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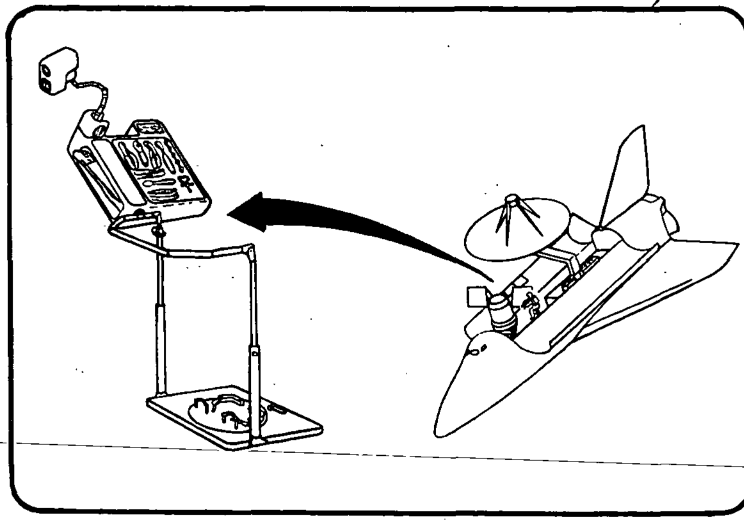

APPLICATION OF EVA GUIDELINES AND DESIGN CRITERIA

VOLUME II - EVA WORKSTATION CONCEPTUAL DESIGNS

FINAL REPORT
APRIL 1973

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APPLICATION OF EVA GUIDELINES AND DESIGN CRITERIA

FINAL REPORT

CONTRACT NAS9-12997

VOLUME II - EVA WORKSTATION CONCEPTUAL DESIGNS

PREPARED FOR:

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FOREWORD

This study contract (NAS9-12997) was awarded by the NASA Johnson Space Center (JSC) to (1) provide information and data concerning orbital Extravehicular Activities (EVA's) in a format most useful to mission planners and experiment designers, (2) develop conceptual design(s) of versatile EVA workstations for future space application, and (3) initiate development of a model for estimating the impact of EVA costs on future payloads.

The report herein is a summary of the technical effort, an overview of the activities performed during the contract effort, and a presentation of the study results pertaining to EVA Workstation Conceptual Design--Volume II.

This report is presented in three volumes as follows:

Volume I: EVA Selection/Systems Design Guidelines and Considerations

Volume II: EVA Workstation Conceptual Design

Volume III: EVA Systems Cost Model

PREFACE

The United States' manned spaceflight programs prior to Skylab have qualified EVA as an operational technique for performing orbital and deep space mission functions outside the spacecraft. The Skylab program will capitalize on the established EVA techniques and equipment to retrieve solar astronomy experiment data, contained in film magazines, from the Skylab Apollo Telescope Mount (ATM). The Space Shuttle vehicle, which will begin orbital tests in the late 1970's, will afford the opportunity to perform a variety of tasks outside the spacecraft--perhaps more economically than any other method. Further, it is anticipated that spaceflights beyond the Space Shuttle and Modular Space Station will utilize manned EVA to great extents, and that each future mission will provide for backup and contingency operations to enhance mission success, including mandatory provisions for crewman safety and rescue.

Since the EVA capability currently appears to be a requirement for many future manned spaceflights, it is desirable to provide the mission planner and vehicle, experiment, and payload designers with information and data concerning the selection of man for extravehicular (EV) functions. This study provides an overview of the factors that must be considered when investigating man as EV method, defines the impact that man and EV equipment have on the mission, vehicle, and payload, and provides conceptual EV workstation designs for performing the EV functions. The study also initiates development of an EVA systems model to allow payload and experiment designers to assess the impact of EVA in terms of costs to future payloads.

In Volume I, parameters that require consideration by the planners and designers when planning for man to perform functions outside the vehicle are presented in terms of the impact the extravehicular crewmen and major EV equipment items have on the mission, vehicle, and payload. Summary data on man's performance capabilities in the weightless space environment are provided. The performance data is based on orbital and transearth EVA from previous spaceflight programs and earthbound simulations, such as water immersion and "zero-g" aircraft.

Several EV workstation concepts were developed and are documented in Volume II of this report. The workstation concepts were developed following a comprehensive analysis of potential EV missions, functions, and tasks as interpreted from NASA and contractor Space Shuttle and Space Station studies, mission models, and related reports. The design of a versatile, yet portable, EVA workstation is aimed at reducing the design and development costs for each mission and aiding in the development of on-orbit serviceable payloads. The workstation concepts developed and supporting data are presented in this volume of the report - Volume II.

The development of a model for estimating the impact of manned EVA costs on future payloads was initiated during the study. Basic information on the EV crewman requirements, equipment, physical and operational characteristics, and vehicle interfaces is provided. The cost model is being designed to allow system designers to quantify the impact of EVA on vehicle and payload systems. The results of this effort are contained in Volume III.

ACKNOWLEDGEMENTS

The NASA Technical Monitor for this study was Mr. David C. Schultz, Chief, EVA and Experiments Branch (CG3), Crew Procedures Division, Flight Crew Operations, Johnson Space Center, Houston, Texas. Technical direction for the study was provided by Mr. Schultz; valuable assistance in obtaining information and data was supplied by personnel within the EVA and Experiments Branch. Appreciation is expressed to Dr. Stanley Deutsch, Director, Bioengineering Division, Office of Life Sciences, NASA Headquarters, for his worthy suggestions and assistance in arranging for the conduct of the study.

The contractor Principal Investigator for the study was Mr. Nelson E. Brown, Division Director, Life and Environmental Sciences Division, URS/Matrix Company, URS Systems Corporation. Principal contributors within the URS/Matrix Company were Dennis C. DeWitt and G. Lloyd Philpot.

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1.1 INTRODUCTION

The variety of future missions with candidate EVA requirements necessitates a new approach to the design of EVA systems. Payloads currently being planned for the Space Shuttle vary in area of interest from earth observation to materials science, and in configuration from small free-flying satellites to manned sortie laboratories.

A portion of the study effort reported in this document was devoted to the development of initial concepts of EVA workstations for future applications. The major objectives of this task were to identify EVA missions associated with future payload and experiment delivery elements for defining EVA tasks, and to develop initial EVA workstation concepts.

At the outset, it was established that the EVA workstations would have to support a wide variety and large number of tasks. This was established as a guideline so that concepts could be evolved which would reduce the design/development costs of EVA systems through utilizing standardized hardware.

The approach that was employed in the workstation concept effort involves four major tasks:

(1) A study of NASA and contractor future missions and payloads documentation for EVA task identification.

(2) An analysis of the factors which impact workstation configuration (task, payload configuration, payload location, crew performance capabilities, crewman support gear, etc.).

(3) A definition of known crewman/equipment performance characteristics.

(4) An integration of the above parameters to develop EVA workstation concepts.

The overall result of the effort is a series of conceptual designs of EVA workstations which include stabilization aids, tools, stowage, safety provisions, etc.

The first task in the workstation development effort was an analysis of future missions and payloads documentation. To accomplish this, both the 1971 and 1972 NASA Mission Models were analyzed. Figure 1-1 illustrates how both mission models were used in deriving workstation requirements.

The 1972 Mission Model was considered in conjunction with, and an expansion to, the URS/Matrix Company study entitled "Teleoperator Systems Performance Requirements" (NAS8-27013). The low earth orbit missions of the 1972 Model were compared with the extravehicular tasks identified in the URS/Matrix studies. Supporting the data from the Matrix studies were the NASA JSC EVA/IVA Support Requirements Studies (Hamilton Standard Division and LTV Aerospace Division), the Research and Applications Modules (RAM) and Shuttle Orbital Applications and Requirements (SOAR) reports, and Large Space Telescope (LST) Program documentation.

Another alternative in payload configurations has been developed in the Lockheed Missiles and Space Company (LMSC) Low-Cost Payloads Study. The most current documentation for this effort utilizes the 1971 Mission Model. The LMSC study was considered to be representative of the extreme modularization end of the payload spectrum. By using these data, consideration was given to the most standardized interface that an EVA crewman could expect to encounter. With respect to standardization, the LMSC study represented a "best case" for EVA workstation design.

From the analysis of missions and payloads, it was determined that the major workstation design drivers are (1) package handling tasks, (2) payload handling tasks, and (3) experiment/payload interfaces. The design parameters

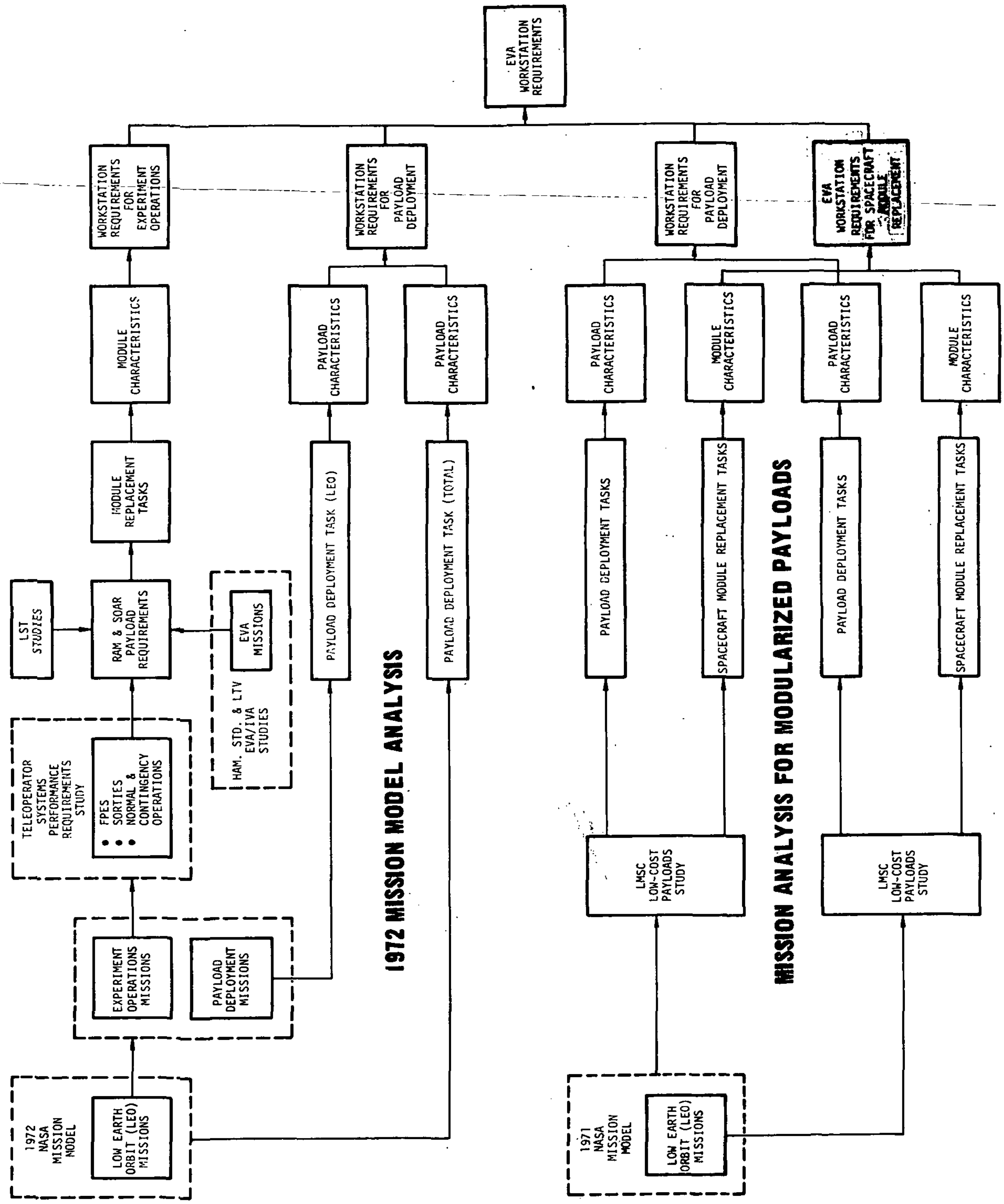


FIGURE 1-1: MISSION ANALYSIS PROCESS

were quantified before workstation concepts were developed. These parameters are presented in later sections of the report.

In order to effectively utilize our knowledge about EVA to date and how it relates to future missions, inflight and simulated EVA crewman capabilities were defined. These data were collected so that they could later be compared to package and payload handling requirements defined from the mission and payload analysis.

The requirements defined in the mission and payloads analysis were then integrated with the known crewman/equipment capabilities data to develop workstation requirements. The workstation requirements were subsequently used to develop preliminary workstation concepts which were evaluated on a cost/effectiveness basis. Preferred concepts were evolved for inclusion in subsequent study phases. The sections to follow describe in detail the methodology and findings of each subtask of the workstation concept development effort.

2.1 1972 NASA MISSION MODEL

Two major sets of workstation requirements were derived through the analysis process presented in Figure 2-1. The low-earth orbit (LEO) payloads from the 1972 NASA Mission Model* were reviewed with respect to payload deployment tasks and experiment operations. The entire NASA Mission Model (i.e., excluding DOD missions which are flown separate from NASA) was then considered in relation to payload deployment. Tables from the traffic model containing (1) the NASA payload characteristics and schedules used in the traffic model, (2) the distribution of payloads per Shuttle flight and number of flights between 1979 and 1990, and (3) a summary of an unlimited model and a "more realistic" traffic model are contained in Appendix A.

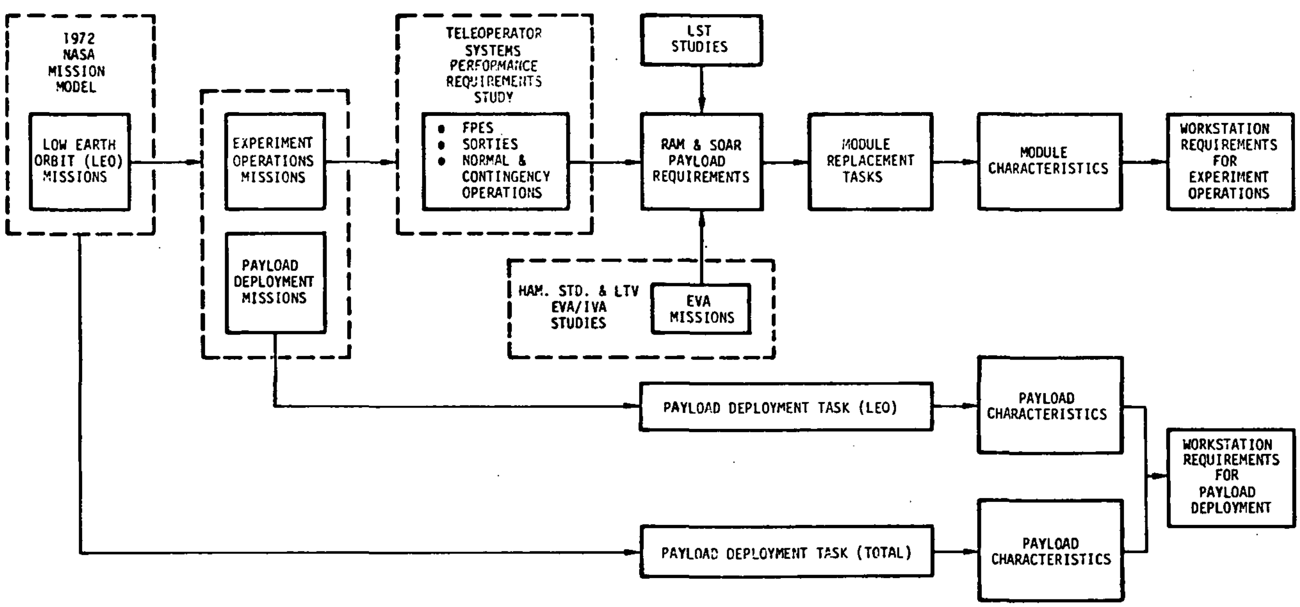


FIGURE 2-1: 1972 MISSION MODEL ANALYSIS

*(NASA/DOD Earth Orbit Shuttle Traffic Model in Support of the March 1972 Request for Proposal)

The low-earth orbit payloads (31 total) designated by NASA/JSC are listed in Table 2-1. The payload reference number, payload title, and number of missions are included. These payloads represent a total of 225 missions in the period between 1979 and 1990. Payload deployment tasks were identified for missions by assuming that each free-flying or low-orbit satellite payload required manually-assisted deployment. The payload weight and dimensions given in the Mission Model were used to derive the payload characteristics required for workstation design. One hundred eighty-four (184) missions representing 19 LEO payloads (PD column in Table 2-1) were selected for inclusion in the payload deployment analyses described in Subsection 2.2.4. The payloads range from small research satellites (e.g., Bioresearch Module) to large free-flying observatories (e.g., LST).

The 31 low-earth orbit payloads were also considered with respect to on-orbit experiment operations. Sixteen (16) payloads (EM column in Table 2-1) representing 79 missions were utilized to derive workstation requirements. The payloads in this group were selected as representative of small satellites, sortie pallets, and shuttle-based sortie labs. This derivation employed the mission analysis results of contract NAS8-27013, Teleoperator Systems Performance Requirements, which identified servicing tasks for most shuttle-based experiments. The extravehicular tasks identified in this study were combined with the component size and weight values stated in the RAM Study (NAS8-27539). Additional tasks and module dimensions were derived from the EVA tasks specified in the Space Shuttle EVA/IVA Support Requirements Studies (NAS9-12506 and NAS9-12507) and the Large Space Telescope (LST) documentation prepared by MSFC. Data from these sources were pooled to establish workstation requirements for experiment operations.

In addition to the LEO analysis, the entire 1972 Mission Model, excluding three palletized experiments (nos. 46, 47, and 49) and nine attached RAM-type payloads (nos. 61-69), was reviewed for payload deployment. In this analysis, a total of 605 deployment missions (72 payloads) was identified. For this study, the weights and volumes of kick-stages were not added into the deployment requirements. Since several payloads will be clustered on a single kick-stage,

TABLE 2-1: LOW EARTH ORBIT PAYLOADS FROM 1972 MISSION MODEL

PAYLOAD NUMBER	PAYLOAD TITLE	# MISSIONS	PD[1]	EM[2]
1a	Astronomy explorer	15	●	●
6	Orbiting Solar Observatory	1	●	●
13	High Energy Astronomical Observatory (HEAO)	4	●	●
14	HEAO revisit	22	●	●
15	Large Space Telescope (LST)	3	●	●
16	LST revisit	17	●	●
17	Large Solar Observatory (LSO)	3	●	
18	LSO revisit	13	●	
19	Large Radio Observatory (LRO)	2	●	
20	LRO revisit	10	●	
38	General science research module	16	●	
39	General applications research module	19	●	
40	Dedicated science and research module astronomy	27	●	
41	Dedicated applications module Earth Observation	17	●	
42	Earth observation	4	●	●
43	Bioresearch module	1	●	●
44	Astronomy	7	●	●
45	Fluid management	2	●	●
46	Teleoperator	1		●
47	Manned work platform	1		●
48	Large telescope minimum test	1	●	●
49	Astronaut maneuvering unit	1		●
61	Station	1		
62	Station modules	25		
63	RAM	6		
64	Physics laboratory	1		
65	Cosmic ray laboratory	1		●
66	Life science laboratory	1		
67	Earth observations laboratory	1		
68	Communications/Navigation laboratory	1		●
69	Space manufacturing laboratory	1		
31	TOTALS	225	184	79

[1] PD - PAYLOAD DEPLOYMENT   [2] EM - EXPERIMENT MODULES

the payloads were considered individually for planning purposes. In determining payload deployment requirements, it was assumed that each payload is deployed with some degree of manual assistance.

2.1.1 Typical Tasks

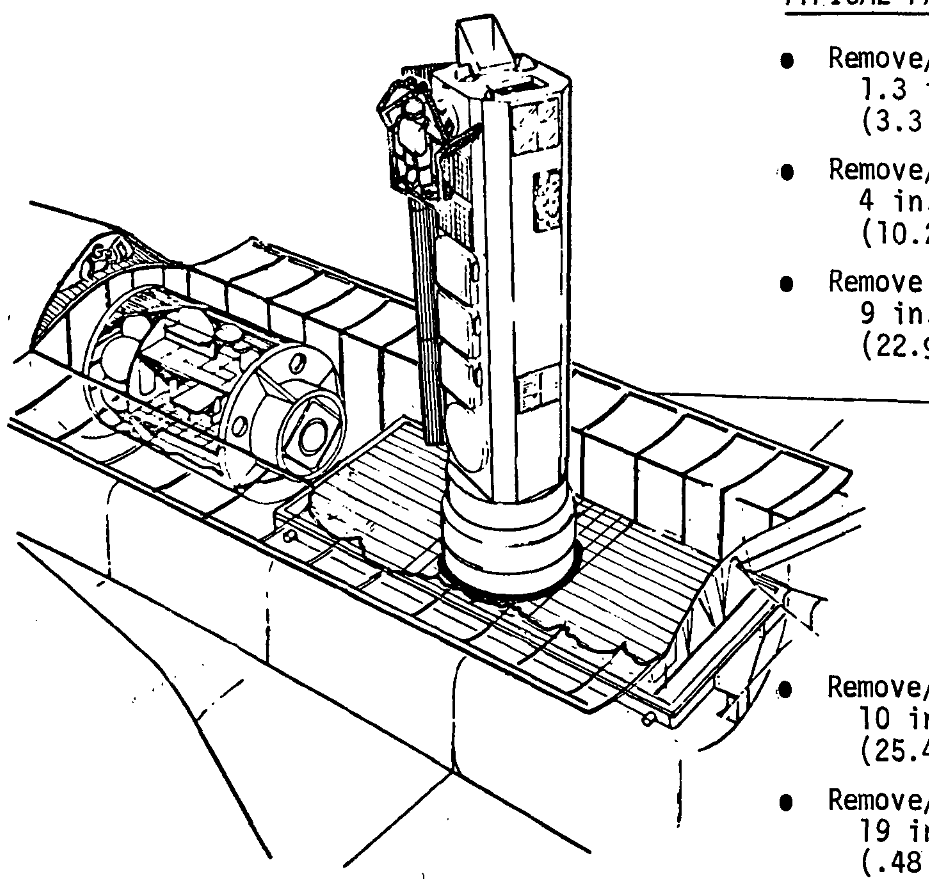
Two typical missions were selected for inclusion in the report as being descriptive of representing major mission classes. The High Energy Astronomical Observatory (HEAO) Servicing Mission (no. 14) is illustrated in Figure 2-2 to depict the types of package handling tasks and weights/dimensions used to derive the experiment operations requirements imposed on the workstation. Seventy-nine (79) missions similar to HEAO servicing were carried through the analysis. Quantities of identical modules are not reflected in the summary charts which follow. Since payloads are not defined in detail, and only representative packages are being considered, it was not necessary to consider quantities of identical packages. A total of 307 packages were identified in the 79 experiment operations missions.

Figure 2-3 illustrates the Intermediate Communications/Navigation Research Laboratory (payload no. 68 from the 1972 Mission Model) which was selected to depict the types of tasks considered from the shuttle-based sortie laboratories. As discussed above, quantities of packages or modules were not considered in the study.

2.1.2 Package Weight and Volume Distribution

Since package handling was considered to be a major workstation design driver, package weight and volume were critical parameters. Table 2-2 presents the distribution of package weight and volume for the LEO missions from the 1972 Mission Model.

The Mission Model was reviewed to identify package handling tasks for the 79 LEO missions which involved 16 payloads. Included in these payloads are the large observatories (e.g., LST, HEAO), free-flying sortie payloads (e.g., astronomy, earth observation), and sortie laboratories (e.g., physics,

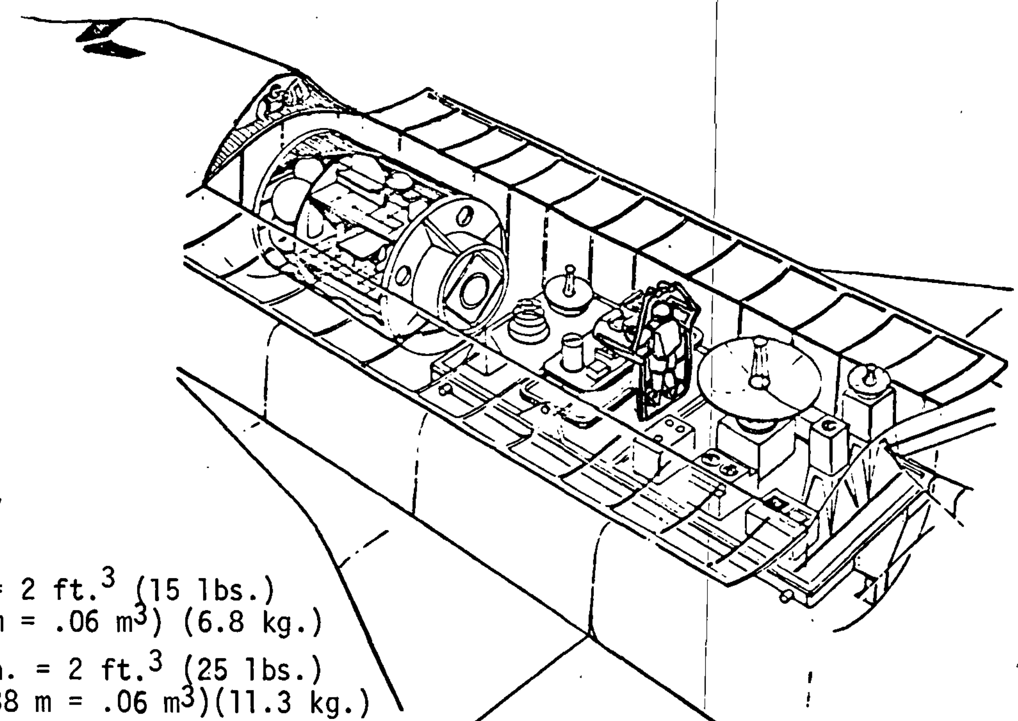


TYPICAL PACKAGE HANDLING TASKS:

- Remove/Replace Contamination Gages
  1.3 in. dia. x 3.5 in. = 4.6 in.^{3} (.5 lbs.)
  (3.3 cm. dia. x 8.9 cm. = 76.0 cm^3 (.23 kg.)
- Remove/Replace Mass Spectrometer Sensor
  4 in. dia. x 6 in. = 75.4 in.^{3} (2 lbs.)
  (10.2 cm. dia. x 15.2 cm. = 1235.2 cm.) (.9 kg.)
- Remove Star Tracker Shield
  9 in. dia. x 13.5 in. = .50 ft.^{3} (43 lbs.)
  (22.9 cm. dia. x 34.3 cm. = .01 m^3) (19.5 kg.)
- Remove/Replace Optical Contamination Monitor
  10 in. x 14 in. x 6 in. = .49 ft.^{3} (22 lbs.)
  (25.4 cm. x 35.6 cm. x 15.2 cm. = .01 m^3) (10.0 kg.)
- Remove/Replace Image Intensifier Power Control Unit
  19 in. x 11.8 in. x 24 in. = 3.1 ft.^{3} (60 lb.)
  (.48 m x .30 m x .61 m = .09 m^3) (27.2 kg.)
- Resupply Cryogenics - 44 lb. (20.0 kg.)

FIGURE 2-2: TYPICAL TASKS - HIGH ENERGY ASTRONOMICAL OBSERVATORY (HEAO) SERVICING

TYPICAL PACKAGE HANDLING TASKS:



- Clean Lenses
- Remove/Replace Optical Components
- Align Optical Components
- Remove/Replace Optical Transmitter/ Receiver Systems
  - Laser Receiver 15 x 15 x 15 in. = 2 ft.^{3} (15 lbs.) (.38 x .38 x .38 m = .06 m^3) (6.8 kg.)
  - Laser Transmitter 15 x 15 x 15 in. = 2 ft.^{3} (25 lbs.) (.38 x .38 x .38 m = .06 m^3)(11.3 kg.)
- Deploy Subsatellite (8 Total) 17 x 17 x 48 in. = 8 ft.^{3} (200 lbs.) (.43 x .43 x 1.2 m = .23 m^3) (90.7 kg.)
- Position Antenna - 40 in. dia. x 12 in. = 8.7 ft^3 (12 lbs.) (1.0 m x .3 m = .25 m^3) (5.4 kg.)
- Microscopically Inspect Inner Walls of Microwave Test Sections (Microwave noise generator 8 x 8 x 8 in. = .3 ft^3 (20 x 20 x 20 cm. = .008 m^3) weighing 6 lbs. (2.7 kg.)
- Deploy Navigation Sensors 13 x 13 x 13 in. = 1.3 ft^3 (40 lbs.) (.33 x .33 x .33 m = .036 m^3) (18.1 kg.)
- Mate Mechanical and Electric Fasteners
- Align Antenna

FIGURE 2-3: TYPICAL TASKS - INTERMEDIATE COMMUNICATIONS/NAVIGATION RESEARCH LABORATORY

TABLE 2-2: PACKAGE WEIGHT AND VOLUME DISTRIBUTION FOR 79 LOW EARTH ORBIT (LEO) MISSIONS FROM 1972 MISSION MODEL

WEIGHT - lbs (kg.)	VOLUME - ft^3 (m^3) 0-.3 (0-.008)	.31-.5 (.009-.014)	.51-1.0 (.014-.02)	1.1-5.0 (.03-.14)	5.1-10 (.14-.28)	11-20 (.31-.56)	21-40 (.59-1.13)	>40 (>1.13)	TOTAL
1 (.45)	15%		7%						22%
1-10 (.45-4.5)	11%	7%		.4%					18.4%
11-30 (5.0-13.6)		.4%	9%	1%	.3%			1.3%	12%
31-100 (14.0-45.4)	8%	7%	1.3%	9%					25.3%
101-200 (45.8-90.7)				7%	7%	2%	2%		18%
201-400 (91-181)					3%	1%			4%
>400 (>181)								.3%	.3%
TOTAL	34%	14.4%	17.3%	17.4%	10.3%	3%	2%	1.6%	100%

communications/navigation). The package (module) weights and dimensions were derived from program documentation. The package (module) assortment included antennas, power supplies, solar arrays, sensors, gages, sun shields, etc.

As indicated by the unshaded area on the chart, over 75% of the package handling tasks identified appear to be within simulated EVA crewman capability. This frequency distribution was based upon the 307 package handling tasks previously referenced.

To illustrate the use of Table 2-2, select an earthweight range of 1-10 lbs. (.45-4.5 kg.) and a volume of less than 0.3 $ft.^3$ (.008 m^3). According to the table, 11% of the packages (i.e., 11% of 307 packages) which must be handled in 79 low earth orbit missions are in this weight and volume region. Since this cell appears in the unshaded area, it is within demonstrated EVA crewman capabilities.

2.1.3 Package Dimension Distribution

The LEO missions discussed above were further studied to establish package (module) dimensions (see Table 2-3). Since the packages are likely to be handled by an EVA crewman, it was considered relevant to define largest and second largest dimensions to augment the weight and volume data shown earlier.

Less than 2% of the packages were found to be larger than 6 x 6 ft. (1.83 x 1.83 m) in their two largest dimensions. As indicated by the unshaded area on the chart, approximately 83% of the package handling tasks identified appear within simulated EVA crewman capability. The workstation concepts described later in this report will allow packages up to 6 x 6 ft. (1.83 x 1.83 m) to be handled (provided excessive weights are not involved) without special provisions. As the workstation design progresses into subsequent phases, the ability to handle larger packages will be analyzed in detail.

The frequency distribution shown in Table 2-3 was based upon 306 package handling tasks. Dimensions were not specified for one of the package handling tasks previously included in the weight and volume analysis.

TABLE 2-3: PACKAGE DIMENSION DISTRIBUTION FOR 79 LOW EARTH ORBIT (LEO) MISSIONS FROM 1972 MISSION MODEL

SECOND LARGEST DIMENSION-ft. (m)	LARGEST DIMENSION - ft. (m) .2-1.0 (.06-.30)	1.1-2.0 (.34-.61)	2.1-3.0 (.64-.91)	3.1-6.0 (.94-1.8)	6.0 (1.8)	TOTAL
≤ .2 (.06)	16%					16%
.2-1.0 (.06-.30)	18%	24%	.8%	.4%	6%	49.2%
1.1-2.0 (.34-.61)		10%	14%	2%		26%
2.1-3.0 (.64-.91)			2%	5%		7%
3.1-6.0 (.94-1.8)				.4%		.4%
6.0 (1.8)					1.4%	1.4%
TOTAL	34%	34%	16.8%	7.8%	7.4%	100%

2.1.4 Payload Deployment

The EVA crewmen may be required to independently deploy payloads or serve as a backup mode for the manipulator systems currently being studied and for automated systems. Considering these possibilities, an analysis was made of payload weights and volumes. Kick-stage weights and volumes were not included in this analysis since the payloads alone appeared to be beyond presently demonstrated EVA capabilities. Furthermore, payloads may be clustered onto a single kick-stage, depending upon the exact capabilities of the kick-stages, which would far exceed the demonstrated EVA capabilities if cluster payload deployment were required.

2.1.4.1 Low Earth Orbit (LEO) Missions

The payload weight and volume frequency distribution for 184 LEO missions (listed in Table 2-1) from the 1972 Mission Model are summarized in Table 2-4. The 184 missions represent 19 different LEO payloads. As indicated by the shading on the chart, the majority of deployment missions involve payloads weighing more than 2000 lbs. (907.2 kg.) and containing volumes greater than 1500 ft.^{3} (42.5 m^3). The EVA crewman's capability to perform tasks in this area is unknown at this time. Research is underway to evaluate single and dual crewman deployment of a module which weighs 8500 lbs. (3856 kg.) and is 19 ft. (5.8 m) long by 3.5 ft. (1.1 m) in diameter. These simulation data, when released by JSC, will be included in subsequent phases of this study along with information concerning planned simulations at the Marshall Space Flight Center's water immersion facility for handling up to 65,000 lbs. (29,484 kg.).

2.1.4.2 Total 1972 Mission Model

Table 2-5 presents the payload weight and volume distribution for 605 missions involving 72 different payloads. With the exception of three pallet-type experiments (nos. 46, 47, and 49) and nine attached RAM series payloads (nos. 61 through 69), this frequency distribution is representative of the total 1972 NASA Mission Model. As indicated by the shading on the chart, approximately 87% of the payload deployment missions are in an area of currently undetermined EVA crewman capability if manual deployment is required (Note: kick-stages not added).

2.2 MISSION ANALYSIS FOR MODULARIZED PAYLOADS

To include the modularized payloads concept in the mission and payloads analysis, documentation from the Lockheed Missiles and Space Company (LMSC) study entitled "Impact of Low Cost Refurbishable and Standard Spacecraft Upon Future NASA Space Programs" was reviewed. This latest Lockheed low-cost payloads report was based on the 1971 NASA Mission Model.

TABLE 2-4: WEIGHT AND VOLUME DISTRIBUTION FOR 184 LOW EARTH ORBIT (LEO) PAYLOAD DEPLOYMENT MISSIONS FROM 1972 MISSION MODEL

WEIGHT - lbs. (kg.)	VOLUME - ft.^{3} (m^3)									TOTAL
	50-100 (1.4-2.8)	101-200 (2.9-5.7)	201-300 (5.7-8.5)	301-500 (8.5-14)	501-1000 (14-28)	1001-1500 (28-43)	1501-2000 (43-57)	2001-5000 (57-142)	>5000 (>142)	
500-750 (226.8-340.2)										
751-1000 (340.7-453.6)	8%									8%
1001-2000 (454.0-907.2)				.5%						.5%
2001-5000 (907.7-2268.0)							34%		.5%	34.5%
5001-10,000 (2268.5-4536.0)									7%	7%
10,001-20,000 (4536.5-9072.0)								1%	.5%	1.5%
20,001-30,000 (9073 - 13,608)								2.5%	46%	48.5%
TOTAL	8%			.5%			34%	3.5%	54%	100%

TABLE 2-5: WEIGHT AND VOLUME DISTRIBUTION FOR 605 PAYLOAD DEPLOYMENT MISSIONS FROM 1972 MISSION MODEL*

WEIGHT - lbs. (kg.)	VOLUME - ft^3 (m^3): 50-100 (1.4-2.8)	101-200 (2.9-5.7)	201-300 (5.7-8.5)	301-500 (8.5-14.2)	501-1000 (14.2-28.3)	1001-1500 (28.3-42.5)	1501-2000 (42.5-56.6)	2001-5000 (56.6-141.5)	5001-10,000 (141.5-283)	TOTAL
500-750 (226.8-340.2)	3%	3%		4%						10%
751-1000 (340.7-453.6)	6%		2%		12%	.3%				20.3%
1001-2000 (454.1-907.2)	4%	11%		.2%	.7%	2%				17.9%
2001-5000 (907.6-2268)				4%	4%	3%	17%	4%		32%
5001-10,000 (2268-4536)					.5%	.2%	.3%	1%	2%	4%
10,001-20,000 (4536-9072)								1%	.2%	1.2%
20,001-30,000 (9072-13,608)								.6%	14%	14.6.%
TOTAL	13%	14%	2%	8.2%	17.2%	5.5%	17.3%	6.6%	16.2%	100%

*Kick-Stage Weights and Volumes not included.

The low-cost modularized payloads concept was considered relevant to the EVA workstations study because it represented one extreme of the EVA crewman's possible interfaces. The modularized concept would afford less variety in package size, mass, and package restraint than any other concept currently being considered. It was felt that the requirements derived from this "least variety" concept should be considered along with those derived from the mission analysis reported in Subsection 2.1.

As in the analysis of the 1972 Mission Model, the modularized payloads mission analysis derived requirements for payload deployment and spacecraft module (package) handling. The process through which these requirements were derived is illustrated in Figure 2-4.

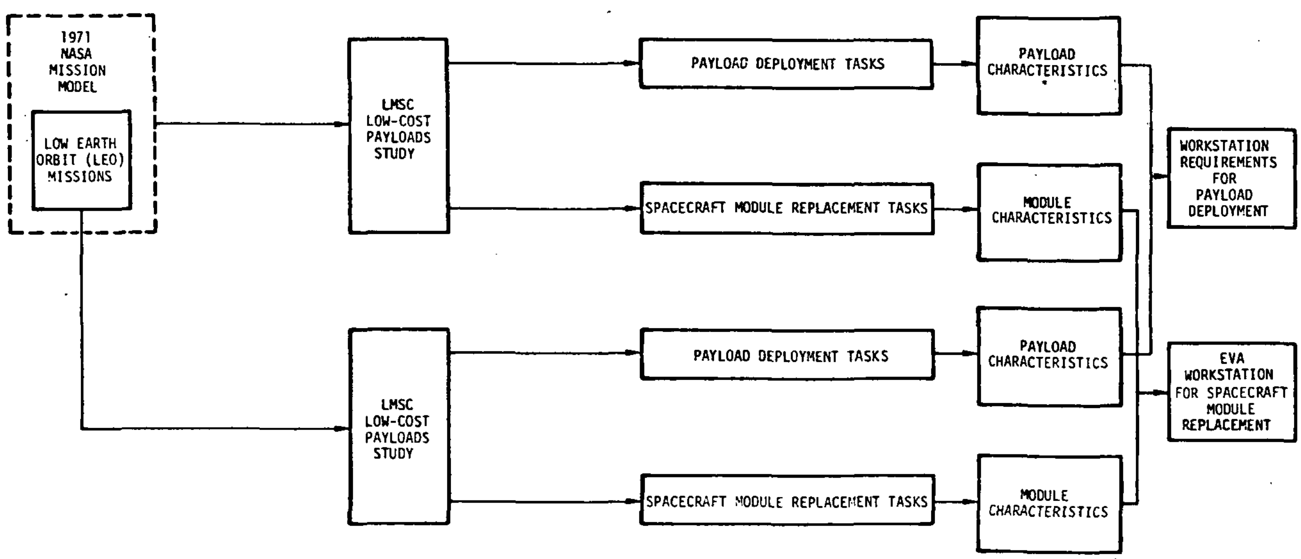


FIGURE 2-4: MISSION ANALYSIS FOR MODULARIZED PAYLOADS

The 52 unmanned deployable payloads designated by NASA in the 1971 Mission Model are listed in Table 2-6. The table lists the following: (1) the payload reference number and payload titles for 52 of the unmanned payloads identified in the 1971 Mission Module, (2) the LEO payloads, and (3) the payloads not modularized or included within the analyses. These payloads represent a total

TABLE 2-6: MISSION LISTING FROM 1971 MISSION MODEL

PAYLOAD NUMBER	PAYLOAD TITLE	LEO*	NM*
1	Astronomy Explorer	●	
2	Astronomy Expl. B		
3	Magnetosphere-Low	●	
4	Magnetosphere-Mid.		
5	Magnetosphere-Upper		
6	OSO	●	
7	Gravity Relativity	●	
8	Gravity Relativity		
9	Radio Interferometer		
10	Solar Orbit Pair-A		
11	Solar Orbit Pair-B		
12	Optical Interferom.		
13	HEAO	●	
15	LST	●	
17	LSO	●	
19	LRO	●	
21	Polar EOS	●	
22	SEO		
23	Earth Physics	●	
24	Sync. Met.		
25	TIROS	●	
26	Polar ERS	●	
27	Sync. ER		
28	ATS		
29	Small ATS-B		
30	Small ATS-A	●	

PAYLOAD NUMBER	PAYLOAD TITLE	LEO*	NM*
31	Coop ATS-A		
32	Coop ATS-B	●	
33	Medical Network		
34	Educ. Broadcast		
35	F.O. Sys. Demonst.		
36	TDRS		
50	Mars Viking		
51	Mars Sample Ret.		●
52	Venus Expl.-Orb.		
53	Venus Radar Map.		
54	Venus Explor.-Ldr.		
55	Jup. Pioneer Orb.		●
56	Grand Tour (JUN)		●
57	Jup. TOPS Orb.		●
58	Uranus TOPS Orb.		●
59	Asteroid Survey		●
60	Comet Rendezvous		●
70	COMSAT		
71	US Dom. Comm.		
72	Foreign Dom. Comm.		
73	NAV/Traf.Contr. B		
74	NAV/Traf.Contr. A		
75	TIROS Op. Met.	●	
76	Sync. Met.		
77	Polar ER	●	
78	Sync. ER		

*LEO Low Earth Orbit Payloads
NM Payloads Not Modularized

of 344 missions in the period between 1979 and 1990. LMSC applied the spacecraft modularization concept to 45 of the 52 payloads. The 45 payloads (331 missions) represent 86% of the 52 payloads and 96% of the 344 missions. Sixteen (16) of the 45 payloads are Low Earth Orbit (LEO) payloads. The 16 LEO payloads (118 missions) represent 31% of the 52 payloads and 34% of the 344 missions. The 45 LMSC modularized payloads were selected for review during this study. All of these payloads were included in (1) the payload deployment, and (2) the module/package handling analyses described in later subsections. Although 29 of the payloads (213 missions) require kick-stages, the weights and volumes of the boosters were not added into the payload deployment analysis. Since the study guidelines were directed primarily toward the Low-Earth Orbit (LEO) payloads, emphasis was placed on the 16 LEO payloads (118 missions) during the analysis.

2.2.1 Low-Cost Modularized Payloads Study Background

The purpose of the Lockheed Missiles and Space Company (LMSC) effort (Contract NASW-2312) was to establish guidelines for the standardization of payload subsystem hardware as a means of reducing overall payload cost. During this effort, LMSC evaluated four primary subsystems for standardization and established design guidelines (physical, operational, and performance) for 44 different modules that would satisfy the subsystem requirements. As previously discussed, the LMSC subsystem requirements were based upon 45 of the 1971 NASA Mission Model unmanned payloads. The following list identifies the subsystems evaluated and the number of different standard subsystem modules that were developed for each subsystem:

- Stabilization and Control (S&C) - 9 modules
- Communications, Data Processing, and Instrumentation (CDPI) - 11 modules
- Electrical Power System (EPS) - 21 modules
- Attitude Control System (ACS) - 3 modules

The LMSC study was limited to standardization of the supporting spacecraft and did not include the mission-peculiar equipment or experiment packages.

However, weights and volumes for mission-peculiar equipment and experiment packages were extrapolated for the URS/Matrix study in order to project future payload weights and volumes using the modularization concept.

Figure 2-5 depicts: (1) a representative module, (2) module and spacecraft relationship, and (3) spacecraft and experiment relationship. Each module is designed to be guided into its location in the spacecraft by rails and aligned/supported by two inboard pins and two outboard cams that engage machined grooves in the rails. The cams also transmit force from the cam actuators on the outboard face of the module to accomplish the controlled engagement and disengagement of the bulkhead-type electrical connectors on the inboard face of the module. The two wrap-around handles are designed to facilitate the handling of the module in orbit by an EVA/IVA crewman. The hardware interfaces and operations depicted are generally compatible with EVA crewman capabilities.

All of the spacecraft modules (i.e., LMSC concepts) are being designed in sizes varying from 18x18x24 in. (.46x.46x.61 m) to 24x24x32 in. (.61x.61x.81 m). Except for a few specialized mission configurations, the mission payloads can be "standardized" into rectangular arrangements approximately 8 ft. (2.4 m) wide by 6 ft. (1.83 m) high with lengths varying from 7 ft. (2.1 m) to 20 ft. (6.1 m). Note that all LMSC spacecraft module dimensions are within simulated EVA crewman package handling capabilities.

2.2.2 Typical Tasks

Figure 2-6 is included to illustrate the tasks involved in handling modularized payloads. The figure depicts (1) the overall configuration of the LMSC concept for a future Earth Observation Satellite (EOS)-type payload incorporating the standard spacecraft concepts, and (2) the internal arrangement of the replaceable spacecraft modules and experiment packages. The tasks listed are representative of the tasks which could be accomplished by an EVA crewman.

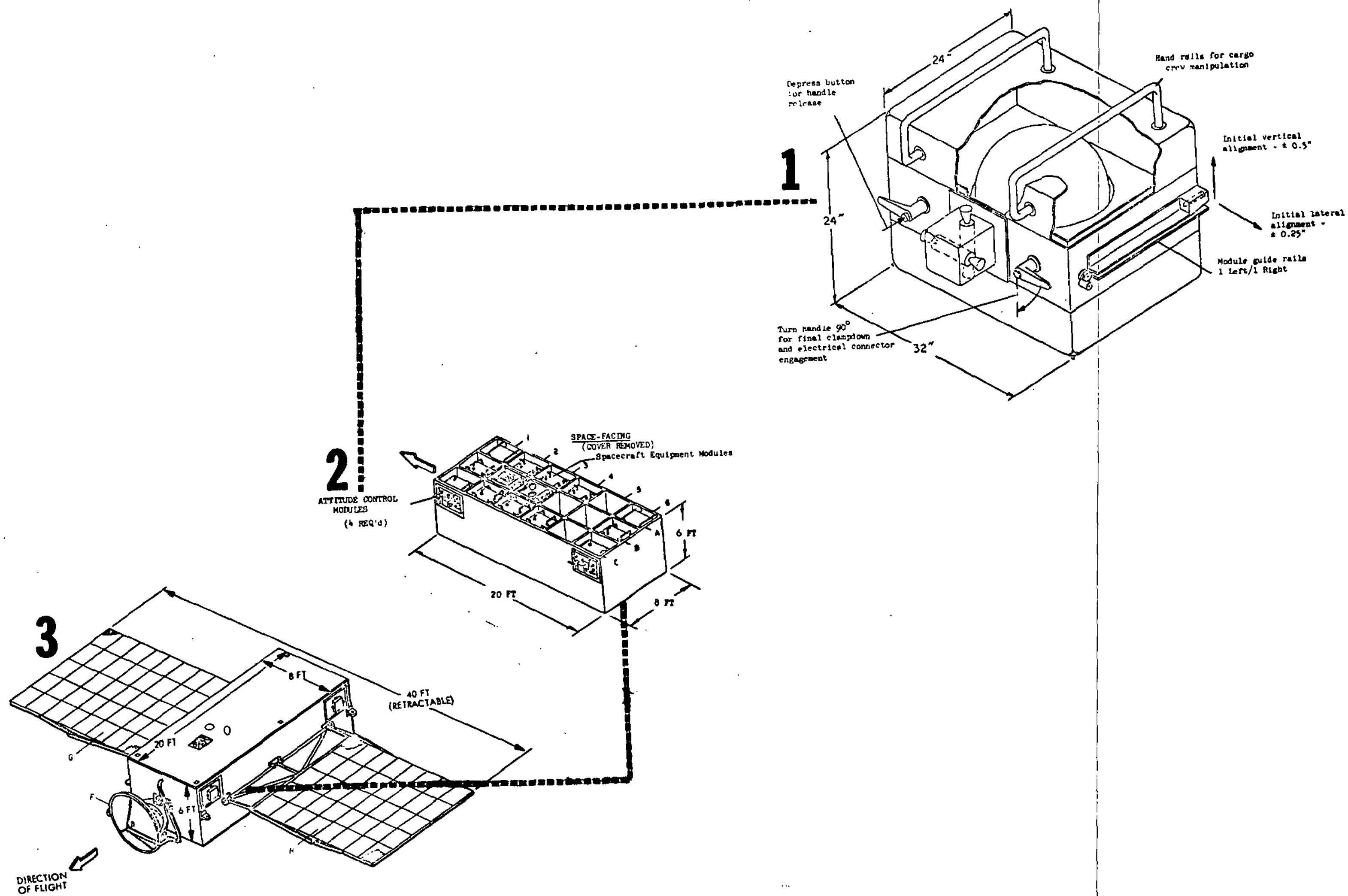
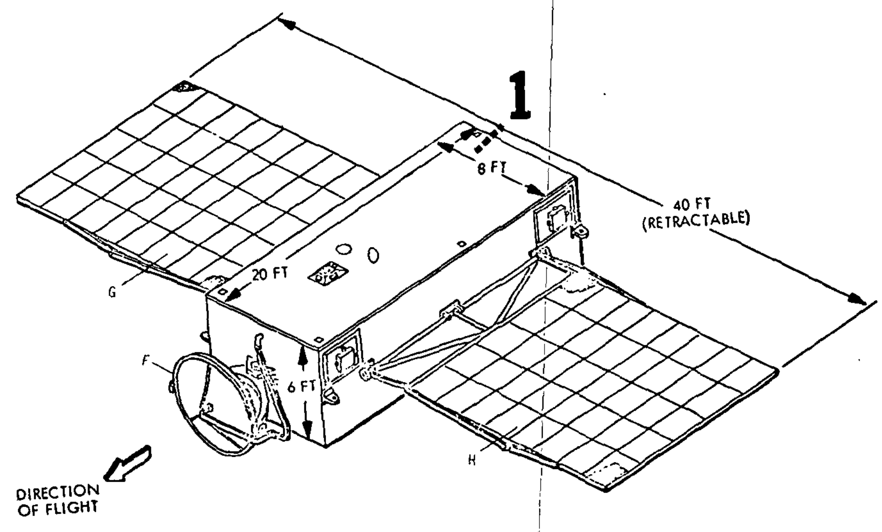
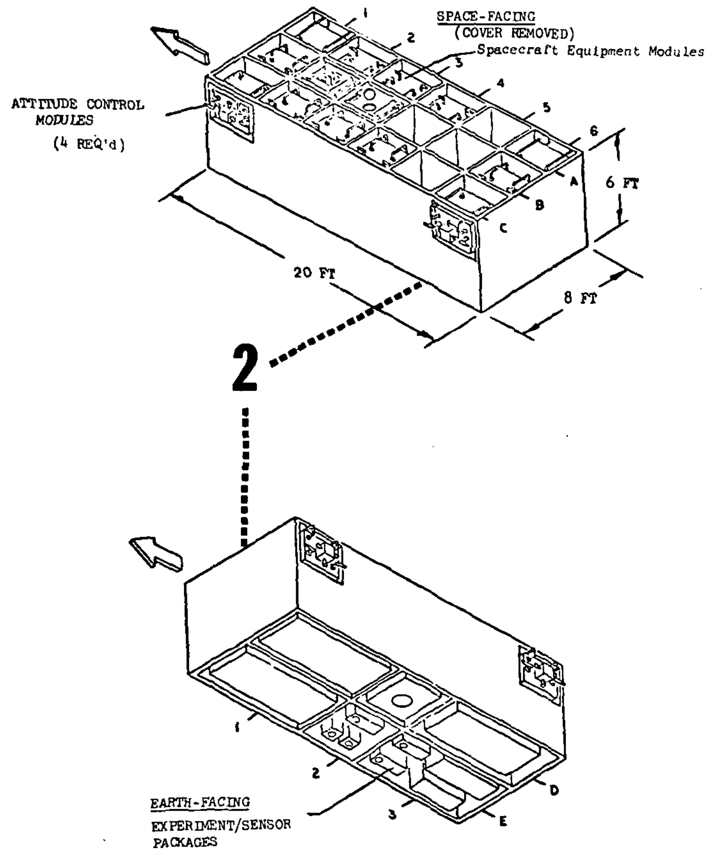


FIGURE 2-5: LOW-COST MODULARIZED PAYLOADS





TYPICAL PACKAGE HANDLING TASKS:

- Replace Modules/Packages
  - Repair
  - Refurbish
  - Update
- Module/Package Adjustment or Calibration
- Latch/Unlatch, Extend, Retract
  - Access Doors
  - Solar Array "Wings"
  - Antennas
  - *Experiment/Sensor Elements*

FIGURE 2-6: TYPICAL TASKS FOR MODULARIZED PAYLOADS

The combination of spacecraft modules and experiment packages contained in Table 2-7 is representative of the 1971 NASA Mission Model payload no. 21, POLAR Earth Orbiting Satellite (EOS). The module/package placement locations (e.g., C-3) correspond to the "call-outs" in Figure 2-6. Weights and sizes for the mission/experiment modules have not been defined.

2.2.3 Package Weight and Volume Distribution

2.2.3.1 LEO Missions

The LMSC spacecraft module assignment for 16 of the LEO payloads defined in the 1971 NASA Mission Model (see Table 2-6) was analyzed in order to project known EVA crewman capabilities across package handling operations. Table 2-8 presents the weight and volume frequency distribution for 2062 spacecraft modules (packages) which represent 118 missions involving the 16 different payloads. Both weight and volume specifications could be derived for only 90% (2062) of the 2288 spacecraft modules required to support the 16 different payloads. Although all of the modules exceed the volume/weight of packages handled on-orbit to date, the unshaded area [(less than 150 lbs.— 68 kg.) and less than 6 $ft.^3$ (.17 m^3)] identifies the modules which are, based upon simulations, now assigned to EVA crewman handling. The unshaded area represents 27% (~555 modules) of the 2062 modules.

2.2.3.2 LMSC Study Missions

The LMSC spacecraft module assignment for 45 of the payloads defined in the 1971 NASA Mission Model (see Table 2-6) was analyzed in order to project known EVA crewman capabilities across package handling operations. Table 2-9 presents the weight and volume frequency distribution for 5350 spacecraft modules which represent 331 missions involving the 45 different payloads. Both weight and volume specifications could be derived for only 91% (5350) of the 5898 spacecraft modules required to support the 45 different payloads. Although all modules exceed the volume/weight of packages handled on-orbit to date, the unshaded area--less than 150 lbs. (68 kg.) and less than 6 $ft.^3$

TABLE 2-7: SAMPLE MODULARIZED PAYLOAD

	Module	Module Title and Location	Weight lbs.	Weight kg.	Size inches	Size meters
SPACECRAFT SUBSYSTEM MODULES	A-1	Attitude Control Module (ACS-1-1)	136	61.7	32x24x24	.81x.61x.61
	A-2	S & VHF Band Comm. Module (CDPI-2)	78	35.4	18x18x24	.46x.46x.61
	A-3	Battery Module (EPS-6)	206	93.4	32x18x24	.81x.46x.61
	A-4	Power Distribution Module (EPS-7)	120	54.4	32x18x24	.81x.46x.61
	A-5	Empty				
	A-6	Attitude Control (ACS-1-1)	136	61.7	32x24x24	.81x.61x.61
	B-1	K-Band Comm. Module (CDPI-1)	85	38.6	18x18x24	.46x.46x.61
	B-2	S&C Secondary Reference Mod. (S&C-1)	105	47.6	32x18x24	.81x.46x.61
	B-3	S&C Primary Reference Mod. (S&C-2)	64	29	18x18x24	.46x.46x.61
	B-4	Empty				
	B-5	Empty				
	B-6	Reaction Torque Module (S&C-3)	153	69.4	32x18x24	.81x.46x.61
	C-1	Attitude Control Module (ACS 1-1)	136	61.7	32x24x24	.81x.61x.61
	C-2	Data Processing Module (CDPI-3)	91	41.3	18x18x24	.46x.46x.61
	C-3	Battery Module (EPS-6)	206	93.4	32x18x24	.81x.46x.61
	C-4	Battery Module (EPS-6)	206	93.4	32x18x24	.81x.46x.61
	C-5	Empty				
	C-6	Attitude Control Module (ACS 1-1)	136	61.7	32x24x24	.81x.61x.61
	F	Antenna Module (CDPI-6)	75	34.0	18x18x24	.46x.46x.61
	G	Solar Array Module (EPS-2-5)	228	103.4	(8'x27')	2.4x11.3
	H	Solar Array Module (EPS-2-5)	228	103.4	(8'x27')	2.4x11.3
MISSION/EXPERIMENT MODULES	D-1	Passive Microwave Radiometer ($\lambda = 0.81$ cm)	NOT AVAILABLE			
	D-2	Thermatic Mapper				
	D-3	Passive Microwave Radiometer ($\lambda = 2.81$ cm)				
	E-1	Passive Microwave Radiometer ($\lambda = 6.01$ cm)				
	E-2	Ocean Scanning Spectrophotometer Atmospheric Pollution Sensor Upper Atmosphere Sounder				
	E-3	Cloud Physics Radiometer Sea Surface Temp. Radiometer Passive Microwave Radiometer ($\lambda = 1.67$ cm) Passive Microwave Radiometer ($\lambda = 1.40$ cm)				

TABLE 2-8: LMSC SPACECRAFT MODULE WEIGHT AND VOLUME DISTRIBUTION FOR 331 MISSIONS FROM 1971 MISSION MODEL

WEIGHT - lbs. (kg.)		VOLUME - ft.^{3} (m^3) 4.5 (.13)	8.0 (.23)	10.7 (.30)	TOTAL
50-75	(22.7-34.0)	6.3%	4.9%		11.2%
75-100	(34.0-45.4)	16.6%		9.1%	25.7%
100-125	(45.4-56.7)	.2%	11.2%	9.0%	20.4%
125-150	(56.7-68.0)		.1%	22.2%	22.3%
150-175	(68.0-79.4)		3.1%		3.1%
175-200	(79.4-90.7)		.7%		.7%
200-225	(90.7-102.1)		9.7%		9.7%
225	(102.1)			6.9%	6.9%
TOTAL		23.1%	29.7%	47.2%	100%

(.17 m)--identifies the modules which are, based upon simulations, now assigned to EVA crewman handling. The unshaded area represents 23% (~1236 modules) of the 5350 modules.

TABLE 2-9: LMSC SPACECRAFT MODULE WEIGHT AND VOLUME DISTRIBUTION FOR 118 LOW EARTH ORBIT (LEO) MISSIONS FROM 1971 MISSION MODEL

	VOLUME - ft^3 (m^3)			TOTAL
WEIGHT - lbs. (kg.)	4.5 (.13)	8.0 (.23)	10.7 (.30)	
50-75 (22.7-34.0)	10.2%			10.2%
76-100 (34.5-45.4)	16.7%			16.7%
101-125 (45.8-56.7)		13.1%	10.5%	23.6%
126-150 (57.1-68.0)			20.5%	20.5%
151-175 (68.5-79.4)		4.5%		4.5%
176-200 (79.8-90.7)				---
201-225 (91.2-102.1)		13.7%		13.7%
226-260 (102.5-117.9			10.8%	10.8%
TOTAL	26.9%	31.3%	41.8%	100%

2,2.4 <u>Payload Deployment</u>

Payload deployment for modularized payloads was considered on the same basis as the 1972 Mission Model described in Subsection 2.1. As in Mission Model analysis, the modularized payload deployment analysis assumed that EVA crewman may be required to perform deployment tasks as a backup to manipulator and automated systems. Kick-stage weights and volumes are not included in the charts which follow. Furthermore, combined payloads involving several payloads clustered on a single kick-stage are not included.

2.2.4.1 LEO Missions (LMSC Study)

The LMSC listing of estimated weights and dimensions for 16 of the LEO payloads defined in the 1971 NASA Mission Model (see Table 2-6) was analyzed in order to project known EVA crewman capabilities across deployment operations. Table 2-10 presents weight and volume frequency distributions for 118 payload deployment missions involving 16 LEO payloads. The LMSC LEO payload estimates were based upon the combined weights and volumes of the spacecraft modules and those extrapolated for the experiment packages. The 118 LEO payload deployment missions are representative of 34% of the total payload deployment missions reflected in the 1971 NASA Mission Model. As indicated in the shaded area on the chart, all of the LEO payload deployment missions are in an area of currently undetermined EVA crewman capability for manual deployment.

2.2.4.2 LMSC Study Missions (45 Unmanned Payloads)

The LMSC listing of estimated weights and dimensions for 45 unmanned payloads defined in the 1971 NASA Mission Model (see Table 2-6) was analyzed in order to continue the projection of known EVA crewman capabilities across payload deployment operations. The LMSC payload estimates were based upon the combined weights and volumes of the spacecraft modules and those extrapolated for the experiment packages.

Table 2-11 presents the weight and volume frequency distribution for 331 payload deployment missions involving the 45 payloads (kick-stage weights and volumes have not been included). The 331 deployment missions are representative of 96% of the total unmanned payload deployment missions reflected in the 1971 NASA Mission Model. The 4% of the payload deployment missions not considered during the LMSC effort include Mission Model payload numbers 51 and 55

TABLE 2-10: WEIGHT AND VOLUME DISTRIBUTION FOR 118 LMSC LOW EARTH ORBIT (LEO) PAYLOAD DEPLOYMENT MISSIONS FROM 1971 MISSION MODEL

WEIGHT - lbs. (kg.)	VOLUME - ft^3 (m^3) 100-500 (2.8-14.2)	501-1000 (14.2-28)	1001-1500 (28-43)	1501-2000 (43-57)	2001-5000 (57-142)	>5000 (>142)	TOTAL
1000-2000 (454-907)	10.2%						10.2%
2001-3000 (908-1361)							
3001-3500 (1361-1588)							
3501-4000 (1588-1814)							
4001-4500 (1815-2041)		5.9%					5.9%
4501-5000 (2042-2268)		12.7%	24.6%				37.3%
5001-5500 (2268-2495)			2.5%				2.5%
5501-6000 (2495-2722)							
6001-6500 (2722-2948)							
6501-7000 (2949-3175)							
7001-7500 (3176-3402)			33.9%				33.9%
7501-9500 (3402-4309)							
>9501 (>4309)						10.2%	10.2%
TOTAL	10.2%	18.6%	61.0%			10.2%	100%

TABLE 2-11: WEIGHT AND VOLUME DISTRIBUTION FOR 331 LMSC PAYLOAD DEPLOYMENT MISSIONS FROM 1971 MISSION MODEL*

WEIGHT - lbs. (kg.)	VOLUME - ft^3 (m^3) 100-500 (2.8-14.2)	501-1000 (14.2-28)	1001-1500 (28-42)	1501-2000 (43-57)	2001-5000 (57-142)	>5000 (>142)	TOTAL
1000-2000 (454-907)	10.8%						10.8%
2001-3000 (908-1361)							---
3001-3500 (1361-1588)		16.0%					16.0%
3501-4000 (1588-1814)		10.6%					10.6%
4001-4500 (1815-2041)		13.9%					13.9%
4501-5000 (2042-2268)		11.8%	8.8%				20.6%
5001-5500 (2268-2495)			.9%				.9%
5501-6000 (2495-2722)		6.3%					6.3%
6001-6500 (2722-2948)		.6%					.6%
6501-7000 (2949-3175)							---
7001-7500 (3176-3402)			14.2%				14.2%
7501-9500 (3402-4309)							---
>9501 (>4310)		.3%	.9%	1.2%		3.7%	6.1%
TOTAL	10.8%	59.5%	24.8%	1.2%		3.7%	100%

*Kick-stage weight and volume not included.

through 60. As indicated by the shading on the chart, all of the payload deployment missions are in an area of currently undetermined EVA crewman capability for manual deployment.

2.3 MISSION AND PAYLOADS ANALYSIS SUMMARY

The 1972 Mission Model analysis and 1971 Mission Model modularized payloads analysis were combined to derive a single set of requirements for EVA workstations. The two major sets of requirements which were derived fall into the (1) package handling and (2) payload deployment. As discussed above, these two operations are considerably different in the requirements they impose on a workstation.

2.3.1 Package Handling

To summarize the package handling requirements from the 1971 Mission Model (per the LMSC study) and the 1972 Mission Model, a consolidated weight and volume table is presented. This integrated frequency distribution presented in Table 2-12 represents 2369 package handling tasks: 307 packages from the 1972 LEO missions and 2062 modules from the 1971 LMSC low cost payloads study.

The inclusion of the LMSC study modules shifted the package distribution toward the heavier weight and larger volume extremes. This was anticipated due to the order of magnitude difference in the number of items in the two samples. Also, the modularization concept involves the replacement of modules as opposed to individual components as considered in the 1972 data. As indicated by the shading on the chart, approximately 65% (1540) of the package handling tasks exceed the currently simulated EVA crewman capability.

2.3.2 Payload Deployment

For summarization purposes, the low earth orbit (LEO) payload deployment missions (118 missions from the 1971 LMSC study and 184 missions from the 1972 Mission Model) were integrated into a single weight and volume table. As may

TABLE 2-12: SUMMARY OF PACKAGE WEIGHT AND VOLUME DISTRIBUTION FOR LOW EARTH ORBIT (LEO) MISSIONS FROM 1971 AND 1972 MISSION MODELS

WEIGHT - lbs. (kg.)	VOLUME - ft3 (m^3) 0-.3 (0-.008)	.31-.5 (.008-.01)	.51-1.0 (.01-.03)	1.1-5.0 (.03-.14)	5.1-10 (.14-.28)	11-20 (.31-.57)	21-40 (.59-1.1)	>40 (>1.1)	TOTAL
1 (.45)	2%		1%						3%
1-10 (.45-4.5)	1.2%	1%		.1%					2.3%
11-30 (5.0-14)		.1%	1%	.1%	.1%			.1%	1.4%
31-100 (14-45)	1%	1%	.1%	25%					27.1%
101-200 (46-91)				1%	16%	27%	.1%		44.1
201-400 (91-181)					12%	10%			22%
>400 (>181)								.1%	.1%
TOTAL	4.2%	2.1%	2.1%	26.2%	28.1%	37%	.1%	.2%	100%

be expected, the distribution did not change dramatically as a result of the consolidation. As indicated by the shading on Table 2-13, the majority of payload deployment tasks, whether the payloads are modularized or not, are in the area of presently unknown EVA crewman capability. A total of 302 payloads missions are represented in this frequency distribution.

2.4 ADDITIONAL MISSION ANALYSES

A review was made of mission tasks identified in parallel studies of EVA/IVA support system requirements for Shuttle missions. Two studies, NAS9-12506 and NAS9-12507 were considered to be relevant to the URS/Matrix study to the extent that they had an objective of identifying EVA mission tasks. These studies did not relate to the URS/Matrix effort in that they were directed toward developing requirements for EVA/IVA support systems.

An engineering memorandum entitled "Shuttle EVA/IVA Study, Task Identification", July 11, 1972, #NA-SVA-0002, was reviewed in detail to determine if additional tasks were identified which affected workstation requirements. The memorandum reported the results of a review of the March 21, 1972, Traffic Model which considered the payloads and kick-stages for Shuttle flights from 1979 to 1990.

The memorandum delineated planned, unscheduled, and contingency EVA/IVA tasks for each Shuttle flight. Typical tasks that were identified for planned EVA were operate cameras, change film packs, inspect, deploy sensors, refuel, operate values, assemble/disassemble electrical and fluid connectors, etc.

A series of appendices was included in the memorandum for more detailed descriptions of EVA/IVA tasks. Most of the tasks described in these sections were unscheduled. In most cases, tasks that were identified were listed in generic fashion (i.e., clean star tracker, inspect thruster module, clean secondary mirror). Since the configurations of most of the payloads are not well defined, this level of description is understandable. However, deriving workstation requirements from tasks at this level is difficult.

TABLE 2-13: SUMMARY DISTRIBUTION OF WEIGHT AND VOLUME FOR LOW EARTH ORBIT (LEO) PAYLOAD DEPLOYMENT MISSIONS FROM 1971 AND 1972 MISSION MODELS

WEIGHT lbs. (kg.)	VOLUME - ft^3 (m^3) 50-100 (1.4-2.8)	101-200 (2.8-5.7)	201-300 (5.7-8.5)	301-500 (8.5-14)	501-1000 (14-28)	1001-1500 (28-43)	1501-2000 (43-57)	2001-5000 (57-142)	>5000 (>142)	TOTAL
500-750 (226.8-340.2)										
751-1000 (340.6-453.6)	5%									5%
1001-2000 (454.1-907.2)			4%	.3%						4.3%
2001-5000 (907.7-2268.0)					7%	10%	21%		.3%	38.3%
5001-10,000 (2268.5-4536.0)						14%			8%	22%
10,001-20,000 (4536.5-9072.0)								.7	.3%	1.0%
20,001-30,000 (9072.5-13,608)								1.4	28%	29.4%
TOTAL	5%		4%	.3%	7%	24%	21%	2.1%	36.6%	100%

The memorandum data provided support to the findings of mission and payloads analyses discussed above in that a wide variety of tasks will have to be performed through EVA. Furthermore, the configurations of the payload interfaces are likely to vary widely. Both of these considerations lead to the conclusion that a general-purpose workstation would be best-suited for the Shuttle tasks. As discussed earlier, it appears that the design drivers for the workstation should be the package handling tasks. If the variety of packages and modules that will have to be removed and replaced can be accommodated, it is likely that the majority of the inspection, cleaning, adjustment, etc. tasks can be accomplished from the same workstation. No additional, quantifiable package handling tasks were identified in the review of Engineering Memorandum NA-SVA-0002. The non-quantifiable tasks such as inspection, adjustment, cleaning, etc. did not significantly affect the requirements derived from other sources.

In order to develop concepts for a versatile EVA workstation, consideration must be given to the payload, vehicle, and mission interfaces and the required EVA tasks. To this point in the report, we have discussed only the tasks which will be required for EVA crewmen. This section presents a discussion of the vehicle, payload and mission considerations which must be taken into account in designing and evaluating workstation concepts.

3.1 PAYLOAD CONSIDERATIONS

The EVA workstation interacts with the payloads by placing requirements on the payload designers that certain interfaces be provided. The workstation design may also affect the payload by requiring that replacement modules be limited to a specified maximum mass and volume. Likewise, the payloads may affect the workstation by virtue of their variety of configurations and sizes. The diversity of the payloads and payload modules may place special demands on workstation equipment such as restraints, temporary stowage provisions, etc.

A design objective was established in the early phases of this study to place emphasis on a versatile workstation which could accommodate a variety of payloads. This will minimize the impact on the payloads by eliminating dedicated workstations for each mission.

The following is a list of areas in which the workstation may affect the payload:

- Structural impact (workstation mounting provisions, loads transferred to payload)
- Contamination of sensitive experiments
- Special hardware provisions (latches, special interfaces)
- Weight
- Volume

Conversely, the following is a list of payload factors which may affect the EVA workstation(s):

- Variety of payload configurations (sizes, shapes, masses, interfaces)
- Kick-stages and clustered payloads
- Payload module arrangement in vehicle (attitude, location, clearances)
- Special payload handling requirements
- Contamination restrictions on the workstation

3.2 VEHICLE CONSIDERATIONS

Since the vehicle will have to house the EVA workstation and its provisions, vehicle factors must be considered in workstation design. The workstation may affect the vehicle in areas such as stowage provisions, mounting provisions, power, weight, etc. Likewise, the vehicle impacts the workstation in areas such as stowage configuration, mounting hardware, power, weight, etc. As in the case with payload interfaces, an attempt was made to minimize the impact of the workstation on the vehicle.

The following is a list of areas in which the workstation may impact the vehicle:

- Vehicle structural design (mounting interfaces)
- Transporting system (transporting aids; manipulator, manual)
- Volume (stored, deployed, ancillary equipment stowage provisions)
- Power requirements on vehicle (scheduling, quantity)
- Weight

Conversely, the following is a list of areas in which the vehicle may impact the workstation(s):

- Workstation configuration and structural design (vehicle interface restrictions)
- Special provisions on workstation (transporting, stowing, deployment)
- Size and volume (stored, deployed, support equipment stowage)

- Power limitations
- Weight restrictions

In the case of the workstation(s)/vehicle impact areas, it is obvious that tradeoffs may have to be made of workstation(s) power vs. vehicle power, workstation(s) complexity vs. vehicle structures, etc.

3.3 MISSION CONSIDERATIONS

The major impact area of the workstation(s) on the missions is crew time. Some second order effects such as crew workload, scheduling, and experiment objectives may be identifiable, but the final analysis reveals crew time as the major impact area.

3.4 IDENTIFIED TASKS

By consolidating the tasks identified through the missions and payloads analysis discussed in Section 2.0, a generic task listing was derived. At a top level, the following is a list of the types of tasks that will be required for EVA operations on future payloads:

- Inspect
- Handle Packages
- Monitor
- Align
- Clean
- Repair
- Remove/Replace
- Activate/Deactivate
- Assemble
- Deploy
- Adjust
- Calibrate
- Checkout

These tasks must be performed on payload configurations with packages and modules similar to those described in Section 2.0 and within the vehicle, payload and mission guidelines described in Subsection 3.5 below.

3.5 DERIVED WORKSTATION DESIGN GUIDELINES

By integrating the results of the mission analysis and payload, vehicle, and mission considerations, a set of workstation design guidelines was developed. Although a variety of inspection, alignment, monitoring, and calibration tasks were specified in the mission documentation, these tasks were not considered major drivers for EVA workstation design. The package/payload handling tasks and vehicle, payload, and mission considerations were determined to be the critical parameters. As workstation concepts are developed which afford maximum mobility, maximum visibility, and flexibility in crewman positioning based on package handling, these concepts should afford the desired access for inspection, alignment, calibration, etc.

Based on this process, a general set of EVA workstation design guidelines was developed. These guidelines are listed below.

The EVA workstation should:

(1) be portable (i.e., can be moved on-orbit by the crewman, if required)
   - lightweight
   - low volume

(2) accommodate a variety of payload configurations

(3) provide auxiliary worksite lighting (if required)

(4) provide crewman and module restraint

(5) provide ingress/egress aids

(6) provide temporary package stowage

(7) provide stowage for small replacement items

(8) provide tool assortment

The various tasks and considerations indicated that a portable, variable configuration, single-man workstation should receive primary design emphasis. The workstations, although portable, are equipped with provisions to allow hard-mounting to the payload bay. The above guidelines are reflected in the concepts that follow.

3.6 WORKSTATION CONCEPTS

The workstation design guidelines listed above were used to develop preliminary workstation concepts. At the outset, it was determined that concepts of varying complexity were worthy of consideration. That is, it appears to be feasible to consider concepts which can satisfy only portions of the total task requirements. No attempt should be made to develop a single concept which satisfies all task requirements and design guidelines.

Four (4) major workstation concepts were developed which represent three levels of complexity. The force levels identified in the mission and payload analysis dictated that foot restraints be provided in all concepts. The guideline that the workstation be portable virtually dictates that a collapsible design be provided. Each of the concepts described below incorporates these features. Existing and proven EVA hardware was incorporated in the design where possible. Each workstation can be rigidly attached prior to launch.

3.6.1 Concept 1

Description--Concept 1 represents the least complex type of EVA workstation. Figure 3-1 illustrates the workstation in its deployed and stowed configuration. Foot restraints developed for the Skylab Program are provided on the base of the workstation. An extendible "arm" (Apollo cross-section grip area) on one side of the workstation serves as an ingress/stabilization aid, a mounting point for a temporary stowage hook, and incorporates a crewman tether point. The stowage hook is deployed by depressing a release button on the stabilization aid. An umbilical clamp is provided at the rear of the workstation, should an umbilical life support system be used.

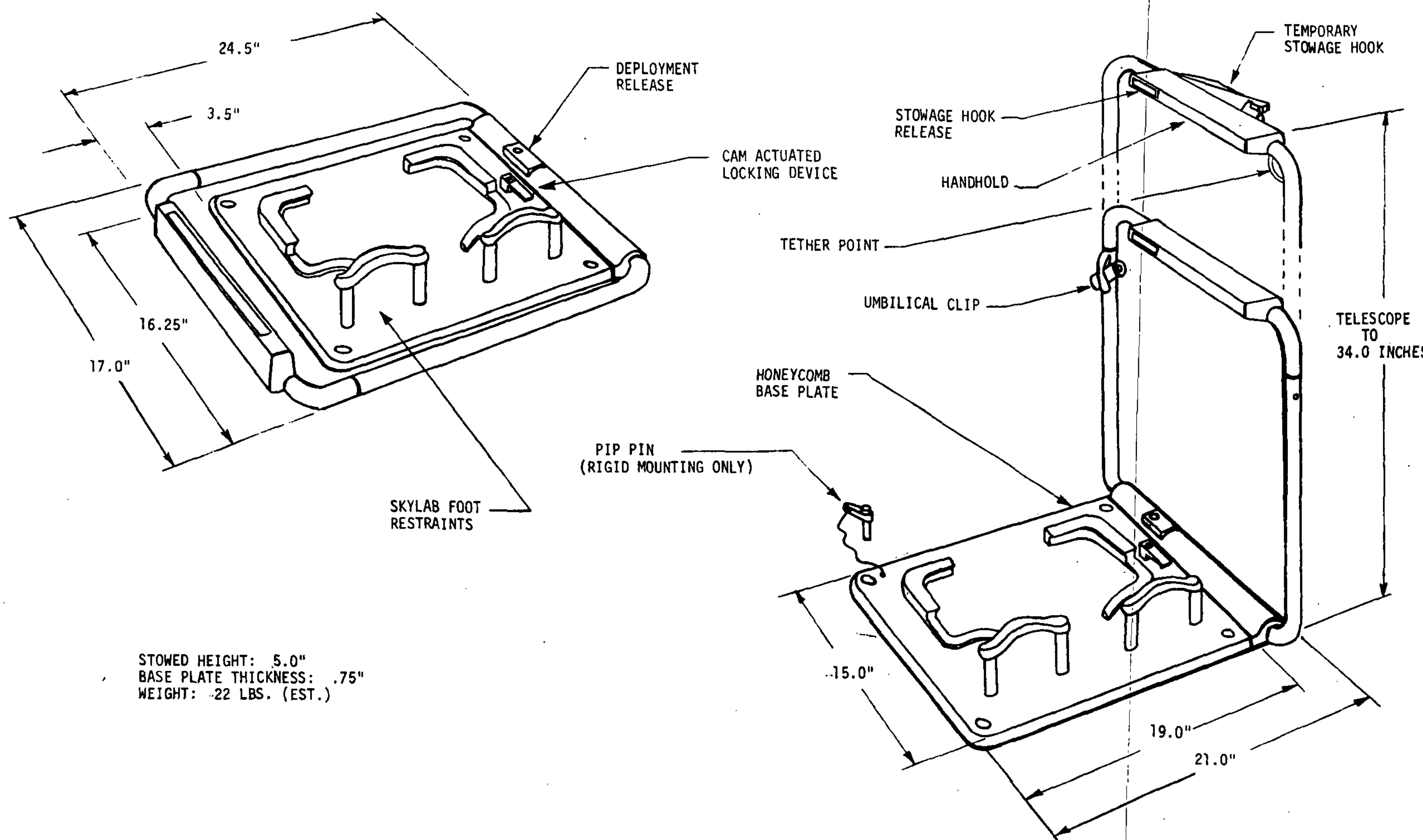


FIGURE 3-1: EVA WORKSTATION CONCEPT--NO. 1

The workstation is fabricated primarily from aluminum. The base plate is of aluminum honeycomb composition with supporting stiffeners and epoxied inserts for foot restraint mounting, vehicle/payload mounting holes, etc. The ingress/stabilization aids are thin-wall aluminum tubing with machined aluminum supporting/actuating hardware. The Concept 1 workstation weighs an estimated 22 lbs. (10.0 kg.) with dimensions of approximately 24.5 x 17.0 x 5.0 in. (.62 x .43 x .13 m) in the stowed configuration. The stowed volume is approximately 1.5 $ft.^3$ (.04 m^3).

The workstation is intended to be either hard-mounted prior to vehicle launch or positioned by the EVA crewman while on-orbit. The hard mounting method can be accomplished either by pip-pins or bolts and by using the mounting holes provided. For on-orbit positioning, the workstation is mounted to the vehicle/worksite by retaining clips on a cam actuated (internal) locking handle indicated in Figure 3-2. The crewman would need only to position the workstation in the "receptacle" for momentary retention and then depress the locking device to secure the workstation. A mounting "receptacle" concept is shown in Figure 3-3.

After positioning, the crewman would depress the ingress/stabilization aid deployment mechanism and swing the arm into a working position (three indexed positions are provided). The workstation is then ingressed and the telescoping stabilization aid adjusted to the desired height. Mounting the workstation on payloads of various external configurations will require special adapters which utilize the workstation base-plate mounting holes. The payload will supply the mating half of the adapter.

Applications--The lightweight and ease of mobility of the Concept 1 workstation make it ideal for short duration, low-force tasks such as inspection, adjustment, calibration, and small module replacement. The workstation is designed to be moved between worksites by either the EVA crewman or the Space Shuttle Orbiter manipulator arms. Since the workstation does not provide tools, lighting, and only limited stowage, it is not well suited for long duration servicing tasks.

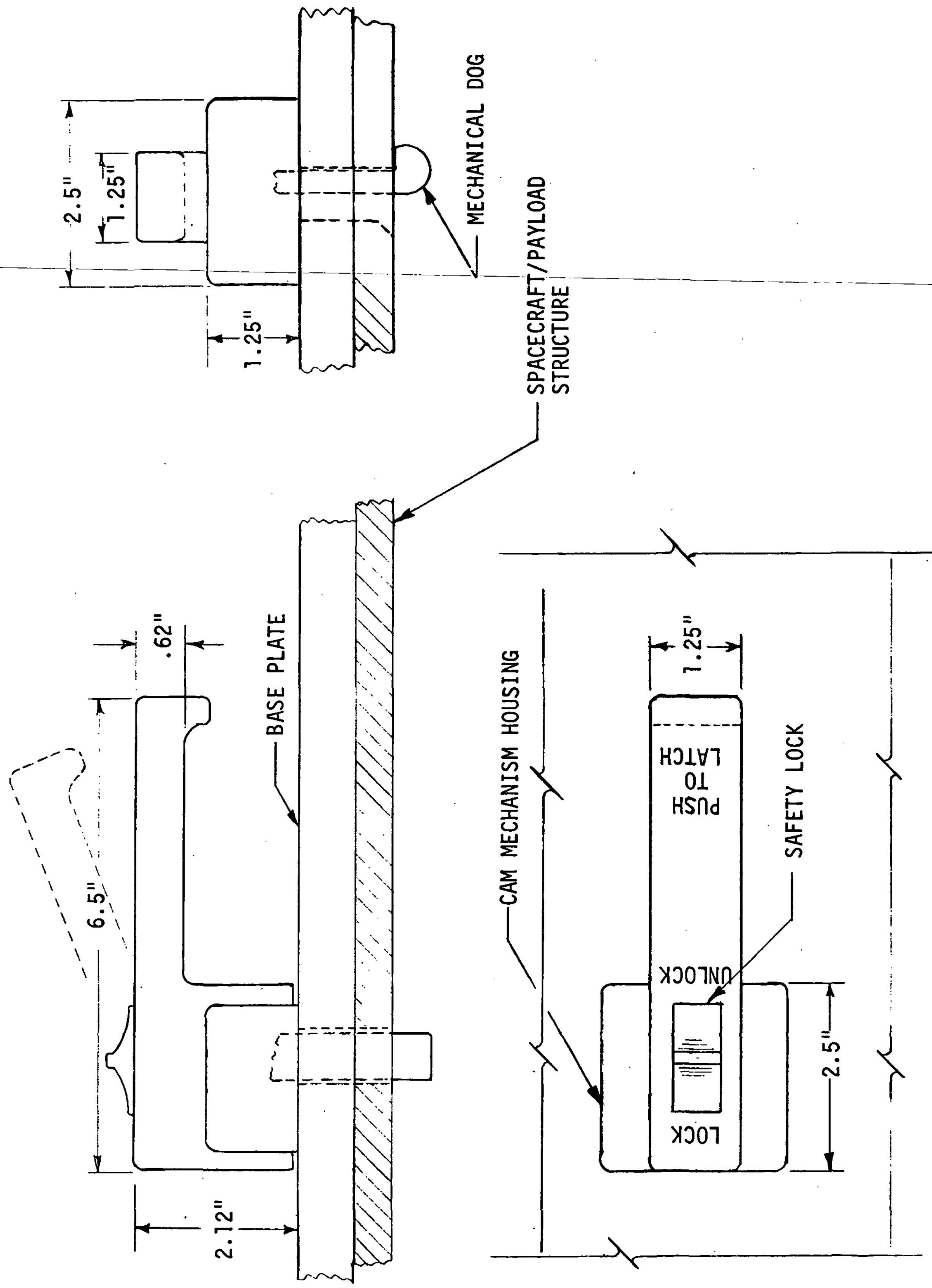


FIGURE 3-2: WORKSTATION-TO-VEHICLE LATCHING DEVICE

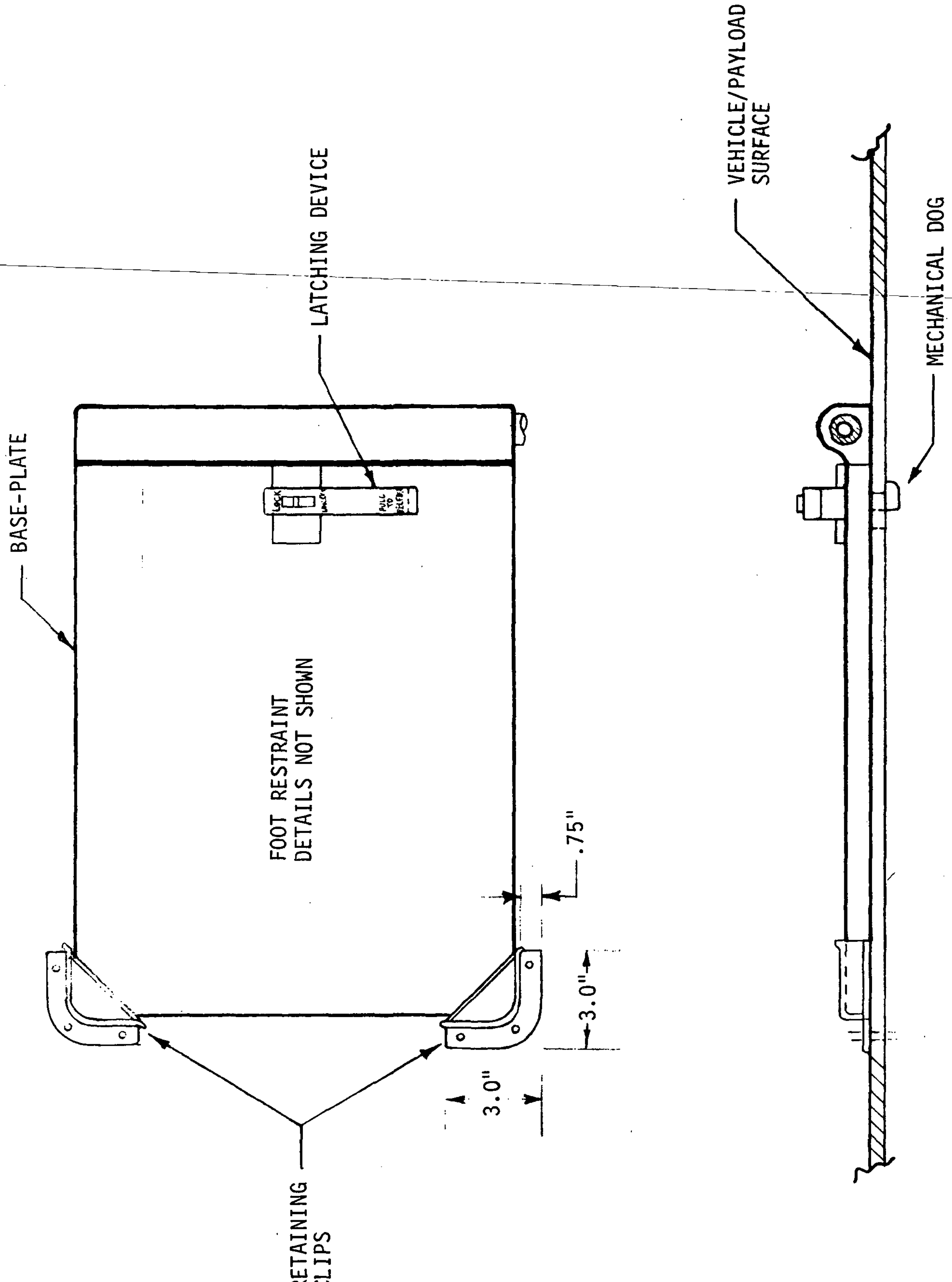


FIGURE 3-3: WORKSTATION ATTACHMENT--PRELIMINARY CONCEPT

3.6.2 Concept 2

Description--EVA Workstation Concept 2 represents a slightly more complex station than Concept 1. A collapsible configuration with Skylab foot restraints and a stabilization aid on one side is shown in Figure 3-4. The only difference between Concepts 1 and 2 is a platform or stowage area provided on the ingress/ stabilization aid on Concept 2. This stowage area could contain a tool kit, modular spare parts, additional temporary stowage hooks, or could be used as a work surface.

The workstation is fabricated from aluminum materials as in Concept 1. The stowage area (or box) is made from welded aluminum plates or stamped from aluminum sheet. For tool stowage, a retaining material would be used inside the box and the tool would be tethered to the crewman during EVA to prevent loss. The work platform on the ingress/stabilization aid rotates through an indexing mechanism to the desired attitude for the work to be performed.

The workstation would be delivered to and mounted on the vehicle/payload in the same manner as Concept 1. Mounting provisions would also be required on the vehicle/payload to mate with the workstation.

The Concept 2 workstation weighs an estimated 25 lbs. (11.3 kg.) with dimensions of approximately 37 x 17 x 6 in. (.94 x .43 x .15 m) in the stowed configuration. The stowed volume is approximately 2.2 $ft.^3$ (.06 m^3).

Applications--EVA Workstation Concept 2 accommodates the same tasks as Concept 1 plus modular package replacement tasks. The workstation is only slightly heavier and larger than Concept 1 and does provide limited tools and additional temporary stowage. The workstation is not recommended for tasks of extended duration but is satisfactory for servicing/replacement tasks of moderate duration (i.e., two hours or less).

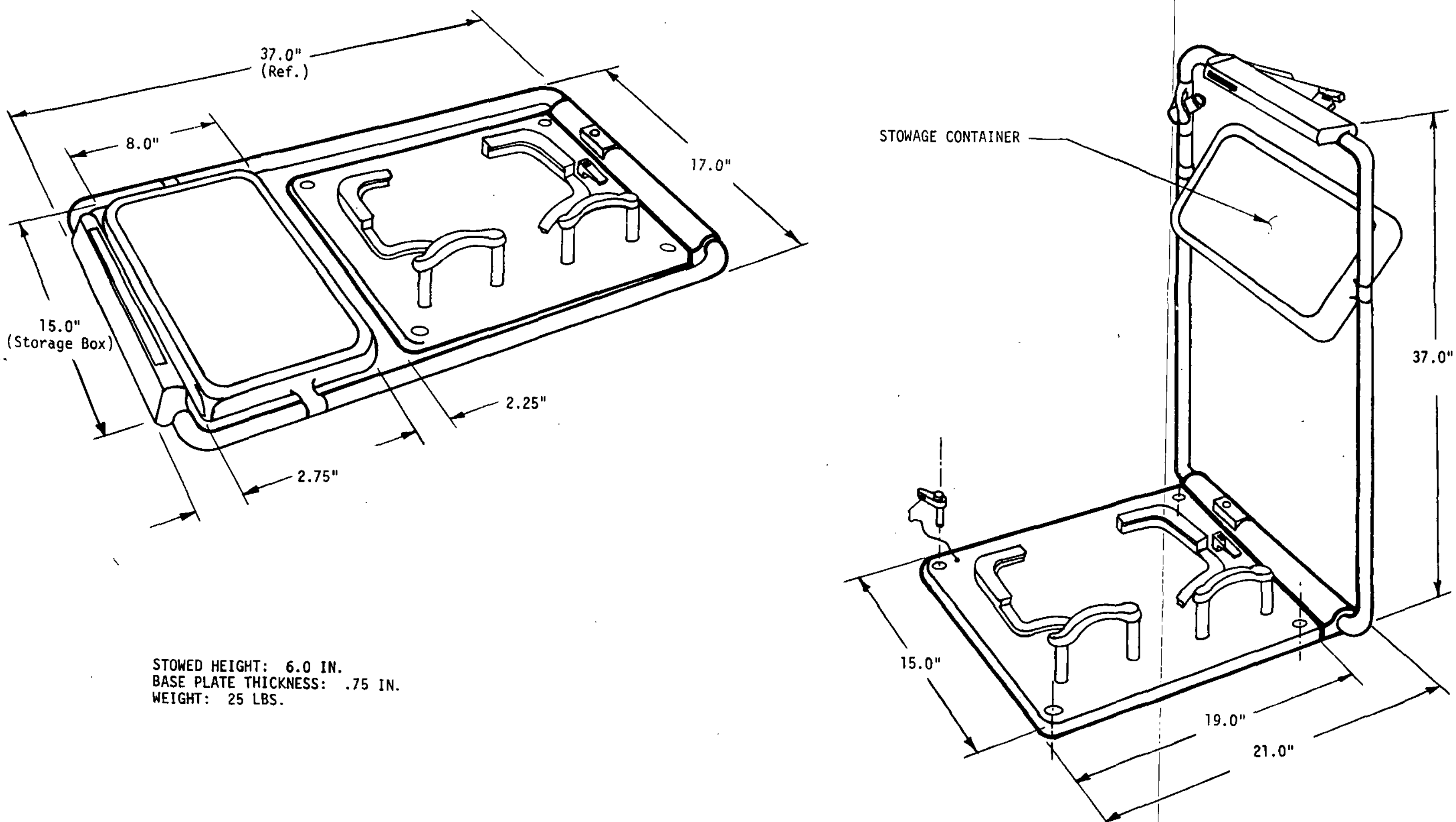


FIGURE 3-4: EVA WORKSTATION CONCEPT--NO. 2

3.6.3 Concept 3

Description--EVA Workstation Concept 3 represents a moderately complex level of workstation, as defined by this study. Figure 3-5 depicts the workstation in its deployed configuration. The workstation consists primarily of the following items and equipment:

- Base-plate--aluminum honeycomb
- Attachment/securing hardware--aluminum and ferrous metals
- Skylab foot restraint components--aluminum
- Rotatable foot restraint plate--aluminum
- Vertical support members--aluminum tubing
- Horizontal ingress/stabilization aid--aluminum
- Tether attach points--aluminum
- Handholds, Apollo cross-section--aluminum
- Umbilical clip--aluminum and ferrous metals
- Mechanical mechanisms for actuating:
  - Rotatable foot restraints
  - Collapsible structural members
  - Pivoting stowage/working unit
- Stowage/working ensemble incorporating:
  - Temporary stowage hooks
  - Auxiliary lighting with stowage provisions
  - 16mm camera with stowage provisions
  - Assortment of tools (as required)
  - Small module stowage (as required)
  - Retractable equipment tethers
  - Work surface
  - Checklist/timeline readout

It should be noted that the configuration, folding techniques, and mechanical actuating devices may be modified from those discussed below as models are developed and detail design initiated. The folding sequence for the Concept 3 workstation is shown in Figure 3-6.

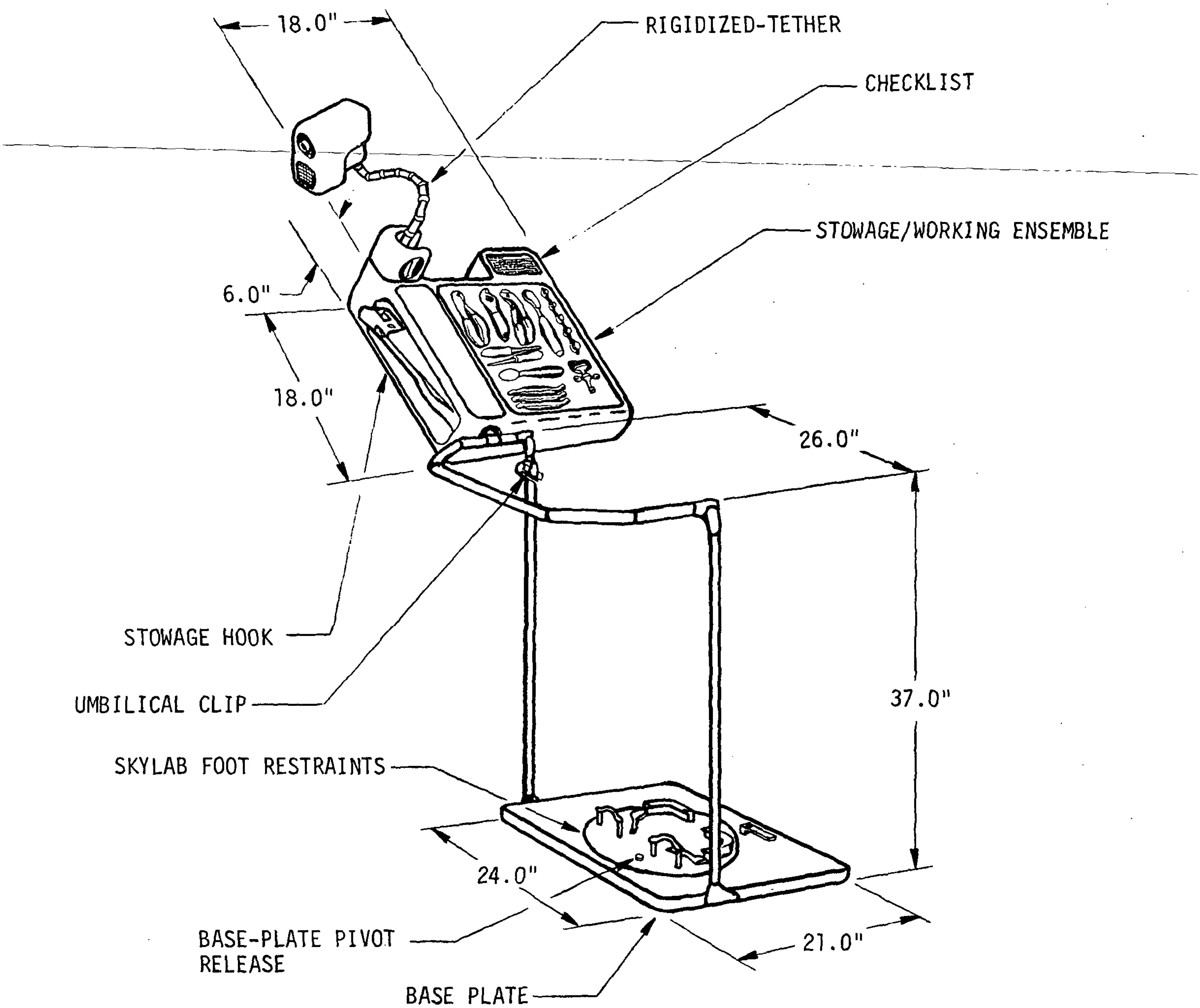


FIGURE 3-5: EVA WORKSTATION CONCEPT--NO. 3

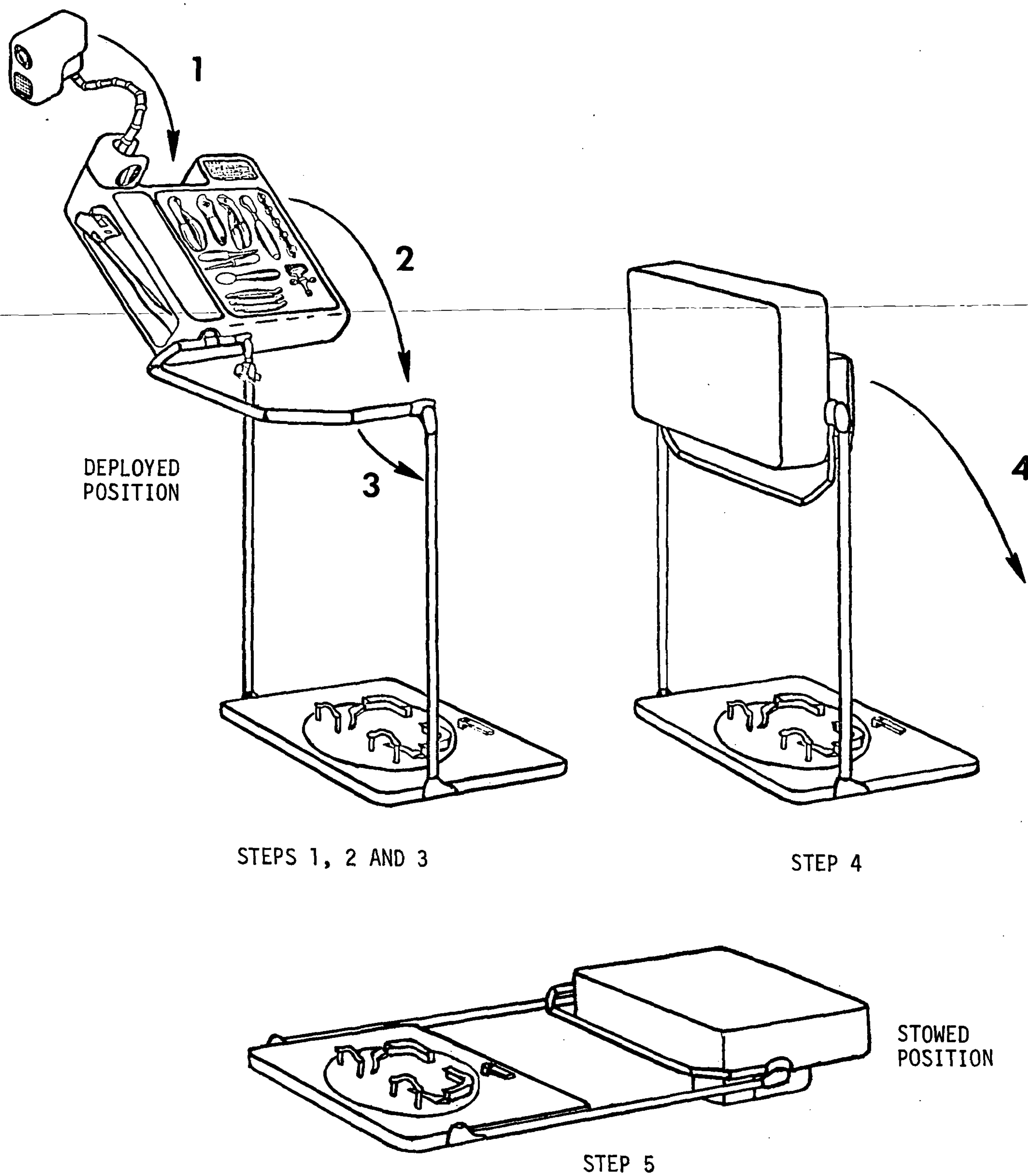


FIGURE 3-6: CONCEPT 3 WORKSTATION FOLDING SEQUENCE

The base-plate is constructed of aluminum honeycomb with provisions for a flush mounted rotatable foot restraint plate. Skylab type foot restraints are provided on the swivel plate. The swivel plate can be rotated by the crewman (while in the workstation) by actuating a spring loaded "foot" release mechanism located on the swivel plate. The swivel plate is locked into the desired position when the mechanism is released.

The two vertical support members are constructed of aluminum tubing with a diameter and wall thickness sufficient to maintain bending within required limits. The top of each vertical member contains a pivot joint for the horizontal rail which supports a stowage/working ensemble. The horizontal rail is constructed in an Apollo cross-section handrail configuration. The workstation is folded into a compact package by: (1) releasing and rotating the stowage/working ensemble counterclockwise (i.e., standing in the workstation) approximately 105 degrees, (2) releasing and folding the horizontal stabilization aid approximately 90 degrees downward, and (3) folding the vertical structural members 90 degrees until all components are in a plane parallel to the base-plate.

Concept 3 also utilizes EVA equipment and hardware configurations from previous space programs. The handholds and handrails are configured from the approved Apollo cross-section, the tether attach points are based on Skylab hardware, and the umbilical clips and temporary stowage hooks are also Skylab-developed equipment/concepts. Handholds are placed at various locations on the workstation, one temporary stowage hook is provided, and one umbilical clip is available on the right-hand vertical support member.

The stowage/working ensemble (box) houses support items ranging from cameras to checklists and includes tools, lights, and spare replacement modules. The camera-light combination is intended to provide auxiliary worksite lighting and record worksite activities. The unit is battery powered, mounted on a rigidized-tether and can be partially stowed inside the stowage/working ensemble for protection during transporation. A work table area is provided to allow placement of small modules for inspection and maintenance.

The modules could be attached by velcro patches and utilize retractable equipment tethers for prevention of loss to space.

The workstation is designed to be either hard-mounted (i.e., in the stowed position) to the vehicle/payload prior to launch or stowed in the vehicle and transported/positioned by the EVA crewman or manipulator systems while in orbit. The entire workstation is attached to the vehicle/payload in the same manner as the previous concepts since mounting commonality is desirable for interchangeable workstation capability.

The tool kit shown in Figure 3-5 is representative of a standard tool assortment that may be useful on Shuttle-based missions. It is anticipated that standard non-powered tools will be adequate for the required operations. Dedicated tools for a specific mission may, however, be required and can be packaged and stowed in the stowage/working ensemble for each EVA mission prior to launch. A view looking from directly above the workstation is shown in Figure 3-7.

The Concept 3 workstation weighs an estimated 44 lbs. (20 kg.) with dimensions of approximately 40 x 26 x 9 in. (1.02 x .66 x .23 m) in the stowed configuration. The stowed volume is about 5.4 ft.^{3} (.15 m^3). These dimensions are based on the concept indicated in Figure 3-5 for folding the workstation. Alternate concepts will allow the workstation to be folded into a package approximately 26 x 26 x 10 in. (.66 x .66 x .25 m). An alternate concept to the basic workstation Concept No. 3 that can be folded into the more compact package is shown in Figure 3-8. The concept incorporates telescoping vertical support members with height adjustments features. The workstation is identical to the basic No. 3 concept in all other respects. The EVA crewman is required to actuate a release mechanism approximately knee-level to telescope the vertical members. This suited maneuver should easily be performed in the 8.0 psi (.56 kg./cm.^{2}) Space Shuttle advanced pressure suit. Figure 3-8 also shows the folding sequence of the alternate concept.

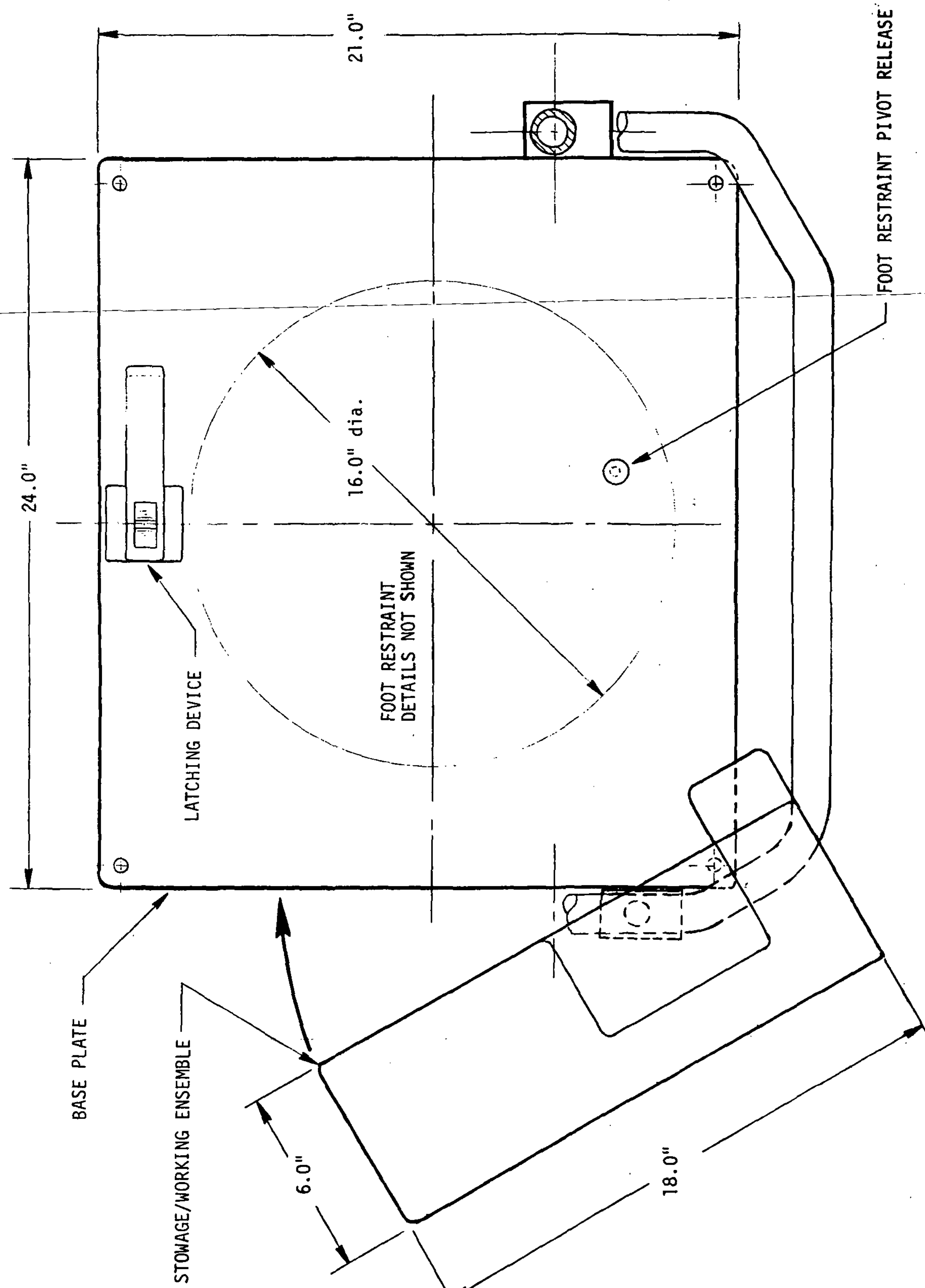


FIGURE 3-7: CONCEPT 3 WORKSTATION--TOP VIEW

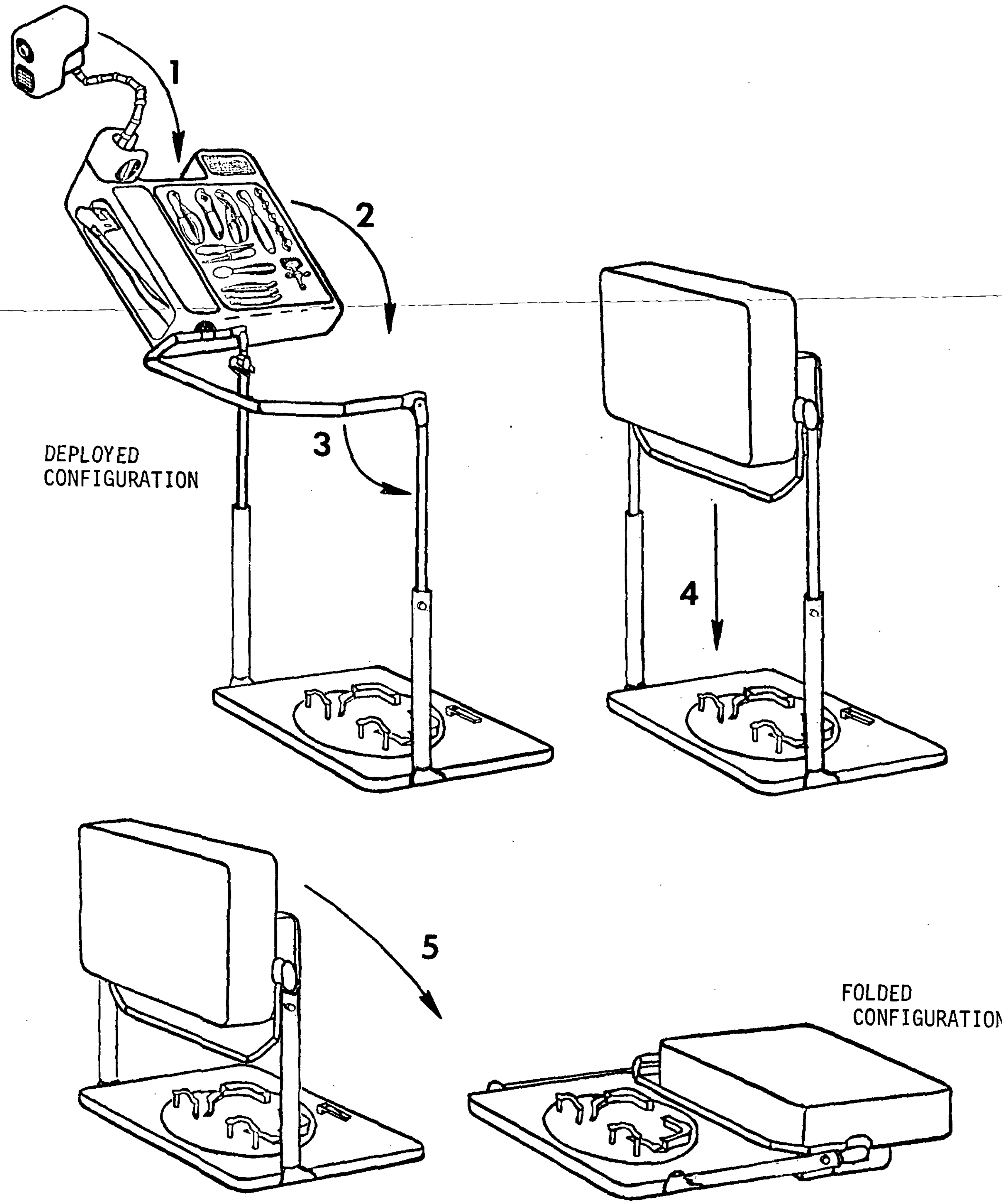


FIGURE 3-8: FIRST ALTERNATE CONCEPT--NO. 3 WORKSTATION

Another alternate workstation to Concept No. 3 is shown in Figure 3-9. This workstation concept depicts a workstation that would normally be attached to the worksite in a folded configuration prior to vehicle launch. The workstation would be deployed by the EVA crewman on-orbit. The two (2) vertical support members are a combination of welded and extruded tubing/sections which house the horizontal stabilization aid sliding "gussets". The "gussets" are automatically positioned when the workstation is deployed and require manual release by actuating two retaining devices located on the vertical support members. The workstation features are identical to the basic No. 3 concept and provides a more rigid structure if large loads are required to be applied by the crewman. Due to the base-plate configuration, this workstation would remain fixed to the worksite during the entire on-orbit mission and folded prior to re-entry.

Applications--EVA Workstation Concept No. 3 is representative of a class of workstations which are well-suited for relatively long duration EVA tasks. The more versatile workstation and stowage facilities render it most useful for tasks or operations where the crewman will be located at not more than 3 worksites during the EVA mission. The larger weight and volume make the workstation more difficult to handle on-orbit than the previous concepts; however, this concept is not intended to be transported as frequently. The longer duration EVA missions may require the crewman to be working in the workstation intermittently for up to 5 hours. These longer duration tasks are likely to involve payload servicing, adjustments, calibration, module replacement, etc.

3.6.4 Concept 4

The final workstation concept developed in the study is similar to Concept 3 in that it represents the more complex class of workstations. The concept (see Figure 3-10) incorporates many of the features as seen in the earlier workstations with the major differences being an additional stowage/working ensemble and the vertical support members which are totally cantilevered from the base-plate. The cantilevered members are required to be structurally capable of

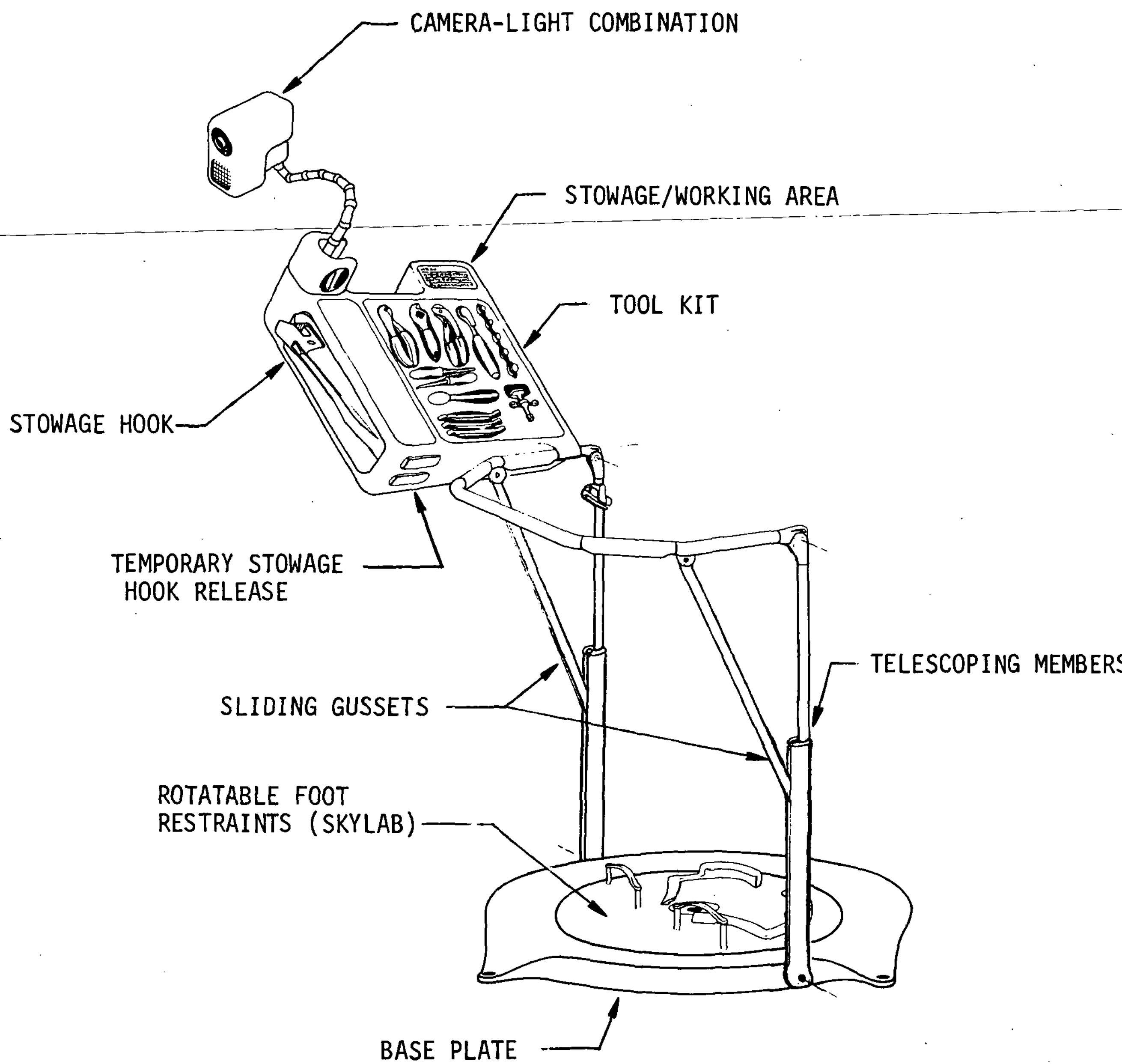


FIGURE 3-9: SECOND ALTERNATE CONCEPT - NO. 3 WORKSTATION

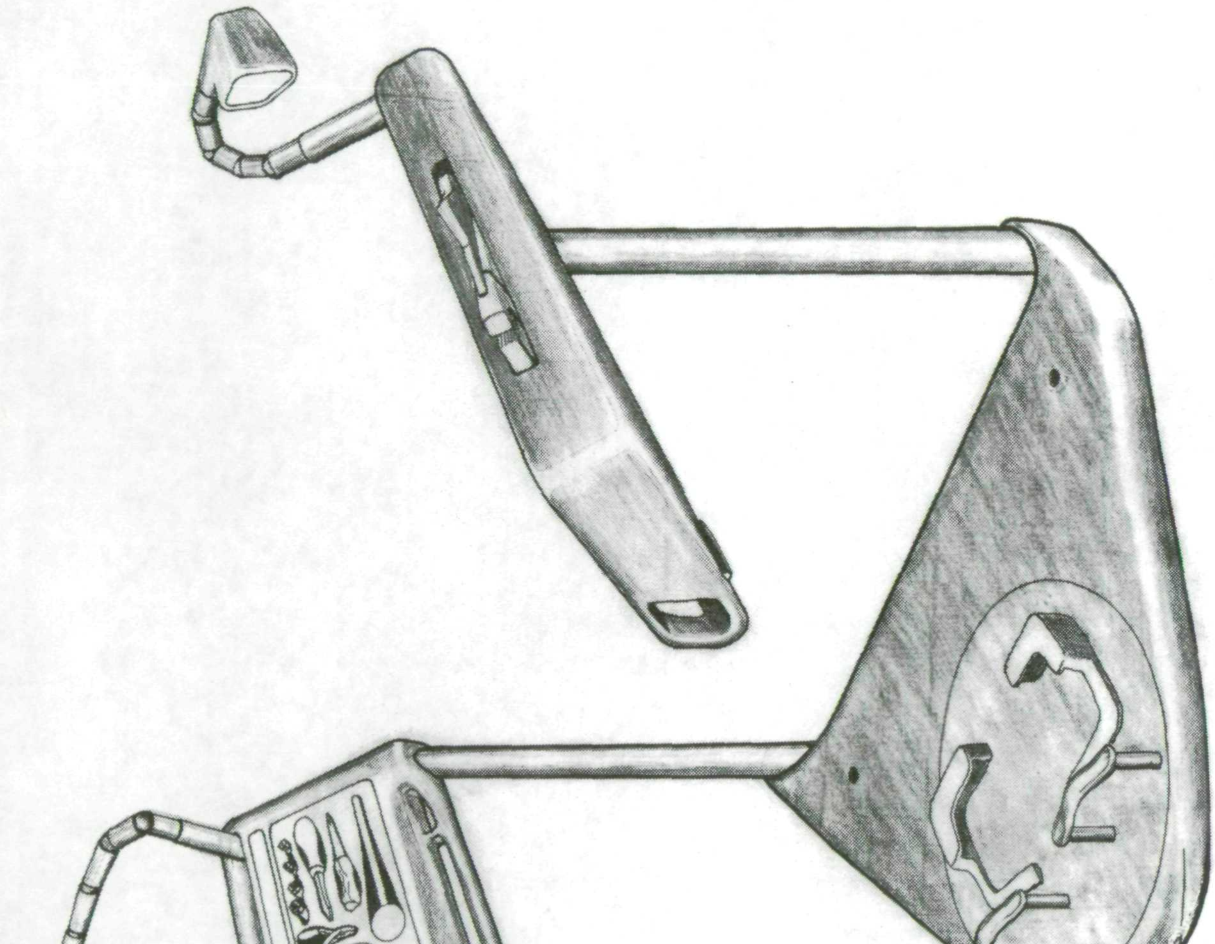


FIGURE 3-11: ALTERNATE CONCEPT--NO. 4 WORKSTATION

withstanding the forces exerted by the EVA crewman without excessive deflection. The workstation is mounted on the vehicle/payload using a single tie-in point at the forward end of the base-plate and bolts on the aft end for rigid mounting. The aft end of the workstation may also use a quick latching mechanism as in previous concepts. The workstation components are fabricated from lightweight aluminum alloy materials as in previous workstations.

The Concept 4 workstation incorporates the following items and hardware:

- Triangular configured honeycomb base-plate
- Rotatable foot restraint plate
- Skylab foot restraint components
- Attachment, securing, and actuating mechanisms
- Two (2) vertical support/structural members
- Two (2) equipment stowage/working ensembles incorporating the following:
  - One integrated camera/light unit
  - One auxiliary flood light
  - Handholds/handrails/stabilization aids
  - Hand tool assortment (optional)
  - Temporary stowage hooks
  - Tether attach points
  - Umbilical clip
  - Work surface
  - Retractable equipment tethers
  - Replacement module stowage
  - Checklist/timeline readout

As in previous concepts, the configuration, folding techniques, and actuating mechanisms may be modified as development efforts are undertaken.

The base-plate, rotatable foot restraint plate, and Skylab type foot restraint components are constructed from the same materials as Concept 3 and utilize identical mechanisms for rotating the foot restraint unit. The base-plate is fabricated to provide a rigid mounting interface for the vertical support members and for the workstation-to-vehicle attachment mechanism. The workstation is attached to the vehicle/payload by inserting the tie-in point into a receptacle, applying a downward force to engage a set of mechanical dogs into the mating units (for temporary restraint), and actuating a lock-unlock lever to rigidly secure the workstation. The workstation can also be bolted into position prior to launch if the unit is not required to be relocated during the mission.

The workstation stowage/working ensembles will rotate up to 270 degrees when additional volume is required by the EVA crewman. The ensembles provide hardware and working/restraint features compatible with those discussed previously for Concept 3; however, additional lighting and stowage are provided in Concept 4. The folding sequence for stowing the unit is also shown in Figure 3-10.

The Concept 4 workstation weighs an estimated 54 lbs. (24.5 kg.) with dimensions of approximately 36 x 26 x 11 in. (.91 x .66 x .28 m) in the stowed configuration. The stowed volume is about 6.0 ft.^{3} (.17 m^3).

An alternate workstation to Concept No. 4 is shown in Figure 3-11. The workstation reflects a somewhat "modern" approach and incorporates EVA support equipment to perform most candidate Shuttle EVA tasks. The workstation stowage/working ensembles will rotate approximately 90 degrees in a plane parallel to the base-plate if additional working volume is required. The ensemble will also tilt-backward approximately 45 degrees (in 5 degree increments) for better access to the ensemble contents.

Applications--EVA Workstation Concept 4 is considered an alternate to Concept 3. Both concepts satisfy essentially the same requirements and are suited for the longer duration operations. Concept 4 provides additional volume for stowage of replacement modules, tools, etc. The front of the workstation is clear from stabilization aids and obstructions that could interfer with certain module handling or servicing operations. The workstation is slightly larger than the previous concepts. This is partially attributed to

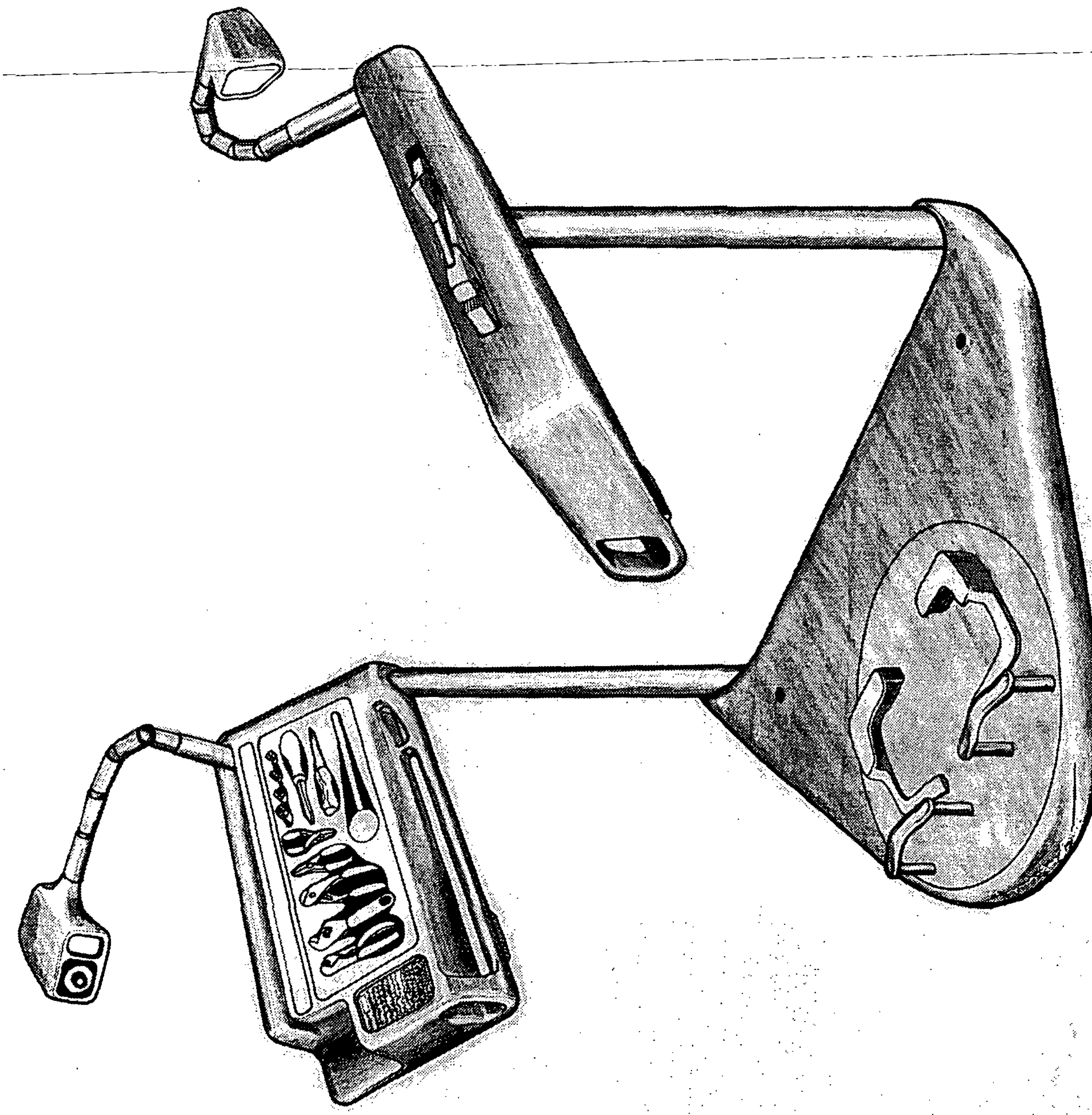


FIGURE 3-11: ALTERNATE CONCEPT--NO. 4 WORKSTATION

the aft location of the vertical members supporting the stowage/working ensembles. This configuration requires approximately 36 in. (.91 m) between structures for portable life support system clearance during workstation activities. Concept 4 places the ensembles outside the volume swept by the suited crewman and life support system when rotated through 360 degrees. The unit can be located very close to the experiment/payload being serviced without workstation component interference. As in Concept 3, the Concept 4 workstation is intended to be repositioned a minimum number of times during the EVA missions.

3.7 EVA WORKSTATION CONCEPT SUMMARY

A summary of the physical characteristics, supporting hardware complement, design features, etc. for each of the concepts described is presented in Table 3-1.

3.8 WORKSTATION DESIGN/SELECTION TRADEOFF PARAMETERS

In later phases of the study, it is anticipated that the workstation concepts described in this report, and others which are developed as payloads become better defined, will undergo comparative evaluation. Evaluations will be based on the impact of each workstation concept on the vehicle, payloads and the mission. Several of the parameters which are relevant to such an evaluation are presented below:

- Weight
- Deployed volume
- Stowed volume
- Vehicle payload interface requirements (mechanical, power, etc.)
- Temporary stowage availability
- Accessibility
- Deploy/stow time
- Working envelope
- Workstation preparation time (workstation positioning, light adjustment, etc.)

TABLE 3-1: SUMMARY OF WORKSTATION CONCEPT CHARACTERISTICS

PARAMETER / CONCEPT NO.	WEIGHT lbs./kg.	STOWED VOLUME $ft.^3/m^3$	DIMENSIONS in./m	STABILIZATION AIDS	RESTRAINTS	TETHER ATTACHMENTS	UMBILICAL CLIPS	EQUIPMENT TETHERS	WORK SURFACES	TEMPORARY STOWAGE HOOKS	ROTATABLE FOOT RESTRAINTS	TOOL KITS	AUXILIARY LIGHTS	CAMERAS	CHECKLISTS/ TIMELINES	MODULE STOWAGE	REMARKS
CONCEPT 1	22.0 / 10.0	1.5 / .042	24.5 x 17.0 x 5.0 / .62 x .43 x .13	HANDRAIL	SKYLAB FOOT RESTRAINTS AND BODY TETHER	YES	YES	YES	NO	YES (1)	NO	NO	NO	NO	NO	NO	SIMPLE INSPECTION/ MONITORING TASKS
CONCEPT 2	25 / 11.3	2.2 / .06	37.0 x 17.0 x 6.0 / .94 x .43 x .15	HANDRAIL	SKYLAB FOOT RESTRAINTS AND BODY TETHER	YES	YES	YES	YES (1)	YES (1)	NO	YES	NO	NO	NO	YES	SIMPLE SERVICING TASKS
CONCEPT 3	44 / 20.0	5.4 / .15	40.0 x 26.0 x 9.0 / 1.02 x .66 x .23	HANDRAIL AND HANDHOLDS	SKYLAB FOOT RESTRAINTS AND BODY TETHER	YES	YES	YES	YES (1)	YES (2)	YES	YES	YES	YES	YES	YES	FULL SERVICING TASKS
CONCEPT 4	54 / 24.5	6.0 / .17	36.0 x 26.0 x 11.0 / .91 x .66 x .28	HANDRAILS AND HANDHOLDS	SKYLAB FOOT RESTRAINTS AND BODY TETHER	YES	YES	YES	YES (2)	YES (2)	YES	YES	YES	YES	YES	YES	FULL SERVICING TASKS

APPENDIX A

APPENDIX A

INTRODUCTION

The March 1972 Shuttle Traffic Model* was used extensively as an information source in developing requirements for EVA workstations applicable to the Space Shuttle and long-range spaceflight programs. The Model is referenced frequently in the body of this report, and it was felt that the information contained in the Model should be readily available to the reader. Therefore, the main body of the Model was reproduced directly from the document and is contained in this Appendix.

The Model contains the results of a payload grouping and unlimited Shuttle traffic model analysis for the years 1979 through 1990. The NASA payloads definition and schedules in the analysis were not considered official but were provided for planning purposes only. As new payload listings are received by NASA, the payload grouping and traffic model will be re-analyzed to reflect the updated payload definitions. No attempt was made by NASA to select flights from the unlimited Model to fit any flight rate numbers because data was not available for assigning priorities to the payloads. As far as the analysis is concerned, one payload has the same probability of "flying" as does another.

The remainder of this appendix was taken directly from the March 1972 Shuttle Traffic Model for reader information.

*NASA/DOD Earth Orbit Shuttle Traffic Model in Support of the March 1972 Request for Proposal (RFP)--MSC-06746.

DISCUSSION

The definition of the unlimited shuttle traffic model is based on the definitions and schedules of NASA payloads in references 1, 2, and 3. The majority of payloads were obtained from reference 1 with additional equatorial geosynchronous missions and revisit data from reference 2 being included in the total payload list. Space station data were derived from reference 3. Reference 4 contains DOD payload characteristics and schedules. Table I defines the NASA payload characteristics and schedules used in the traffic model. Table II shows the distribution of payloads per shuttle flight and the number of required shuttle flights during the years 1979 through 1990 for an unlimited traffic model. The flight numbers given in this table do not dictate the order in which the payloads would be flown. A payload priority list would have to be determined for each mission year to schedule the actual order in which the payloads would be flown. Table III is a summary of the unlimited traffic model and a more realistic shuttle flight frequency model.

In this study, the attempt was made to combine payloads with similar inclination and destination characteristics. Lengths, diameters, and weights of the cargo also had to be considered in combining the payloads. How the payloads would be combined was dictated more by the lengths than by the diameters or weights. When more than one payload of the same kind were scheduled in any year, these payloads were not combined on the same flight.

Some payloads can be placed in orbit by the shuttle alone, while others require a third stage. Approximately 45 percent of the shuttle flights placed the payloads in orbit directly, while 55 percent carried payloads requiring third stages (the characteristics are defined in Table IV). Payloads were combined primarily with the condition that weight and volume be within the performance capability of the shuttle. No attempt was made to study in detail the mission planning necessary for flying combined payloads on a single shuttle launch.

In some instances, the shuttle with only the integral OMS tanks on board did not have the capability for payload placement. For these situations, extra sets of tanks were added until placement could be achieved. In those cases (payload 13 up and 15 down of Table II) where the last additional OMS set could not be filled completely without violating the shuttle capability curves of the figures, the maximum payload weight (45,000 lbs. to a 350-n. mi. circular orbit) that can be taken to the orbit of interest was computed. The figure presents the capability curves for the heavy 040 shuttle configuration. The top altitude scale corresponds to payloads requiring no rendezvous while the bottom scale accounts for rendezvous maneuvers.

The desired orbits of the NASA payloads ranged from 100 n. mi. circular to 38,646 circular with smaller elliptical orbits interspersed. In addition, some payloads required earth escape velocities. The inclinations encountered range from 0° to 101°. Because information pertaining to DOD orbital parameters are classified, these data are not presented for DOD shuttle flights.

The payload packaging with the two Agenas and the reusable tug as kick-stages assumed that each stage had multiple restart capability. For all tug flights, the assumption was that the tug would return to rendezvous with the shuttle in the shuttle orbit and would take no longer than 7 days to complete the total mission (satellite placement and rendezvous). For some payload placements, that is, most of the planetary missions and the Applications Technology satellite, the tug is not capable of a round trip. These missions are footnoted in Table II. In all instances where a third stage was required and weight was not a limiting shuttle parameter, the third stage propellant tanks were assumed to be fully loaded. This maximum propellant loading is reflected in the weight data of Table II.

Table II presents the propulsion stages used to deliver the NASA payloads to their target orbit. No data other than flight number and mission number (the numbers are fictitious; the actual mission numbers are used by the Air Force) are presented for DOD in order to avoid any breach of security. The Agena stage was used from 1979 through 1985 to deliver payloads from the shuttle orbit (in most instances the shuttle will place the kick-stage plus satellite into a 100-n. mi. circular orbit) to higher earth-orbit altitudes and to delivery small payloads (less than approximately 2800 lbs.) to equatorial geosynchronous orbits. The evolutionary stage Agena was used to deliver the heavier payloads to equatorial geosynchronous orbits, earth escape, and planetary injection missions. After 1984, the reusable tug was employed for all missions requiring a third stage.

CONCLUSIONS

The unlimited shuttle traffic model for the years 1979 through 1990 results in a total of 677 shuttle flights which transport 966 payloads to orbit. This is 80 flights more than a realistic, but not official, shuttle flight frequency. With no priorities being assigned to the payloads, a selection of payload traffic based on the shuttle frequency limitations is impossible. Of the 677 flights, 225 required third stages (99 Agena and 126 tug flights) to accomplish satellite placement.

SYMBOLS--ACRONYMS

DOD	Department of Defense
ETR	Eastern Test Range
fps	feet per second
h_a	height of apogee
h_p	height of perigee
IOC	initial operational capability
i	inclination
MPAD	Mission Planning and Analysis Division of JSC
MSC	Manned Spacecraft Center (JSC - Johnson Space Center)
NASA	National Aeronautics and Space Administration
n. mi.	nautical miles
OMS	on-orbit maneuvering system
RFP	Request for Proposal
SAMSO	Space and Missile System Organization
STS	Space Transportation System
USAF	United States Air Force
WTR	Western Test Range

TABLE I: PAYLOAD CHARACTERISTICS AND SCHEDULE

Ref. no.	Payload title	Orbit characteristics: i	$h_a \times h_p$	Dia.	L	Wt.	Schedule: 1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1a	Astronomy explorer	28.5	270	4.5	4	890	2		1	2	2	1		2	1	2	2	
1b	Astronomy explorer	0	19 323	4.5	4	890		2	1			1	2		1			2
2	Radio explorer	28.5	19 323	4.5	3.5	900		2	1			1	2		1			
3	Magnetosphere explorer - low	28.5-90	1800 × 180	4	8	1 200	1	1	1	1	1	1	1	1	1	1	1	1
4	Magnetosphere explorer - middle	28.5-90	20 000 × 1000	6	8	1 000	1	1	1	1	1	1	1	1	1	1	1	1
5	Magnetosphere explorer - high	28.5	1 A.U.	4	6	600	1	1	1	1	1	1	1	1	1	1	1	1
6	Orbiting solar observatory	28.5	350	7	10	1 980		1										
7	Gravity/relativity exp. C, E	90	300	5	7	1 500						1						1
8	Gravity/relativity exp. B, D	28.5	1 A.U.	4	5	500			1						1			
9	Radio interferometer	28.5	38 646	11	25	10 350			2									
10	Solar orbit pair	28.5	19 323	10	12	1 880						1					1	
11	Solar orbit pair	28.5	1 A.U.	10	12	2 520						1					1	
12	Optical interferometer	28.5	19 323	7	10	3 140										2		
13	High energy astron. observ.	28.5	200	11	50	21 450	UP		UP		DN		UP		DN		UP	
14	HEAO revisit	28.5	200	14	13	3 500		2	2	2	2	2	2	2	2	2	2	2
15	Large space telescope	28.5	350	13	45	22 300			UP		UP		DN		UP		DN	
16	LST revisit	28.5	350	14	13	3 500				2	2	2	1	2	2	2	2	2
17	Large solar observatory	28.5	350	15	57	27 700					UP		UP		DN		UP	
18	LSO revisit	28.5	350	14	13	3 500						2	2	2	2	1	2	2
19	Large radio observatory	28.5	350	14	30	20 000							UP		UP		DN	
20	LRO revisit	28.5	350	14	13	3 500								2	2	2	2	2
21	Polar earth obs. sat.	99.15	500	12	15	2 590	1	1	1	1	1	1	1	1	1	1	1	1
22	Sync. earth obs. sat.	0	19 323	4	6	1 030		1		1		1		1		1		1
23	Earth physics sat.	90	400	3.5	6.5	600		1	1	1	1		1		1		1	
24	Sync. meteorological sat.	0	19 323	5	8	1 035				1	1							
25	TIROS	100.7	700	5	10	1 030			1				1					1
26	Polar earth res. sat.	99.15	500	12	15	2 590								2	4			
27	Sync. earth res. sat.	0	19 323	4	6	1 030			1	2	1				1	2		
28	Applications tech. sat.	0	19 323	15	21	8 230	1		1		1	1		1		1	1	
29	Small applications sat.	0	19 323	6.5	12	620	1	1	1	1	1	1	1	1	1	1	1	1
30	Small applications sat.	90	3000 × 300	6.5	12	620	1	1	1	1	1	1	1	1	1	1	1	1
31	Cooperative applications	0	19 323	6.5	12	850	1					1						
32	Cooperative applications	90	3000 × 300	6.5	12	850				1							1	
33	Medical network sat.	0	19 323	12	15	2 070	2											
34	Education broadcast sat.	0	19 323	10	19	3 520		2										
35	Follow-on systems dem.	0	19 323	12	15	2 070			2	2	2	2	2	2	2	2	2	2
36	Tracking and data relay	0	19 323	10	17	2 380	1	2	1		2	1			2	1		
38	General science res. mod.	55	200	14	54	27 500			2	3	4	4	3					
39	General applications res. mod.	65	100	14	51	30 000			2	3	2	3	2	3		3	1	
40	Ded. sci. and res. mod. astron.	55	200	14	54	29 500						1	3	4	5	4	5	5
41	Ded. apl. mod. - E.O.	75	100	14	51	22 500						2	2	2	2	2	3	4
42	Earth observation	90	125	14	37	6 000		1	1	2								
43	Bio. research	28.5	200	14	37	4 300	1											
44	Astronomy	28.5	200	14	37	5 700		2	2	2	1							
45	Fluid management	28.5	200	14	37	7 100		1			1							
46	Teleoperator	28.5	200	14	37	5 000		1										
47	Manned work platform	28.5	200	14	37	6 700			1									
48	Large telescope min. test.	28.5	200	14	37	13 000	1											
49	Astro. maneuver. unit	28.5	200	14	37	3 800		1										
50	Mars, Viking	ΔV = 15 400		10	12	7 720	1		1									
51	Mars sample return	ΔV = 15 400		14	16	10 600												2
52	Venus explorer	ΔV = 13 400		5	12	1 000		1										
53	Venus radar mapping	ΔV = 13 400		10	12	7 900				1								
54	Venus explorer lander	ΔV = 13 400		10	25	7 420							1			1		
55	Jupiter Pioneer orbiter	ΔV = 22 700		10	15	930				2								
56	Grand Tour (JUN)	ΔV = 25 900		10	12	1 510	2											
57	Jupiter TOPS orbiter	ΔV = 22 700		10	15	3 290							1		1			
58	Uranus TOPS probe	ΔV = 24 000		10	15	3 700								1			1	
59	Asteroid EROS rend.	ΔV = 13 400		10	17	2 240						1						
60	Comet rendezvous	ΔV = 13 400		10	20	2 070				1			1					
60-1	Encke comet	ΔV = 21 100		10	20	2 300		1										
60-2	Halley's comet	ΔV = 10 800		10	15	6 900					1							
60-3	Saturn orbiter	ΔV = 18 600		12	22.5	4 050											1	

TABLE I: PAYLOAD CHARACTERISTICS AND SCHEDULE (CONT'D.)

Ref. no.	Payload title	Orbit characteristics: i	$h_a \times h_p$	Dia.	L	Wt.	Schedules: 1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
61	Station	55	270	14	40	20 000							1					
62	Station modules	55	270	14	30	20 000							5	5	5	3	3	4
63	RAM	55	270	14	30	20 000								1	1 UP	UP	2 UP	1 UP
															2 DN		2 DN	1 DN
64	Physics lab	55	270	14	32	20 000							1 UP					1 DN
65	Cosmic ray lab	55	270	14	52	30 000										1 UP		
66	Life sciences lab	55	270	14	40	20 000							UP		DN			
67	Earth obs. lab	55	270	14	40	20 000							UP		DN			
68	Comm/nav lab	55	270	14	38	19 000							UP		DN			
69	Space manufac. lab	55	270	14	40	20 000												UP
70	COMSAT	0	19 323	9	22	1 490	2	1	1		2	1	1			2	1	
71	U.S. domestic comm.	0	19 323	15	25	3 545	1	2	1	1	2	2	2	2	2	2	2	2
72	Foreign domestic comm.	0	19 323	4	12	1 030		2	6	2	2			4	5	2	1	2
73	Nav. and Traf. control	28.5	30 000 × 16 000	5	8	725	3	1	2		1		1		1		1	
74	Nav. and Traf. control	5	19 300	5	8	725	1		1		1		1		1		1	
75	TOS Met.	100.7	700	5	6	1 030	1	1	1	1	1	1	1	1	1	1	1	1
76	Sync. Met.	0	19 323	5	8	1 035	1	1	1	1	1	1	1	1	1	1	1	1
77	Polar earth res.	99.15	500	6	12	2 590	4		4		4		4				6	
78	Sync. earth res.	0	19 323	6	6	1 030							4			4		
79	Comm. sats. gen.	0	19 323	8	10	850	4	4	4	4	4	4	4	4	4	4	4	4
80	Broadcast sats.	0	19 323	10	12.5	2 500	2	2	2	2	2	2	2	2	2	2	2	2
81	Broadcast sats.	0	19 323	8	10	1 000	2	2	2	2	2	2	2	2	2	2	2	2

TABLE II: PAYLOAD COMBINATIONS AND FLIGHTS

Shuttle flight no.	[a]Payload no.	PL + kick stage + OMS sets dimension	[b]PL + kick stage + OMS sets weight	Kick stage	Shuttle flight no.	Payload no
		NASA - 1979			DOD - 1979	
1	1a,43	14 × 41	7 190	--	1	1(2),3
[c]2	1a,13	11 × 59	37 290	--	2-3	8
3	3,73,5	5 × 43	19 345	Agena	4-8	14
4	80,73	10 × 43.5	56 025	E. Agena	9	5,21
5	28,4,73	15 × 60	62 755	E. Agena	10-11	18
6	48	14 × 37	15 000	--	12	13(2)
7	50	10 × 35	60 520	E. Agena	13-14	17
8-9	56	10 × 35	54 315	E. Agena	15-17	19
10	79,33,81	12 × 58	56 720	E. Agena	18-20	20
11	33,70	12 × 60	56 360	E. Agena		
12	79,36,81	10 × 60	57 030	E. Agena		
13	79,80,29	10 × 57.5	56 770	E. Agena		
14	74,79	8 × 39	18 395	Agena		
15	31,71	15 × 60	57 195	E. Agena		
16	70,76	10 × 53	55 325	E. Agena		
[e]17	21,77	12 × 48	22 000	Agena		
[e]18	30	6.5 × 33	17 420	Agena		
[e]19	77,75	5 × 45	20 440	Agena		
[e]20-21	77	5 × 33	19 410	Agena		
		NASA - 1980			DOD - 1980	
1	2,3,4	10 × 42.5	55 900	E. Agena	1	3,1
2	2,73,5	10 × 40.5	55 025	E. Agena	2-10	4
[c]3	45,6	14 × 52	24 030	--	11	8
4-5	44,14	14 × 50	11 200	--	12-16	14
6	46	14 × 37	7 000	--	17-18	18
7	49	14 × 37	5 800	---	19-20	17
8	60-1	10 × 43	55 100	E. Agena	21-23	19
9	52	5 × 33	17 820	Agena	24-25	10
10	1b,34,80	10 × 58.5	59 710	E. Agena	26	12(3)
11	79,1b,70	10 × 59	56 030	E. Agena	27	13(2)
12	80,36,22	12 × 58.5	58 710	E. Agena	28-30	20
13	36,81,79	12 × 60	57 030	E. Agena		
14	81,79,29	10 × 55	55 270	E. Agena		
15	34,76,79	10 × 60	58 205	E. Agena		
16-17	71,72	15 × 60	57 375	E. Agena		
[e]18	21,75	12 × 42	20,440	Agena		
[e]19	23,30	6.5 × 39.5	18 040	Agena		
[e]20	42	14 × 37	8 000			
		NASA - 1981			DOD - 1981	
1	2,73,9	14 × 59.5	64 775	E. Agena	1	1
[c]2	13,1a	11 × 59	37 290	--	2-3	8
3	9,5	14 × 54	63.750	E. Agena	4-5	18
4	73,8	5 × 34	18 045	Agena	6	5
[c]5	15	13 × 50	37 250	--	7	10
6-7	14,44	14 × 50	11 200	--	8	12(3)
8	47	14 × 37	8 700	--	9-10	17
9	50	10 × 35	60 520	E. Agena	11-13	19
10	27,81,79	10 × 49	55 680	E. Agena	14-16	20

TABLE II: PAYLOAD COMBINATIONS AND FLIGHTS (CONT'D.)

Shuttle flight no.	[a]Payload no.	PL + kick stage + OMS sets dimension	[b]PL + kick stage + OMS sets weight	Kick stage	Shuttle flight no.	Payload no.
	NASA - 1981 - Concluded					
11	28,72,1b	15 × 60	62 950	E. Agena		
12	80,72,79	10 × 57.5	57 180	E. Agena		
13	80,81,29	10 × 57.5	56 920	E. Agena		
14-15	35,72,79	12 × 60	56 750	E. Agena		
16	36,72,76	10 × 60	57 245	E. Agena		
~~17~~	~~74,70~~	~~9 × 51~~	~~19 035~~	~~Agena~~		
18	71,72	15 × 60	57 375	E. Agena		
19-20	38	14 × 54	29 500	--		
21-22	39	14 × 51	32 000	--		
[e]23	3,30	6.5 × 41	18 640	Agena		
[e]24	23,4	6 × 35.5	18 420	Agena		
[e]25	42	14 × 37	8 000	--		
[d]26	21,77	12 × 48	22 000	Agena		
[d]27	77,25	6 × 43	20 440	Agena		
[d]28	77,75	6 × 39	20 440	Agena		
[d]29	77	6 × 33	19 410	Agena		
		NASA - 1982			DOD - 1982	
1	3,4,5	6 × 43	19 620	Agena	1	3,1
[f]2	16,44	14 × 60	37 100	--	2-3	8
[c]3	44,14,1a	14 × 59	25 040	--	4-8	14
[f]4	14,16,1a	14 × 40	35 790	--	9	16
5	53	10 × 35	60 700	E. Agena	10-11	18
6-7	55	10 × 38	53 730	E. Agena	12	10
8	60	10 × 43	54 870	E. Agena	13-14	17
9	22,27	5 × 33	18 880	Agena	15-17	19
10	35,79,29	12 × 60	56 340	E. Agena	18-20	20
11	24,27,81	10 × 47	55 865	E. Agena		
12	81,80,79	10 × 57.5	57 150	E. Agena		
13	76,80,79	10 × 53.5	57 185	E. Agena		
14	35,72,79	12 × 60	56 750	E. Agena		
15	71,72	15 × 60	57 375	E. Agena		
16-18	38	14 × 54	29 500	--		
19-21	39	14 × 51	32 000	--		
[e]22	23,30,32	6.5 × 51.5	19 890	Agena		
[e]23-24	42	14 × 37	8 000	--		
[d]25	21,75	12 × 42	20 440	Agena		
		NASA - 1983			DOD - 1983	
1	14,45	14 × 50	12 600	--	1	2(2),3
2	1a,73,5	5 × 39	19 035	Agena	2-4	4.
[f]3	14,16,1a	14 × 40	35 790	--	5-9	14
[g]4	15 up	13 × 50	37 250	--	10	8
	13 down	11 × 55	24 650	--	11	5
[f]5	16,44	14 × 60	37 100	--	12	16
[c,g]6	17	15 × 60	42 650	--	13-14	17
7	60-2	10 × 38	59 700	E. Agena	15-16	18
8	24,74	5 × 37	18 580	Agena	17-19	19
9	36,81,79	10 × 60	57 030	E. Agena	20-22	20

TABLE II: PAYLOAD COMBINATIONS AND FLIGHTS (CONT'D.)

Shuttle flight no.	[a]Payload no.	PL + kick stage + OMS sets dimension	[b]PL + kick stage + OMS sets weight	Kick stage	Shuttle flight no.	Payload no.
	NASA - 1983 - Concluded				DOD - 1983 - Continued	
10	28,27,79	15 × 60	62 910	E. Agena	23-24	9(2)
11	36,81,79	10 × 60	57 030	E. Agena	25	10
12	80,29,79	10 × 57.5	56 770	E. Agena	26	12(3)
13	80,76	10 × 43.5	56 335	E. Agena		
14-15	35,70	12 × 60	56 360	E. Agena		
16-17	71,72	15 × 60	57 375	E. Agena		
18-21	38	14 × 54	29 500	--		
22-23	39	14 × 51	32 000	--		
[e]24	3,4	6 × 37	19 020	Agena		
[e]25	23,30	6.5 × 39.5	18 040	Agena		
[d]26	21,77	12 × 48	22 000	Agena		
[d]27	77,75	5 × 39	20 440	Agena		
[d]28-29	77	5 × 33	19 410	Agena		
	NASA - 1984				DOD - 1984	
1	2,10,5	10 × 44.5	56 180	E. Agena	1	2(2),3
[c]2	14,1a,11	14 × 55	34 760	Agena	2-4	4
[f]3	14,16	14 × 36	34 900	--	5-9	14
[f]4	16,18	14 × 36	34 900	--	10-11	8
[f]5	18	14 × 23	31 400	--	12	16
6	59	10 × 40	55 040	E. Agena	13-14	17
7	28,22,1b	15 × 54	62 950	E. Agena	15-16	18
8	36,81,79	10 × 60	57 030	E. Agena	17-19	19
9	71,79	15 × 58	57 195	E. Agena	20-22	20
10	80,76,79	10 × 53.5	57 185	E. Agena	23	10
11	35,79,29	12 × 60	56 340	E. Agena	24	12(3)
12	71,31	15 × 60	57 195	E. Agena		
13	80,81	10 × 45.5	56 300	E. Agena		
14	35,70	12 × 60	56 360	E. Agena		
15-18	38	14 × 54	29 500	--		
19-21	39	14 × 51	32 000	--		
22	40	14 × 54	31 500	--		
23-24	41	14 × 51	24 500	--		
[e]25	3,4	6 × 37	19 020	Agena		
[e]26	7,30	6.5 × 40	18 940	Agena		
[d]27	21,75	12 × 42	20 440	Agena		
	NASA - 1985				DOD - 1985	
1	5,4,2	15 × 52.5	65 000	Tug	1	3
2	3,2,73	15 × 54.5	65 000	Tug	2-4	4
[f]3	13 up	11 × 60	45 000	--	5-6	6
	15 down	13 × 55	25 500		7-8	8
[f]4	14,16	14 × 36	34 900	--	9	16
[f]5	14,18	14 × 36	34 900	--	10-11	17
[c,g]6	17	15 × 60	42 650	--	12-13	18
[f]7	18,19	14 × 53	45 000	--	14-16	19
[h]8	54	15 × 60	65 000	Tug	17-19	20
[h]9	57	15 × 50	65 000	Tug	20	9(2)
10	60	15 × 55	65 000	Tug	21-24	11

TABLE II: PAYLOAD COMBINATIONS AND FLIGHTS (CONT'D.)

Shuttle flight no.	[a]Payload no.	PL + kick stage + OMS sets dimension	[b]PL + kick stage + OMS sets weight	Kick stage	Shuttle flight no.	Payload no.
	NASA - 1985 - Concluded					
11	78,16,81	15 × 55	65 000	Tug		
12	79,16,78	15 × 55	65 000	Tug		
13	29,80	15 × 59.5	65 000	Tug		
14-15	35,79	15 × 60	65 000	Tug		
16-17	71	15 × 60	65 000	Tug		
18	70	15 × 57	65 000	Tug		
19	79,76,78	15 × 59	65 000	Tug		
20	80,78	15 × 53.5	65 000	Tug		
21	74,81	15 × 53	65 000	Tug		
22	61	14 × 40	22 000	--		
[c]23-27	62	14 × 35	34 950	--		
[c]28	66	14 × 45	34 950	--		
[c]29	67	14 × 45	34 950	--		
30-32	38	14 × 54	29 500	--		
33-34	39	14 × 51	32 000	--		
35-37	40	14 × 54	31 500	--		
38-39	41	14 × 51	24 500	--		
[e]40	23,30	15 × 53.5	30 000	Tug		
[d]41	21,75	15 × 56	35 000	Tug		
[d]42	77,25	15 × 57	35 000	Tug		
[d]43-45	77	15 × 47	35 000	Tug		
[c]46	64	14 × 37	34 950	--		
[c]47	68	14 × 43	33 950			
	NASA - 1986				DOD - 1986	
1	5	15 × 41	65 000	Tug	1	2
[f]2	14,18,1a	14 × 40	35 790	--	2	8
[f]3	16,20,1a	14 × 40	35 790	--	3-7	14
[f]4	14,16	14 × 36	34 900	--	8	16
[f]5	18,20	14 × 36	34 900	--	9-10	17
[h]6	58	15 × 50	65 000	Tug	11-12	18
7	28	15 × 56	65 000	Tug	13-15	19
8	22,76,79	15 × 59	65 000	Tug	16-18	20
9	29,81	15 × 57	65 000	Tug	19	9(2)
10-11	35,79	15 × 60	65 000	Tug	20	12(3)
12	72,79	15 × 57	65 000	Tug		
13-14	71	15 × 60	65 000	Tug		
15-16	72,80	15 × 59.5	65 000	Tug		
17	72,81	15 × 57	65 000	Tug		
[c]18-22	62	14 × 35	34 950	--		
[c]23	63	14 × 35	34 950	--		
24-26	39	14 × 51	32 000	--		
27-30	40	14 × 54	31 500	--		
31-32	41	14 × 51	24 500	--		
[e]33	3,4	15 × 51	60 000	Tug		
[d]34	21	15 × 50	35 000	Tug		
[d]35	26	15 × 50	35 000	Tug		
[d]36	26,75	15 × 56	35 000	Tug		
[e]37	30	15 × 47	30 000	Tug		

TABLE II: PAYLOAD COMBINATIONS AND FLIGHTS (CONT'D.)

Shuttle flight no.	[a]Payload no.	PL + kick stage + OMS sets dimension	[b]PL + kick stage + OMS sets weight	Kick stage
NASA - 1987				
1	8,2	15 × 43.5	65 000	Tug
[f]2	14,16,1a	14 × 40	35 790	--
3	5,73	15 × 49	65 000	Tug
[f]4	15 up	13 × 55	45 000	--
	13 down	11 × 60	24 650	
[f]5	14,18	14 × 36	34 900	--
[f]6	16,20	14 × 36	34 900	--
[c]7	19	14 × 35	34 950	--
[f,i]8	17	15 × 60	45 000	--
[f]9	18,20	14 × 36	34 900	--
[h]10	57	15 × 50	65 000	Tug
11	74,36	15 × 60	65 000	Tug
12	29,1b	15 × 51	65 000	Tug
13	72,79	15 × 57	65 000	Tug
14	27,81	15 × 51	65 000	Tug
15	72,79	15 × 57	65 000	Tug
16-17	35,79	15 × 60	65 000	Tug
18-19	80,72	15 × 59.5	65 000	Tug
20	36,76	15 × 60	65 000	Tug
21	81,72	15 × 57	65 000	Tug
22-23	71	15 × 60	65 000	Tug
24-28	40	14 × 54	31 500	--
29-30	41	14 × 51	24 500	--
[c]31-35	62	14 × 35	34 950	--
[c]36-38	63	14 × 35	34 950	--
[e]39	3,4	15 × 51	30 000	Tug
[e]40	23,30	15 × 53.5	30 000	Tug
[d]41	26,75	15 × 56	35 000	Tug
[d]42-44	26	15 × 50	35 000	Tug
[c]45	66	14 × 45	34 950	--
[c]46	67	14 × 45	34 950	--
[c]47	68	14 × 43	33 950	--
48	21	15 x 50	35 000	Tug
NASA - 1988				
1	1a,3,12	15 × 57	65 000	Tug
[c]2	1a,14	14 × 22	19 340	--
3	5,4,12	15 × 59	65 000	Tug
[f]4	14,20	14 × 36	34 900	--
[f]5	16,18	14 × 36	34 900	--
[f]6	16,20	14 × 36	34 900	--
[h]7	54	15 × 60	65 000	Tug
8	78,79	15 × 51	65.000	Tug
9	78,22	15 × 47	65 000	Tug
10	78,79,27	15 × 57	65 000	Tug
11	78,79,27	15 × 57	65 000	Tug
12	79,72	15 × 57	65 000	Tug
13	80,72	15 × 59.5	65 000	Tug
14	28	15 × 56	65 000	Tug

Shuttle flight no.	Payload no.
DOD - 1987	
1	3
2	6
3-4	8
5-9	14
10	16
11-12	17
13-14	18
15-17	19
18-20	20
21-22	11
23	12(3)
DOD - 1988	
1	2,3
2-4	4
5-6	8
7-11	14
12	16
13-14	17
15-16	18
17-19	19
20-22	20
23	9(2)

TABLE II: PAYLOAD COMBINATIONS AND FLIGHTS (CONT'D.)

Shuttle flight no.	[a]Payload no.	PL + kick stage + OMS sets dimension	[b]PL + kick stage + OMS sets weight	Kick stage
	NASA - 1988 - Concluded			
15	29,80	15 × 59.5	65 000	Tug
16-17	35,81	15 × 60	65 000	Tug
18	36,76	15 × 60	65 000	Tug
19-20	70	15 × 57	65 000	Tug
21-22	71	15 × 60	65 000	Tug
23-25	39	14 × 51	32 000	--
26-29	40	14 × 54	31 500	--
30-31	41	14 × 51	24 500	--
[e]32	30	15 × 47	30 000	Tug
[d]33	21,75	15 × 56	35 000	Tug
[c]34	63	14 × 35	34 950	--
[c]35	65 up	14 × 57	34 950	--
[c]36-38	62	14 x 35	34 950	
	NASA - 1989			
[f]1	1a,14,16	14 × 40	35 790	--
[f]2	1a,20	14 × 27	32 290	--
3	5,73	15 × 49	65 000	Tug
4	11,10	15 × 59	65 000	Tug
[f]5	13 up	11 × 60	45 000	--
	15 down	13 × 55	25 500	
[f]6	14,18	14 × 36	34 900	--
[f]7	16,20	14 × 36	34 900	--
[c,g]8	17	15 × 60	45 000	--
[f]9	18	14 × 23	31 400	--
[f]10	19	14 × 40	45 000	--
[h]11	58	15 × 50	65 000	Tug
[h]12	60-3	15 × 57.5	65 000	Tug
13	28	15 × 56	65 000	Tug
14	29,79	15 × 57	65 000	Tug
15-16	35,79	15 × 60	65 000	Tug
17	79,80	15 × 57.5	65 000	Tug
18	70	15 × 57	65 000	Tug
19	80,81	15 × 57.5	65 000	Tug
20	71	15 × 60	65 000	Tug
21	72,81	15 × 57	65 000	Tug
22	74,76	15 × 51	65 000	Tug
23	3,4	15 × 51	65 000	Tug
24	39	14 × 51	32 000	--
25-29	40	14 × 54	31 500	--
30-32	41	14 × 51	24 500	--
[c]33-35	62	14 × 35	34 950	--
[c]36-39	63	14 × 35	34 950	--
[e]40	30,32	15 × 59	30 000	Tug
[e]41	23	15 × 41.5	30 000	Tug
[d]42	21,75	15 × 56	35 000	Tug
[d]43-48	77	15 × 47	35 000	Tug
49	71	15 × 60	65 000	Tug

Shuttle flight no.	Payload no.
DOD - 1989	
1	2,3
2-4	4
5	6
6	8
7	16
8-9	17
10-11	18
12-14	19
15-17	20
18	9(2)
19-20	11
21	12(3)

TABLE II: PAYLOAD COMBINATIONS AND FLIGHTS (CONCLUDED)

Shuttle flight no.	[a]Payload no.	PL + kick stage + OMS sets dimension	[b]PL + kick stage + OMS sets weight	Kick stage	Shuttle flight no.	Payload no.
	NASA - 1990				DOD - 1990	
1	5	15 × 41	65 000	Tug	1	2,3
[f]2	14,16	14 × 36	34 900	--	2-4	4
[f]3	14,18	14 × 36	34 900	--	5-6	8
[f]4	16,20	14 × 36	34 900	--	7-11	14
[f]5	18,20	14 × 36	34 900	--	12	16
[h]6-7	51	15 × 51	65 000	Tug	13-14	17
8	79,1b	15 × 49	65 000	tug	15-16	18
9	72,1b	15 × 51	65 000	Tug	17-19	19
10	29,72	15 × 59	65 000	Tug	20-22	20
11-12	35,79	15 × 60	65 000	Tug	23	12(3)
13	79,80	15 × 57.5	65 000	Tug		
14-15	71	15 × 60	65 000	Tug		
16	80,81	15 × 57.5	65 000	Tug		
17	22,76,81	15 × 59	65 000	Tug		
18-22	40	14 × 54	31 500	--		
23-26	41	14 × 51	24 500	--		
[c]27-30	62	14 × 35	34 950	--		
[c]31	63	14 × 35	34 950	--		
[e]32	3,4	15 × 51	30 000	Tug		
[e]33	7,30	15 × 54	30 000	Tug		
[d]34	25,75	15 × 51	35 000	Tug		
[d]35	21	15 × 50	35 000	Tug		
[c]36	64	14 × 37	34 950	--		
[c]37	69	14 x 45	34 950			

[a]Payload numbers are defined in table I.

[b]2000 pounds have been added to each payload to account for payload adapter.

[c]The addition of one OMS set is required to accomplish mission.

[d]Shuttle is launched from WTR.

[e]Shuttle is launched from ETR.

[f]The addition of two OMS sets is required to accomplish mission.

[g]Length must be reduced to 55 feet in order that one OMS set can be added.

[h]Tug was expended because it did not have the capability for a round trip.

[i]Length must be reduced to 50 feet in order that two OMS sets can be added.

TABLE III: TRAFFIC MODEL SUMMARY

(a) Unlimited Traffic Model

Year

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
NASA payloads	40	43	57	47	54	48	69	54	70	59	67	53	661
NASA flights	21	20	29	25	29	27	47	37	48	38	49	37	407
DOD payloads	23	34	18	21	32	28	25	23	25	25	25	26	305
DOD flights	20	30	16	20	26	24	24	20	23	23	21	23	270
Total payloads	63	77	75	68	86	76	94	77	95	84	92	79	966
Total flights	41	50	45	45	55	51	71	57	71	61	70	60	677

(b) More Realistic Shuttle Flight Frequency

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
NASA + DOD flights	6	15	24	32	40	60	60	60	60	60	60	60	60	597

TABLE IV: THIRD STAGE CHARACTERISTICS

	Agena	Evolutionary stage Agena	Tug[a]
Dry weight, lb	1380	2000	7528
Maximum propellant loading, lb	13 440	48 800	54 018
I_{sp}, sec	310	322	470
Dimensions, ft	5 × 21	10 × 23	15 × 35

[a]Tug lifetime of 20 missions.

URS MATRIX

REFERENCES

1. Aerospace Corporation: Integrated Operations/Payloads/Fleet Analysis Final Report. Aerospace Report No. ATR-72(7231)-1, Vol. II, Aug. 1971.

2. Sprince, R. H.: Payload Item List August 1971. Datafax From NASA Headquarters to MSC/J. Hoisington, LP. Sept. 20, 1971.

3. MSC Shuttle Program Office: Modular Space Station Report. MSC Report 02471, Jan. 1972.

4. USAF: DOD Mission Model for Space Transportation System Mission Analysis. STS Document, March 21, 1971 (Revised Aug. 1971), Secret (title unclassified).