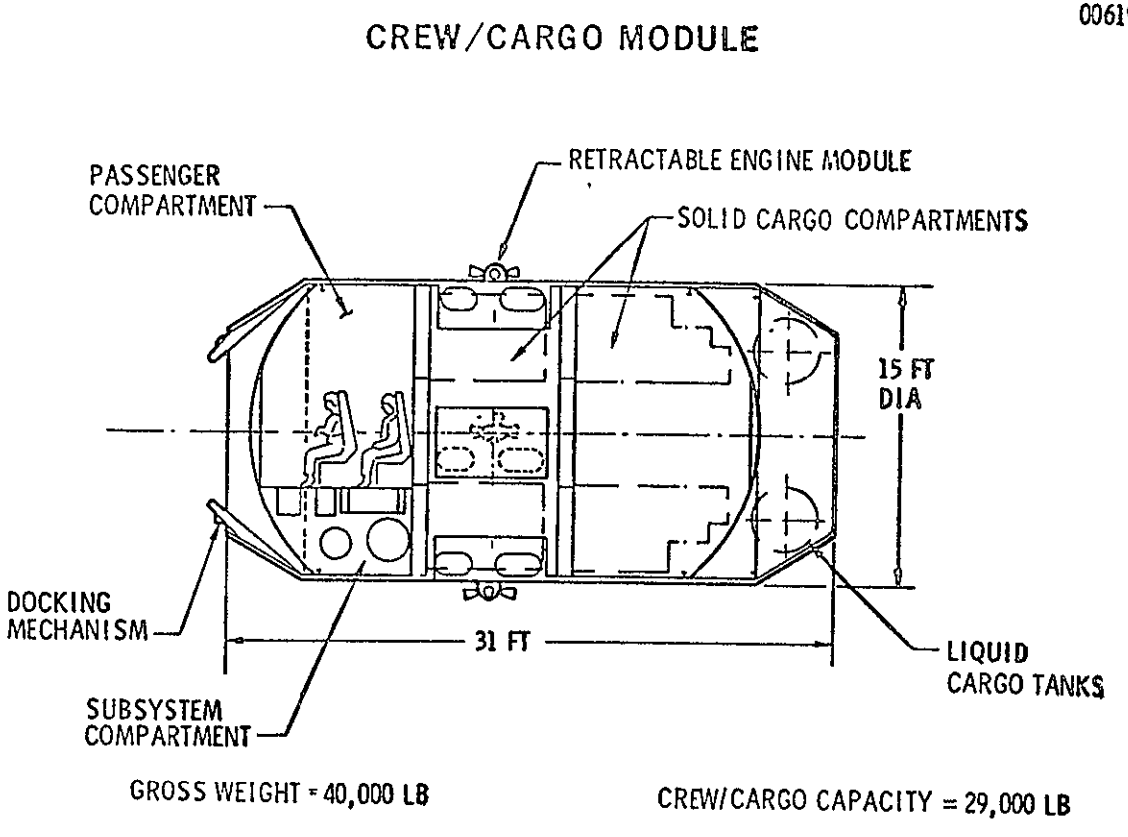


Figure A-4 - C/CM Concepts

DESIGN CONCEPT

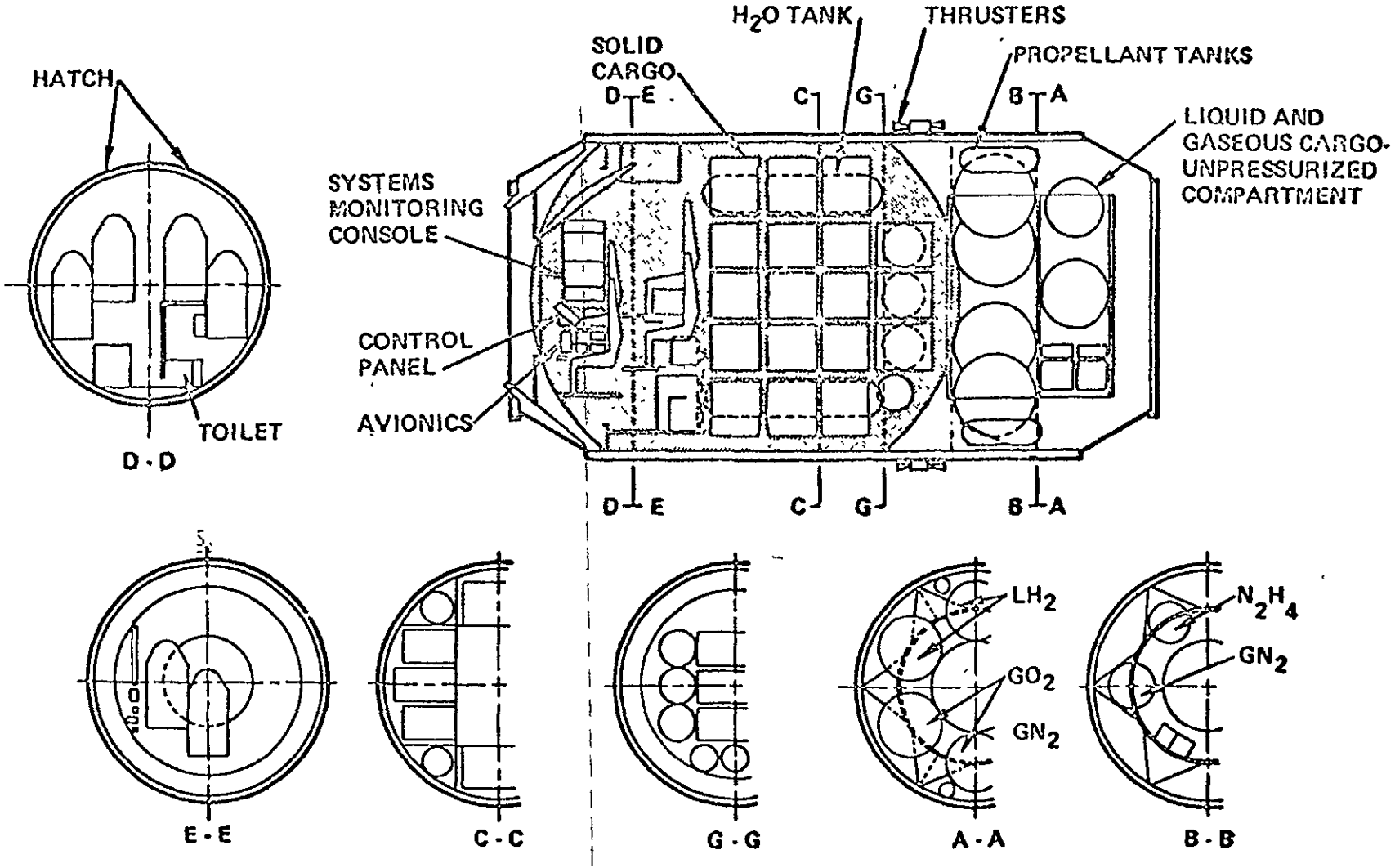


Figure A-5 - C/CM Concepts

CCM ARRANGEMENT AND CONFIGURATION VARIATIONS

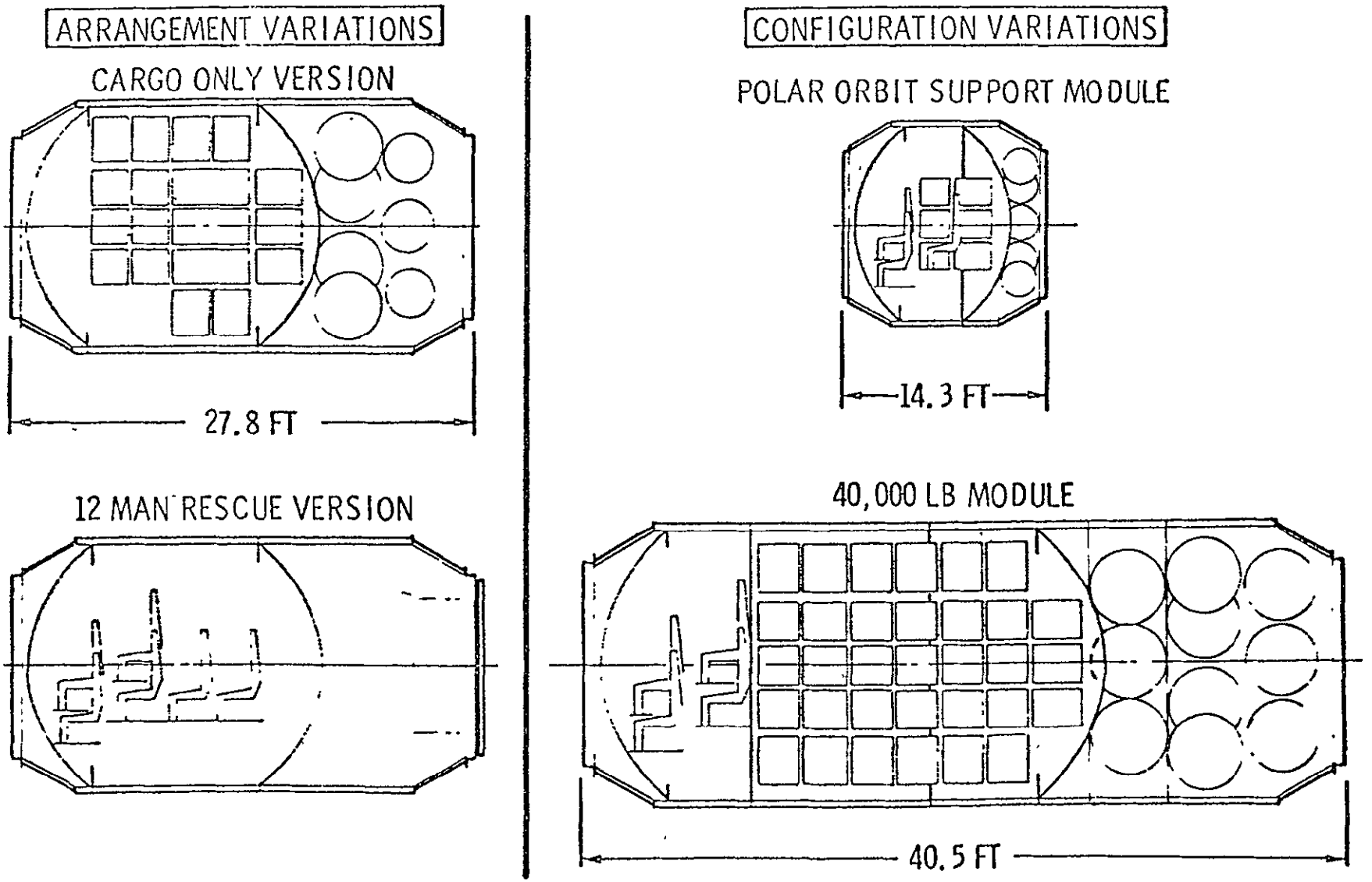
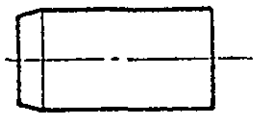
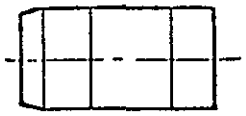
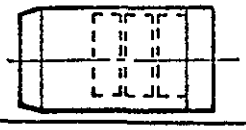


Figure A-6 - C/CM Concepts

Table A-1 - INITIAL CONCEPT COMPARISON

CONCEPT	ADVANTAGES	DISADVANTAGES
INTEGRAL 	• MAXIMUM CARGO CAPABILITY • INTACT SUBSYSTEMS	• LIMITED GROWTH POTENTIAL • LIMITED FLEXIBILITY FOR INTERNAL REARRANGEMENT
MODULAR 	• HIGH CARGO CAPABILITY • MAXIMUM ADAPTABILITY • HIGH GROWTH POTENTIAL • COMMONALITY WITH OTHER MODULAR ELEMENTS	• INTERFACE COMPLEXITIES BETWEEN MODULES • POSSIBLE SUBSYSTEM DUPLICATION
PALLETIZED 	• HIGH ADAPTABILITY • INTACT SUBSYSTEMS • EASE OF CARGO LOADING	• REDUCED CARGO CAPABILITY • DUPLICATED STRUCTURE • LIMITED GROWTH POTENTIAL

GENERAL PURPOSE LABORATORY
CARGO SIZE DISTRIBUTION

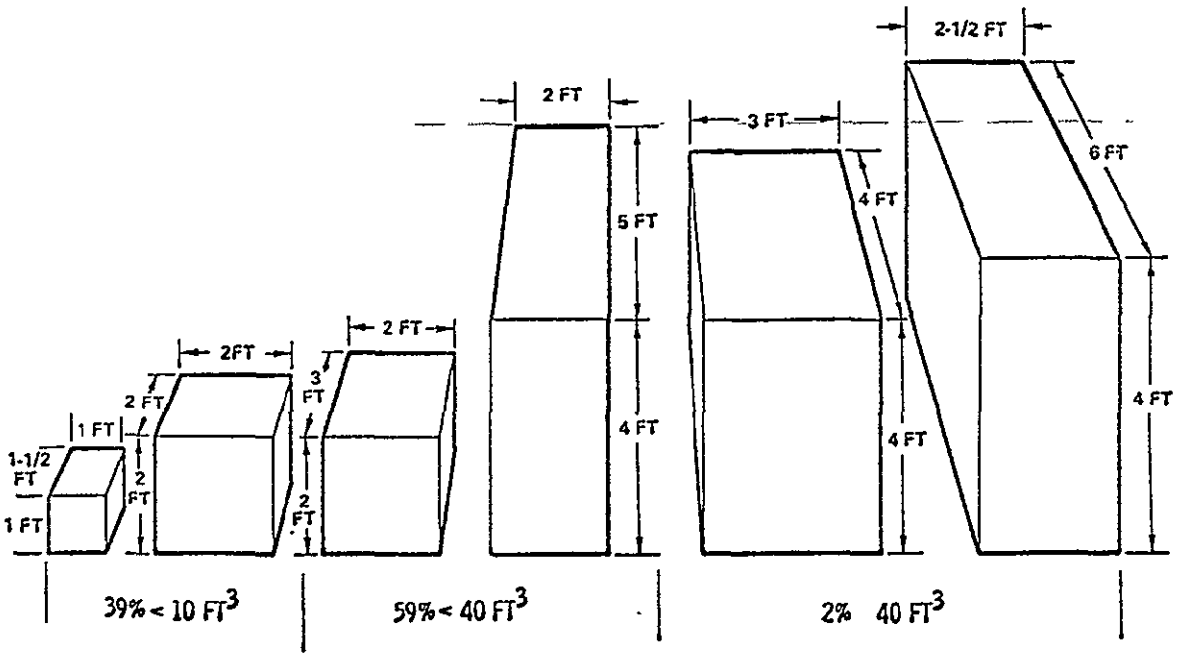
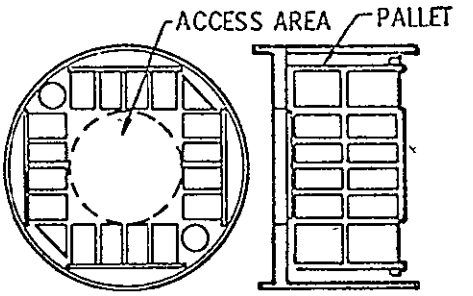


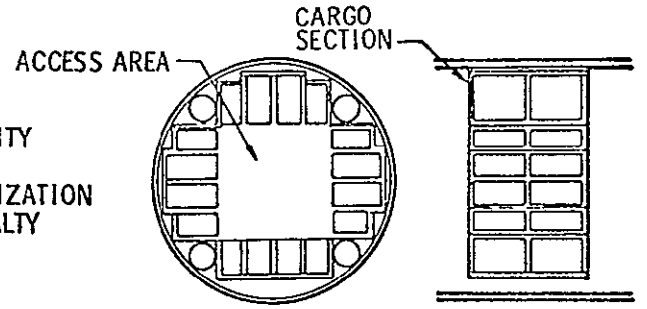
Figure A-7 - Cargo Packaging Estimate

CCM CARGO STOWAGE CONCEPTS

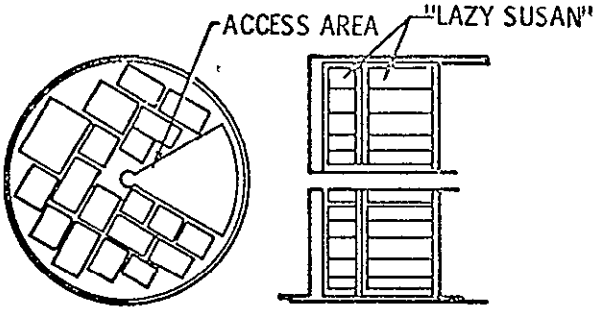
- GOOD ACCESSIBILITY
- GOOD FLEXIBILITY
- FAIR VOLUME UTILIZATION
- WEIGHT PENALTY



- GOOD ACCESSIBILITY
- GOOD FLEXIBILITY
- FAIR VOLUME UTILIZATION
- HIGH WEIGHT PENALTY



- MAXIMUM ACCESSIBILITY
- VERY LIMITED FLEXIBILITY
- GOOD VOLUME UTILIZATION
- WEIGHT PENALTY



- LIMITED ACCESSIBILITY
- MAXIMUM FLEXIBILITY
- MAXIMUM VOLUME UTILIZATION
- LOWEST WEIGHT

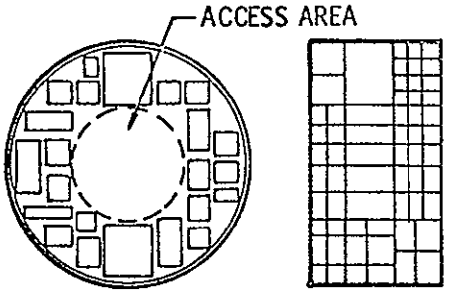


Figure A-8a - C/CM Stowage Concepts

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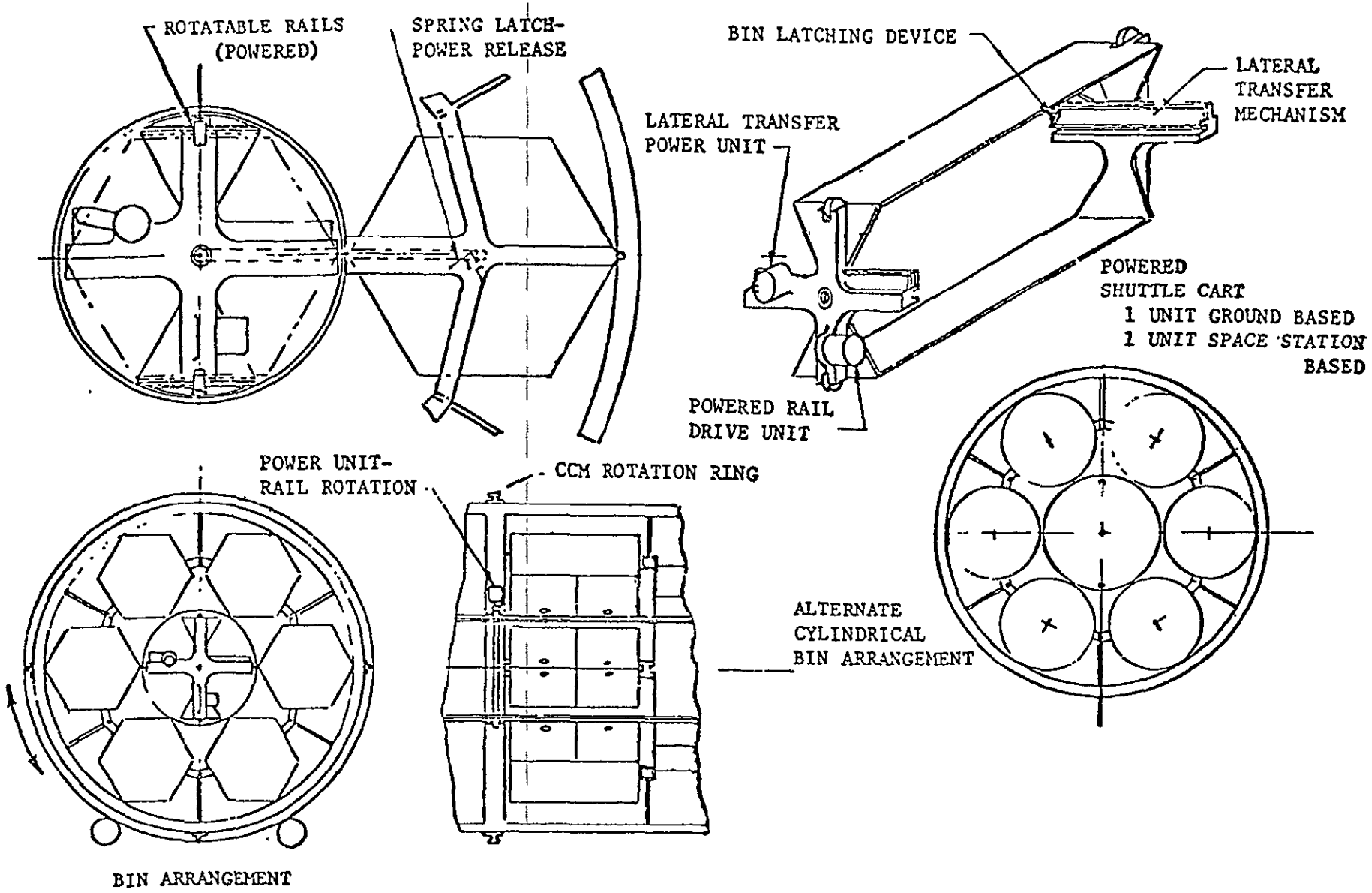


Figure A-8b - C/CM Rotating Bin Stowage System

Space Station Concepts - It is evident from this review that a number of space station concepts still are under investigation due to the uncertainty of funding for the eventual 10-year program. The primary, long-term design concept, however, appears to be what is referred to as the "integral station" (see Figure A-9)."[14] The integral station normally would be launched as a single unit, although several proposed concepts call for sending the station up in sections.

The integral SS will be launched into a circular 500-km, 55-degree inclination orbit. Its operations will be largely autonomous, making extensive ground support unnecessary. It will have facilities for a crew of 12. The basic element of the integral SS is the core module, consisting of an external 33-foot cylinder, an internal 10-foot tunnel and a toroidal closure at each end. Figure A-10 shows a more detailed breakdown of the several decks and their functions. There are seven docking ports, five on the cylindrical surface and one at either end of the station. Each port has a 5-foot diameter access hatch and an atmosphere seal between the station and the docked module.

Modular station concepts under study involve configurations that permit station assembly in earth orbit by means of various space shuttle payloads (a typical configuration is shown in Figures A-11 and A-12)."[14] The principal advantages of this approach relate to scheduling -- i.e., payload development, integration and checkout -- and to refurbishment and/or modification of a particular module by returning it to earth. The basic structural elements and central assembly are approximately 29 feet long and 14 feet in diameter, with airlock hatches of 5-ft. diameter.

In addition to the integral and modular station concepts, a Shuttle-Sortie program also has been considered. In essence this approach envisions short individual missions in which the Shuttle vehicle serves as a temporary platform that takes an experimental module into orbit until the experimental test is completed, then returns to earth with the module. Since this concept was not considered germane to the present study, no further discussion of it is provided. Similarly no detailed examination was made of other station concepts, such as artificial-g configuration missions and systems.[84]

Figure A-9 - Integral Space Station

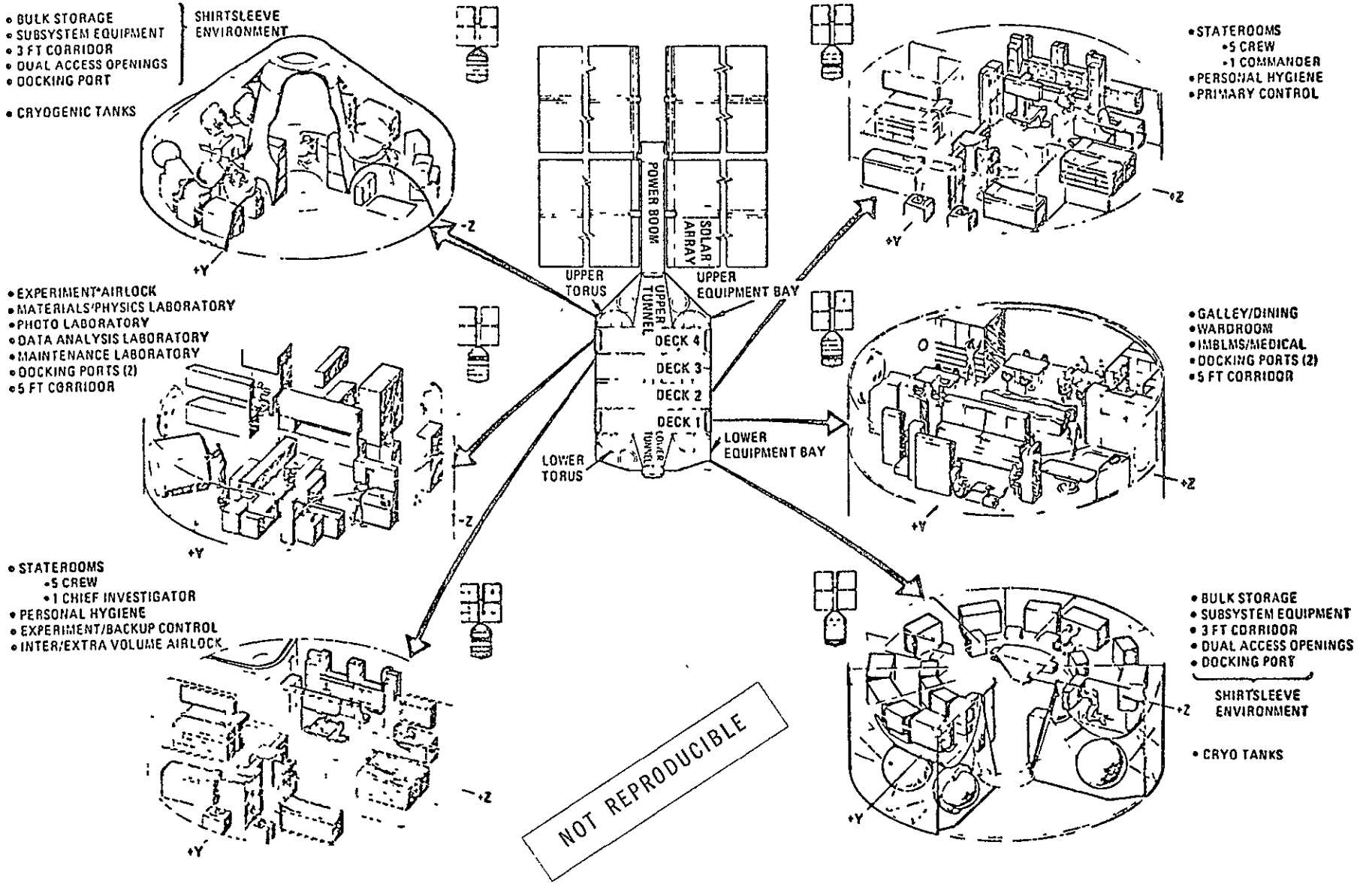


Figure A-10 - Solar-Powered Integral Space Station

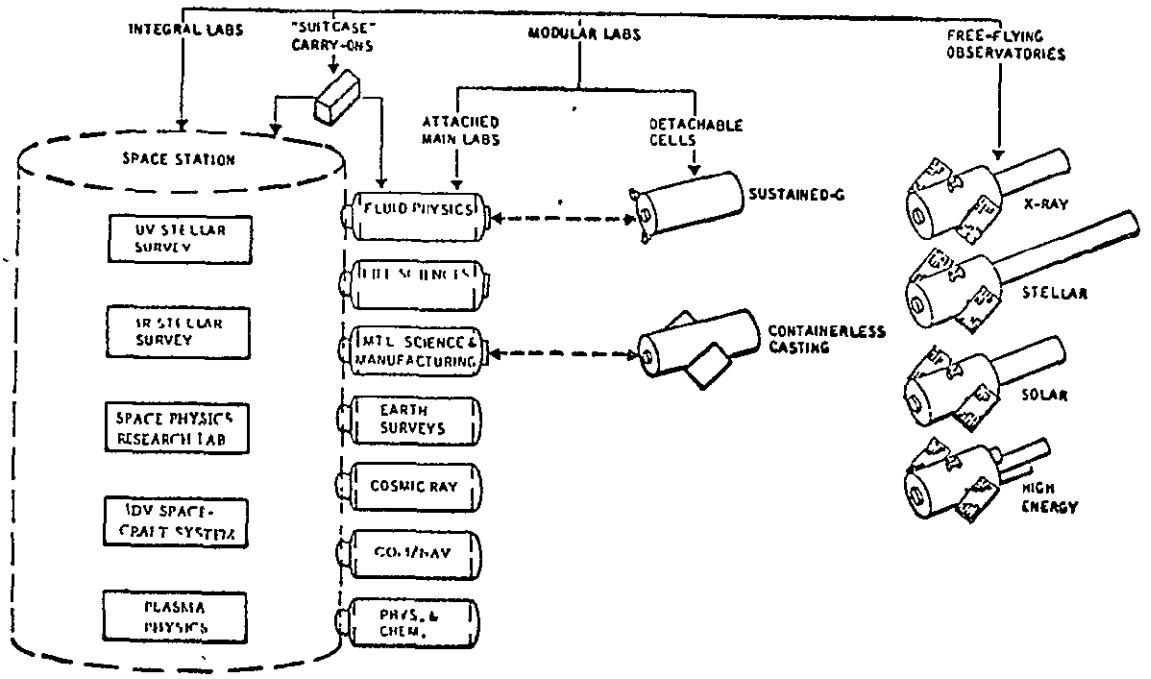
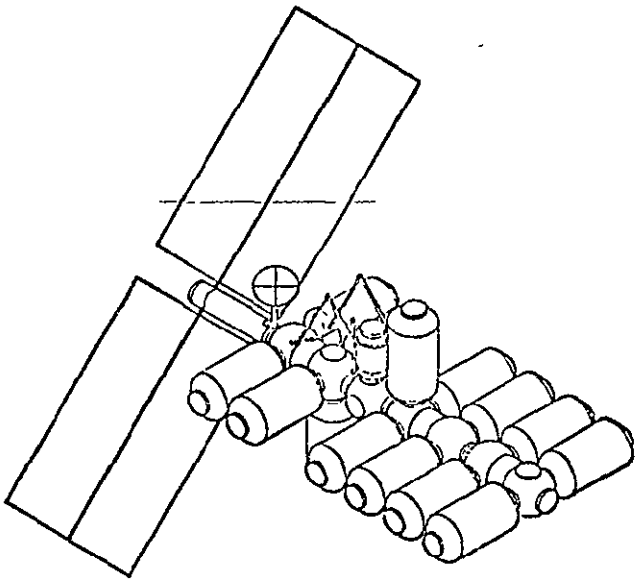


Figure A-11 - **Space Station Research and Applications Capabilities**



17 SHUTTLE LAUNCHES TO A COMPARABLE 12-MAN INTEGRAL SPACE STATION

Figure A-12 - **Twelve-Man Modular Space Station**

In summary, then, it appears from the present review of mission/system literature that the in-space cargo transfer problem can be described in terms of the following parameters, very few of which are sufficiently well defined to provide a good basis for tradeoff analyses:

a. C/CM dimensions (14-ft interior diameter; 5-ft diameter docking hatch; varies between about 14 and 40 feet in length, including pressurized and non-pressurized areas).

b. Other experimental modules (little dimensional information, although it appears the dimensions are similar to those in (a)).

c. Cargo stowage systems for C/CM are not fully defined nor have optimum concept decisions been made. However, it would appear that mission requirements will dictate maximum loading capacity for certain resupply events, making it likely that this type of loading will pace the stowage hardware development and package interface specifications.

d. Cargo packaging method decisions in terms of preferred technique, standardization of container characteristics, etc. have not been made. It appears that hatch and passage dimensions will be a key factor regardless of other criteria. It is probable that a limited number of standard container modules (perhaps four sizes) will be designed to take the major share of the non-liquid resupply cargo items, i.e., foodstuffs, equipment spares, experimental support items, etc. Other items that will be transferred on an occasional basis probably will be packaged individually. Due to the uncertainty of final packaging parameters, it is important to consider maximum flexibility when examining possible transfer systems.

e. Resupply requirements for SS missions are only partially defined and in rather gross terms. It seems clear at this point in time, however, that shuttle excursions will be at least every 45 days and possibly as frequent as once a month. The implication is for considerable numbers of redundant cargo to support general station

operation using a "pantry concept," i.e., a C/CM will be docked, but only part of the cargo will be moved immediately. The remainder of the cargo will remain aboard the C/CM and be removed only as it is called for to service experiments and equipment maintenance.

f. The integral space station will create two, somewhat different cargo transfer problem areas. The first is the central tunnel which may be as much as 60 feet or more in length by 10 feet in diameter. Each floor within the tunnel will have a 5-foot diameter hatch plus one or more access hatches into deck compartments. These latter hatches have not been clearly defined in terms of dimensions. Since the compartment hatches are pressure hatches, it is probable that they will be relatively small (perhaps about 30" x 60").

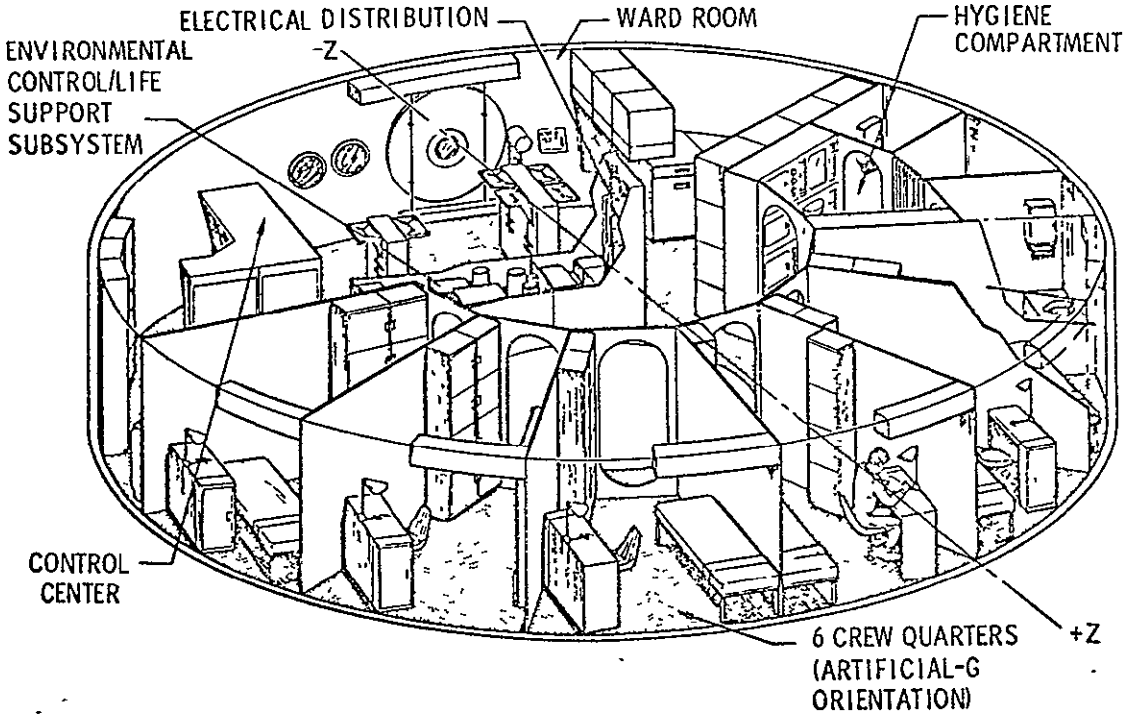
g. Space Station compartment design still appears to be in the artist rendering stage of development (see Figures A-13 and A-14).[80] From these sketches it is clear that a considerable variety of methods will be required to handle cargo packages and that most cargo handling probably will be accomplished manually. By rough estimate it does not appear that cargo will be moved more than 20 feet in a straight line and that most translations will be on the order of 4- to-5-foot segments with frequent stops and turns.

Cargo Handling Systems

Since a major objective of this study was the performance of a tradeoff study of potential cargo transfer subsystems, considerable effort was expended in an attempt to gather information about such systems. During this part of the literature search typical earth-bound cargo handling systems as used by the railroads, airlines and the shipping industry, as well as unique systems developed for warehousing, production lines, and any devices created especially for space application were examined. Although considerable effort was expended, few systems were found that appeared to be directly applicable to the zero-g environment. The few exceptions consisted of devices such as STEM, the Serpentuator, etc., which are of a developmental nature.[97,119,122]

Characteristically, most of the known earth-bound systems

CREW FACILITIES AND OPERATIONS
DECK 1 AND 3



EXPERIMENTS DECK 2

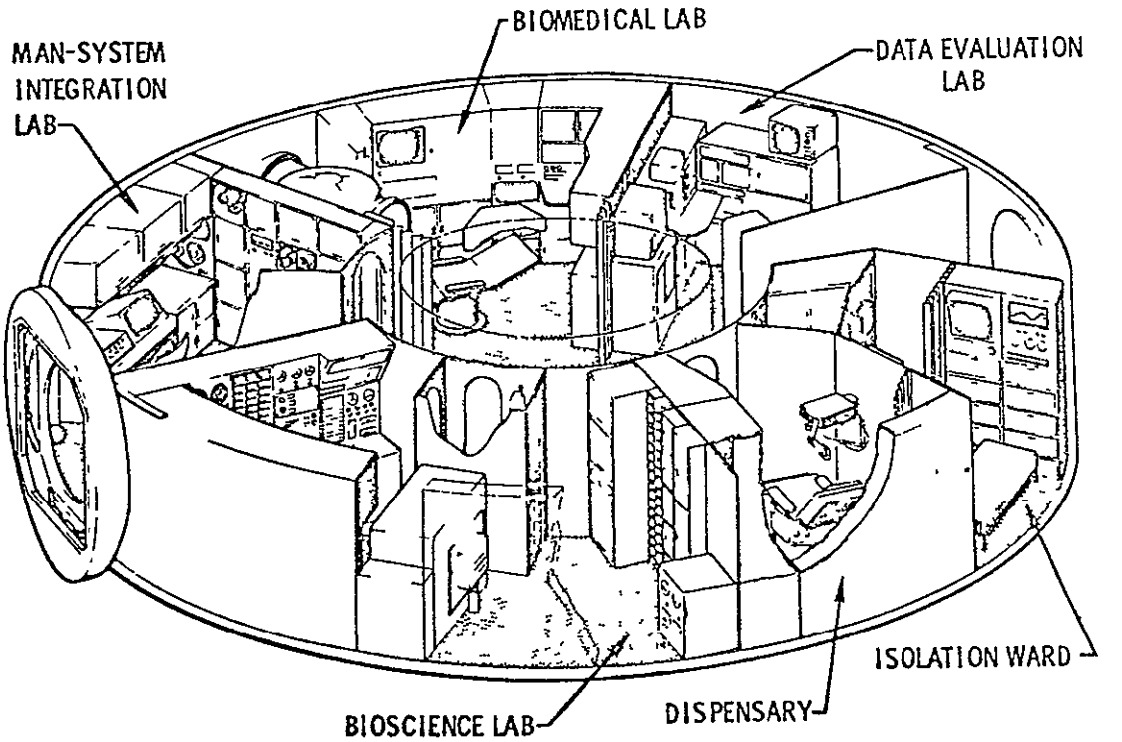


Figure A-13 - SS Compartment Layout Concepts

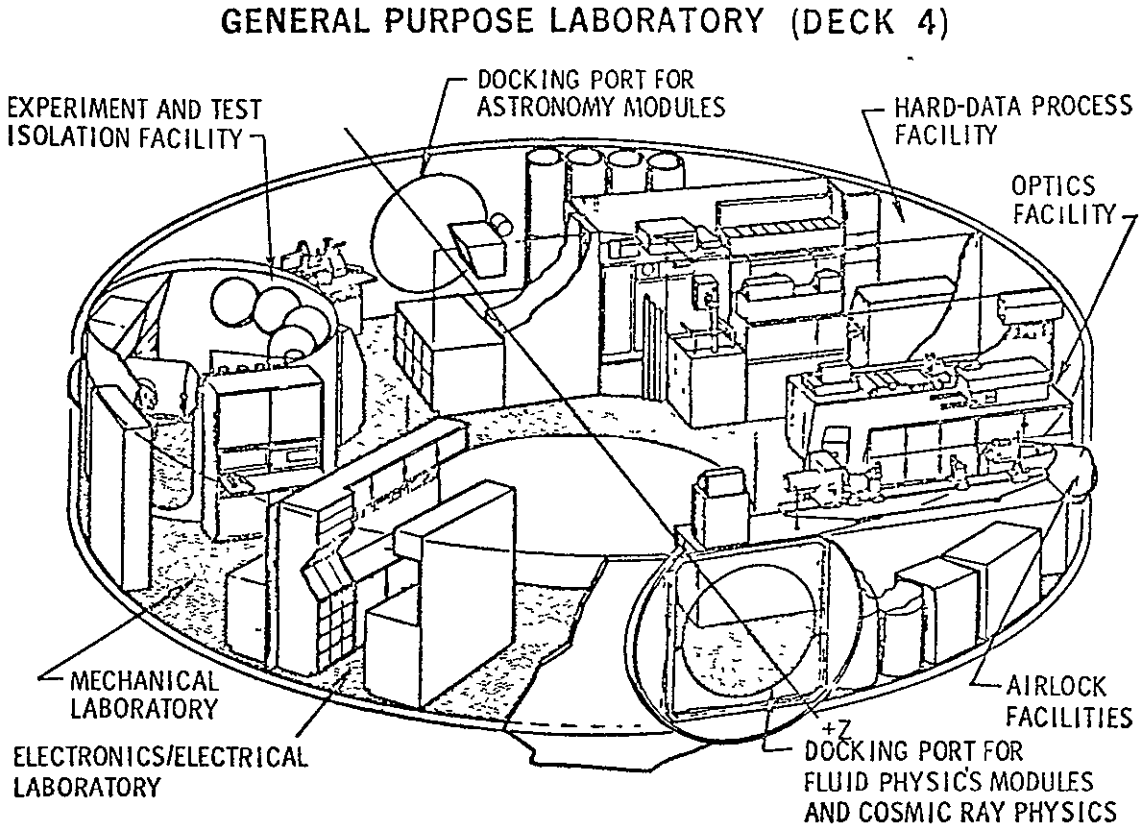


Figure A-14 - Compartment Layout Concepts

for manipulating cargo depend on earth gravity, primarily to keep packages in place or to increase their frictional characteristics. Although it appears that some of these systems can be modified to overcome the lack of gravity in space, none of them is space qualified or even designed to a level of detail such that weight, power and cost estimates, etc. can be compared.

Among the systems examined are those summarized in Table A-II. Of these, the Roller Conveyor, Chute and AMU or Propulsion Wand techniques are not considered appropriate to the IVA cargo handling problem. During the latter part of the study a new semi-automatic system came to our attention.[85] Actually it is of the conveyor type, although somewhat more sophisticated in design. Known as the "Telelift" it consists of a track-rail upon which a programmed cart or package can be placed and routed to any point under computer-control. This system appears to have good possibilities for IVA cargo handling. However, insufficient information is available at present to assess either the cost or possible operational problems involved in adapting it to the zero-g environment. This system is shown in Figure A-15.

Manual Cargo Handling in Zero-G

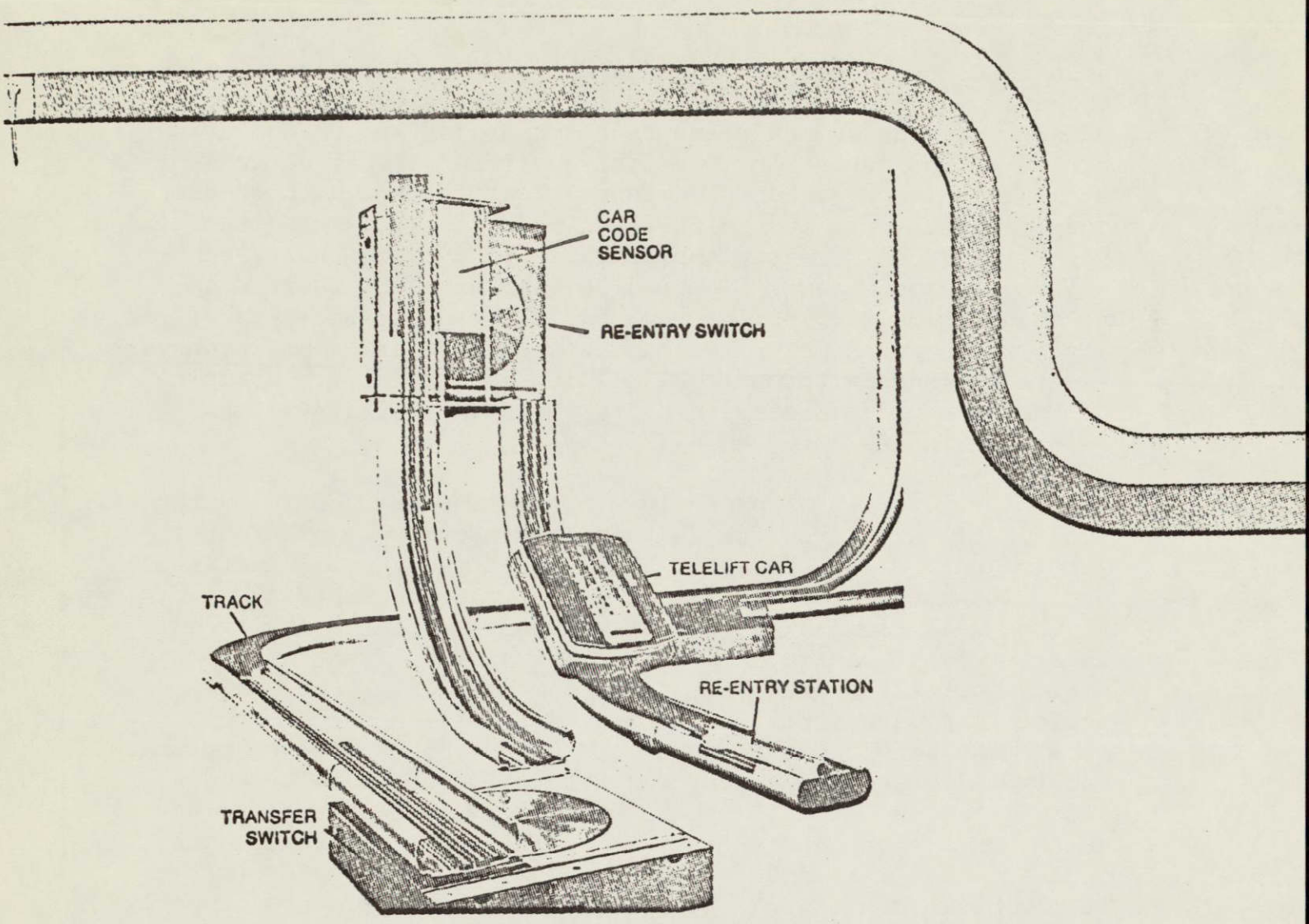
The final and perhaps most important area covered by the literature survey had to do with human performance in the zero-g environment (in most cases a simulated zero-g environment). Included in this search were reports of experimental studies, actual flight experience, and memoranda, symposia and other commentaries on the subject of human performance in a weightless environment.

A review of the reference list makes it clear that information on the subject varies from subjective observations of demonstrations to meticulously-designed experiments, tests in space and in parabolic aircraft flights, ground simulations using varying types of air bearing, frictionless platforms, suspension systems, neutral buoyancy media, and so on.

One considerable body of information deals with the matter of how space suits constrain astronauts and increase task performance times. Another group of studies deals with the problem of walking in a reduced-g environment. Still another group of

Table A-II - CARGO TRANSFER SYSTEMS

	SEMI AUTOMATIC	MANUAL AIDED	MANUAL
Free flight			X
Pitch/catch		X	X
Bucket Brigade			X
Firepole - ladder		X	X
Trolley/rail	X	X	
Rail/tether		X	X
Cable/clothesline	X	X	X
Dumbwaiter/elevator	X	X	
STEM/Serpentuator	X	X	
Conveyor (belt)	X	X	
Conveyor (roller)	X	X	
Chute/tube	X		
AMU/Propulsion wand	X		



SWITCHING UNITS

Switching units of one basic design accomplish all car transfer functions within the system. They "read" the programmed code on passing cars and direct them to designated stations; and provide crossover paths to permit cars to travel the shortest route between dispatching and receiving locations. All functions are carried out automatically.

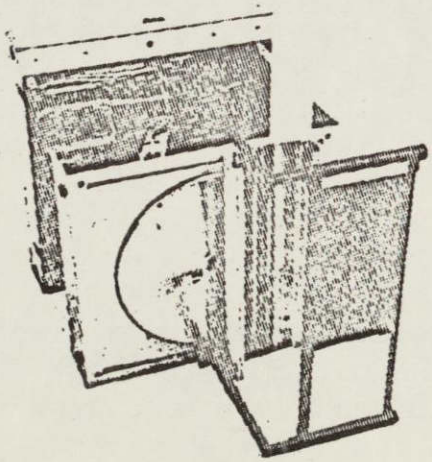


Figure A-15 - TELELIFT by Mosler[85]

studies concentrates on in-space maintenance problems, including the use of tools and restraints. Permeating many of these studies are the common elements of restraint system and translation method investigation. The specific area of cargo handling seems to have had only minor attention, and much of that does not relate to the shirtsleeve mode. Perhaps the most significant and directly applicable efforts were those accomplished by the General Electric Co. for the NASA wherein an attempt was made to define some basic human capability profiles, e.g., reach envelope vs restraint, package storage position vs restraint, and performance efficiency vs restraint.[27] Examples of the type of data developed are shown in Tables A-III and A-IV and Figures A-16 and A-17.

Other studies also provide information that bears on the subject of cargo transfer, although most of it is of a subjective nature and therefore has little if any reliability or applicability for making design decisions (see Table A-V and Figures A-18 and A-19). One fact stands out in reviewing all these studies, namely, that the various bits of information are poorly correlated and there is no complete catalog of human performance data (shirtsleeve/zero-g) that can tell us how much a man can or cannot do under various conditions of restraint, package size and shape, or how best to locate mobility and restraint aids, etc. On the other hand, there appears to be a consensus that neutral buoyancy simulation can provide the best and most reasonable test medium for developing useful zero-g performance data, assuming subjects are trained properly. The opinion also prevails that part-task verification using parabolic flights is a wise precaution before final design decisions are made.

Table A-VI has been prepared to summarize the most significant study information reviewed. It will be noted that the general conclusion that can be drawn from the remarks column is that nearly all the work done to date is lacking in some respect. Also, that at present we do not know enough about human performance capability within the context of IVA weightless package handling under the typical, expected geometric characteristics and limitations of advanced space system hardware.

Table A-VII provides a summary by one NASA engineer of his impression of reduced gravity simulation capabilities.[136] It

The conclusions of Experiment A are as follows:

- Handhold Restraint - Provides a large range of motion, but poor subject stability. This was particularly true in the suited mode. Subjects became extremely fatigued while using the handhold.

- Waist Restraint - Provides a very restricted access envelope. Two handed access envelopes behind the subjects while suited were impossible to obtain. The waist restraint provided good stability.

- Shoe Restraint - Provides excellent stability and large access envelopes to the front, rear, and to the sides of the subject. The subjects unanimously agreed that this was the most desirable mode of restraint.

The following table depicts some approximate reach envelope date. Locations are in reference to the subject.

Table A-III

Some Approximate Comparisons of Reach Data (Measurement in Inches)

	Suited		Shirtsleeve	
Handhold				
Front	66		69	
Left	32		62	
Right	45		64	
Top	40		66	
Bottom	35		63	
	One Hand	**Two Hands**	**One Hand**	**Two Hands**
Waist				
Front	24	12	24	24
Back	24	None	36	24
Left	8	10	29	27
Right	34	13	40	29
Top	16	13	35	34
Bottom	15	15	28	26
Shoe				
Front	60	48	60	48
Back	72	36	84	60
Left	34	21	60	59
Right	47	30	63	58
Top	22	12	36	34
Bottom	33	29	54	61

Ref. G.E. Doc. 69SD4294 [27]

Table A-IV

Receptacle Location Adequacy as a Function of Module Mass and Restraint

Restraint		Modules - Mass and Size					
		50 lb		118 lb		235 lb	
		12x12x12	12x12x18	16x16x16	16x16x24	20x20x20	20x20x30
Hand	Front	OK	OK	OK	OK	Severely Degraded	Severely Degraded
	Top	Slightly Degraded	Slightly Degraded	Severely Degraded	Degraded	Severely Degraded	Severely Degraded
	Right	Degraded	Degraded	Severely Degraded	Severely Degraded	Severely Degraded	Severely Degraded
Waist	Front	OK	Interference	Interference	Interference	Interference	Interference
	Top	OK	OK	OK	OK	OK	OK
	Right	Reach Prob	Reach Prob	Reach Prob	Reach Prob	Reach Prob	Reach Prob
H&W	Front	OK	Interference	Interference	Interference	Interference	Interference
	Top	OK	OK	OK	OK	OK	OK
	Right	Reach Prob	Reach Prob	Reach Prob	Reach Prob	Reach Prob	Reach Prob
Shoes	Front	OK	OK	OK	OK	OK	OK
	Top	OK	OK	OK	OK	OK	OK
	Right	OK	OK	OK	OK	OK	OK
H&S	Front	OK	OK	OK	OK	OK	OK
	Top	OK	OK	OK	OK	OK	OK
	Right	OK	OK	OK	OK	OK	OK

Legend

Reach Prob - One subject could not reach the module handle in the right module location when restricted by the waist restraint.

Interference - The module could not be removed from the receptacle due to interference with the waist restraint.

Slightly Degraded - Some trials, but less than 15 percent resulted in loss of control of the module and complete failure.

Degraded - More than 15 percent, but less than 50 percent, of the trials resulted in loss of control of the module and complete failure.

Severely Degraded - More than 50 percent of the trails resulted in loss of control of the module and complete failure.

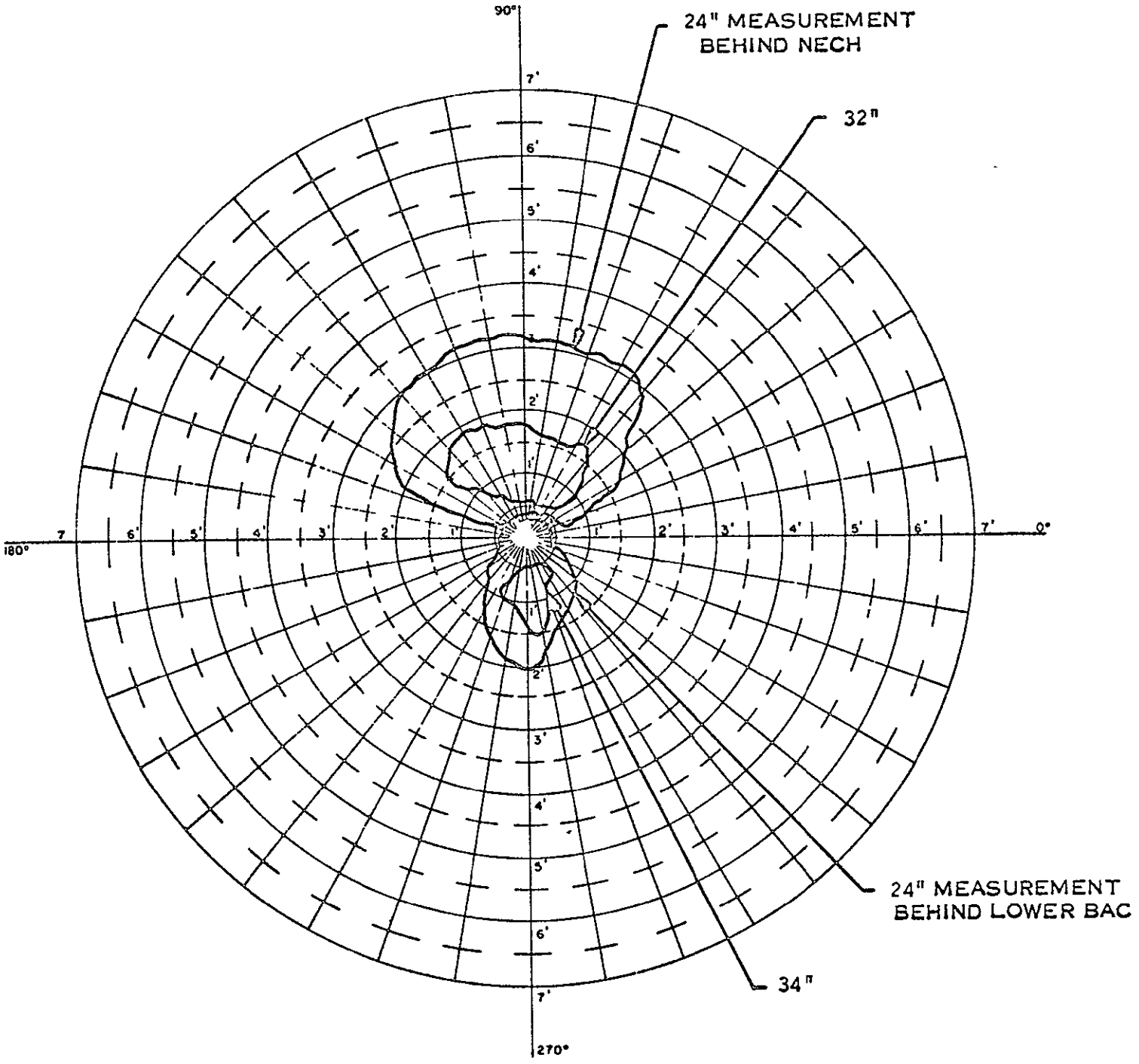


Figure A-16 - Composite of Means: Shirtsleeved Waist (24 in. and 30 in.) - Back, Two Hand

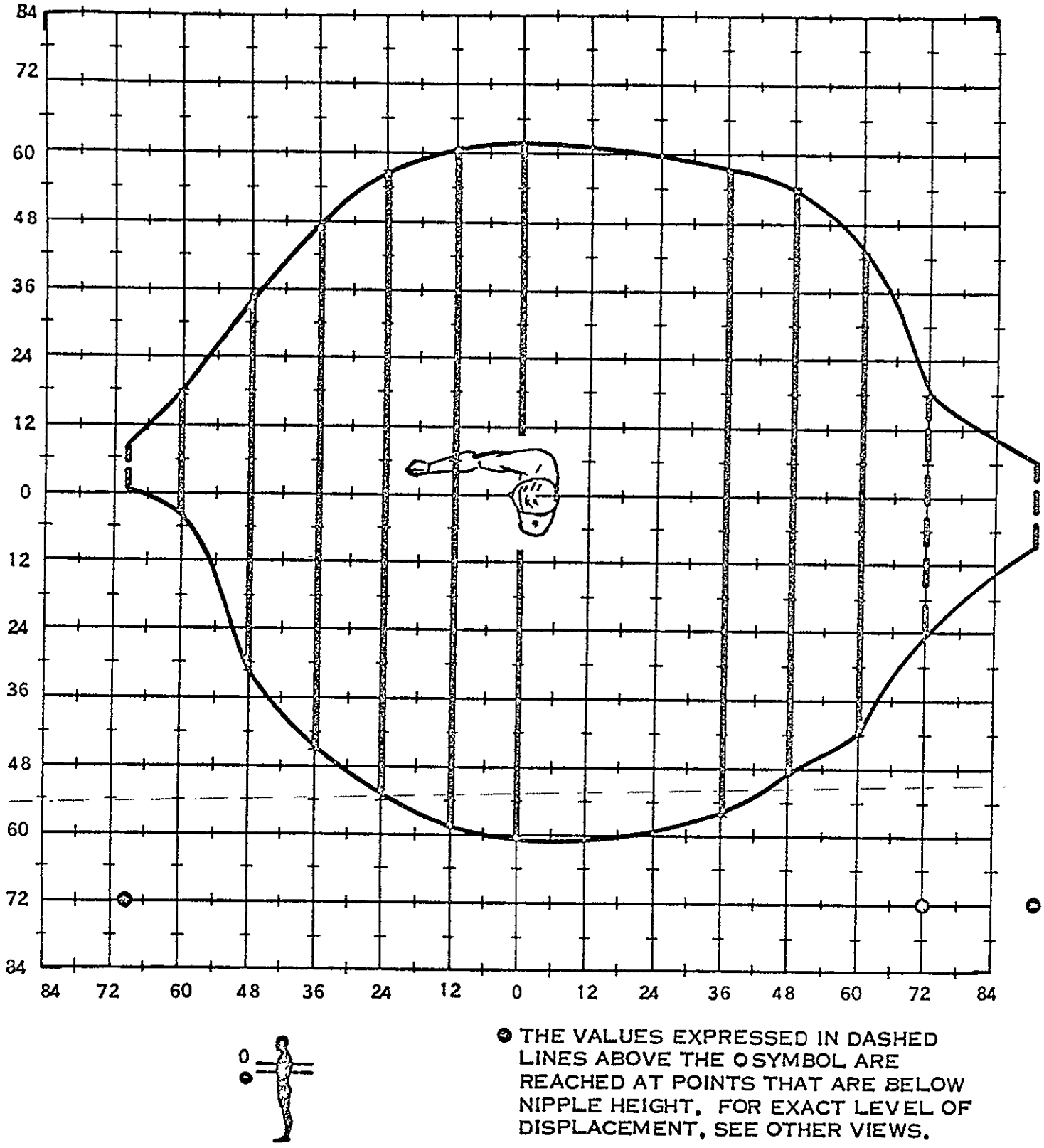
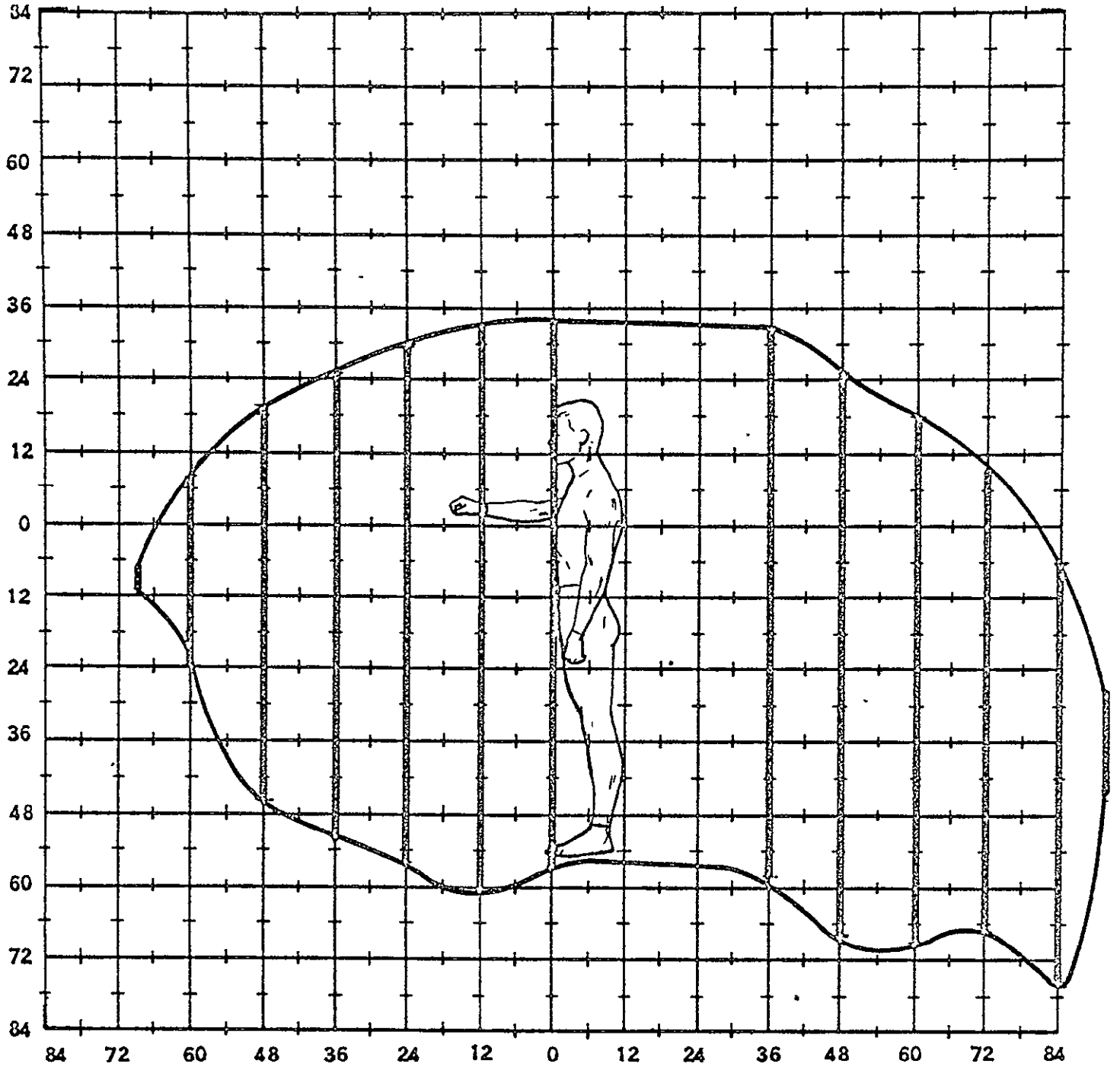


Figure A-17a - Top View: Shirtsleeved, Dutch Shoes Restraint One Hand

(Measurements in Inches)



Fibure A-17b - Side View: Shirtsleeved, Dutch Shoes Restraint One Hand

(Measurements in Inches)

Table A-V - MOMENT-OF-INERTIA LIMITS

Maneuverability	Moments of Inertia (in.-lbf-sec^2)	Moments of Inertia (N-m-sec^2)
Excellent	0 - 65	0 - 0.735
Good	66 - 150	0.745 - 1.70
Fair	151 - 240	1.71 - 2.71
Poor	241 - 330	2.72 - 3.73
Unacceptable	331 →	3.74 →

Note: Subjective estimates of test subjects handling four packages

Ref. NASA TN D-5111 [115]

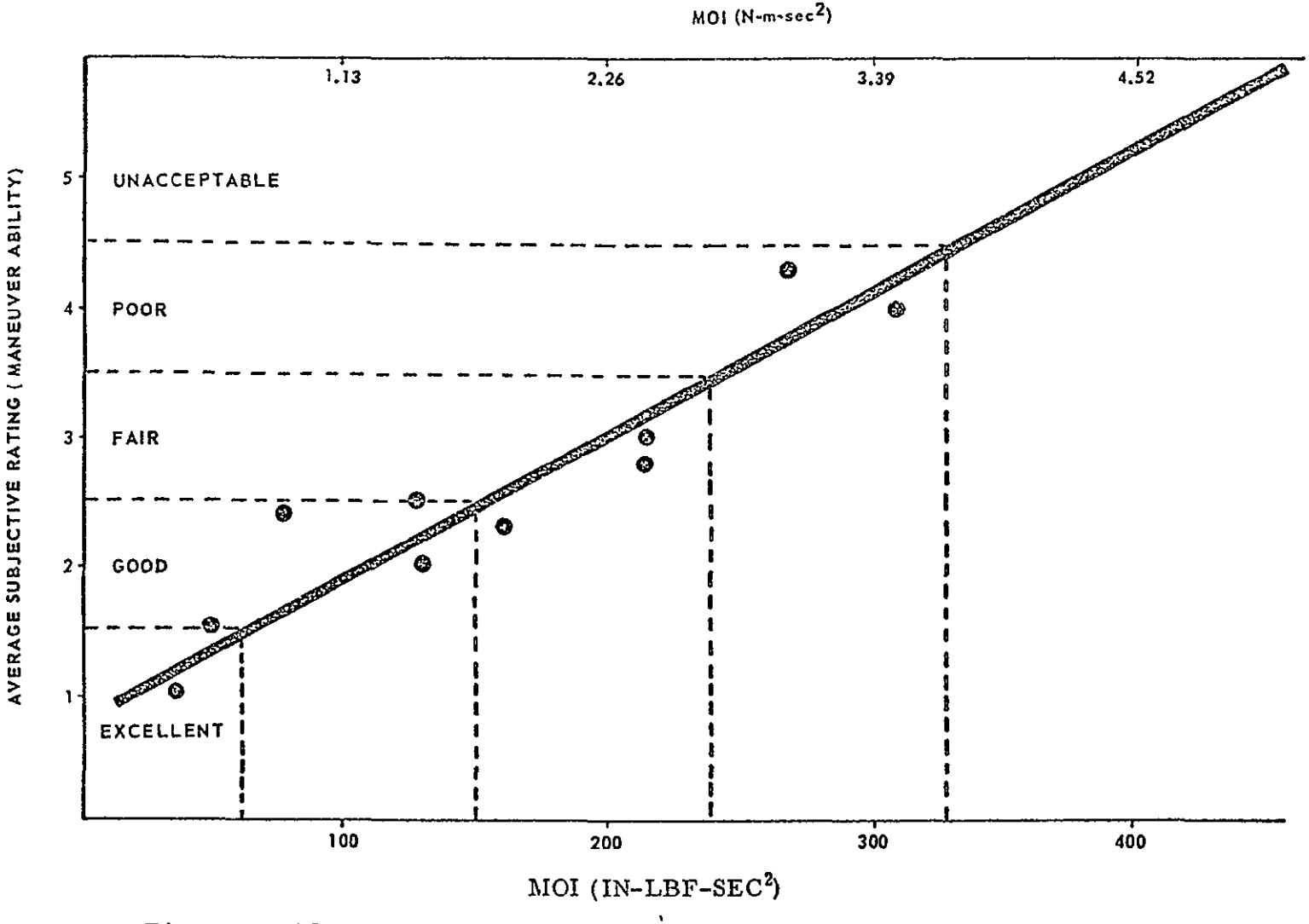


Figure A-18 - SUBJECTIVE RATING VERSUS MOMENT OF INERTIA

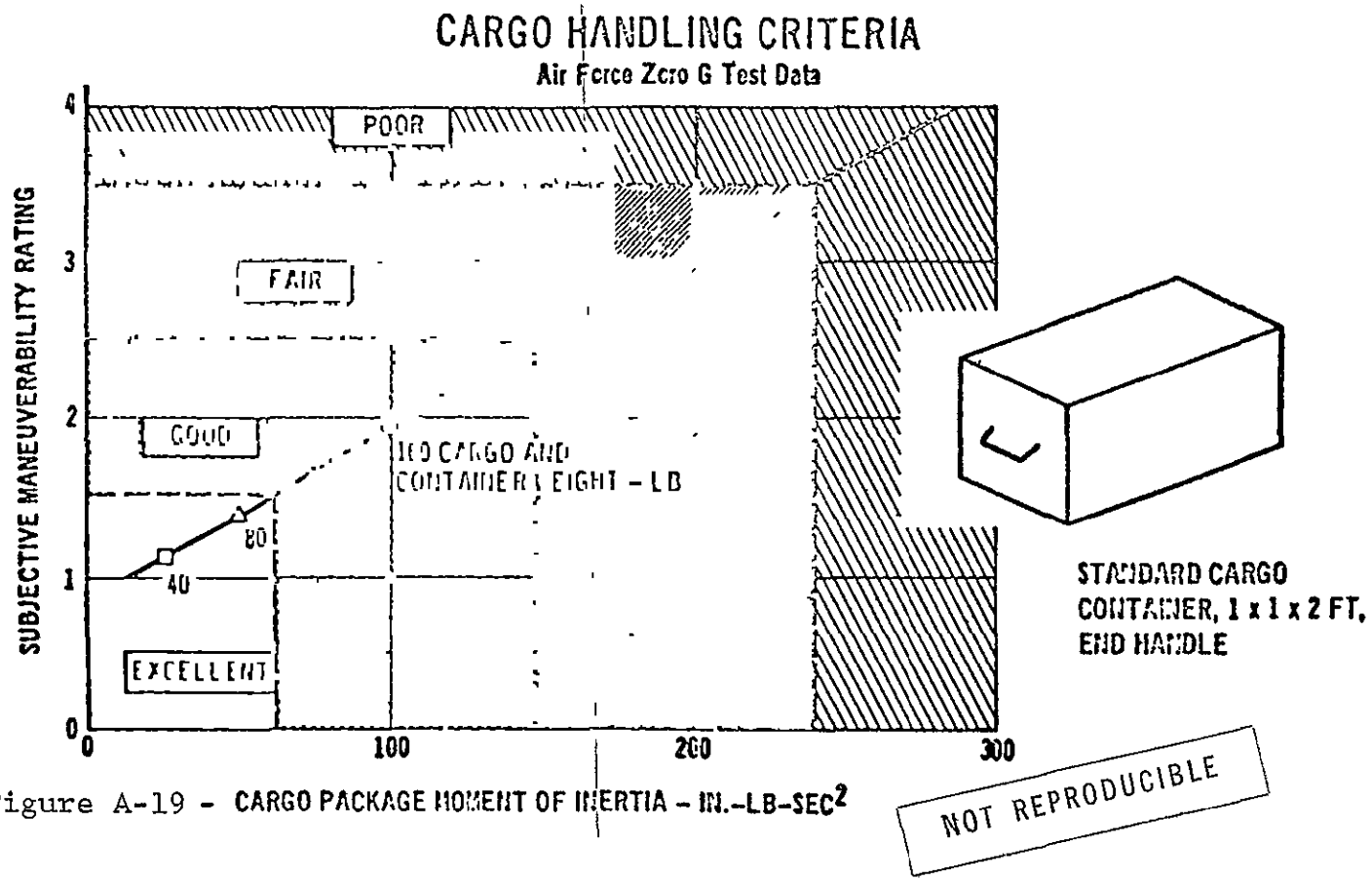


Figure A-19 - CARGO PACKAGE MOMENT OF INERTIA - IN.-LB-SEC^2

Table A-VI - A Summary of Pertinent Sub-Gravity Studies

AUTHOR OR SOURCE	STUDY/PURPOSE	MEDIA/CONDITIONS	RESULTS	REMARKS
Marton, T - General Electric reprint	Handhold, Toe Trap, Thigh Trap restraints vs reaction time, eye hand coordination, spatial location & precision alignment, maneuverability	Neutral Buoyancy	Toe & thigh traps superior to handholds	No handling of packages as for cargo transfer
Nelson, C - NASA MSFC NASA TN D-5111	Manual package transfer of various masses by fireman's pole; studied 3 pkg sizes and weights, maneuvering procedure, pkg movement of inertia effects re: single handle	6-degree, neutral buoyancy, KC-135	Developed subjective rating of pkg characteristics	Only one transfer procedure; limited variation of pkg parameters, no quantitative data re: performance efficiency
Sasaki, E. - AMRL-TR-65-152	Feasibility of translation using rails; single, double, various spacing	JC-131B Airplane	16-24 spacing double rails best	Qualitative; no package handling
Hammer, L. - WADD TR-60-715	Compilation of demonstration experiments in JC-131B; walking, using tethers, eating, pushing controls on console, etc	JC-131B Airplane	Generally, activities more difficult in 0-g	No package handling
Bulk, G. & Adams, C Douglas A/C Co HFS paper	Techniques for locomotion & restraint re design of MORL, EVA & rescue	Neutral Buoyancy	General configuration recommendations re: space station design, i.e., sleeping, assembly, repair tasks, etc.	Data qualitative; no package handling
____ General Electric Co DOO# 67SD 4306, 1967	Feasibility studies re S IV B workshop mockup; equip transfer tasks - task times & subjective comments - erect & prone manual transfer	Neutral Buoyancy	Task times to move cylinder from one position to another	Very limited data re: package variables, transfer techniques, etc

Table A-VI - A Summary of Pertinent Sub-Gravity Studies (Cont'd)

AUTHOR OR SOURCE	STUDY/PURPOSE	MEDIA/CONDITIONS	RESULTS	REMARKS
Dean, R & Langan, R. P. Boeing Co. (Symposium Proceedings)	Evaluates NB for studying transfer, use of tools, design of airlocks, etc	Neutral Buoyancy	Tasks were generally feasibility demonstration type; no general catalog of date	Qualitative information; very limited variation in task-equipment parameters; no typical pkg transfer
Loats, H , et al Env Res Assoc NAS1-4059 Vols I, II, III	Pressure suited performance translating through airlock, tethers & other aids	Neutral Buoyancy	Demonstration of problems	No package transfer; suited only
Spady, A - NASA TN D-5802	Review of various reduced-gravity simulators - primarily with regard to walking	All types	No experimental data - personal assessment	No applications data; primarily 1/6-g walking consideration
Schultz, D. & Covington, J. NASA MSC June 1967	Gemini EVA task demonstrations	Neutral Buoyancy	No experimental data - subjective evaluation of media for training	No applications data; press suit only
Schuster, D. - Collins Radio	Radio repair task in 1-g and 0-g comparison (time to complete, remove & replace task)	Neutral Buoyancy	No data other than task time and subjective opinions regarding tool use problems; twice as long in simulated 0-g	No pkg transfer other than specific two units remove and replace
Schwinghamer, R. - NASA MSFC N67-12716	Discusses demonstration studies of tools, lanyards, tethers	Neutral Buoyancy	Discussion, no data	Primarily tool operation; no transfer info
Kama, W. - ASD TR 61-555	Effects of 0-g on ability to position various masses in various directions & distances	Air bearing 2 degrees	Positioning errors vs mass, distance, direction	General conclusions have very little applicability to package handling problems in terms of ranges or limits
General Electric Doc 69SD4294 June 1969	Studied reach capability using foot, waist and single handhold restraint; proficiency of package removal from several rack positions	Neutral Buoyancy	Graphs showing reach envelopes, tables of mass-positioning time; tables of discrete positioning accuracy	Data is operationally sterile except for very limited mass positioning (this is less than useful because of poor restraint design & task protocol. In addition it only suggests subjective reaction to certain package positioning conditions

Table A-VII - COMPARISON OF REDUCED-GRAVITY SIMULATORS USED FOR LUNAR-GRAVITY STUDIES

[Experienced subject with and without suit]

Type	Comment
Inclined plane	Only three degrees of freedom
Straight walkway	Energy measurements difficult
Circular walkway, 94-ft (28.6-m) diam	Feels similar to straight walkway Provides continuous surface
Treadmill	Unusual gait, foot impact Useful for energy measurements
Vertical suspension -	Six degrees of freedom Body supported by suit Extremities function at earth weight
Counterbalance	Lacks dynamic simulation
Negator spring	Overhead friction and inertia produce lateral stability problems
Stalled turbine, air pad	Overhead friction and inertia produce lateral stability problems Fair vertical response
Pneumatic vertical servo	Excellent vertical response Inertial effect on fore-aft motions
Underwater	Six degrees of freedom Slow walk only Ballasting very critical
Airplane trajectory	Six degrees of freedom Limited test time and space

NASA TN D-5802 [136]

also is significant to note that this engineer expresses the opinion that inclined plane, neutral buoyancy, and airplane trajectory simulations felt much alike to him. Unfortunately this comment is not too significant, for the same man did not experience long-term zero gravity in space. Astronauts returning from space indicate that these simulators feel similar to the space environment, however, that there are no quantitative data by which to compare performance on similar tasks.

A related area covered in the literature review concerned the specific subject of restraint system technology and use experience. This is particularly important in the cargo handling situation since one of the major problems associated with any transfer system is that of loading and unloading, which requires that the crewman be properly anchored. Although restraints fall into two general categories (astronaut restraints and package restraints), some of the systems are the same for both. Fortunately, several good state-of-the-art reviews had already been made, thus reducing the amount of effort required during this analysis.

The most recent of these was performed by the Matrix Research Corporation in it's "Man and Manipulator" study[73,74,75,76]. Three tables have been extracted from the Matrix final report which summarize the current situation regarding restraint techniques. Table A-VIII presents a summary prepared by North American Rockwell which indicated their conclusions as to what still needs to be done in the area of astronaut restraint system design. Table A-IX includes a more comprehensive summary of all types of restraint systems, identifying the dominant problems with each. Table A-X, on the other hand, summarizes restraint systems relative to equipment and package retention.

One fact seems to stand out: despite all these state-of-the-art estimates there is insufficient information to permit a really consistent judgment about the several types of restraint devices and their interaction with crew tasks and hardware interfaces. Since many of the evaluations are peculiar to a suited EVA operation, a unique type of task or equipment situation, a given restraint may or may not compare favorably in the "new" cargo transfer situation context. Many of the unique restraining devices that have been tried out are not practical for cargo transfer for many reasons, including their lack of placement flexibility, their interference or inconvenience or

Table A-VIII

Restraint Technology Summary

SYSTEM	REQUIREMENTS	STATE-OF-THE-ART	CURRENT WORK	NEEDED WORK
Foot Restraints	Restraint at site Allow for repositioning	Dutch Shoes S-IVB Workshop Grid floor	None	Angular repositioning Decreased weight Portable system Grid floor study
Variable Flexibility	Provide waist restraint Ease of attachment & repositioning 25-50 lbs force	Prototype GE	GE	Increased loads Decreased weight
Rigid Waist	Ease of attachment & reposition 25-50 lbs force	Telescoping rods	STEM & BI-STEM	Rods variable between 1-3 feet Easily operable STEM

Table A-IX - Evaluation of Current Restraint Concepts

RESTRAINT SYSTEMS	GEMINI	FORCE APPL. G.E. 1967	MECHAR WORK-REACH	MECHAR CARGO HANDLING	NORTH AMERICAN	SITE OPERATIONS GARRETT	A A P	DOMINENT PROBLEMS
FIXED RESTRAINTS								
o Single Point								
handholds	useful	left forces good	poor stab. good reach	poor - time			in design	stabilization
waist	GT XII inter-ference	push-all good	limited reach	interference				attack points
foot restraints	GT XII-best	up/dwn good	good reach	best			in design	repositioning
wrist							recommended	interference
o Dual Point								
handhold - shoe	GT-XII satisf.	up-down right-left					in design	pull-push force
handhold - waist	GT-XII satisf.	poorest impulse						any force
shoe -waist						good - time		attack points
o Three Point								
handhold-shoe-waist		best suit						structures
o Cage					not sufficient	best		sizing
o Variable flexibility					inadequate force			forces
o Rigid waist					rotational problems			adjustments
o STEM					feasible		feasible	operations
PORTABLE RESTRAINTS								
o Flexible velcro	poor stability							
o Rigid velcro	poor stability							stability
o Pip pin	adequate							
o Triangular shoe					feasible		in test	

Table A-X

Summary of Equipment Restraint Technology

SUBSYSTEM	REQUIREMENT	STATE-OF-THE-ART	CURRENT WORK	NEEDED WORK
Fixed mech. pin Mech. latch	Rigid 80-lb restraint Rigid 40-lb restraint	"Pip-pin" mating logs Vise grip pliers	None Vise grip update	Standardization Standardization modification
Velcro patch	1-hand attachment for 10-pound equipment	Velcro available	Commercial	Improve peel
Adhesive	Rigid 50-pound restraint	Encapsulated Exothermic heaters Electric heaters	Several in industry	Further development Application attach point

the fact that they are not compatible with the typical shirt-sleeve attire of the crew.

It is noteworthy that many restraint designs appear not to have been examined or compared with each other under similar circumstances of geometry, task, or other related equipment factors, i.e., there is no complete catalog of restraint system characteristics and their efficiencies in terms of what an astronaut can do with them in zero-g.

Several photographs have been included to emphasize the rather limited nature of current simulation study information. These photos were extracted from some of the most pertinent study reports and represent the most significant work dealing specifically with in-space cargo handling. These pictures (Figures A-20 through A-30) emphasize the limited coverage as well as some of the unique test setups used to obtain zero-g related performance data.[50,9,27]

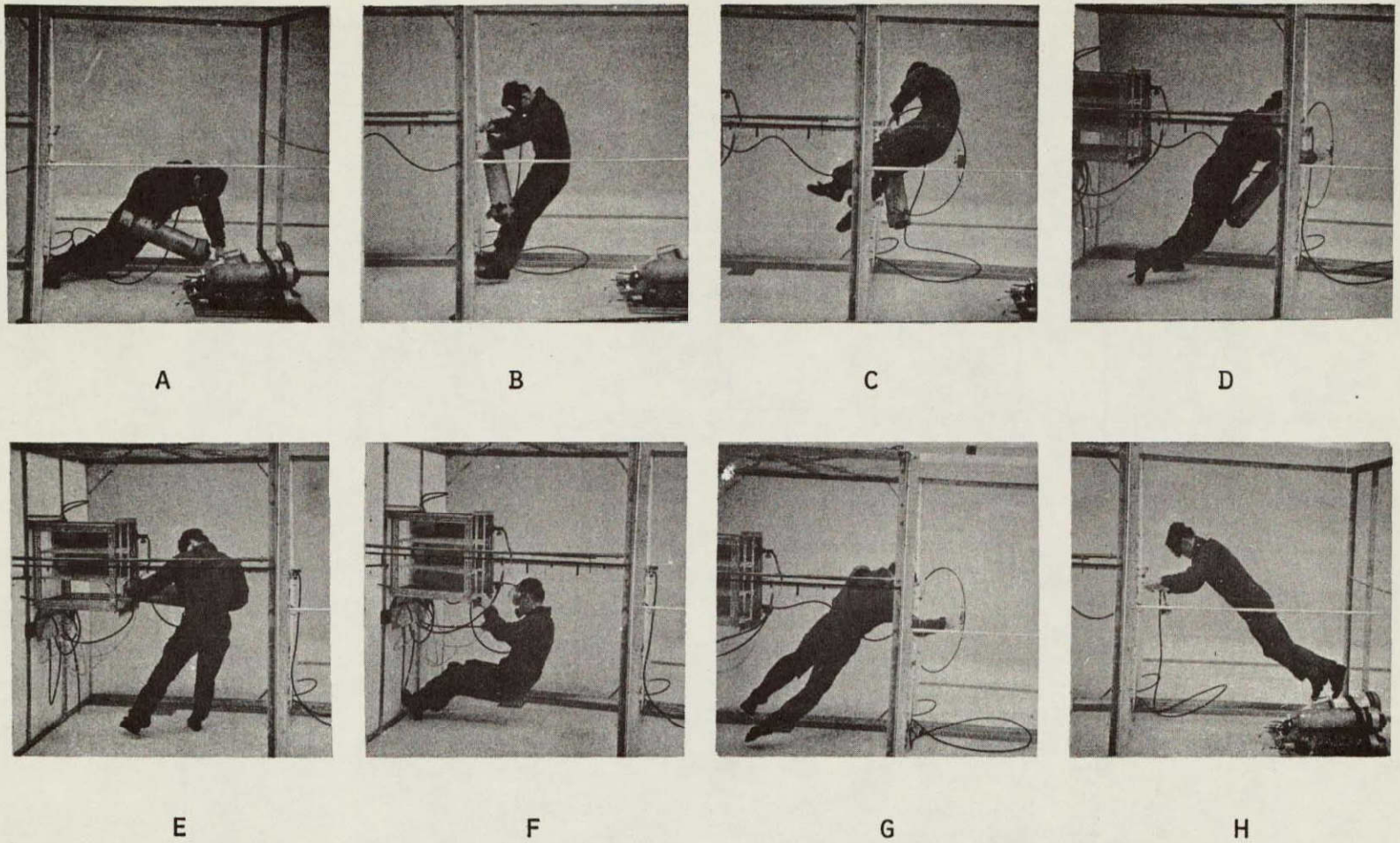


Figure A-20 - CARGO HANDLING TASK SEQUENCE (A)[60]

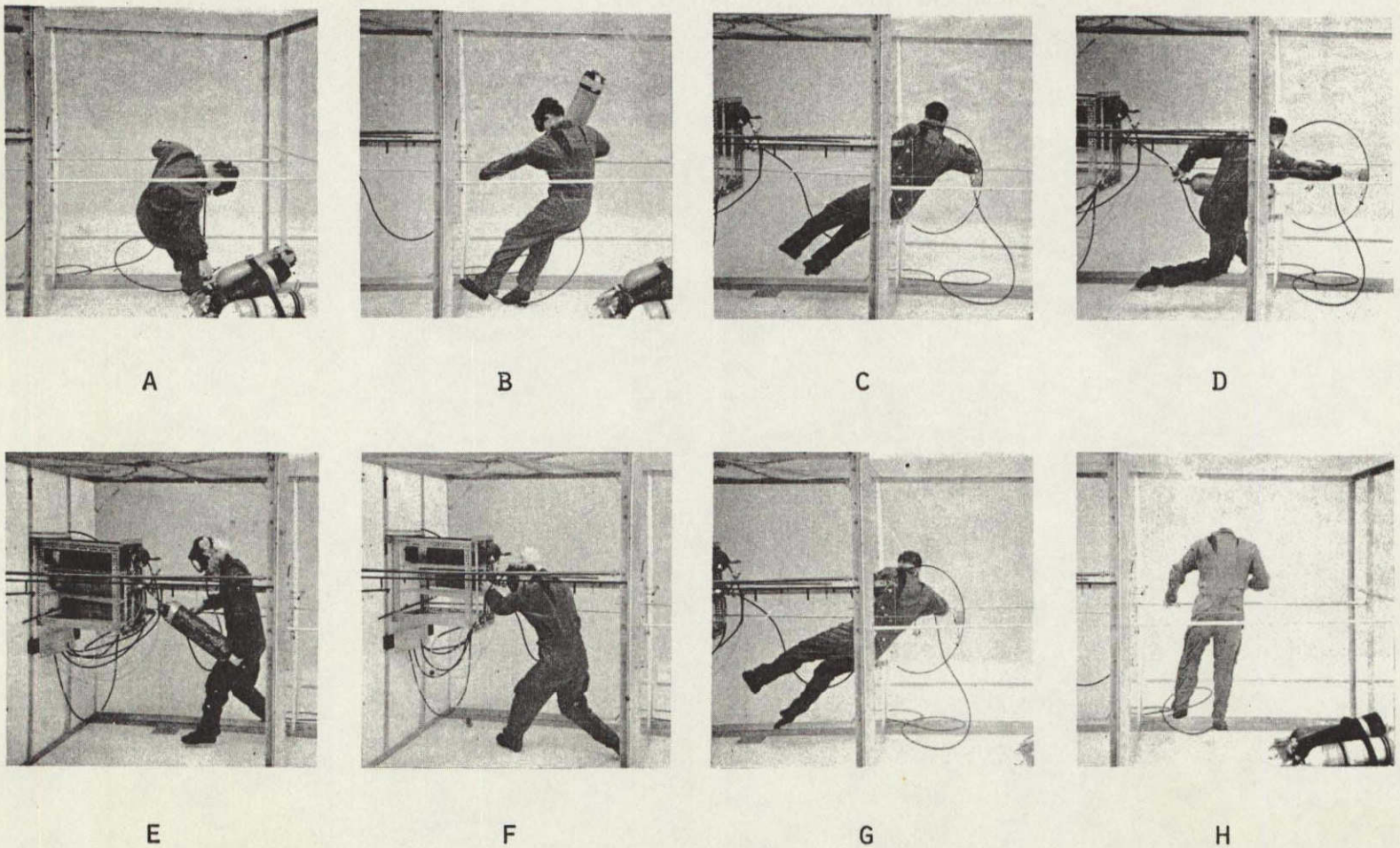


Figure A-21 - CARGO HANDLING TASK SEQUENCE (D)[60]

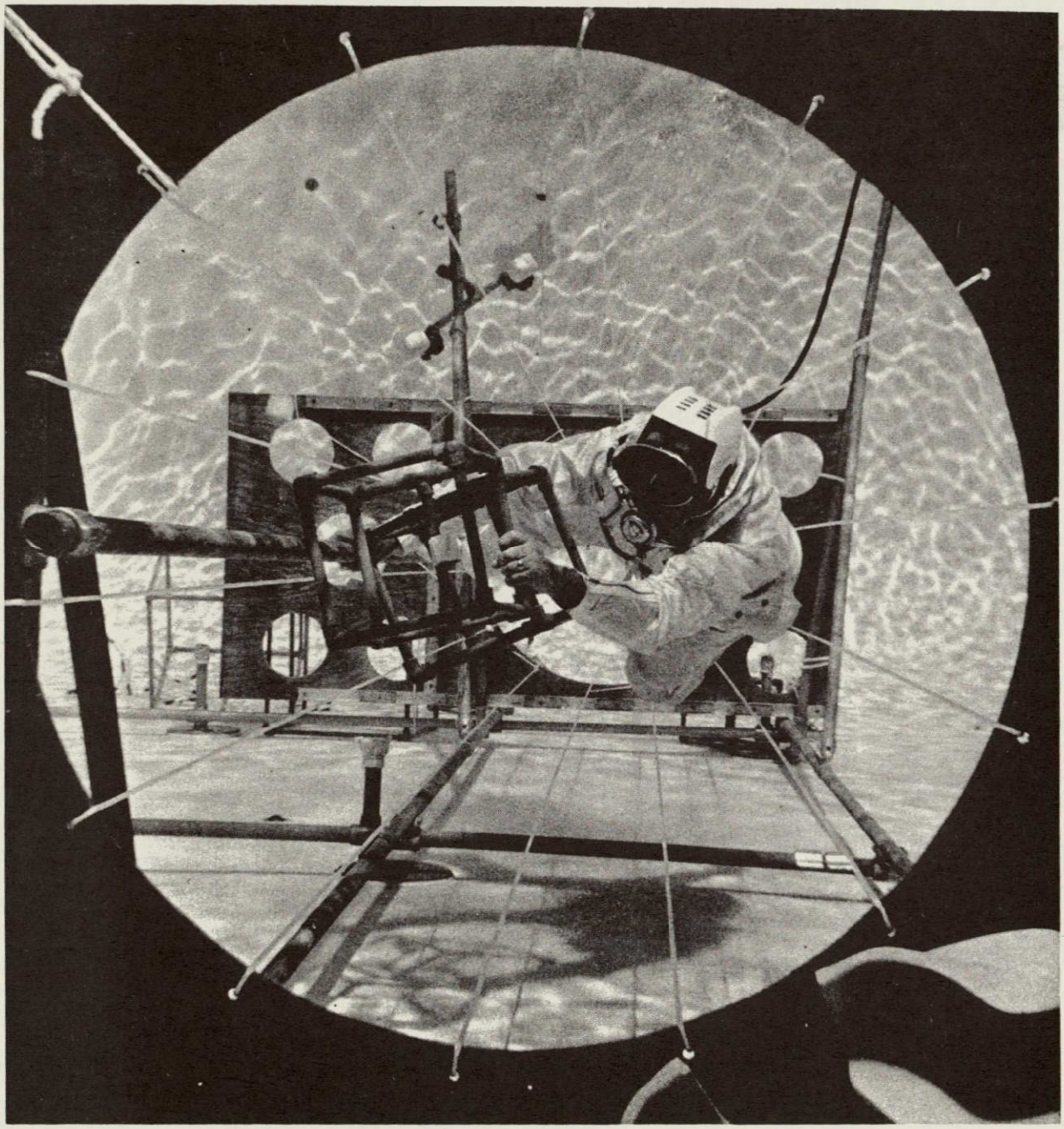


Figure A-22 - Single Crewman Transfer of Cargo [9]

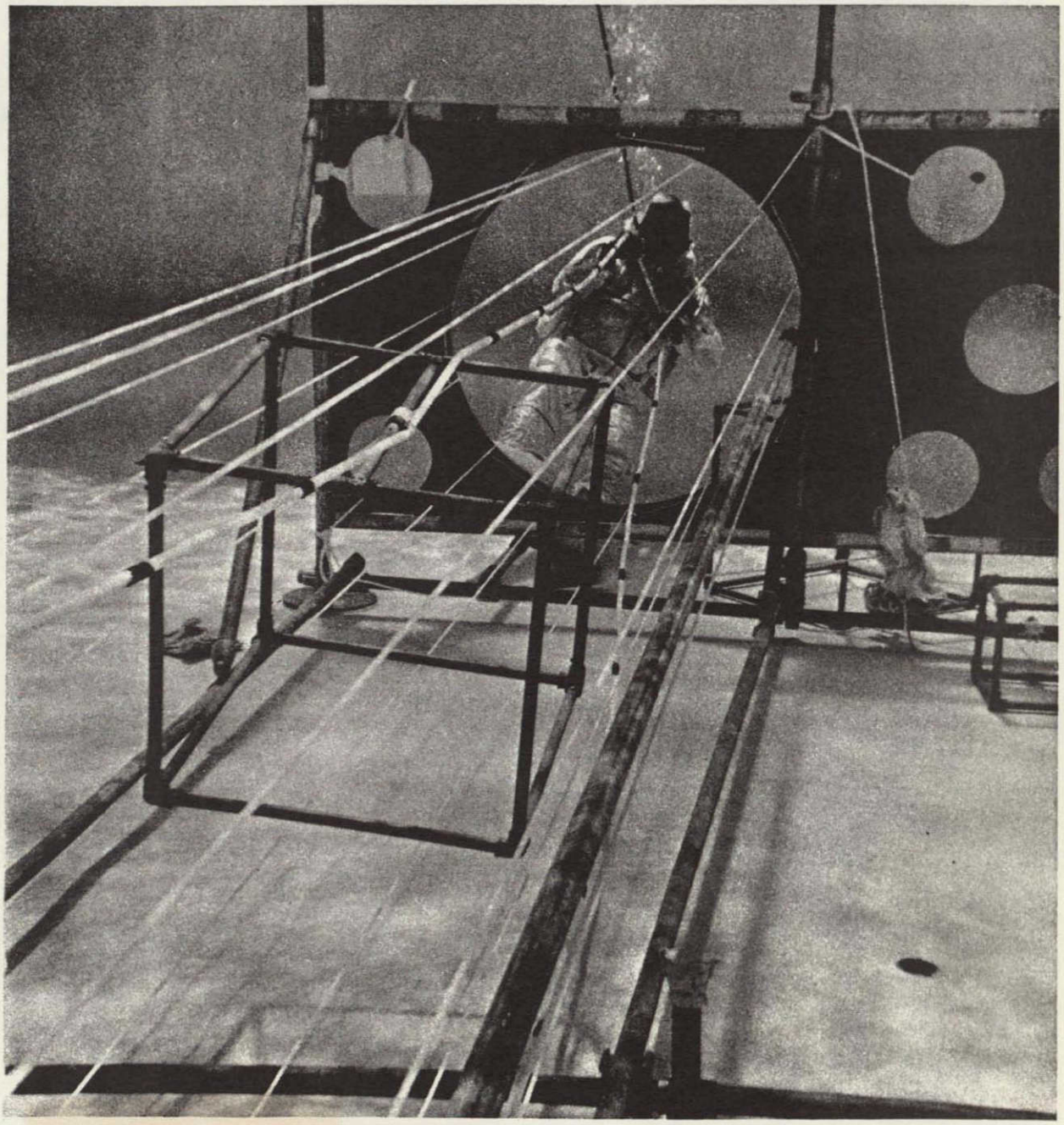


Figure A-23 - Cargo Unit Transfer by Transfer Line [9]

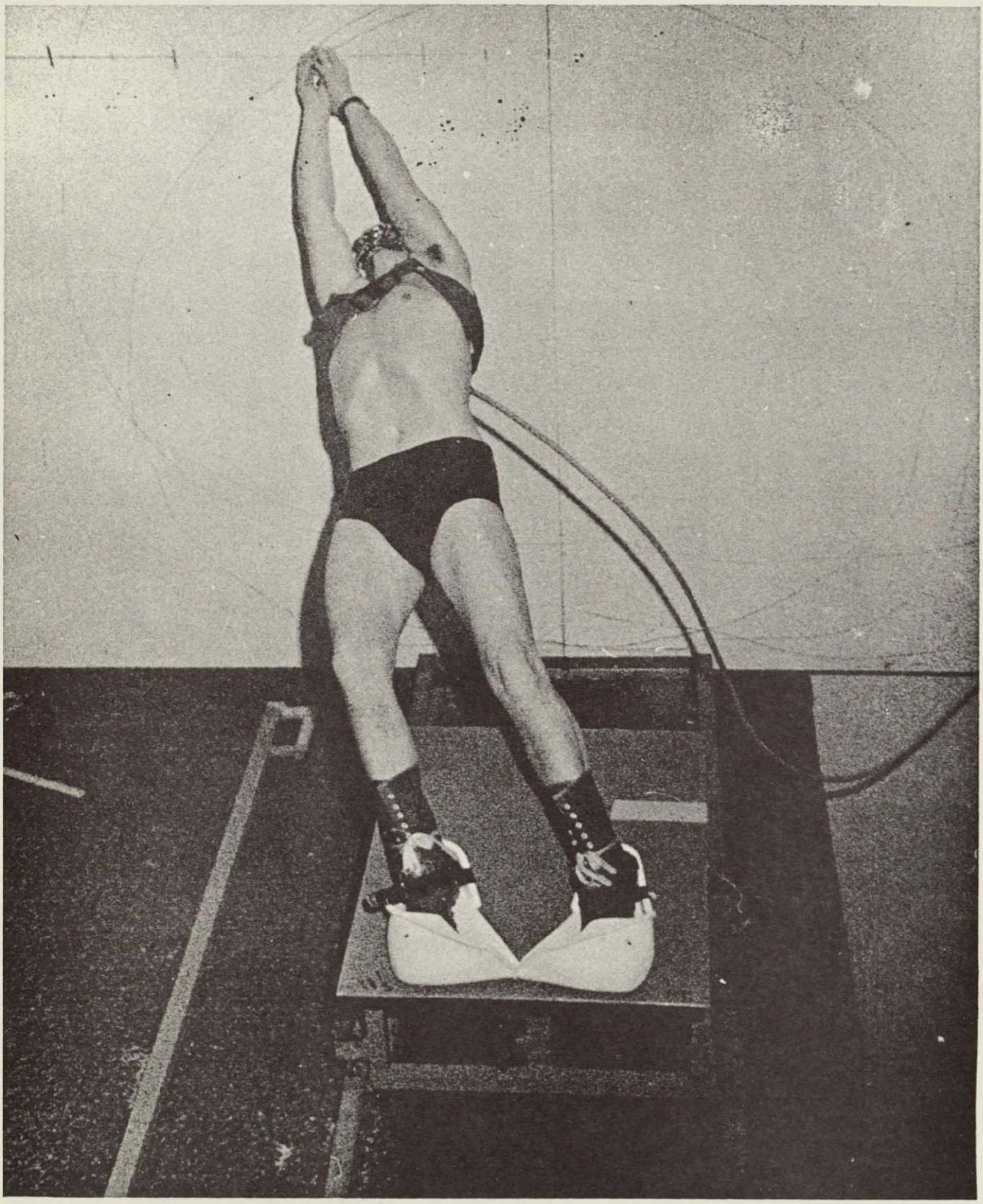


Figure A-24 - Shirtsleeved Subject in Shoe Restraint Drawing Two-Hand Access Measurements to the Rear [27]

Figure A-25 - Subject Removing Small Module While in Dutch Shoe Restraint [27]

Figure A-26 - Subject Removing Large Module While in Dutch Shoe Restraint [27]

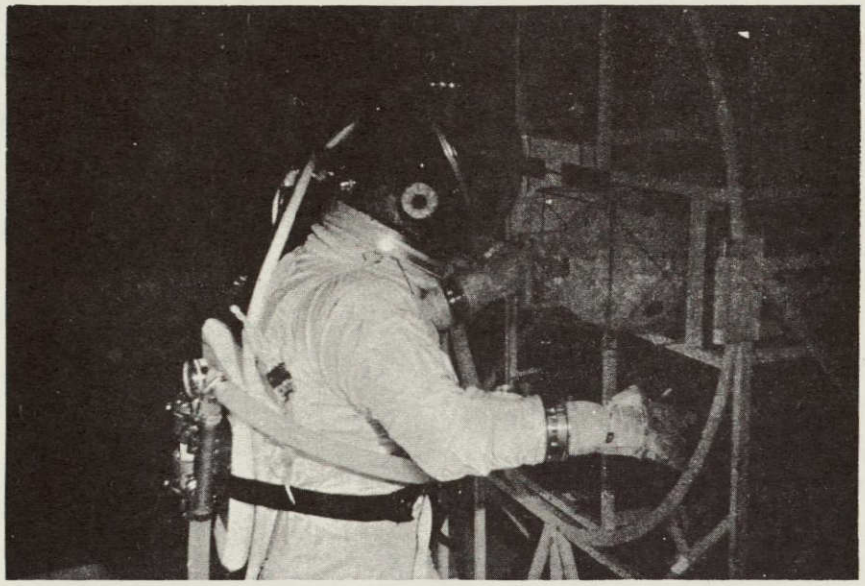


Figure A-27 - Subject Replacing Small Module While in Dutch Shoe Restraint [27]

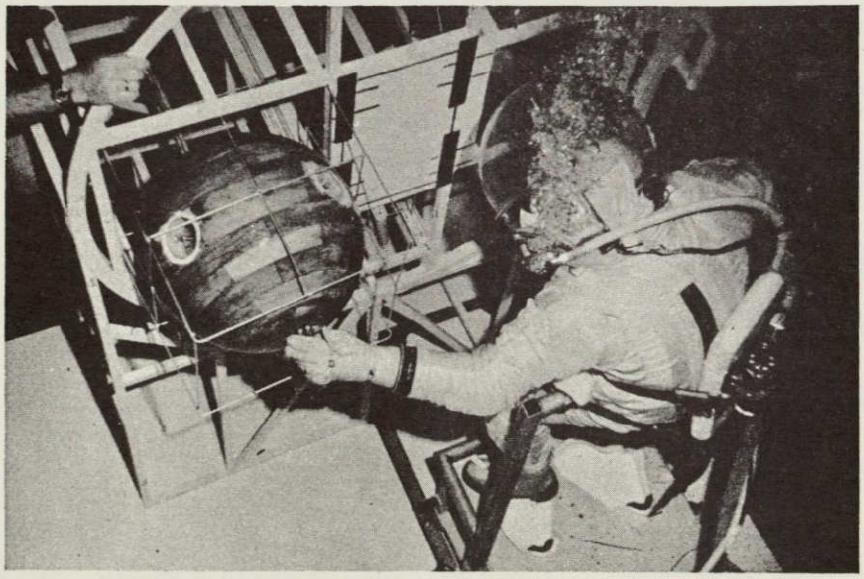


Figure A-28 - Subject Removing Large Module While in Waist Restraint [27]

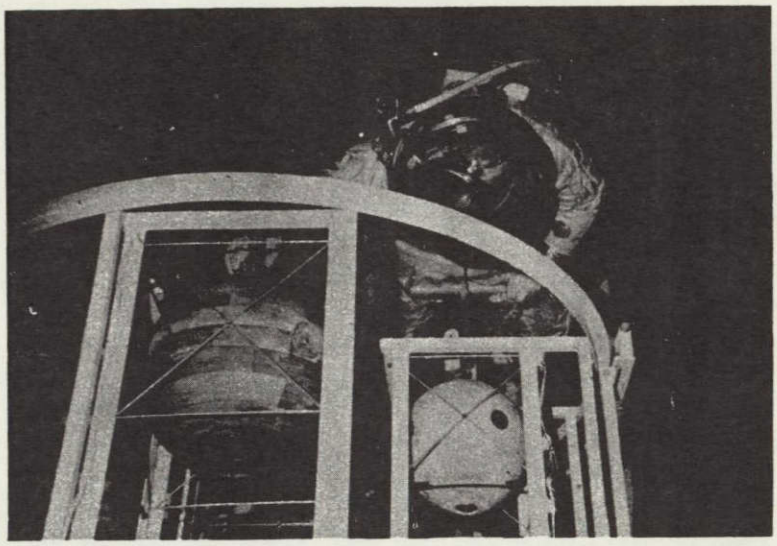


Figure A-29 - Subject Removing Middle Module While in Waist Restraint [27]

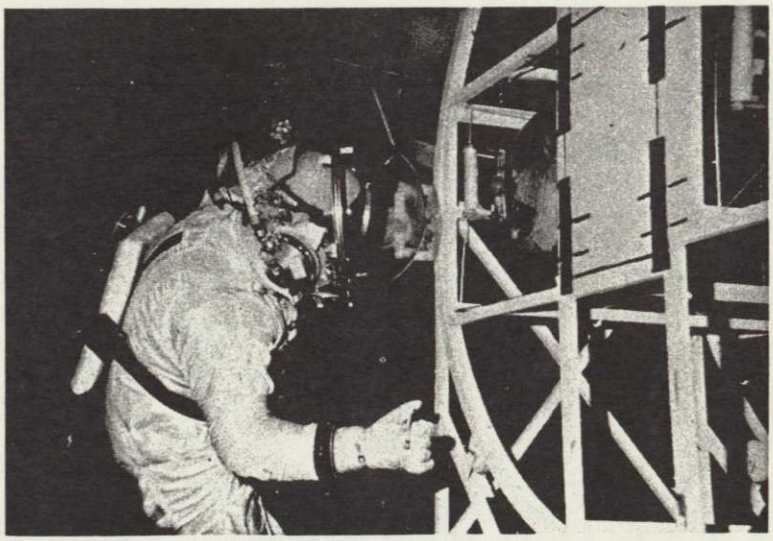


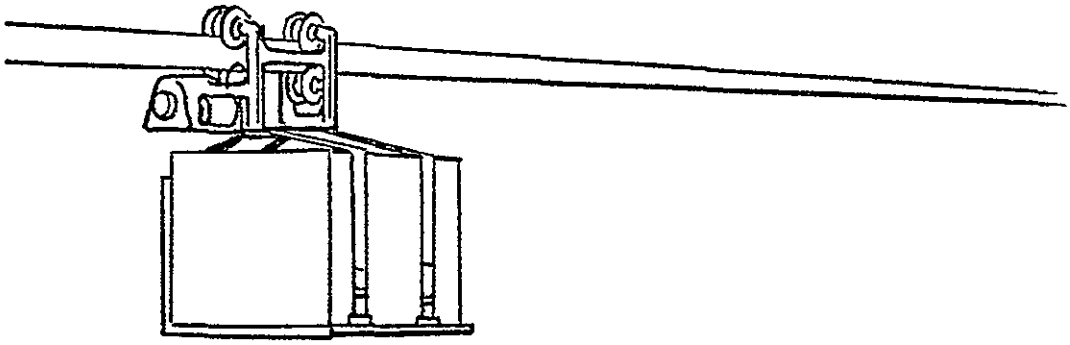
Figure A-30 - Subject Getting in Position using Handhold to Remove Large Module [27]

APPENDIX B

CARGO TRANSFER SYSTEM (CTS) DESCRIPTIONS HARDWARE AND TRADEOFF ANALYSES DATA

Considerable information was collected regarding hardware devices and systems that appeared to have potential for in-space cargo handling. Although no attempt has been made to reproduce all the data gathered, items considered most relevant to the interpretation of conclusions and recommendations presented in this report are provided in the following pages.

SELF-POWERED TROLLEY TRANSFER: Electrical power on trolley; single fixed rail, although could have switching and multiple sidings; remotely controlled; package secured by adjustable straps



CONSTRAINTS:

1. Cargo size probably limited since motor is part of moving package total; load limited by motor size.
2. Trolley-rail consumes passage space; could create interference in event of failure.
3. Transports only one package at a time.

CAPABILITIES:

1. Could have multiple rail and trolleys similar to rail yard; could all be controlled by a single switchboard operator from remote position.
2. Easy to load and unload.
3. Could transfer personnel.
4. Unlimited distance; rails could be portable and assembled in any compartment.

Could be used for total system of CM, SS compartments and tunnel.

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

SYSTEM TITLE	REFERENCES	ANALYST	DATE
SELF-POWERED TROLLEY TRANSFER (S/A)	MSFC ATM TROLLEY DRAWINGS SPACETOOL HANDBOOK	F E VAN LEEUWE	23 DEC 10

SYSTEM DESCRIPTION

ELECTRIC POWER ON TROLLEY, SINGLE FIXED RAIL SWINGS & SWITCHING ARE FEASIBLE SYSTEM IS REMOTE CONTROLLED CARGO MODULES ARE STRAP SECURED

PKG SIZE/SHAPE

CAN BE MODIFIED TO ACCEPT NEARLY ANY SHAPE PACKAGE SIZE MAY BE LIMITED DUE TO LARGE CTS MASS

ATTACH/RELEASE

TBD — NO RESTRICTIONS

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
≈ .01 MTBF - TBD	1 REPAIR - TBD 2 SERVICE - ≈ 1 HR

HAZARD/DAMAGE POTENTIAL

TBD — PROBABLY CAN BE MADE ACCEPTABLE

SYSTEM/CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
S-ANIC STABILIZATION AT WORKSITE FOR BOTH MEN	NOT REQUIRED

VISUAL	DEXTERITY
NEED UNOBSTRUCTED VIEW ONLY AT LOADING & UNLOADING SITES	HIGH

AUDITORY	MOBILITY
INTERCOM	UPPER ARM & TORSO AT LOAD/UNLOAD ONLY

SPECIAL ENERGY REQMTS	SPECIAL (SKILLS, TRNG, ETC)
NONE	NO SPECIAL SKILLS FOR OPERATIONS RUDIMENTARY KNOWLEDGE OF ELECTRICAL COMPONENTS REQUIRED FOR MAINTENANCE NO PHYSICAL REQUIREMENTS

SYSTEM/ENVIRONMENT FLEXIBILITY

SPACE ALLOTMENT	SPACE GEOMETRY	MASS
LARGE VOLUME, PROBABLY >10 CU/FT	MAY HAVE PROBLEM WITH SIDE DOCK	≈ 1-3 SLUGS

ZERO-g	ONE-g	ARTIFICIAL-g
MINIMAL	TBD	TBD

SYSTEM OPERATION CAPABILITIES

DEPLOYMENT TIME	TRANSFER RATE
≈ 1-2 HOURS	LIMITED ONLY BY MOTOR & CARGO SIZE SELECTED

PACKAGE POSITION/VELOCITY CONTROL

POSITION 1 LOCATION MONITOR COULD PROVIDE ± 2 IN OF POSITIONING ACCURACY IN TRANSLATION AXIS ALL OTHER AXES ARE STATIC

2 DIRECT VISION & VOICE COMM WOULD PROVIDE 1G IN OR ACCURACY WITH A TIME PENALTY

VELOCITY 1 RATE COULD BE ± .2 FT/SEC

2 ACCELERATION & DECELERATION COULD BE ± .2 FT/SEC

INTERFERENCE WHEN FAILED

FAIRLY LARGE BLOCKAGE APPROXIMATELY 1/3 FIELD OF VIEW MAY BLOCK EMERGENCY EGRESS

EMERGENCY ALTERNATES

MANUAL TRANSFER ONLY PO GLY HAND OR CRANK OPERATION FOR SHORT PERIOD.

SYSTEM SUPPORT REQUIREMENTS

TOOLS	POWER	EXPENDABLE
STANDARD TOOL KIT & POSSIBLY AN IMPACT HAMMER	1. ≈ 300 - 450 WATTS 2 28 VDC POWER SOURCE	TBD — NONE KNOWN

CTS INSTALLATION & TAKEDOWN (IF TEMPORARY) CRITERIA

TBD

SYSTEM/PACKAGE INTERFACE FLEXIBILITY

PACKAGE MASS/WEIGHT (DIST.)

DEPENDENT ON DESIGN — TBD

NUMBER OF CREWMEMBERS REQUIRED

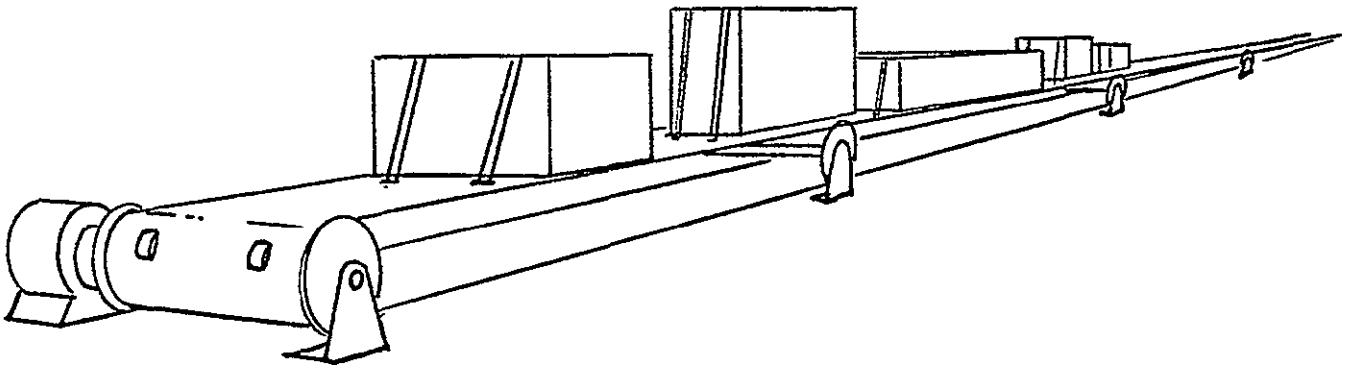
TWO — ONE TO LOAD CARGO CONTAINERS & OPERATE CTS, ONE TO UNLOAD CARGO AT DESTINATION

EVALUATION REMARKS

THIS SYSTEM AS DESCRIBED OCCUPIES A LARGE AMOUNT OF SPACE BUT CAN POSSIBLY BE ULTIMATELY REFINED DOWNWARD LOAD IS LIMITED BY MOTOR POWER OUTPUT SYSTEM CAN BE DESIGNED TO NEGOTIATE CORNERS ONLY WITH EXTREME COMPLEXITY REQUIRES PM

T/O RATING

CONVEYOR BELT TRANSFER: Electrical power; continuous belt, package control; control at one end only; cargo secured by adjustable straps or cable.



CONSTRAINTS:

1. Although several packages could be transported at once, belt must be stopped for each loading and unloading.
2. Good only for straight passage.
3. Consumes considerable passage space.
4. Probably a permanent installation.
5. Load limited by drive motor; motor must drive both directions or belt must be mounted so packages can be fastened to both sides of system.
6. System probably quite heavy.

CAPABILITIES:

1. Accommodates all size/shape/mass packages; could transfer personnel.
2. Easy to load and unload.
3. Considerable interference with failure, but could be manually operated.
4. Unlimited distance.

Probably practical only for Space Station tunnel.

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

SYSTEM TITLE	REFERENCES	ANALYST	DATE
CONVEYOR BELT TRANSFER SYSTEM (S/A)	MSFC ATM CONVEYOR BELT TRAILINGS, CHANGE 00 HANDBOOK	P E VAN LEEUWEN	29 DEC 70

SYSTEM DESCRIPTION

ONE CONTINUOUS ELECTRICALLY POWERED BELT WITH SINGLE END CONTROL AND ADJUSTABLE PACKAGE SECURING STRAPS OR CABLES

PKG SIZE/SHAPE

DEPENDING UPON ATTACHMENT MECHANISM, PACKAGE SIZE/SHAPE SHOULD BE GREAT

ATTACH/RELEASE

TBD — NO RESTRICTIONS

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
≈ .01 MTBF — TBD	1 REPAIR — TBD 2 SERVICE — ≈ 1 HR

HAZARD/DAMAGE POTENTIAL

TBD — INHERENTLY CAN BE MADE ACCEPTABLE

SYSTEM/CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
2 AXIS STABILIZATION ASSIST WORKS GOOD FOR BOTH LN	NOT REQUIRED

VISUAL	DEXTERITY
NEED UNOBSTRUCTED VIEW ONLY AT LOADING AND UNLOADING SITES	HIGH

AUDITORY	MOBILITY
INTERCOM	UPPER TORSO AT 250 AT 10K ft LOCAL ONLY

SPECIAL ENERGY REQMTS	SPECIAL (SKILLS, TRNG, ETC)
NONE	NO SPECIAL SKILLS FOR OPERATION. SOME DEGREE OF ELECTRICAL COMPONENTS REQUIRED FOR MAINTENANCE. NO PHYSICAL REQUIREMENTS

SYSTEM/ENVIRONMENT FLEXIBILITY

SPACE ALLOTMENT	SPACE GEOMETRY	MASS
VERY LARGE VOLUME REQUIRED	MAY HAVE PROBLEMS WITH SIDE DOCK	

ZERO-g	ONE-g	ARTIFICIAL-g
MAXIMAL		TBD

SYSTEM OPERATION CAPABILITIES

DEPLOYMENT TIME	TRANSFER RATE
≈ 2 HRS ±	LIMITED ONLY BY MOTOR SIZE SELECTED

PACKAGE POSITION/VELOCITY CONTROL

POSITION 1. LOCATION MONITOR COULD PROVIDE ±2 IN OF REPEATABILITY IN TRANSLATION AXIS ALL OTHER AXES ARE STATIC

2. DIRECT VISION & VOICE COMM WOULD PROVIDE ±6 IN OF ACCURACY WITH A TIME PENALTY

VELOCITY 1. RATE COULD BE ± 2 FT/SEC
2. ACCELERATION & DECELERATION COULD BE ± 2 FT/SEC

NUMBER OF CREWMEMBERS REQUIRED

TWO — ONE TO LOAD CARGO CONTAINERS & OPERATE CTS
ONE TO UNLOAD CARGO AT DESTINATION

INTERFERENCE WHEN FAILED

VERY LARGE BLOCKAGE CONSIDERING BELT & CARGO MAY BLOCK EMERGENCY EGRESS

EMERGENCY ALTERNATES

1 HAND OR CRANK OPERATION (MANUAL OVERRIDE)
2 MANUAL SYSTEMS

SYSTEM SUPPORT REQUIREMENTS

TOOLS	POWER	EXPENDABLE
STANDARD TOOL KIT & POSSIBLY AN IMPACT HAMMER	1 115 200 — 1500 WATTS 2 28 VDC POWER SOURCE	— BD — NONE KNOWN

CTS INSTALLATION & TAKEDOWN (IF TEMPORARY) CRITERIA

TBD

SYSTEM/PACKAGE INTERFACE FLEXIBILITY

PACKAGE MASS/WEIGHT (DIST.)

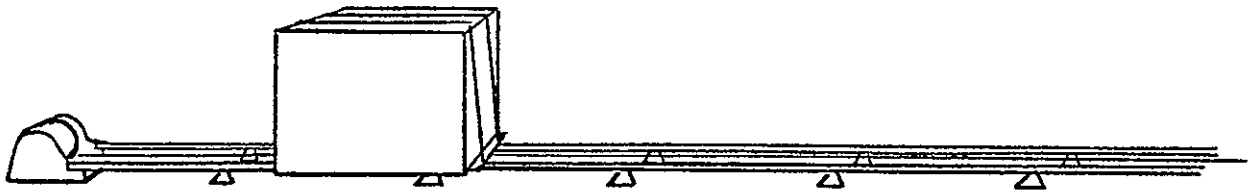
DEPENDENT ON DESIGN — TBD

EVALUATION REMARKS

SYSTEM PERMITS TRANSPORT OF MANY PACKAGES INITIALLY OUT BUT WITH DISADVANTAGE OF WAY TO STOP BELT FOR EACH PACKAGE LOADED AND UNLOADED. STRAIGHT LINE DISTANCE IS UNLIMITED BUT SYSTEM WILL NOT NEGOTIATE CORNERS. SYSTEM OCCUPIES LARGE AMOUNT OF SPACE AND MAY HAVE TO BE A PERMANENT INSTALLATION

T/O RATING

DUMBWAITER-DOLLY TRANSFER: Pallet cable drawn on dual rails; electric power; control located either end of system; package secured by adjustable straps.



CONSTRAINTS:

1. Dolly pallet has to return to starting point to pick up next package (although an empty could be carried on return trip).
2. Load limited only by drive motor; motor must turn in both directions.
3. Permanent rail system required.
4. Probably good only for straight run.
5. May have considerable weight if system transports large masses.
6. If system fails with large load, may cause considerable time delay to clear passage.

CAPABILITIES:

1. Accommodates all size/shape/mass packages.
2. Could transfer personnel also.
3. Very little space required.
4. Easy to load and unload.
5. Should require little maintenance.
6. If electrical power fails, possible to use manual power.
7. Unlimited distance.

Primarily useful in Space Station tunnel, although smaller versions could be used elsewhere.

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

SYSTEM TITLE
DUMBWAITER-DOLLY TRANSFER (C/A)

REFERENCES

ANALYST
P E VAN LEEUWEN

DATE
29 DEC 70

SYSTEM DESCRIPTION
MOTORIZED (ELECTRICAL) PALLET DRAWN ON DUAL RAILS WITH CONTROLS LOCATED AT EITHER END OF SYSTEM PACKAGE SECURED BY ADJUSTABLE STRAPS

PKG SIZE/SHAPE

ATTACH/RELEASE
TBD - NO RESTRICTIONS

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
≈ .01 MTBF - TBD	1 REPAIR - TBD 2 SERVICE - ≈ ½ HR.

HAZARD/DAMAGE POTENTIAL
TBD - PROBABLY CAN BE MADE ACCEPTABLE.

SYSTEM/CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
VISUAL	**DEXTERITY**
AUDITORY	**MOBILITY**
SPECIAL ENERGY REQMTS	**SPECIAL (SKILLS, TRNG, ETC)**

SYSTEM/ENVIRONMENT FLEXIBILITY

SPACE ALLOTMENT	SPACE GEOMETRY	MASS
ZERO-g	**ONE-g**	**ARTIFICIAL-g**

INTERFERENCE WHEN FAILED
FAIRLY SMALL BLOCKAGE (DETERMINED BY CARGO SIZE) BUT IN SOME SITUATIONS MAY BLOCK EMERGENCY EGRESS.

EMERGENCY ALTERNATES
1 HAND OR CRANK OPERATION (MANUAL OVERRIDE)
2 MANUAL SYSTEMS.

SYSTEM OPERATION CAPABILITIES

DEPLOYMENT TIME	TRANSFER RATE

PACKAGE POSITION/VELOCITY CONTROL

SYSTEM SUPPORT REQUIREMENTS

TOOLS	POWER	EXPENDABLE
STANDARD TOOL KIT & POSSIBLY AN IMPACT HAMMER	1 ≈ 300-400 WATTS 2 28 VDC POWER SOURCE	TBD - NONE KNOWN

CTS INSTALLATION & TAKEDOWN (IF TEMPORARY) CRITERIA

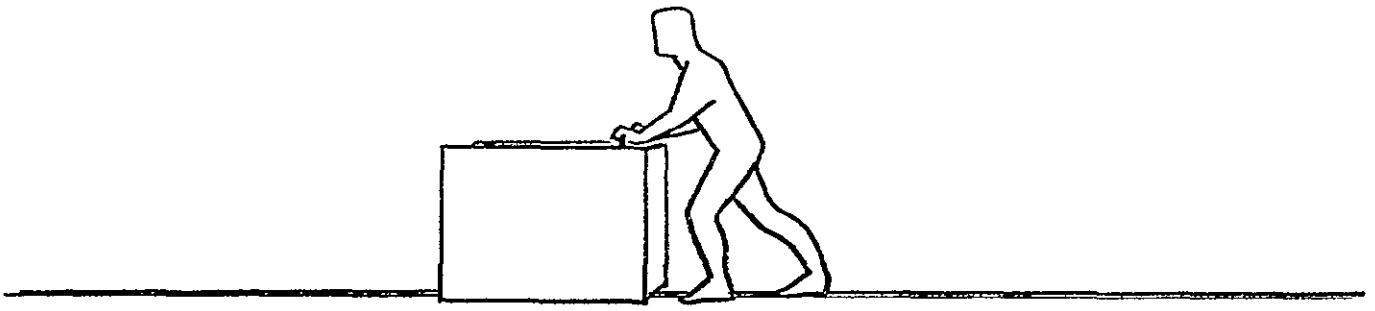
SYSTEM/PACKAGE INTERFACE FLEXIBILITY
PACKAGE MASS/WEIGHT (DIST.)

NUMBER OF CREWMEMBERS REQUIRED

EVALUATION REMARKS
LOAD IS LIMITED BY SIZE OF MOTOR WHICH MUST BE REVERSABLE TO RETURN PALLET TO LOADING POINT AFTER EACH RUN. SYSTEM CANNOT NEGOTIATE CURVES & REQUIRES PERMANENT INSTALLATION. SYSTEM HAS ADVANTAGE OF BEING ABLE TO CARRY LARGE LOADS INCLUDING PERSONNEL SINCE IT OCCUPIES LITTLE SPACE

RATING

FLOOR-MOUNTED, MAN-POWERED DOLLY TRANSFER: Man power; rail-dolly secures and guides package; mechanical or strap package fastening; astronaut mobility maintained by keeping tension force between floor and package - through the astronaut.



CONSTRAINTS:

1. Package mass limited by operator's ability to provide traction on floor surface (which interacts with holding himself down by means of package handles).
2. May be difficult for a man to keep himself in contact with floor surface and provide adequate propelling force.
3. Requires special fasteners for trolley-package interface; also handles on package for astronaut to grasp.
4. Requires permanent rail; also flat floor surface or segments thereof.

CAPABILITIES:

1. Simple operation (if it works as hypothesized).
2. Could go around corners in compartment.
3. Should provide good package control.
4. Takes very little space.

Probably most applicable in compartments with flat floor surface, although could work in other areas if dolly-floor added.

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

SYSTEM TITLE: FLOOR MOUNTED, MAN PROPELLED, MANUALLY TRANSFER (M/A)

SYSTEM DESCRIPTION: MAN PROPELLED, RAIL MOUNTED SYSTEM ADJUSTABLE TO SUIT SIZE OF CARGO MODULE TO PALLET

REFERENCES

ANALYST: J. LOCKLEAR

DATE: 1 DEC 70

SYSTEM/PACKAGE INTERFACE FLEXIBILITY:

PKG SIZE, SHAPE	ATTACH/RELEASE
3' OF UNIFORM SIZE DOES NOT PRESENT A PROBLEM AS LONG AS MAXIMUM WEIGHT IS NOT EXCEEDED	3 TAPES

PKG MASS-WEIGHT(distribution)

TBD

SYSTEM OPERATION CAPABILITIES

PREPARATION TIME	TRANSFER RATE
TBD POSSIBLY MORE THAN WITH E/A AT 2 MIN	TBD, LESS THAN W/A SYSTEMS

PKG POSITION/VELOCITY CONTROL

CARGO RIGIDLY ATTACHED TO SYSTEM, VEL AT MANUAL

NUMBER OF CREWMEMBERS REQUIRED

2 ACTIVE, 1 STANDBY.

SYSTEM CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
CRITICAL FACTOR, MUST BE ABLE TO TRANSMIT FORCE TO PROVIDE SUFFICIENT TRACTION TO TRANSFER THE CARGO	OR ALL UNIT SYSTEMS DEPEND ON MANUAL LOCOMOTION

VISUAL	DEXTERITY	SPECIAL (skills, training, physical
(DOES NOT HAVE TO BE UNRESTRICTED AT ALL TIMES) GENERAL KNOWLEDGE, UNDERSTAND	MAINTAIN CONTACT WITH CARGO MODULE	TBD

AUDITORY	MOBILITY
NORMAL VOICE COMM.	2 TO WALK ON PROCESS OF UNIT

SYSTEM/ENVIRONMENT FLEXIBILITY:

Zero - g	SPACE ALOTTMENT
LCG	MIN M
One - g	SPACE GEOMETRY
FOR UNIT	
Artificial - g	
ACCEPTABLE	

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
TBD, PRESENTLY MINIMAL	TBD PROBABLY MINIMAL

HAZARD/DAMAGE POTENTIAL

TBD, PRESENTLY MINIMAL

INTERFERENCE WHEN FAILED

TBD

EMERGENCY ALTERNATES

MANUAL UNAIDED SYSTEMS

SYSTEM SUPPORT REQUIREMENTS

TOOLS	POWER
TOOLS ON BOARD SKILLS REQUIRED FROM MAINTENANCE, REPAIR, ETC	N/A

EXPENDABLES

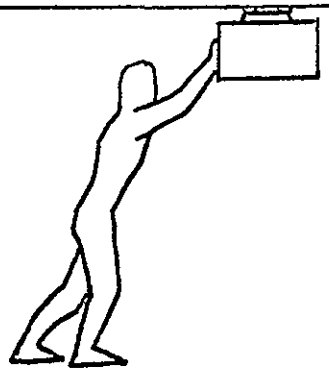
NONE

EVALUATION REMARKS

CARGO MASS LIMITED BY MEN'S ABILITY TO MOVE AND MAINTAIN STATION WHILE HELPING HIM [illegible] OF HANDLES OF UNIT [illegible] MODULE [illegible] HANDLES PROVIDED FOR MAN/MODULE INTERFACE. SYSTEM REQUIRES FLAT SMOOTH AND FLAT FLOOR. SYSTEM IS SIMPLE, WILL NEGOTIATE CORNERS AND BEAMS 5 INCHES SPACE

T/O RATING

CEILING MAN-POWERED TROLLEY TRANSFER: Man power; rail-trolley secures and guides package; mechanical fasteners; astronaut mobility maintained by keeping spring force between floor surface and trolley-rail system.



CONSTRAINTS:

1. Only small packages should be transferred because of distance between floor surface and trolley.
2. It may be difficult for man to keep feet in contact with floor surface and provide adequate propelling force.
3. Requires special fasteners for trolley-package interface; also handles for astronaut to grasp and hold onto package.
4. Requires permanent rail.

CAPABILITIES:

1. Simple operation (if it works as hypothesized)
2. Could go around corners within a compartment.
3. Should provide good package control (e.g., orientation, starting, stopping, etc.)
4. Takes up very little space.

Applicable primarily to compartments with flat ceilings and floor, although it could work in other areas if trolley-rail is dropped.

SYSTEM TITLE SUSPENDED MAN-POWERED TROLLEY TRANSFER (M/A)

SYSTEM DESCRIPTION MAN POWERED SUSPENDED RAIL/TROLLEY

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

REFERENCES

ANALYST R. E. VAN ALLEN

DATE 1 DEC 76

SYSTEM/PACKAGE INTERFACE FLEXIBILITY:

PKG SIZE, SHAPE	ATTACH/RELEASE
TBD	SPECIAL (TAD) EXT ENC'S

PKG MASS-WEIGHT(distribution)

TBD

SYSTEM/ENVIRONMENT FLEXIBILITY:

Zero - g	SPACE ALOTTMENT
TBD	MINIMAL
One - g	SPACE GEOMETRY
FEASIBLE	
Artificial - g	
FEASIBLE	

SYSTEM OPERATION CAPABILITIES

PREPARATION TIME	TRANSFER RATE
TBD, PROBABLY MINIMAL AS SYSTEM IS PERMANENTLY INSTALL'D	TBD, DEPENDS ON MAN'S OPERATIONAL MANEUVER + TRANSLATION RATE

PKG POSITION/VELOCITY CONTROL

CABLE AND TROLLEY ENGEL INTERFACE - ATTITUDE, C

NUMBER OF CREWMEMBERS REQUIRED

1 ACTIVE, 1 STANDBY

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
TBD, PROBABLY MINIMAL	TBD, PROBABLY MINIMAL

HAZARD/DAMAGE POTENTIAL

TBD, PROBABLY MINIMAL

INTERFERENCE WHEN FAILED

TBD

EMERGENCY ALTERNATES

MANUAL UNAIDED BY EMS.

SYSTEM CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
CRITICAL FACTOR SINCE C.M. DEPENDS ON IT	R ~ M (ITEMS AS VAC C~ MOTION)

VISUAL	DEXTERITY	SPECIAL
VISIBILITY MUST BE CONSTRUCTED IN ALL PHASES	MANIPULATION ATTENUATED/DISRUPTED BY MANY FACTORS UNDER EQUIPMENT C~	(skills, training, physical) TBD
AUDITORY	**MOBILITY**	
A PAL / ICC COMM	TA WALL-IN ~ VISION SCREEN ON FREEDOM IVAL	

SYSTEM SUPPORT REQUIREMENTS

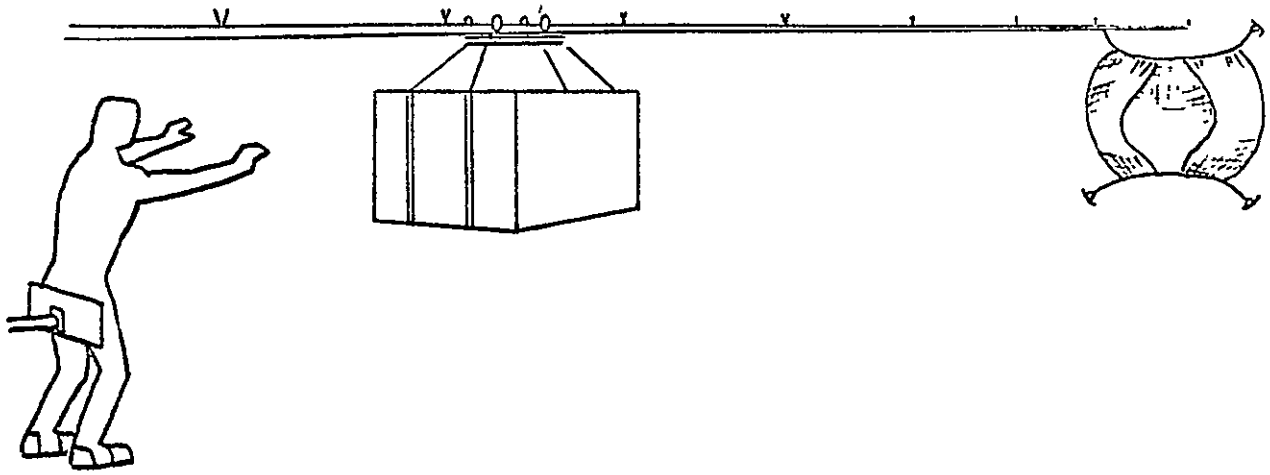
TOOLS	POWER
TBD, SUIT TRACTION AND ORIENTATION AIDS WILL BE REQUIRED	N/A
	EXPENDABLES
	TBD

EVALUATION REMARKS

SMALLER THAN NORMAL IA / ABLE TO TRANSFER ~ D ~ DISTANCE FROM TROLLEY TO WORK AREA NEAR SIDE OF C AS THIS IS A PROBLEM ~ LEAL FACTOR / ~ LOW RC HIGH LEVEL OF SEC IN ~ NEGLIGIBLE / FEASIBLE AND CYCLIC MODE OF USE IN LC SPACE

T/O RATING

RAIL-DIAPHRAGM (or net) TRANSFER: Manual power; diaphragm or net package capture; single or double rail with freely mobile, suspended trolley.



CONSTRAINTS:

1. Package mass probably limited by operator's capabilities; size and shape limited because of probable tumbling or swinging motion.
2. Only one package at a time.
3. Good only in straight passage.
4. Capture system may be a nuisance and interference to other activities; difficult package recovery.
5. Rail would probably have to be permanent installation.

CAPABILITIES:

1. Requires only man power.
2. Could also be used for personnel transfer.
3. Rail could be recessed so as not to intrude into usable space.

Practical use only in Space Station tunnel.

SYSTEM TITLE KYLE - DIAPHRAGM (OR NET) TRANSFER SYSTEM (U/A)

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

SYSTEM DESCRIPTION MAN-POWERED, DIAPHRAGM OR NET & FOO
- CARTAGE CABLE OR SMALL RAIL WITH APPLIED
- SUPPLIED TROLLEY INSIDE IN
- IN FLOOR

REFERENCES

ANALYST [illegible] DATE [illegible]

SYSTEM/PACKAGE INTERFACE FLEXIBILITY:

PKG SIZE, SHAPE	ATTACH/RELEASE
TBD	TBD

PKG MASS-WEIGHT(distribution)

MASS LIMITED TO OPERATORS LIMITS
HAVE CRITICAL TRAN WITH RELEASE ATTACHED CARGO SYSTEMS

SYSTEM OPERATION CAPABILITIES

PREPARATION TIME	TRANSFER RATE
PRIMA W VISUAL LIN DEPLOYMENT OF NET	MOD DEFICIENCY MIN'S CREW MTI MAINTENANCE

PKG POSITION/VELOCITY CONTROL

ALL MANUAL; PAY LOAD'S MOBILITY IN TRANSIT MODE IS HARD ALL

NUMBER OF CREWMEMBERS REQUIRED

2 ACTIVE, 2 STANDBY

SYSTEM CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
CRITICAL FACTOR FOR SYSTEM IS CLOSED	ZERO-G IN SHIP REPLACES ON-SITE FOOT MOTION

VISUAL	DEXTERITY	SPECIAL
VISIBILITY NOT AN OBSTRUCTION IN ALL PHASES	MAXIMUM AMOUNT OF FORCES FAIRLY TO TRANSFER RECEIVING SYSTEM	(skills, training, physical) TBD

AUDITORY	MOBILITY
NO COMMUNICATIONS	ALL MANUAL HANDLING

SYSTEM/ENVIRONMENT FLEXIBILITY:

Zero - g	SPACE ALOTTMENT
TBD	DEPENDING ON CONFIGURATION, MINIMAL TO MODERATE

One - g	SPACE GEOMETRY
FEASIBLE	

Artificial - g	
FEASIBLE	

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
TBD PROBABILITY MINIMAL	TBD PROBABILITY MINIMAL

HAZARD/DAMAGE POTENTIAL

PROBABILITY GREATER THAN WITH RIGID CARGO
MATERIAL TO SYSTEMS.

INTERFERENCE WHEN FAILED

TBD

EMERGENCY ALTERNATES

MANUAL UNAIDED SYSTEMS

SYSTEM SUPPORT REQUIREMENTS

TOOLS	POWER
TBD [illegible] IN [illegible] SIENTA IN A UNIT PC REQUIRED	N/A

EXPENDABLES

EVALUATION REMARKS:

PAYLOAD MASS PROPERLY LIMITED DUE TO OPERATORS LIMITATIONS, SIZE & SHAPE LIMITED DUE TO PROPERLY TO LOCATE OR CONFIN IN MOTION IN TRANSFER LOCK OVERALL TRANSIT TIME LOCK TO SITE MINIMAL AT TIME TRANSFER FINALIZED ON 1" RAIL AT CARGO CAPTIVING DEVICE(S) MAY BE HOT TIME & SOME AREAS SACRIFICABLE MEET REQUIRED CRITERIA MAY PRECLUDE ITS APPLICATION, AUTO PAYLOAD RECOVERY MAY BE DIFFICULT. ONE MAN OPERATION CAN BE USED FOR PERSONNEL TRANSFER, RAIL COULD BE ACCESSED TO ALLOW MORE [illegible]

T/O RATING [illegible]

STEM (SPAR) TRANSFER: Self contained unit, either electrical or manual crank powered; unit held in hand by operator or secured to structure; cargo secured by special fitting; control is at the power unit; unit can be portable.

CONSTRAINTS:

1. Package size/shape/mass limited by particular unit motor and stem extension material and strength.
2. Handles only one package at a time.
3. Good only for straight passage.
4. Package orientation may be hard to control; requires direct view of package.
5. Requires special fitting for package interface.
6. Travel distance limited.
7. Nuisance if it fails extended; easily damaged.

CAPABILITIES:

1. Generally portable; can be taken to any compartment.
2. Does not take much space; easy to store.
3. Easy to change direction of travel; is not restricted to structure-space geometry except for maintaining straight line-of-sight.

Could be used in practically all compartments.

STLM TITLE STEM (SPAR) TRANSFER SYSTEM (N/A)

CARGO TRANSFER SYSTEMS EVALUATION

SYSTEM DESCRIPTION SELF CONTAINED UNIT EITHER ELECTRICAL OR MANUAL CRANK OPERATED, UNIT WOULD BE HAND HELD OPERATOR OR SECURED TO STATIONARY SURFACE CARGO (SIMILAR TO CM FOOT CONTROL PANEL - BE OF UNIT) IS PORTABLE

REFERENCES

ANALYST PE VAN LEEUWEN | DATE 7 DEC 70

SYSTEM/PACKAGE INTERFACE FLEXIBILITY

PKG SIZE, SHAPE: PACKAGE SIZE/SHAPE LIMITED BY MAXIMUM SIZE PKG CAN BE MANIPULATED WITH AVAILABLE SPACE

ATTACH/RELEASE: TBD PROCEDURE AT ACQUISITION DOCKING REQUIRED

PKG MASS-WEIGHT(distribution): LIMITED DUE TO NATURE OF SYSTEM

SYSTEM OPERATION CAPABILITIES

PREPARATION TIME: MINIMAL

TRANSFER RATE: PROBABLY VERY SLOW

PKG POSITION/VELOCITY CONTROL: VELOCITY CONTROL VERY GOOD POS'T POSITION CONTROL IN TRANSIT MODE FAIR TO POOR (POSITION DIMINISHES WITH DISTANCE - SEE 1A)

NUMBER OF CREWMEN REQUIRED: 1 ACTIVE, 1 STANDBY

SYSTEM CREW REQUIREMENTS

CREW STABILITY: SYSTEM BE BOUND IT

CREW LOCOMOTION: TBD, MINIMAL

VISUAL: UNRESTRICTED VISION ESSENTIAL AT ALL TIMES

DEXTERITY: TBD PROPERLY

SPECIAL (skills, training, physical): TBD

AUDITORY: FOR ALL VOICE COMMS

MOBILITY: MINIMAL

SYSTEM/ENVIRONMENT FLEXIBILITY:

Zero - g: FEASIBLE

SPACE ALOTTMENT: MINIMAL

One - g: PROBABLY NOT FEASIBLE (MATERIAL STRENGTH AND OPERATOR FATIGUE ARE POTENTIAL PROBLEM AREAS)

SPACE GEOMETRY

Artificial - g: TBD

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE: TBD

REPAIR/SERVICE TIME: TBD

HAZARD/DAMAGE POTENTIAL: MAXIMAL DUE TO EASE OF LOSS OF CONTROL WHEN FULLY EXTENDED

INTERFERENCE WHEN FAILED: MINIMAL

EMERGENCY ALTERNATES: PITCH-CATCH & BUCKET BRIGADE SYSTEMS

SYSTEM SUPPORT REQUIREMENTS

TOOLS: NO SPECIAL REQUIRED

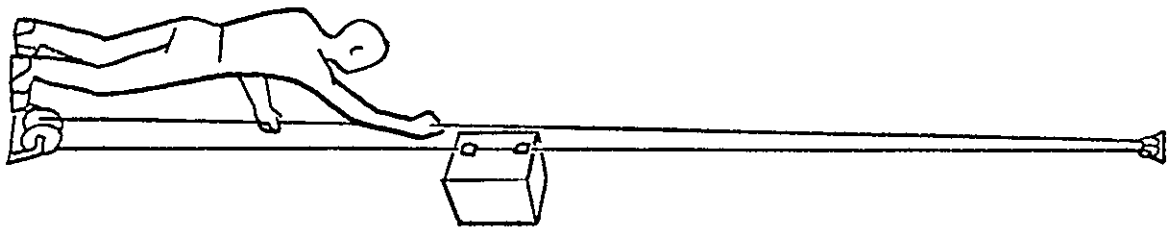
POWER: MANUAL (IN USAGE), OR MANUAL CRANK OPERATION

EXPENDABLES: N/

EVALUATION REMARKS: CARGO SIZE/SHAPE/MASS, DISTANCE OF CONTROL SEVERELY LIMITED. FEASIBLE FOR STRAIGHT LINE OPERATION ONLY REQUIRES SPECIAL FITTING AND IF SYSTEM FAILS IN EXTENDED POSITION (MUST BE WELL CLEAR OF PANELS, ETC.) SYSTEM IS COMPACT, LIGHT WEIGHT & EASY TO STORE. DIRECTION IS SIMPLE AND SYSTEM IS NOT CRITICAL TO INPUT-ARE-SPACE GEOMETRY EXCEPT FOR MAINTENANCE OF STRAIGHT LOS. NO POSSIBILITY FOR PERSONNEL TRANSFER

T/O RATING

CLOTHESLINE TRANSFER: Electrical or mechanical-manual or manual power; cargo secured by special fasteners.



CONSTRAINTS:

1. Cargo size/shape/mass somewhat limited.
2. Relatively poor control of package orientation.
3. Only good for straight passage.
4. Requires special package fasteners or dual lines to keep package from swinging.
5. Lines can become entangled during operation or assembly.

CAPABILITIES:

1. Fairly easy to install.
2. Fairly portable hence can be installed in various places on temporary basis.
3. Takes little space, either during operation in place or when stored.
4. Can be used for personnel transfer as well as package transfer.
5. No particular limit in transfer distance,

Most appropriate use in Space Station tunnel, although it could be erected in other compartments or within the Cargo Module.

SYSTEM TITLE CLOTHESLINE TRANSFER SYSTEM (M/A)

SYSTEM DESCRIPTION ELECTRICAL, MECHANICAL, OR MANUAL POWER, CARGO SECURED BY SPECIAL FASTENERS TO A PULLEY MOD TYPE CLOTHESLINE TYPE DEVICE.

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

ANALYST [illegible] DATE 3 SEP 70

REFERENCES

SYSTEM/PACKAGE INTERFACE FLEXIBILITY:

PKG SIZE, SHAPE	ATTACH/RELEASE
FAIR TO POOR (SIZE & SHAPE LIMITED)	TBD, SPECIAL FASTENERS REQUIRED

PKG MASS-WEIGHT(distribution)

LIMITED DUE TO NATURE OF SYSTEM

SYSTEM/ENVIRONMENT FLEXIBILITY:

Zero - g	SPACE ALOTTMENT
TBD	MINIMAL

One - g	SPACE GEOMETRY
FEASIBLE	

Artificial - g

TBD

SYSTEM OPERATION CAPABILITIES

PREPARATION TIME	TRANSFER RATE
PROPORTIONAL TO LENGTH	DEPENDING ON POWER SYSTEM MOD CAPABILITY

PKG POSITION/VELOCITY CONTROL

PACKAGE VELOCITY CONTROL DEPENDS ON POSITION CONTROL OF PACKAGE ORIENTATION

NUMBER OF CREWMEMBERS REQUIRED

1 ACTIVE 1 STANDBY

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
TBD, PRESENTLY MINIMAL	TBD, PROBABLY MINIMAL

HAZARD/DAMAGE POTENTIAL

NOT CONSIDERED A SERIOUS HAZARD UNLESS PACKAGE SEPARATES FROM SYSTEM DOWNSTREAM

INTERFERENCE WHEN FAILED

MINIMAL TO MODERATE (DEPENDING IF PULLEY SYSTEM IS CENTERED IN TUNNEL, OR WALL OR NEAR WALL MOUNTED)

EMERGENCY ALTERNATES

PITCH CATCH OR BUCKET BRIGADE SYSTEMS (DEPENDING ON CONFIGURATION OF THIS SYSTEM—SEE ABOVE)

SYSTEM CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
CREW CAN BE A SINGLE SYSTEM TYPE, MINIMAL DOWNTIME	

VISUAL	DEXTERITY	SPECIAL (skills, training, physical)
UNRESTRICTED VISUALITY REQUIRED AT ALL TIMES	MAY HAVE TO DISCONNECT/DISCARD PACKAGE FROM SYSTEM.	TBD
AUDITORY	MOBILITY	
NORM VOICE COMM	TBD (PROBABLY MINIMAL)	

SYSTEM SUPPORT REQUIREMENTS

TOOLS	POWER
NONE REQUIRED	ALL MANUAL

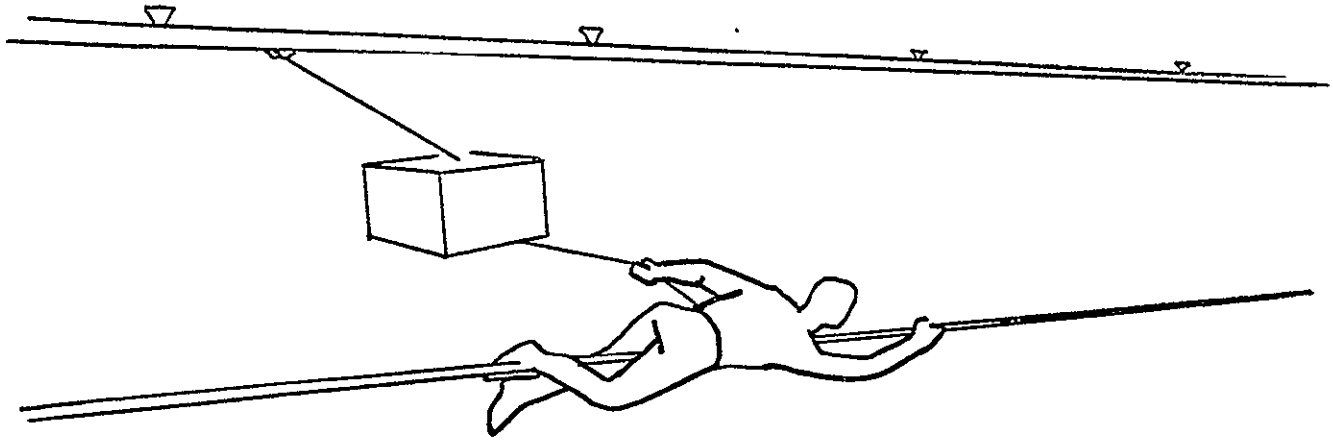
EXPENDABLES

N/C

EVALUATION REMARKS CARGO SIZE/SHAPE/MASS IS RESTRICTED, RELATIVELY POOR CONTROL OF PACKAGE ORIENTATION, GOOD FOR STRAIGHT-LINE OPERATIONS, SPECIAL FASTENERS AND DUAL TRANSFER LINES REQUIRED WHICH MAY BE PRONE TO ENTANGLEMENT. SYSTEM FAIRLY EASY TO INSTALL & USE AT OCI'S SUFFICIENTLY PORTABLE FOR OPERATIONS IN VAN - AREAS REQUIRE LITTLE SPACE AND IS APPLICABLE TO PERSONNEL TRANSFERRAL WHERE DISTANCE IS UNCONFINED (IF MEANS OF PREVENTING LINE ENTANGLEMENT ARE EMPLOYED)

T/O RATING

RAIL-TETHER TRANSFER: Manual power; package tethered to rail for capture and guidance; astronaut pulls package by means of tether using hand rail aid.



CONSTRAINTS:

1. Package shape/size and mass somewhat limited but less so than free pitch/catch mode (see alternate sketch).
2. Poor package orientation control.
3. Good for straight passage only.
4. Probably requires permanent rail instalation.

CAPABILITIES:

1. Simple package attach/release.
2. Takes up very little space.
3. Only manpower required; one man operation.

Practical use only in Space Station tunnel.

SYSTEM TITLE RAIL-TETHER TRANSFER SYSTEM (TM)

SYSTEM DESCRIPTION PACKAGE TETHERED TO RAIL FOR MANUAL OR MECHANICAL TRANSFER, MAN RIDES PACKAGE USE OF TETHER

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

REFERENCES

ANALYST [illegible]

DATE 2 DEC 70

SYSTEM/PACKAGE INTERFACE FLEXIBILITY:

PKG SIZE, SHAPE	ATTACH/RELEASE
LIMITED MORE TO SIZE AND SHAPE	

PKG MASS-WEIGHT(distribution)

LIMITED MORE CRITICAL THAN EARTH STATION N/A SYSTEMS

SYSTEM/ENVIRONMENT FLEXIBILITY:

Zero - g	SPACE ALOTTMENT
TBD	OPTIMAL MINIMAL SPACE
One - g	**SPACE GEOMETRY**
FEASIBLE	
Artificial - g	
FEASIBLE	

SYSTEM OPERATION CAPABILITIES

PREPARATION TIME	TRANSFER RATE
PROBABLY HIGH DEPENDS ON CARGO STATION AIR	PROBABLY LOW

PKG POSITION/VELOCITY CONTROL

ALL MANUAL, PACKAGE STABILITY IN TRANSIT MODE POOR

NUMBER OF CREWMEMBERS REQUIRED

2 / TWO, 1 STANDBY

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
TBD HIGH MINIMAL	TBD, PROBABLY MINIMAL

HAZARD/DAMAGE POTENTIAL

GREATER THAN WITH RIGID CARGO ATTACHMENT SYSTEMS

INTERFERENCE WHEN FAILED

TBD NOT CONSIDERED TO BE A SERIOUS PROBLEM

EMERGENCY ALTERNATES

MANUAL U AIDED SYSTEMS

SYSTEM CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
CRITICAL FACTOR SINCE SYSTEM DEPENDS ON	CRITICAL SINCE SYSTEM DEPENDS ON MANUAL LOCOMOTION

VISUAL	DEXTERITY	SPECIAL
UNOBSTRUCTED VISION ESSENTIAL IN ACTIVE PHASES	TBD, DEPENDS ON COMPLEXITY OF ATTACHMENT SYSTEMS	(skills, training, physical) TBD
AUDITORY	**MOBILITY**	
VERBAL VOICE COMMAND	MAY BE OF LIMITED USE	

SYSTEM SUPPORT REQUIREMENTS

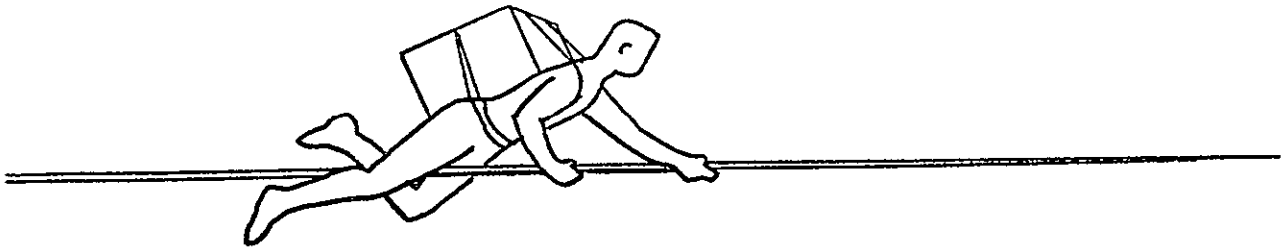
TOOLS	POWER
TBD	N/A
	EXPENDABLES

EVALUATION REMARKS

PACKAGE SIZE/SHAPE MINIMAL LIMITED POOR PACKAGE MOBILITY, COULD BE OPERATED ONLY, IF NO IRCU PERMANENT [illegible] REQUIRED, TAKES UP [illegible], AND HAS MOBILE PACKAGE ATTACH/RELEASE.

T/O RATING

FIREMAN POLE TRANSFER: Manual power; package strapped to astronaut handrail aid used for astronaut movement.



CONSTRAINTS:

1. Package shape/size/mass limited.
2. Probably very fatiguing.
3. Probably requires second astronaut to assist in donning and doffing package.
4. Probably requires permanent handrails.

CAPABILITIES:

1. Only manpower required.
2. No special space requirement.
3. Allows transfer to all areas without package unloading and reloading.

Useful primarily in Space Station tunnel.

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

SYSTEM TITLE: FICHANA'S PALLET TRANSFER (M)

SYSTEM DESCRIPTION: MANUAL POWER, PACKAGE STRADDLED BY TWO ARMS WITH ROLLERS AND SKIDS FOR LATERAL MOVEMENT

ANALYST: PE VAN LEEUWEN DATE: 2 DEC 70

REFERENCES:

SYSTEM/PACKAGE INTERFACE FLEXIBILITY

PKG SIZE, SHAPE	ATTACH/RELEASE
SIZE AND MASS RESTRICTED	PKG READILY SUITABLE SINCE MASS IS SMALL AND SYSTEM HAS VARIABLE ACCESSIBILITY

PKG MASS-WEIGHT (distribution): VERY LIMITED

SYSTEM OPERATION CAPABILITIES

PREPARATION TIME	TRANSFER RATE
MINIMAL	TBD, PROBABLY LOW

PKG POSITION/VELOCITY CONTROL: PASSIVE SELF-TURN/STOP MECHANISM AT EACH END OF SYSTEM

NUMBER OF CREWMEMBERS REQUIRED: 1 ACTIVE, 2 STANDBY

SYSTEM CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
CRITICAL FACTOR SINCE SYSTEM DEPENDS ON IT	SYSTEM DESIGNED TO BE USED BY TWO CONSECUTIVELY HULL CREWMEN FOR PRIORITY

VISUAL	DEXTERITY	SPECIAL (skills, training, physical)
UNRESTRICTED VISION ESSENTIAL IN ALL PHASES	TBD	TBD

AUDITORY	MOBILITY
VOICE COMM	OPERATOR STANDS ON SYSTEM

SYSTEM/ENVIRONMENT FLEXIBILITY

Zero - g	SPACE ALLOTMENT
FEASIBLE	MINIMAL

One - g	SPACE GEOMETRY
FEASIBLE	

Artificial - g: TBD

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY RATE	REPAIR/SERVICE TIME
TBD, PROBABLY LOW	TBD, PROBABLY LOW

HAZARD/DAMAGE POTENTIAL: MINIMAL, UNLESS MAN SEPARATED FROM PALLET AND BECOMES DISORIENTED

INTERFERENCE WHEN FAILED: MINIMAL

EMERGENCY ALTERNATES: PITCH-CATCH, OR BUCKET BRIGADE

SYSTEM SUPPORT REQUIREMENTS

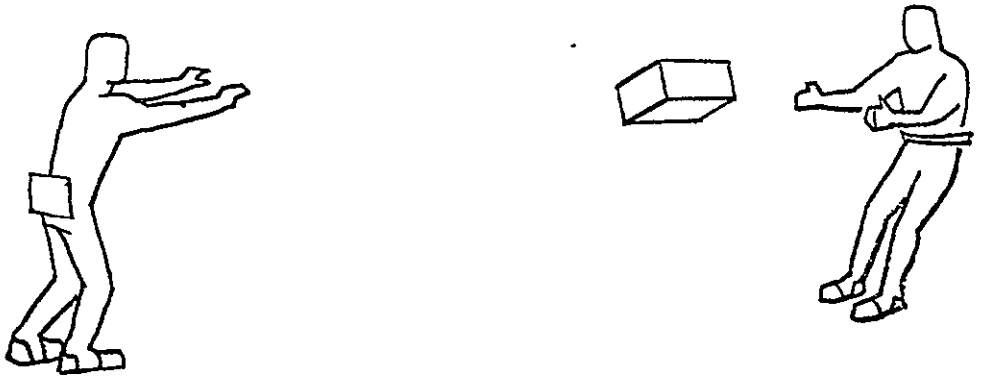
TOOLS	POWER
NONE REQUIRED	N/A

EXPENDABLES

EVALUATION REMARKS: PACKAGE MASS IS TO BE VERY LIMITED FOR EASILY HANDLED LOADS AS A UNIT IN LOADING/UNLOADING SO AS TO PLACE NO PROBLEM TO OPERATOR HAVING A LOW CENTER OF GRAVITY PERMANENTLY MOUNTED ON A PALLET WITH A LOW PROFILE. LOADING, NO SPECIAL APPARATUS REQUIRED.

T/O RATING

PITCH-CATCH TRANSFER: Manual power; man catch or net catch modes; both astronauts secured by Dutch shoes and assisted by body support device or structure.



CONSTRAINTS:

1. Package size/shape/mass limited to what man can grasp, manipulate, push and catch conveniently.
2. Difficult to control direction, velocity and orientation of package (poor control could lead to damage of package or adjacent equipment or structure and could injure receiver).
3. Should be limited to short distances and straight paths.

CAPABILITIES:

1. No special preparation required.
2. Very flexible in terms of direction or area.

Practical use only in small compartments where short distances are involved.

STEM TITLE PITCH-CATCH TRANSFER METHOD (M)

YSTEM DESCRIPTION ALL MANUAL, 2 MEN SECURED BY DUTCH SNUBS AND ROPE - USE OF DEVICES ONE MAN RELEASES PACKAGE TO CATCHER, RETRIEVES SNUBS

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

REFERENCES

ANALYST P E VAN LEEUWEN DATE 3 DEC 70

SYSTEM/PACKAGE INTERFACE FLEXIBILITY.

PKG SIZE, SHAPE

INCREASE SIZE/SHAPE FLEXIBILITY

ATTACH/RELEASE

ATTACHMENT DEVICES NOT MAN-SYSTEMED (NOT CRITICAL MAN TO PITCH/CATCH STATIONS)

PKG MASS-WEIGHT(distribution)

LIMITED DUE TO NATURE OF SYSTEM

SYSTEM OPERATION CAPABILITIES

PREPARATION TIME: MINIMAL

TRANSFER RATE: PRIMARILY LOW

PKG POSITION/VELOCITY CONTROL

PACKAGE ATTITUDE/VELOCITY CONTROL POOR

NUMBER OF CREWMEMBERS REQUIRED

2 EFFECTIVE

SYSTEM CREW REQUIREMENTS

CREW STABILITY: BODY SUPPORT DEVICES DESIRED SINCE MOVEMENT

CREW LOCOMOTION: N/A

VISUAL	DEXTERITY	SPECIAL (skills, training, physical)
UNRESTRICTED VISIBILITY REQUIRED AT ALL TIMES	MINIMAL REQUIRED	TBD
AUDITORY	**MOBILITY**	
VOICE COMM	WITHIN PACKAGE DEVICES	

SYSTEM/ENVIRONMENT FLEXIBILITY:

Zero - g

SPACE ALOTTMENT: MINIMAL

FEASIBLE

One - g

SPACE GEOMETRY

UNIFORM LOC FOR FRAGILE CARGO

Artificial - g

TBD

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE, REPAIR/SERVICE TIME: MINIMAL - DECREASING INTEGRITY WITH REPEATING SUCCESS — N/A

HAZARD/DAMAGE POTENTIAL

MAXIMAL - LOSS OF PACKAGE ORIENTATION AND/OR CONTROL CAN RESULT IN DAMAGE TO CARGO AND/OR TUNNEL

INTERFERENCE IF FAILED

NONE

EMERGENCY ALTERNATES

BUCKET BRIGADE SYSTEM

SYSTEM SUPPORT REQUIREMENTS

TOOLS: N/A

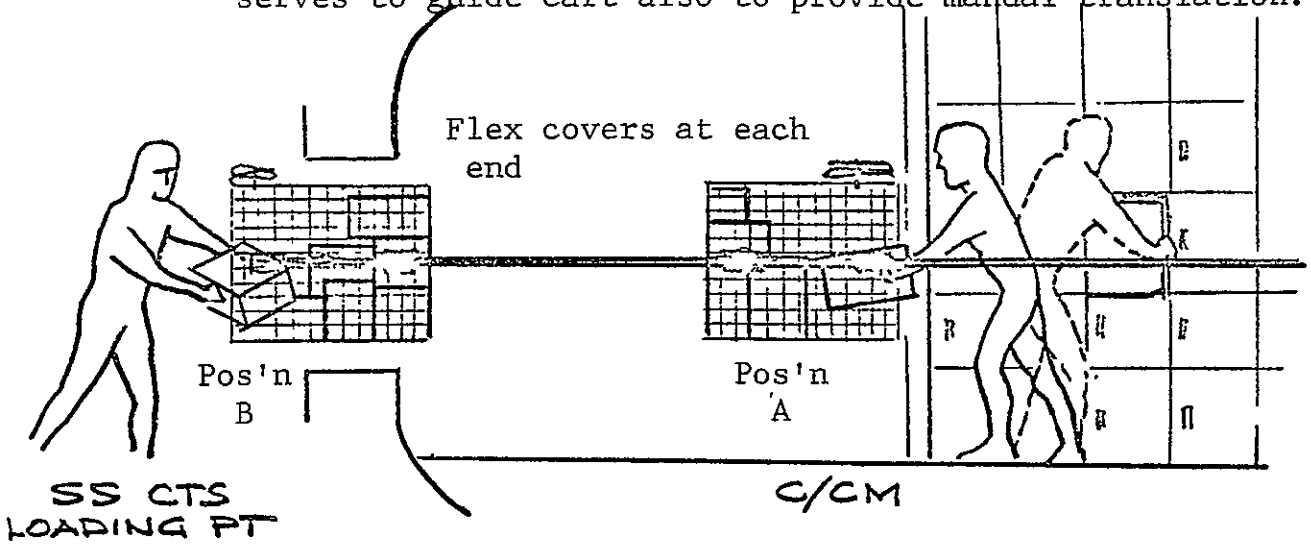
POWER: N/A

EXPENDABLES: N/A

EVALUATION REMARKS: PACKAGE SIZE/SHAPE/MASS LIMITED [illegible] CONTROL OF VELOCITY DIFFICULT TO CONTROL AND THIS MAY RESULT IN DAMAGE TO CARGO, ABSENCE OF [illegible] SYSTEMS TO ACCOMPLISH SYSTEM NOT A [illegible] TERMS OF DIRECTION AND AREA, NO SYSTEM INSTALLATION OR PREPARATION REQUIRED

T/O RATING

SHOPPING CART-RAIL CONCEPT FOR C/CM: Manually powered; double rail serves to guide cart also to provide manual translation.



CONSTRAINTS:

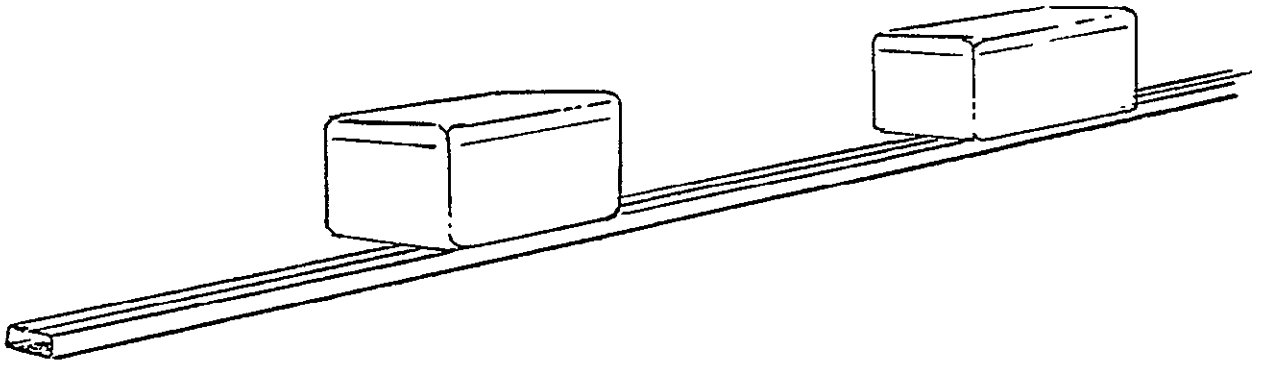
1. Although guide rail could be permanently installed in cargo area of C/CM, a removable section will be required in Crew/Seating area. This requires minimum preparation before transfer of cargo begins.
2. Minor interference possible to pure manual transfer.
3. Simultaneous two-way cargo transfer is not feasible.
4. Some limitation of "cart" size, which may limit cargo size capability.

CAPABILITIES:

1. Can be completely manual translation, or easily adapted to other means.
2. Provides very flexible package capture and translation method.
3. Easy to load and unload.
4. Distance limited only by hatch sizes or turning clearances.
5. Individual packages do not have to be secured independently.
6. Guide rail and cart guide system should be simple and trouble free; easy to erect and assemble - or remove and store.

Could be used in almost any area of the C/CM-SS complex although present view is that it is best for the C/CM area.

MOSLER TELELIFT ("ThingBringer") SYSTEM: Most fully automatic electrically powered captive rail and gear system which is presently available. Zero-g operations are feasible.



CONSTRAINTS:

1. Cargo size probably limited since motor is part of moving package total; load limited by motor size.
2. As available, cargo module size and volume severely limited: (a) 4" x 12" x 15"; (b) 8" x 12" x 18".
3. As available, unable to transfer personnel.
4. Provisions required for removal and replacement of sections of track passing through pressure seal.

CAPABILITIES:

1. System based on building block method; curved and straight track available as well as switching system. Growth potential is unlimited.
2. More than one cargo module can be transferred at any given time.
3. With double rails, system can be simultaneously multi-directional.
4. Each module preprogrammed for destination.

Could be used for total system of CM, SS compartments and tunnel.

CARGO TRANSFER SYSTEMS EVALUATION WORKSHEET

SYSTEM TITLE: MOSLER TELELIFT "THINGBRINGER" (S/A)

REFERENCES:

ANALYST: P E VAN LEEUWEN

DATE: 23 DEC 70

SYSTEM DESCRIPTION:
CAPTIVE RAIL/GEAR MOUNTED AND ELECTRICALLY POWERED, AUTOMATIC PREPROGRAMMED DISPERSAL THIS BASIC SYSTEM IS OFF-THE-SHELF.

PKG SIZE/SHAPE:
LIMITED IN OFF-THE SHELF VERSION BUT CAN BE MODIFIED TO SUIT MISSION REQUIREMENTS.

ATTACH/RELEASE:
TBD—NO RESTRICTIONS

SYSTEM RELIABILITY/MAINTAINABILITY

FAILURE PROBABILITY/RATE	REPAIR/SERVICE TIME
TBD	1 REPAIR - TBD 2 SERVICE — ≈1 HR

HAZARD/DAMAGE POTENTIAL:
TBD.

SYSTEM/CREW REQUIREMENTS

CREW STABILITY	CREW LOCOMOTION
3-AXIS STABILIZATION AT WORKSITE FOR BOTH MEN	NOT REQUIRED

VISUAL	DEXTERITY
NEED UNOBSTRUCTED VIEW ONLY AT LOADING & UNLOADING SITES	HIGH (FOR SETTING DESTINATION PROGRAMMER)

AUDITORY	MOBILITY
INTERCOM	UPPER ARM & TORSO AT LOAD/UNLOAD ONLY

SPECIAL ENERGY REQMTS	SPECIAL (SKILLS, TRNG, ETC)
NONE	NO SPECIAL SKILLS FOR OPERATIONS RUDIMENTARY KNOWLEDGE OF ELECTRICAL COMPONENTS REQUIRED FOR MAINTENANCE NO PHYSICAL REQUIREMENTS.

SYSTEM/ENVIRONMENT FLEXIBILITY

SPACE ALLOTMENT	SPACE GEOMETRY	MASS
SMALL VOLUME		

ZERO-g	ONE-g	ARTIFICIAL-g
TBD	MAXIMAL	TBD

INTERFERENCE WHEN FAILED:
TBD— PROBABLY MINIMAL TO MODERATE

EMERGENCY ALTERNATES:
MANUAL TRANSFER ONLY

SYSTEM OPERATION CAPABILITIES

DEPLOYMENT TIME	TRANSFER RATE
≈ 15-30 MIN	LIMITED BY MOTOR & CARGO SIZE SELECTED

SYSTEM SUPPORT REQUIREMENTS

TOOLS	POWER	EXPENDABLE
TBD	1 ≈ 300-450 WATTS 2 28 VDC POWER SOURCE	TBD - NONE KNOWN

PACKAGE POSITION/VELOCITY CONTROL

POSITION 1. OFF-THE SHELF SYSTEM IS CAPABLE OF ACCEPTABLE POSITIONING ACCURACY.

VELOCITY 1 CONSTANT VELOCITY @ 100 FPM.

CTS INSTALLATION & TAKEDOWN (IF TEMPORARY) CRITERIA:
TBD

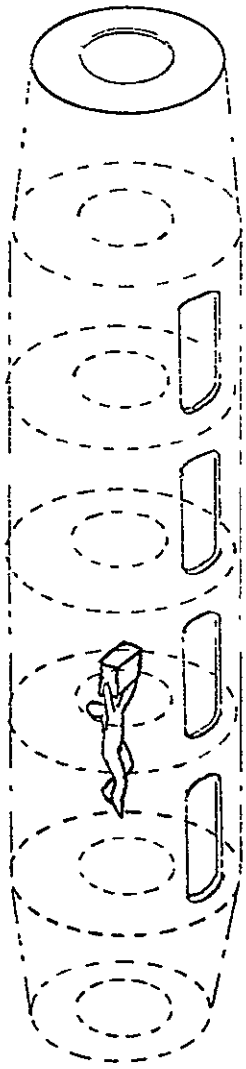
SYSTEM/PACKAGE INTERFACE FLEXIBILITY

PACKAGE MASS/WEIGHT (DIST.):
DEPENDENT ON DESIGN-TBD

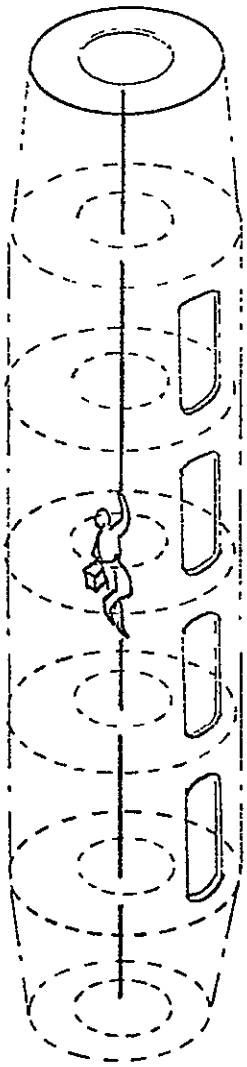
NUMBER OF CREWMEMBERS REQUIRED:
TWO— ONE TO LOAD CARGO CONTAINERS & OPERATE CTS
ONE TO UNLOAD CARGO AT DESTINATION

EVALUATION REMARKS:
TO RENDER THIS SYSTEM APPLICABLE TO A CTS (0-g) FUNCTION EXTENSIVE MODIFICATIONS ARE NECESSARY, ESPECIALLY POWER SYSTEM REDUNDANCY. LOAD IS LIMITED ONLY BY MOTOR OUTPUT. SYSTEM OCCUPIES LITTLE SPACE AND CAN EASILY TRAVERSE CORNERS. BUILDING-BLOCK CONCEPT PERMITS ADDITION OF SPURS (SIDINGS) AT ALL DESIREABLE OFF-LOADING STATIONS. RANGE IS UNLIMITED.

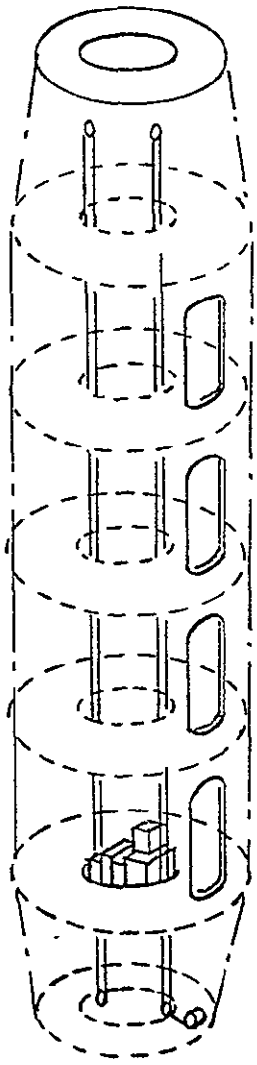
T/O RATING



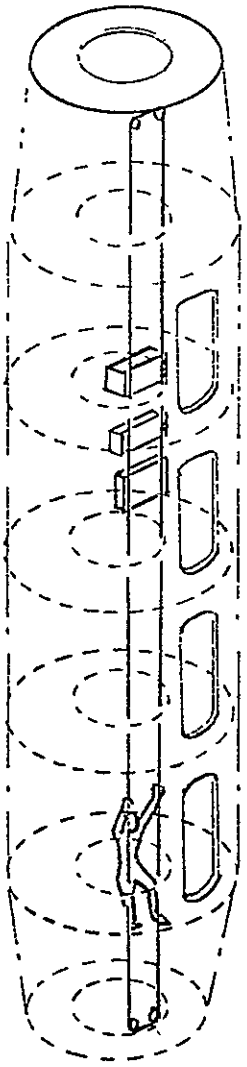
"Free floating" technique possible for translating between single floors; requires special skill and perhaps assistance from other personnel to aid in deceleration and capture.



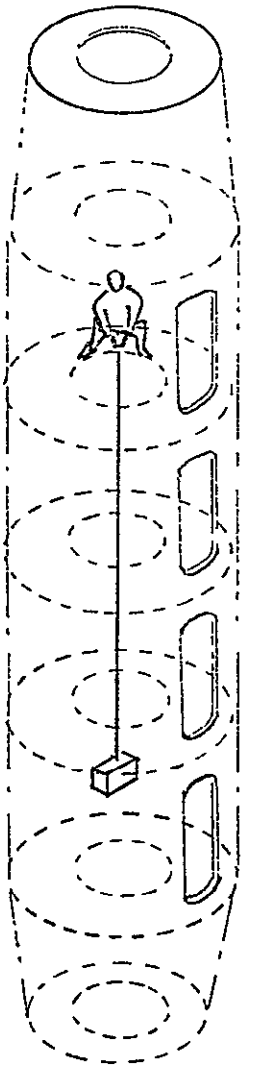
"Fire Pole" technique possible for personnel and small package transfer; would probably be extremely slow.



Elevator system would allow for transfer of palletized assemblage of packages and/or several persons at same time. Probably not possible to utilize more than one pallet at a time.



Dumb-Waiter Type System with detachable fastener assemblies allows packages to be attached at will; personnel can utilize in same manner.



SPAR system can be used independently from any floor for transfer of small packages.

APPENDIX C

PRELIMINARY HUMAN ENGINEERING CRITERIA FOR USE IN SPACE SHUTTLE CARGO TRANSFER SYSTEMS DESIGN [149]

During the current study it was natural that a number of human engineering design considerations should evolve. General criteria covering the following four principal problem areas have been defined and are presented for consideration by others who may be involved in developing various aspects of the Shuttle-Space Station Systems: (1) cargo packaging, (2) cargo stowage, (3) location of cargo, and (4) cargo transfer.

These criteria are not intended to represent a comprehensive listing of all the man/system interface principles that eventually must be considered. However they may provide an immediate and useful guide to hardware component and system design as it relates to in-space cargo handling.

1. SPACE CARGO PACKAGING DESIGN

Criteria for designing cargo packages so that they can be handled efficiently and safely, whether by a single crewman or by some combination of crew and equipment, fall into three general categories: (1) external package factors, (2) internal package factors, and (3) handling aids.

External Packaging Design Considerations

a. All cargo should be containerized where possible in order to minimize the possibility of damage, to make it easier to stow and transport, and to provide for reuse for DOWN cargo transfer.

b. Cargo containers should be designed so that they do not have sharp edges, corners or protuberances that could cause injury to personnel or damage to space vehicle structure or equipment with which they come into contact.

c. Containers should have resilient, shock-damping devices on exterior corners.

d. Containers should be vented where required to preclude rapid compression/decompression upon opening.

e. Simple, one-hand operated fastening latches (that can be operated either in shirtsleeve or space suit mode) should be provided. Latches should be of the "squeeze" type in which the operator provides his own closed-loop force system; latches should not stick out when they are open and thus create projection hazards. Integrated stowage/CTS attachment latch designs should be considered with self-aligning characteristics, fail-safe locking mechanisms and visual accessibility from the normal or expected viewing position.

f. Handholds for either or both zero-g and 1-g handling should be provided. These should be mounted for maximum ease in handling the loaded container under all anticipated conditions (e.g., zero-g and 1-g, one- and/or two-man carry, unique mass distributions, manipulation through hatches, into racks, on work benches, etc.). Handholds must be easily accessible but must not create projecting interference or hazard. (see Figure C-1)

g. Containers that are used to house a single, fairly heavy instrument should be designed so that the instrument is mounted to the base of the container, with the major portion of the container removable as shown in Figure C-2.

h. Containers should be as lightweight as practical but not at the expense of any of the previous criteria.

i. Provisions should be made for identifying containers from all normal viewing points (i.e., several sides). Labels should be located so that they will not be obscured while the package is in storage and can not be erased easily or obscured by typical handling. Color coding and other identification aids (see MIL-STD 167A) should be considered.

j. Package mass, mass distribution or other instructional information should be placed on the exterior in conspicuous locations to tell the astronauts whether the package can be handled safely by one man, whether two or more are required, or whether special transfer equipment should be used.

k. Cargo container identification marking should be consistent with all identification or instruction placards placed at permanent and semipermanent cargo storage locations on the space vehicles and in ground handling facilities.

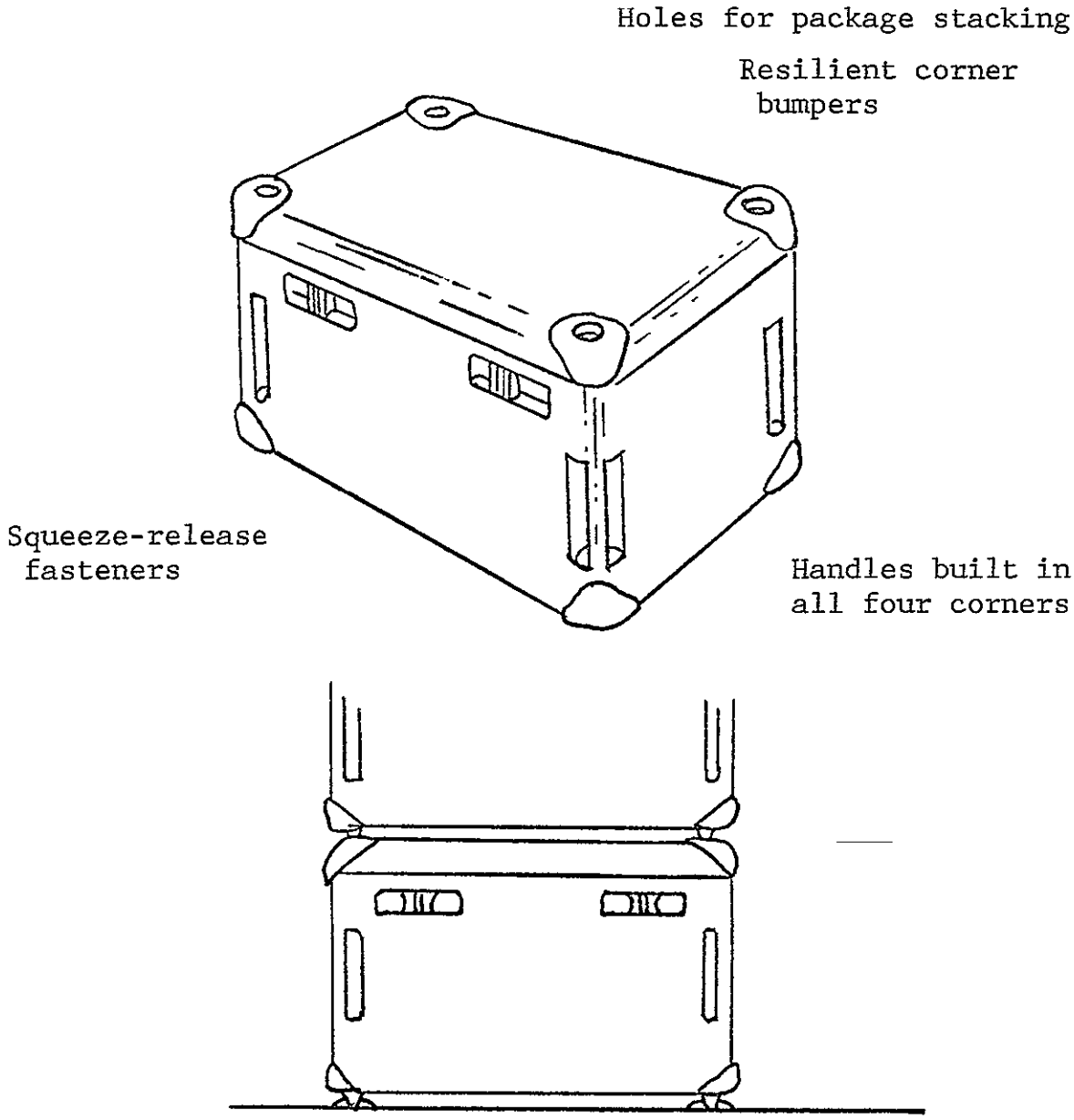


Figure C-1 - A Package Handhold Concept in Which Accessibility is Provided Without Introducing Projections or Making it Necessary to Erect the Handles

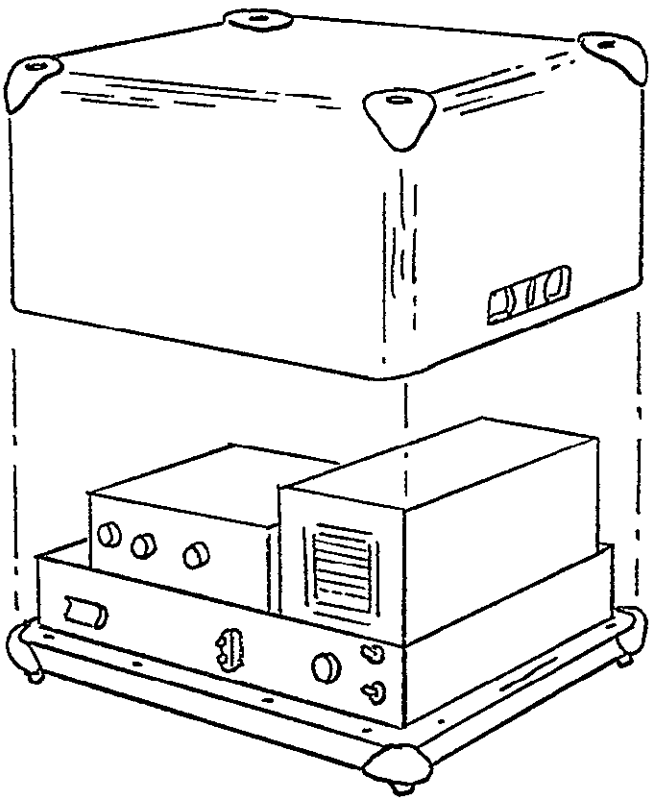


Figure C-2 - Example of Container Being Removed From Equipment to Avoid Lifting Equipment Out of Container

l. Whenever possible container shapes should be regular and flat sided, with sides normal to each other.

m. Container size variations should be kept at a minimum to avoid unnecessary inventory problems and general confusion.

n. Sizes and shapes of containers should be amenable to complementary stacking and nesting in order to save space. (see Figure G-3).

o. At least 2-inches of clearance should be available on all sides of the largest container relative to the limiting hatch dimension through which it must pass, in order to minimize the amount of time and care required to guide the package through the hatch.

p. In determining container shape and size, a consideration should be given to the problem of removing contents from a container (or the container from the contents) i.e., anticipating situations in which interference may be caused by adjacent structure or equipment.

q. The shape of a container should be such that it precludes the necessity for digging deep into the container to get items at the bottom, and does not impose difficulties in navigating the package around corners or rotating it through narrow passages. (see Figure C-4).

Internal Packaging Design Considerations

a. A system for internal securing of container contents should be provided to prevent them from shifting position within the container. Modular concepts should be devised to provide maximum flexibility for shipping and storing all shapes and sizes of equipment, materials, parts (e.g., removable partitions, molded forms, etc.). The system should be designed so that severe loads will not be imparted to fragile packages. It is desirable that the act of closing the container lid provides the final securing operation (as opposed to separate, numerous fastening steps).

b. Internal, package-securing materials and/or devices must be designed so that they will not be distorted by the expected shuttle departure loads and thus allow parts or equipment to move about within the container.

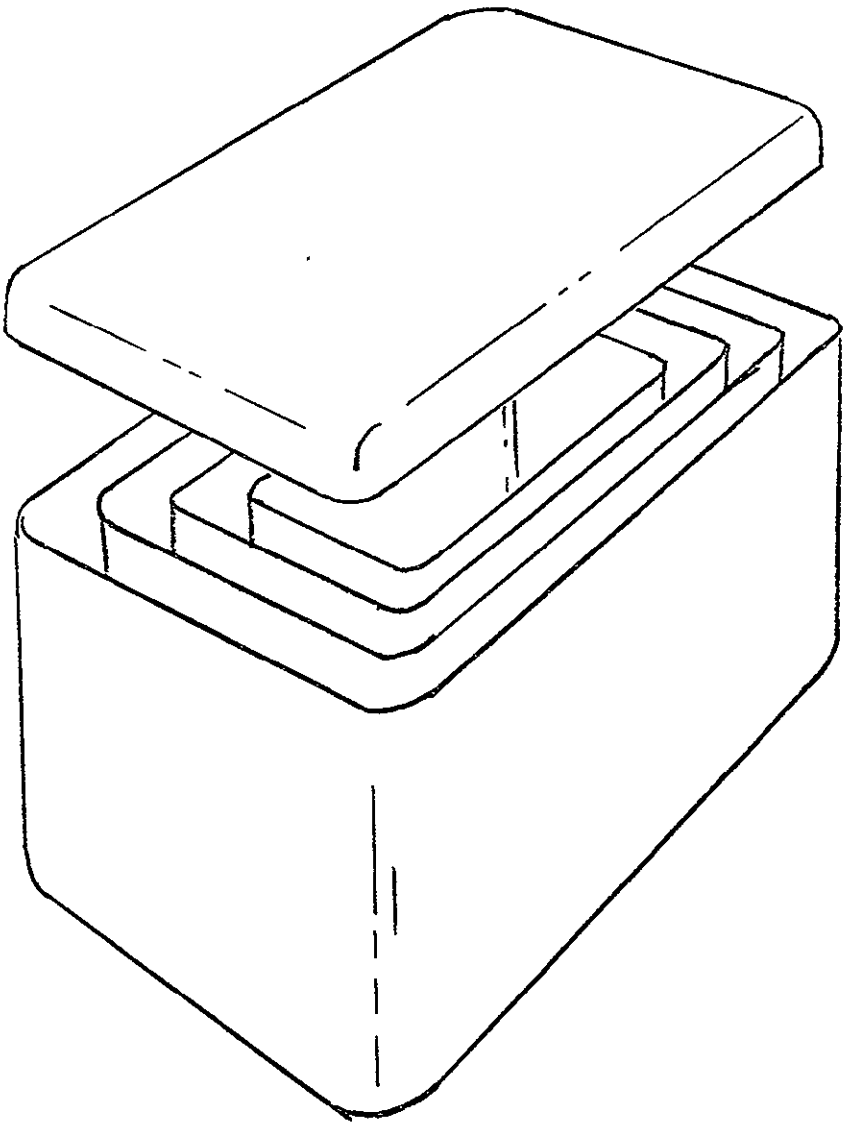
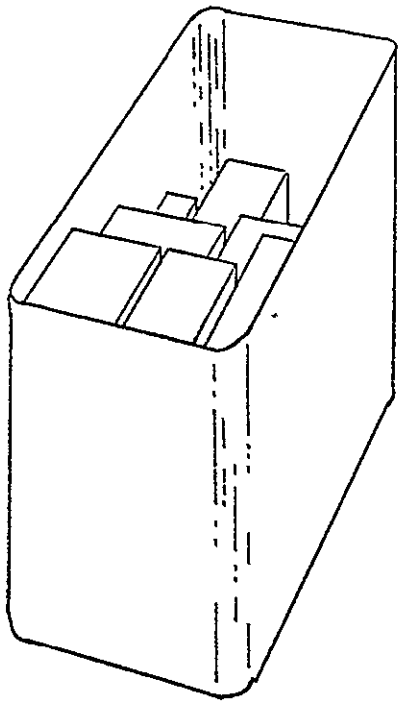
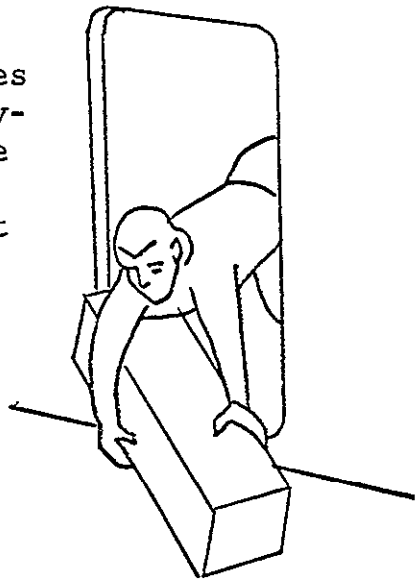


Figure C-3 - Nesting Container Modules Conserve Space When Not in Use



A "deep" package requires digging to retrieve items at the bottom of the container.

Certain container shapes present serious maneuvering problems for the crewman - especially when restraints cannot be located in optimum positions.



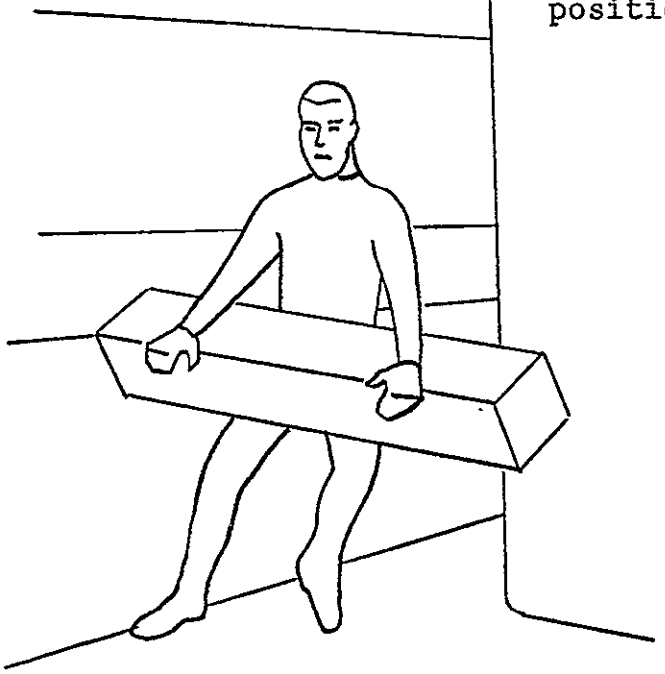


Figure C-4 - Container Shape Affects Cargo Handling

c. Internal compartmentalization should be considered not only to maintain physical separation but also to prevent odors, spillage, etc. where necessary. The compartmental system should be designed so that it is easy to get to one series of packages without necessarily removing others.

d. Special attention must be given to the control of internal package environment for containers that may be subject to severe shock, vibration, temperature extremes, humidity, etc. As noted earlier pressure venting may be required for opening or closing the container in space.

e. Where feasible, internal sensors with external monitors should be provided for containers where it is necessary that crewmen inspect for cargo integrity and useability prior to opening the container.

Hardware/Handling Aids Design Considerations

a. Consideration should be given to such matters as package tie-down (including appropriate design and the location of strap hardware that will be accessible but not create interference or hazard), fastening devices that are easily assembled and adjusted (preferably, operable with one hand), and total strap-down systemization, which precludes inadvertent introduction of slack that could allow the package to shift.

b. Slide-rack type package-mounting systems should be designed so that containers can be mated with the slide simply and quickly, with a minimum possibility of misalignment and binding, damage to the container, or injury to the astronaut. Such systems should require a minimum of energy to move the package but also must not allow the package to be pulled from the slide inadvertently -- or for the package to free itself from the slide because of vehicle-induced inertial forces. The system should be fail-safe.

c. Containers should have appropriate handholds on all four corners as shown in Figure C-5 so that the package can be manipulated from several sides.

d. Where it seems desirable to provide a single handle to manipulate small, lightweight containers a detachable, pistol-type handle should be designed so that it can be inserted

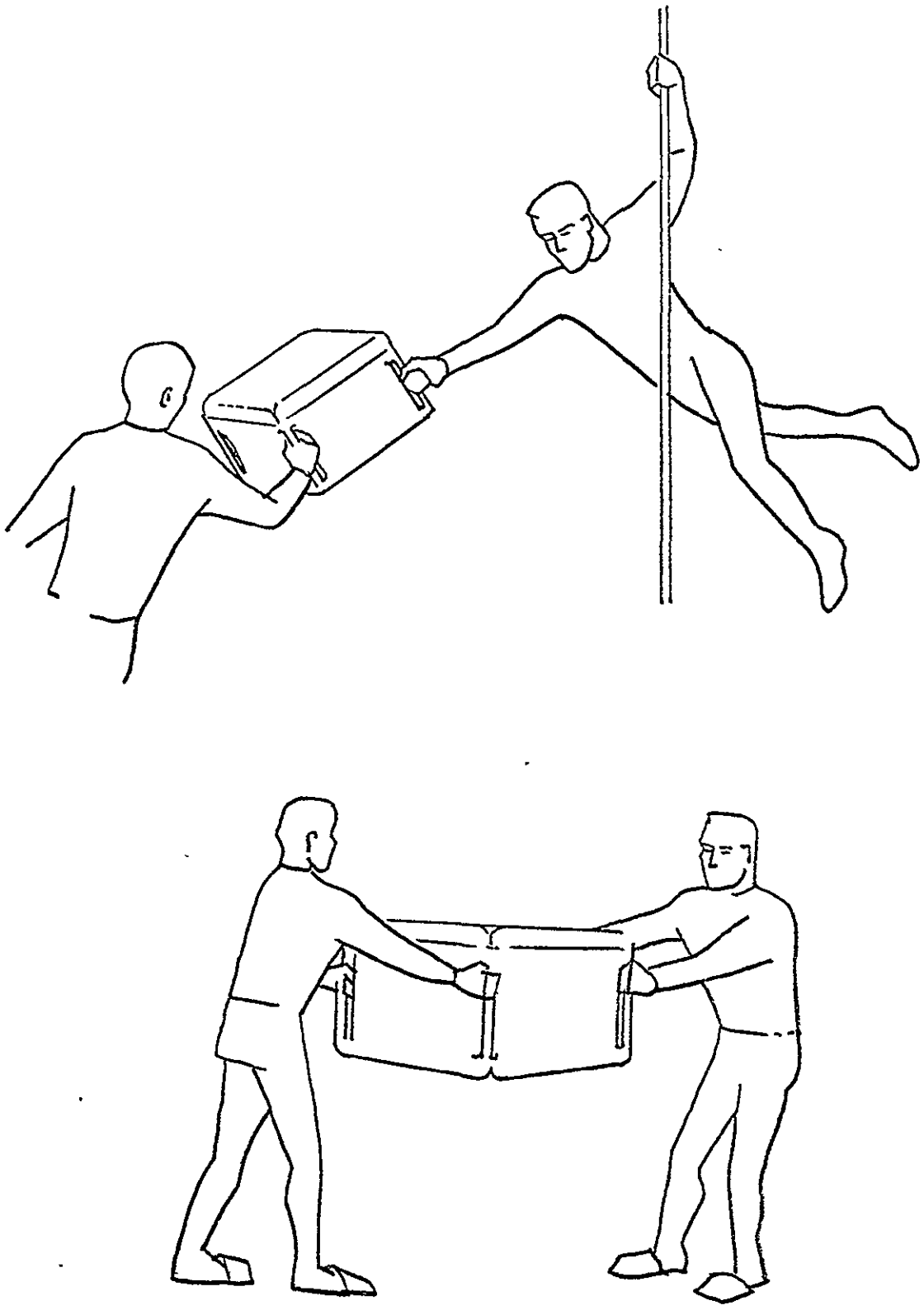


Figure C-5 - Handles at all Four Corners of a Package Provides Maximum Handling Flexibility

into a container reptacle and removed quickly without being subject to accidental disengagement. Tool interfaces should be located relative to the package center of mass so that the package will maintain and follow sppropoate inputs by the operator when the package is being moved from one place to another (see Figure C-6).

e. Where a portion of a container may remain as the base for an instrument or piece of equipment, appropriate fastening interface devices should be provided for mounting the base on a work bench or other appropriate surface. The design should be such that location and attachment requires a minimum of precise alignment or package manipulation. Wherever possible, interface designs should be compatible with requirements for container stacking.

2. CARGO STORAGE AREA DESIGN (C/CM)

This set of criteria provides preliminary guidelines for design and layout of areas where cargo removal, replacement, manipulation, and sometimes usage occurs. These criteria consider workspace requirements for manual handling.

C/CM Storage Area Design Considerations

a. Maximum flexibility should be provided in compartmentalizing cargo storage areas so that various size and shape multiples and quantities of cargo can be accommodated in a given compartment. Cargo compartment structure in the C/CM, for example, should be designed to fit the cargo containers, not vice versa.

b. Locator identification marking should be provided on or in compartment areas and be compatible with the cargo marking requirements outlined in Section 3.4.1.

c. Wherever possible cargo compartment stowage arrangements should bear some positional relationship to mission events and to Space Station organization so that first things needed come off first, farthest distances are minimized, etc.

d. Where design criteria a, b, and c are not violated, large, heavy containers requiring two man operations should be stored nearest the C/CM-SS transfer hatch. (This criterion

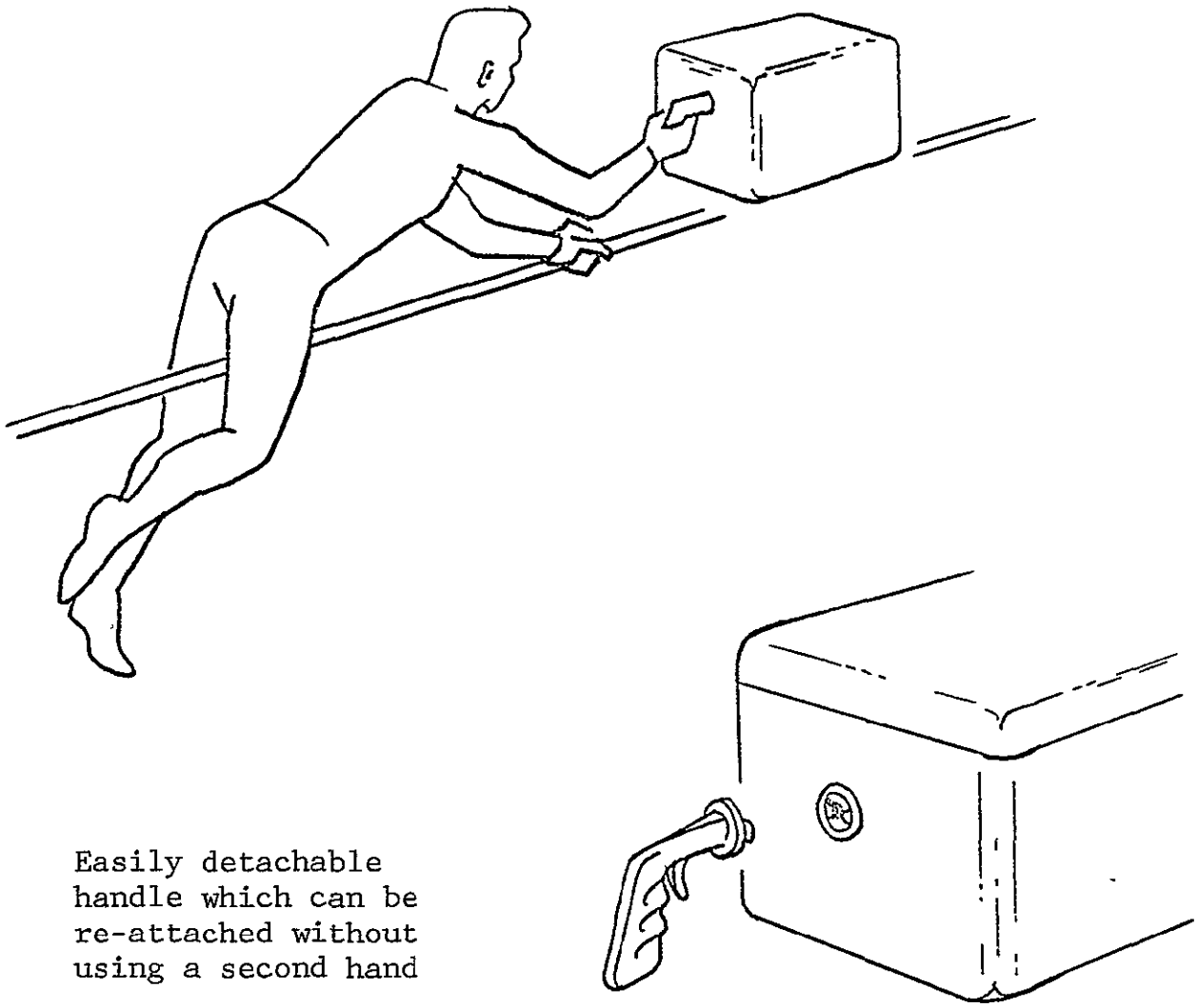


Figure C-6 - Pistol Grip Handle Provides More Efficient Method for Small Package Handling

is, of course, subject to the Shuttle vehicle center-of-gravity requirements.)

e. Cargo storage compartments should provide a means for securely restraining individual cargo containers in all directional axes until intentionally released by the crewman.

f. A positive, fail-safe method should be provided for determining that all cargo containers are secured properly. The crew should not have to checkout each container securing mechanism manually.

g. Container release mechanisms that are not integral to the cargo container should be operable by one hand and should be of the "squeeze" type, i.e., the operator provides his own closed force loop.

h. An open rectangular-shaped access space for retrieval of cargo from storage racks should be provided in the cargo bay of the C/CM. It should not be less than 4 inches wider than the largest diagonal measurement of any individual container of stowed cargo, not less than 6 ft. 2 inches high, and open at the end nearest the space station.

i. A series of foot restraints -- or a continuous foot restraint system -- providing complete upper torso and arm freedom to the crewman should be installed in the cargo bay retrieval area. The restraint system should permit the crewman to position his centerline within 20-30 inches standoff distance from the leading edge of any individual container to be handled in the cargo bay area.

j. The ambient illumination level in the cargo storage area should not be less than 10 foot candles while crewmen are working in the C/CM cargo.

k. No sharp edges or protrusions should be present in any portion of the storage area, particularly when containers are missing from racks.

l. If moving parts are utilized in the stowage system design, these should be protected so as to preclude inadvertent contact by crew members.

SS Space Cargo Storage Area Design Considerations

a. Storage areas should be located as close to user workstations as possible without causing interference with typical activity.

b. C/CM storage area labeling should be consistent with SS storage area labeling and should be immediately visible, legible and understandable.

c. Appropriate foot restraint systems permitting complete freedom of upper torso and arm movement should be provided for each storage area.

d. Where several items are to be removed in succession from a cargo container in the storage area, means should be provided to secure individual items at the immediate locale, i.e., a crewman should not be required to hold one item while trying to retrieve another.

e. Criteria b, e, f, g, j, k, from the C/CM Storage Design list also apply to the design of SS cargo storage areas.

f. If special handling placards are required at the storage area, they should be located so that they are easily visible when the cargo container is secured and stored.

3. CARGO LOCATOR/INFORMATION SYSTEMS

The functional and task analyses performed during this study imply an important requirement for identifying and locating cargo easily and quickly. To do this effectively in a complex geometric configuration such as the C/CM-SS, it is necessary to consider information needs at several points, e.g., at each deck of the SS and in the C/CM.

Although a locator/information system could be as simple as a series of card files and intercom positions, it may be more cost effective to provide an automated storage-retrieval-communication system. It is not the purpose of this section to recommend an actual system but rather to identify some of the characteristics such a system should have, plus some guidelines for designing such a system.

Preliminary analysis indicates that (at least) the following information should be known about each item of cargo:

a. Nature of contents of a package.

b. An identifying code, part, catalog, or other number that can be associated with its procurement and use.

c. Physical information relating to how to handle the package or its contents (i.e., whether it is fragile, needs refrigeration, should be kept in some particular position, should not be kept in storage longer than, etc.).

d. Destination and store information (i.e., where the package is located in the C/CM, where it is to go in the SS, the sequence in which it should be transferred, etc.).

In addition, certain information should be known about a container that may be independent of its contents but which is important to the handling and routing of the container. For example:

a. Container weight with and without content.

b. Handling instructions, i.e., lift points, whether it should be handled by one or two crewmen, disposition, etc.

c. Attachment and opening instructions relative to the particular transfer system in use (i.e., latches, fastener or closure hardware operation, container stacking requirements, stowage rack mating, etc.)

The mechanics of a locator/information system should be as simple as possible in terms of operating procedures. Laborious sorting, complex deciphering of codes, or abstract push button identifications should be avoided. The tendency toward sophisticated systems (which probably requires a specialist to understand and operate it), should be avoided since the crew complement of the planned SS mission will be fully occupied with other primary assignments which, if nothing else, will occupy each individuals major attention and interest. A complex,

coded cargo information system would be very distasteful to these men under any circumstance.

4. CARGO TRANSFER SYSTEMS

The last set of criteria generated by the present study relates to specific cargo transfer systems hardware design. As with the previous criteria an assumption is made that man will always be involved somewhere in any cargo transfer system -- at least in a backup capacity. The following criteria are largely an outgrowth of the tradeoff analysis and were developed while trying to describe pertinent parameters of transfer systems.

Transfer System Operability (in zero-g)

a. A cargo transfer system should be capable of moving a package approximately 5 x 4 x 3.5 ft.; weighing up to 500 lbs/mass; a distance of up to 40 feet including a 90° turn; at a rate of up to 0.5 ft/sec. Acceleration and deceleration capability should be on the order of 0.1 ft./sec/sec for the above maximum cargo package.

b. A cargo transfer system should be capable of stabilizing a 350-lb cargo package in all axes, within 5 sec., with no more than a 6-inch total displacement in any axis from the intended path.

c. The cargo transfer system should be capable of positioning the centerline axes of any cargo item within $\pm$ 3 inches of the center of any hatch or limited passageway.

d. If controls or displays are required to operate the cargo transfer system they should conform to MSFC Human Engineering STD-267A and MSFC Drawing 10 M 32158.

Transfer System Safety

a. If a failure occurs the cargo transfer system should not block free manual translation of personnel or cargo to any point in the C/CM or Space Station. This implies that the cargo transfer system should have an alternate manual power mode or that it can be completely circumvented.

b. The cargo transfer system should not obscure the field

of view within the SS cargo transfer tunnel area so that on-loading or other activities might introduce hazards to personnel, i.e., it should always be possible to check the transfer path visually before the system is put in motion.

Cargo Transfer System Erection, Assembly and Maintainability

a. The number of elements that have to be erected or assembled before the CTS becomes operational should be minimized.

b. CTS elements or parts should be stowable at or near the points at which they are to be erected or assembled. It is preferrable that they be captive and need only to be "swung into place," or the system should be designed so that it is a permanent installation.

c. A minimum time should be required to erect, assemble and/or otherwise get the system ready for operation. This should not exceed one hour, if possible, and should not be required more than once per C/CM deployment.

d. System erection or assembly should not require more than two crewmen.

e. A maintainability goal for semi-automatic transfer systems should be that they can be repaired (at least 90%) within no more than one hour and that the minimum number of special tools will be required (preferably, no tools).

f. Maintainability guidelines contained in MSFC STD 267A concerning test point provisions, component replacement accessibility, quick-release, captive fasteners, access covers, etc. Should be followed wherever possible in the design of semi-automatic transfer systems.

g. Transfer systems should be designed so that a minimum of special skills and training is required to service and maintain them.