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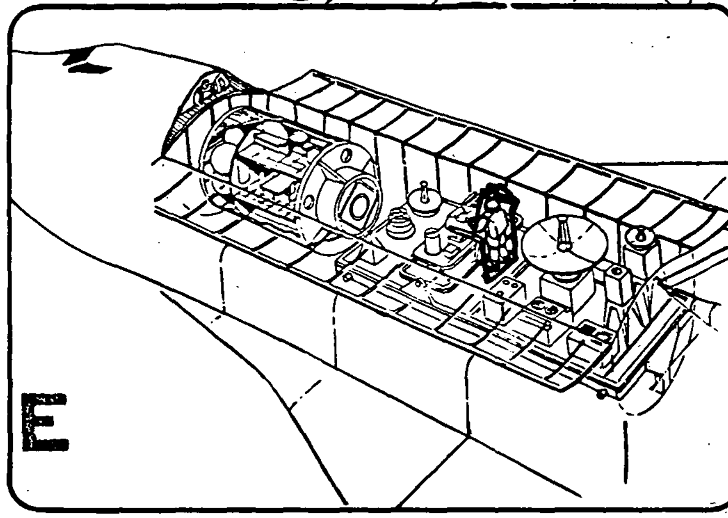

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APPLICATION OF EVA GUIDELINES AND DESIGN CRITERIA

VOLUME III - EVA SYSTEMS COST MODEL FORMATTING

FINAL REPORT

APRIL 1973

URS/MATRIX COMPANY

LIFE and ENVIRONMENTAL SCIENCES DIVISION

SUITE 103, 1275 SPACE PARK DRIVE, HOUSTON, TEXAS 77058

APPLICATION OF EVA GUIDELINES AND DESIGN CRITERIA

FINAL REPORT

CONTRACT NAS9-12997

VOLUME III - EVA SYSTEMS COST MODEL FORMATTING

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

PREPARED BY:

NELSON E. BROWN

URS/SYSTEMS CORPORATION
URS/MATRIX COMPANY
LIFE AND ENVIRONMENTAL SCIENCES DIVISION
1275 SPACE PARK DRIVE
HOUSTON, TEXAS 77058

URS MATRIX

APRIL 1973

FOREWORD

This study contract (NAS9-12997) was awarded by NASA Johnson Space Center (JSC) to (1) provide information and data concerning orbital Extravehicular Activities (EVAs) in a format most useful to mission planners and experiment designers of future experiments, (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 contract 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 Formatting

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 the EVA Systems Cost Model--Volume III.

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 utilizing man as an 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 <u>man</u> 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 also provided.

The performance data are 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 replacement of dedicated EVA workstations with portable modular units, which can be readily adapted to numerous worksites, represents a sizeable cost savings to payloads using EVA.

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 this volume of the report--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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ACRONYMS AND ABBREVIATIONS

AES	Advanced Extravehicular Suit
A/L	Airlock
ALSS	Advanced Life Support System
AMU	Astronaut Maneuvering Unit
ATM	Apollo Telescope Mount
CCA	Communications Carrier Assembly
CCU	Crew Communications Umbilical
CSM	Command Service Module
CWG	Constant Wear Garment
ECS	Environmental Control System
EMU	Extravehicular Mobility Unit
ESC	External Sequence Camera
EV	Extravehicular
EVA	Extravehicular Activity
EVCS	Extravehicular Communications System
FCMU	Foot Controlled Maneuvering Unit
FTB	Film Transfer Boom
GATV	Gemini-Agena Target Vehicle
HHMU	Handheld Maneuvering Unit
IVA	Intravehicular Activity
JSC	Lyndon B. Johnson Space Center
LCG	Liquid Cooling Garment
LSS	Life Support System
LSU	Life Support Umbilical
MDA	Multiple Docking Adapter
MEED	Microbial Environment Exposure Device
MWP	Maneuvering Work Platform
NASA	National Aeronautics and Space Administration
OBS	Operational Bioinstrumentation System
OPS	Oxygen Purge System

ACRONYMS AND ABBREVIATIONS (Cont'd.)

PGA	Pressure Garment Assembly
PLSS	Portable Life Support System
PSI	Pounds per Square Inch
SIM	Scientific Instrument Module
SLSS	Secondary Life Support System
UCTA	Urine Collection Transfer Assembly
UMB	Umbilical
WIS	Water Immersion Simulation

DEFINITION OF TERMS

Many of the terms used in the report have various connotations within the NASA and aerospace community. Some are readily familiar only to personnel involved directly in the EVA field. Therefore, as an aid to the reader, several of the perhaps unfamiliar EVA terms are defined below.

PRESSURE GARMENT ASSEMBLY (PGA) — A PGA consists of the following items which constitute the basic space suit:

- Torso-limb suit
- Gloves
- Controls and Displays
- Electrical and Bio-instrumentation Harness
- Helmet
- Boots
- Neck Dam

EXTRAVEHICULAR MOBILITY UNIT (EMU) — An EMU consists of the following items which make up a complete extravehicular support system:

- Pressure Garment Assembly (PGA)
- Liquid Cooling Garment (LCG)
- Life Support System (LSS)
- Secondary Life Support System (SLSS)
- Constant Wear Garment (CWG)
- Extravehicular Visor Assembly
- Urine Collection Transfer Assembly (UCTA)
- Fecal Containment Subsystem (FCS)
- Communications Carrier Assembly (CCA)

ADVANCED EXTRA-VEHICULAR SUIT (AES) — Any space suit in the development stage with "improvements" over existing suits.

LIQUID COOLING GARMENT (LCG) — A garment worn in direct contact with the skin which incorporates liquid coolant tubes to accomplish the primary body cooling requirements.

CONSTANT WEAR GARMENT (CWG) — A one-piece, short-sleeved garment covering the crewman's torso and feet, leaving the neck, head and lower arm exposed. May be worn EVA in place of LCG but depends on workload, time, etc.

LIFE SUPPORT SYSTEM (LSS) — A primary system, either portable or umbilical, which supplies the required breathing medium and pressure to provide a viable atmosphere for the suited EVA crewman.

SECONDARY LIFE SUPPORT SYSTEM (SLSS)	A backup system serving the same functions as the LSS. Usually a self-contained unit with less capacity than the primary LSS.
EXTRAVEHICULAR VISOR ASSEMBLY	A visor attached to the helmet to provide visual, thermal, impact, and micrometeoroid protection during EVA.
URINE COLLECTION TRANSFER ASSEMBLY (UCTA)	A flexible bag type device worn inside the space suit used to temporarily store urine while wearing the PGA.
FECAL CONTAINMENT SUBSYSTEM (FCS)	The FCS consists of a "diaper" type garment which acts as a comfort pad while wearing the PGA.
COMMUNICATIONS CARRIER ASSEMBLY (CCA)	The CCA consists of a head fitted assembly incorporating redundant microphones and earphones which provide the EMU system communications requirements.
OPERATIONAL BIO-INSTRUMENTATION SYSTEM (OBS)	The OBS is a rectangular section of woven Teflon cloth containing pockets and restraining features which house signal conditioners, dc-dc converters, and crewman identification modules used in the EVA transmission of critical body functions.
PORTABLE LIFE SUPPORT SYSTEM (PLSS)	A completely self-contained life support system usually carried on the back of the EVA crewman. The units normally contain communications, telemetry, and secondary life support capabilities.
OXYGEN PURGE SYSTEM	A unit functioning in the same capacity as a Secondary Life Support System. Usually associated with a PLSS.
WATER IMMERSION SIMULATION (WIS)	Refers to EVA simulations/hardware evaluations when the suited crewman is totally submerged and made neutrally buoyant.
FILM TRANSFER BOOM (FTB)	Electrically and manually actuated extendible boom used to transfer film modules a distance of approximately 30 feet (9.1 m) on Skylab. Also used in aerospace antenna applications.

A MODEL FOR ESTIMATING THE COST OF EVA/IVA

SECTION 1.0 PURPOSE OF THE MODEL

Extravehicular activity (EVA) and intravehicular activity (IVA) have been proposed as methods of accomplishing numerous tasks on future spacecraft. Experimenters, mission planners, and spacecraft designers are interested in the most economical means of servicing experiment payloads, deploying satellites, and collecting experiment data. The spacecraft designers and mission planners are also concerned with spacecraft external inspection, performing minor maintenance activities and emergency safety/rescue operations. The model proposed and partially formatted in this report, when complete, will provide a means of estimating the cost of placing a crewman outside the vehicle to perform the desired tasks.

In order to effectively propose the use of EVA/IVA, the potential user must have information on the considerations which go into specifying EVA capability. Volume I of this final report presents a qualitative description of the many factors which are impacted by the specification of EVA. The EVA Cost Model is intended to present a quantitative indication of the costs of including EVA/IVA capability to perform certain tasks.

The EVA Cost Model is designed for the experimenter or mission planner who is not working directly in the EVA field. The model does not require that experiment or payload equipment be designed before it is employed. In fact, it is preferred that the model be exercised in the early design stages since the costs and provisions for EVA or alternative techniques are likely to affect designs. The model will not define all costs or quantify exact costs of providing EVA but is intended as a planning device to aid in the comparison of EVA with other techniques. It should be noted that this report does not attempt to provide a completed EVA Cost Model; but a methodology and format for later development.

The terms "mission planners" and "experiment/payload designers" are used frequently throughout the report. The contractor's use of these terms have no implications toward identifying or indicating the NASA center, organization, or personnel that may be responsible for vehicle, experiment, or payload design/selection. The terms only refer to the assemblage of Government, industrial, institutional, or foreign organizations involved in developing a payload/vehicle to be included in the Space Shuttle Program with no indication toward specifying a governing organization. Since the NASA-JSC is responsible for developing the complement of EVA supporting systems for the Space Shuttle, the experiment and payload planners and designers will be required to design their hardware around those EVA systems. The payload planning and designing teams will be involved in specifying the quantity of each EVA support component based on the specific requirements of their experiments.

SECTION 2.0 BACKGROUND

The EVA Cost Model has evolved from an increasing desire on the part of NASA to assist spacecraft users in identifying an economical means of servicing future payloads. The Model also serves to reduce the dollar cost to the user in selecting EVA systems for the servicing operations. At present, the basic argument used to justify EVA as an operational technique is that the capability already exists; why not use it? The Space Shuttle will afford EVA capability for the crewmen according to current study directives. However, the fact that an EVA capability exists does not imply that EVA is the most cost effective method to perform on-orbit tasks; trade studies must be made.

In mid-1972 the URS/Matrix Company completed an Extravehicular Activities (EVA) Guidelines and Design Criteria document. This report marked the completion of an effort to collect and synthesize information that is currently known about EVA and IVA. The EVA Guidelines and Design Criteria document contains major sections on the history of EVA, the capabilities of EVA hardware, EVAs planned for future missions, human performance capabilities in orbit, and EVA crewman physiology. If studied from cover to cover, one could be brought up to date on many of the general aspects in the EVA field.

A logical step beyond the Guidelines document was the expansion of selected areas of the report for more thorough coverage. This is being accomplished in Volume I of the study effort reported here. Another logical step beyond the original document was the preparation of an EVA cost model. The model could be constructed on the basis of what is currently known about EVA and EVA systems, and could be structured for use by individuals not directly involved in EVA design.

As initially concerned, the cost model would allow an experimenter or mission planner to roughly estimate the costs of utilizing EVA to accomplish a selected task. The major costs which are relevant to this type of decision are weight, volume, and crew time--all of which are charged against the payload which requires them. Such "charges" are not unique to EVA but are assessed to the payload independent of the system/technique used in servicing the payload. Weight and volume penalties, of course, reduce the weight and volume of the payload scientific equipment that can be carried on an individual flight should that flight be weight critical. Similarly, EVA crew time reduces the amount of on-orbit time available to conduct experiments and reduce data as would the crew time used in the preparation, checkout, and operation of systems such as teleoperators and remote manipulators.

Estimates of EVA costs may be affected by developments in the EVA hardware field. For example, the development of an 8.0 psi space suit for use on a 14.7 psi spacecraft (i.e., cabin pressure) would eliminate pre-breathing time from the pre-EVA time allotment (ref. 3.1). Improved designs of the suit joints and access provisions may also reduce donning and doffing times from the pre- and post-EVA periods, respectively. The increased mobility of the proposed suits could further decrease pre- and post-EVA times by altering the worksite ingress/egress times. Improvements in portable life support systems may change the configuration of these systems (such as ice packs instead of sublimators). However, these improvements are not expected to have a major effect on the weight, volume, and time required for systems checkout, donning, doffing, servicing, etc.

SECTION 3.0 OVERALL METHODOLOGY

The basic procedure to be used in exercising the EVA Cost Model involves three preliminary steps:

(1) Prepare a description of the task(s) to be performed in EVA--This description may include statements such as: retrieve 30 lb. (13.6 kg) film magazine and return it 50 feet (15.2 m) to the Shuttle Orbiter airlock; adjust antenna pointing with special tool; inspect and monitor payload operations; etc.

(2) Review of EVA capabilities data--Demonstrated on-orbit and simulated EVA capabilities are described in Section 4.0 to enable the user to estimate the duration and number of crewmen required to perform the task(s).

(3) Estimate EVA requirements--After reviewing the EVA capabilities data, the user will prepare an estimate of the number of EVA crewmen required for the task, the duration of each EVA, and the number of EVAs required.

With the three basic preparatory steps completed, the user enters the cost charts of the model. The overall flow of this sequence is depicted in the diagram in Figure 3-1.

The Cost Model is arranged as a series of charts and tables presenting each dependent variable (e.g., suit weight, life support system volume, work-station power, LiOH cannister weight) as a function of the independent variables (e.g., number of crewmen EVA, EVA duration) quantified earlier. Task description is included as an input to the Cost Model in the flow diagram to allow package sizes, masses, translation distances, etc. to be included in the model.

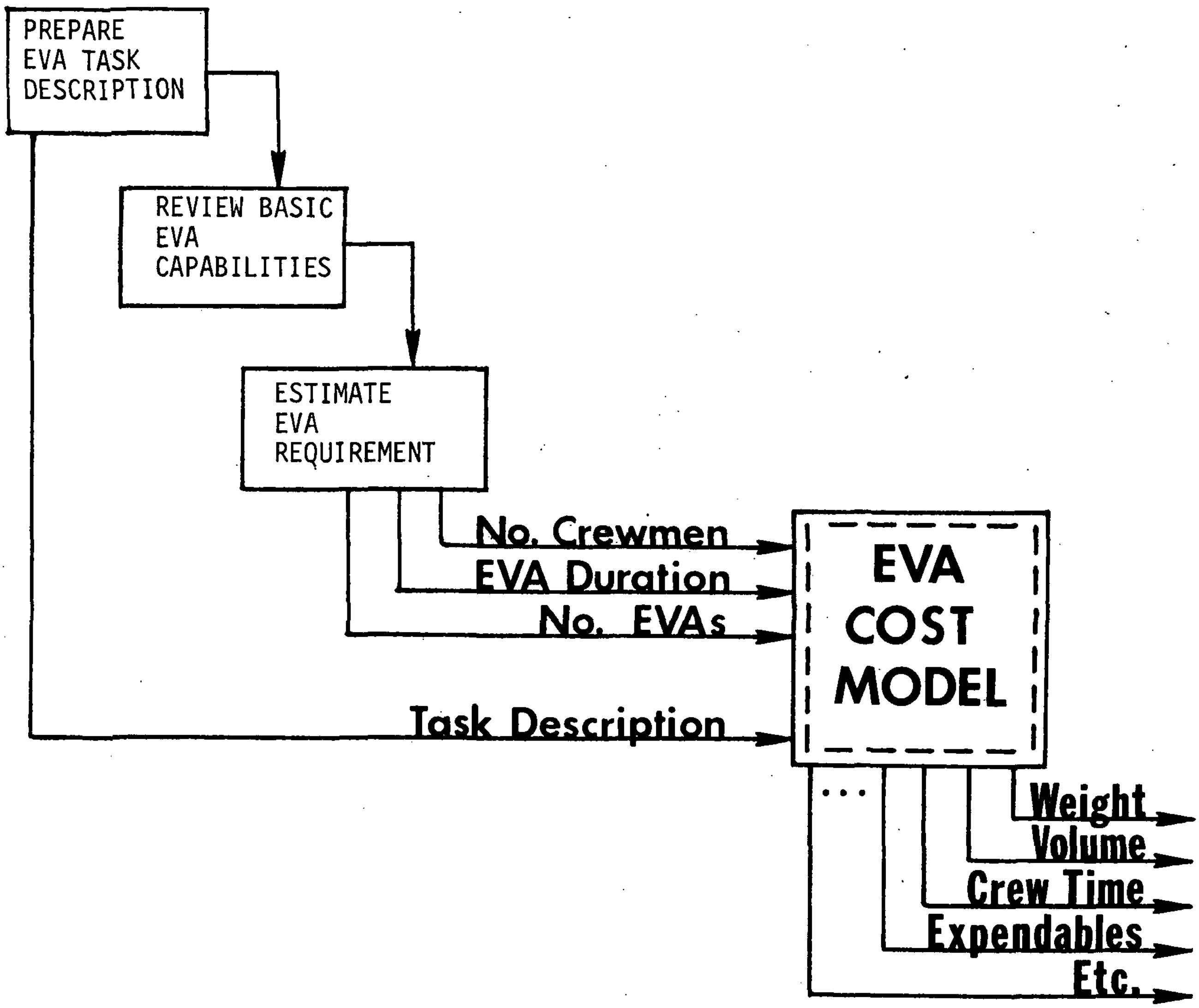

FIGURE 3-1: COST MODEL FLOW SEQUENCE

Descriptions of the way to use each Cost Model Chart are included with the charts in subsequent sections of this report.

In order to estimate the number of crewmen required for EVA, the EVA duration, and the number of EVAs required for a particular task, the following data are provided. The data are presented in two major sections: Flight Results and Simulation Results. Although Flight Results are more accurate in many cases, the variety of tasks which have been performed and quantified is limited. Also, many of the inflight tasks were performed in conjunction with the evaluation of EVA crewman restraint and stabilization equipment/techniques which were significantly improved for later missions and may not be totally representative of current capabilities and time requirements. Flight and simulated capabilities are arranged by the major task activities required in EVA which include the following:

A. FLIGHT RESULTS

- Hatch Ingress/Egress
- Workstation Ingress/Egress
- Worksite Activities
  - Gemini
  - Using foot restraints (Gemini)
  - Apollo
- Various EVA Activities

B. SIMULATION RESULTS

- Cargo Transportation
- Payload Deployment
- Crewman Translation
- Worksite Activities

The times shown for performing the various tasks were derived from an assessment of the following: (1) final flight timelines developed through water immersion simulation for the Gemini and Apollo Orbital EVAs, (2) correlation studies of the Gemini EVA simulations with flight results, and (3) flight plans developed for Skylab EVA. The crew times found in each of the above sources for comparable tasks varied somewhat and were considered to be dependent upon the restraint system used, EVA hardware configuration variations, and other concurrent subtasks. Therefore, the times given for performing the tasks listed in this report are "best estimates" to the nearest minute. These times can be used only as an initial indication for tasks on future EVA missions. Knowledge of each task, the supporting hardware involved (restraints, workstations, mobility aids), and the crewman support systems (pressure suit, life support system) is required as an initial input to time estimation. Best-time estimates are obtained only from end-to-end task simulations using state-of-the-art simulation facilities and techniques.

A. FLIGHT RESULTS

- Hatch Ingress/Egress

  (a) Assuming a hatch no less than 30 inches (.76 m) in diameter with mobility aids (ref. 3.2):

  * Less than 2 minutes to egress or ingress without cargo

  * Less than 4 minutes to egress or ingress with cargo being transferred to a crewman inside the hatch. (Cargo amount equal to or less than what can safely be carried by a single crewman in transportation.)

- Workstation Ingress/Egress

  (a) Assuming handholds are provided for ingress/egress of Apollo "Dutch Shoes" or Skylab foot restraints (ref. 3.2):

* Less than 2 minutes for ingress or egress

- Worksite Activities (Refs. 3.3 and 3.4)

(a) Gemini (various restraints)

Task	Time (Min.)	No. Crewmen	Restraint System
S013 experiment camera mounting	1	1	Tethers
Photograph M410 color plate	4	1	Tethers
Fluid quick-disconnect hookup	2	1	Dutch shoes
Spacecraft (GATV) tether attachment	1	1	Vehicle/ handholds
Change film (EVA camera)	4	1	Tethers
Telescoping handrail deployment (3 ft. stowed)	1	1	Tethers
Tether hookup (restraint evaluation)	3	1	Vehicle/ handholds
Install camera (ESC)	2	1	Tethers
Disconnect & connect electrical connectors	1	1	Dutch shoes
Remove cutters from suit pouch	2	1	Dutch shoes
Cutting cables & fluid hose	4	1	Dutch shoes
Saturn bolt tightening (using tools)	2	1	Dutch shoes
Wiping command pilot's window	2	1	Vehicle/ handrail
Torquing bolthead with torque wrench	4	1	Tethers/Dutch shoes
Camera mounting (16mm)	2	1	Tethers
Connect tether hooks	1	1	Dutch shoes
Unstow AMU control arm	1	1	Dutch shoes
Unstow oxygen hose	3	1	Dutch shoes

(b) Using Foot Restraints (Gemini):

* Apply 25 lb. (11.3 kg.) force
* Align connectors
* Cut electrical cables

* Apply torque of 200 in. lbs. (2.3 kgm.) with 9 in. (22.9 cm.) wrench
* Apply 100 in. lbs. (1.2 kgm.) torque with 5 in. (12.7 cm.) wrench

  (NOTE: Force limits have not been defined for EVA crewmen in weightlessness but with proper restraints should approach those of the crewman on earth under shirtsleeve conditions.)

(c) Apollo (Ref. 3.5)

* Retrieve 85 lb. (38.6 kg.) panoramic camera - 19.3 in. dia. x 6.2 in. (.49 m x .16 m)
    - Translate to Scientific Instrument Module (SIM) bay - approx. 10 ft. (3.05 m) using single handrails and handholds
    - Retrieve camera
    - Transport camera from SIM bay to Command Service Module (CSM) hatch - approx. 10 ft. (3.05 m)
* Retrieve 27 lb. (12.2 kg.) mapping camera cassette - 10.5 in. dia. x 8.5 in. (26.7 cm. x 21.6 cm.)
    - Translate to SIM bay - approx. 10 ft. (3.05 m) using handrails and handholds
    - Retrieve cassette
    - Transport cassette from SIM bay to CSM hatch - approx. 10 ft. (3.05 m)
* Inspect equipment at SIM bay

  (NOTE: Three round trips were made to the SIM bay on Apollo 15 during a 38-minute EVA period. [Retrieval tasks could have been accomplished in less time if desired.])

- Various EVA Activities
    - Hand Held Maneuvering Unit (HHMU) evaluation
    - Umbilical evaluation (tether dynamics)

- Velcro pad evaluation (removal, holding ability, shear, tension)
- Package retrieval (micrometeorite)
- Free-space translation and attitude control evaluations (HHMU)
- Astronaut Maneuvering Unit (AMU) preparation (unstow controller arms, umbilicals, etc.)
- Package retrieval from remote vehicle
- Handhold evaluation (cylindrical, oval, various cross-sections)
- Operate electrical and fluid connectors
- Evaluate life support systems
- Deploy, conduct, and retrieve MEED experiments

B. SIMULATION RESULTS

- Cargo Transportation (Ref. 3.6 and 3.7)

    - Assuming use of single handrail:

        * Average translation velocity 0.5 to 1.0 ft./sec. (.15 to .30 m/sec.) while EVA--with cargo

    - Water Immersion Simulation (WIS) used to verify transfer of a 1650 lbs. (744.1 kg.), 142 ft^3 (4.02 m^3) package at average velocity of approximately 0.3 ft./sec. (.09 m/sec.) using dual handrails

    - WIS used to verify transfer of a 1650 lbs. (744.1 kg.), 142 ft^3 (4.02 m^3) package at average velocity of approximately 0.2 ft./sec. (.06 m/sec.) using single handrail

    - WIS has indicated that average translation rates of 0.75 ft./sec. (.229 m/sec.) are realistic while transporting a 320 lbs. (145.9 kg.) mass

- Payload Deployment (Ref. 3.8)

  - WIS used to verify 2-man deployment of simulated payload weighing 8,500 lbs. (3855.6 kg.). Dimensions were approximately 19 ft. (5.8 m) by 3.5 ft. dia. (1.07 m dia.). Additional payload deployment/handling simulations are scheduled to be conducted in the NASA Marshall Space Flight Center water immersion facility. No limit has been set on the size and mass of the largest payloads to be handled. Up to 65,000 lbs. (29,484 kg.) is being considered.

- Crewman Translation (Ref. 3.9)

  - Assuming use of single handrail:

    * WIS used to establish 1.0 to 2.0 ft./sec. (.3 to .6 m/sec.) IVA translation velocities

    * Average translation velocity 1.0 ft./sec. (.3 m/sec.) while EVA

- Worksite Activities (Ref. 3.10)

  - WIS has indicated that crewmen can apply approximately 60 lb. (27.2 kg.) force in a forward direction on an object 28 to 52 inches (.7 to 1.3 m) above the floor where foot restraints (Skylab) are provided.

  - WIS has indicated that crewmen can apply in excess of 60 lb. force (27.2 kg.) in an isometric (force reacting) horizontal pulling fashion to a lever approximately 1 ft. (.3 m) above the floor where foot restraints (Skylab IVA) are provided.

- WIS has indicated that horizontal pulling forces are greater than horizontal pushing forces using foot restraints.

- Various EVA Simulations - Skylab (Ref. 3.9)
  - Workstation ingress/egress (5 workstations)
  - Package handling from airlock--size up to approximately 30 x 24 x 16 in. (.8 x .6 x .4 m)
  - Crewman translation via a combination of single and dual handrails of approximately 30 ft. (9.1 m)
  - Deployment and actuation of package transfer systems--Film Transfer Boom (FTB) and clothesline
  - Umbilical management
  - Film magazine access door actuation
  - Visual alignment of Apollo Telescope Mount (ATM) Canister
  - Deploy mechanical booms/arms
  - Retrieval/replacement of film magazine and cassettes
  - Actuation of electrically powered control devices
  - Package handling from experiment to transfer devices
  - Camera (16 mm) deployment, alignment, actuation and retrieval

The general capabilities cited in the above paragraphs do not constitute the total spectrum of activities that the EVA crewman has successfully performed in simulation programs. The total EVA simulations conducted by NASA and industry are far too numerous to include in a single document. This EVA capabilities section will, however, be expanded in the final EVA Cost Model under the "Man's Capabilities in EVA" section.

SECTION 5.0 EVA COST MODEL FORMATTING

The tables and charts which follow, when complete, will allow an estimate to be made of the costs of an existing EVA capability to perform a selected task on the Space Shuttle or future vehicle. By combining the task requirements for a selected task(s) with the EVA capabilities information provided in the previous section, an estimate can be derived of the weight, volume, crew time, etc. required for EVA systems to support that task.

No costs are provided for automated or aided EVA systems. It is likely that such systems could be competitive with EVA for many tasks. The remotely operated Shuttle manipulator arms/booms, for example, may be useful in handling payloads. Free-flying or restrained teleoperators may find application in the servicing of certain payloads. These systems will most likely require similar (or perhaps more) crew time, weight, and volume as the EVA operations when all impacts are identified and supporting data are available.

This preliminary Cost Model development effort provides the required methodology and formatting for building a complete model. In follow-on contracts to this effort, the EVA Cost Model will be totally expanded into a tool for use by vehicle designers and payload planners. The tables contained in this section will be completed, based primarily on Skylab EVA systems and EVA systems developed for the Space Shuttle Orbiter. Provisions for additional entries into each cost chart will be included to reflect advanced EVA systems resulting from JSC EVA/IVA support systems study and development contracts and inhouse programs.

The cost tables and charts are included for the major EVA areas listed below:

(5-1) SPACE SUITS AND SUPPORT EQUIPMENT

(5-2) STOWAGE SUPPORT EQUIPMENT (Space Suits)

(5-3) MAINTENANCE, DON/DOFF AND DRYING SUPPORT ITEMS

(5-4) LIFE SUPPORT SYSTEMS

(5-5) CREWMAN TRANSLATION AND PACKAGE TRANSPORTATION AIDS

(5-6) WORKSITE FORCE REQUIREMENTS VS. RESTRAINTS

(5-7) PRE-EVA CREW TIME

(5-8) POST-EVA CREW TIME

(5-9) CONSUMABLES AND EXPENDABLES

(5-10) SPECIAL TOOLS

(5-11) EVA CREWMAN OPERATIONAL ENVELOPE

(5-12) EVA SUPPORTING EQUIPMENT

5.1 SPACE SUITS AND SUPPORT EQUIPMENT

It is anticipated that an advanced pressure suit will be developed and approved for the Space Shuttle program; the suit will provide improved mobility, don/doff characteristics, minimum energy expenditure, etc. over current models. This will essentially preclude an option to the payload planner or designer in selecting the major torso assembly for use during EVA payload servicing. However, the ancillary equipment (e.g., helmets, visors, glove components, etc.) from the existing A7L-B suits may be used with the advanced suits.

Since each payload servicing operation will vary with respect to task requirements, performance time, workload, crewmen required, etc., the payload user will be involved in selecting the quantities of certain pressure suit ancillary equipment. Each payload EVA servicing mission is considered from an end-to-end basis in selecting the quantity of gear necessary. Spare pressure suits and hardware items are based on the number of EVA crewmen, total pressurized time, and severity of use per mission. (Spares requirements for the suits and support equipment aboard the Shuttle have not been established.) As a minimum, the following suit components are required by each EVA crewman based on one EVA mission:

- 1 Pressure Garment Assembly (includes boots)
- 1 helmet
- 1 extravehicular helmet visor assembly
- 1 pair EVA gloves
- 1 bioinstrumentation system
- 1 communications carrier assembly
- 1 set constant wear garments or 1 liquid cooling garment
- 1 personal radiation dosimeter
- 1 passive radiation dosimeter
- 1 urine collection transfer system
- 1 fecal containment system
- 1 drinking bag assembly (optional)

The experiment/payload planning team is responsible for determining the total number of each EVA item required and the total weight and volume penalty to his payload.

Table 5-1 is provided to allow an estimate to be made of the weight and volume of space suits and supporting equipment. The items listed are those currently required for Skylab EVA/IVA. The weight and volume values are based upon the A7L-B suits for use with umbilical or portable life support systems. The table is designed to accommodate entries for advanced suits and equipment.

To use the table,

(1) Establish the number of crewmen that will be required in EVA to perform the selected task(s).

(2) Establish the number of EVAs required to perform the selected task(s).

(3) Identify the column which corresponds to the number of crewmen EVA established above.

(4) Obtain component weights and volumes by descending the appropriate column to the row containing the item desired. The weight and volume of the item under the use conditions established above are given in the cell at the intersection of the row and column.

(5) Establish the number of inflight spare components required.

(6) Adjust component weights and volumes by multiplying the values given by the number of EVAs required according to the Spares and Remarks columns. <u>This Remarks column contains an entry of "1 per crewman per EVA" for items that must be replaced after each EVA. The weights and volumes of these items must be multiplied by the number of EVAs established above</u>. Record in "FOR USE BY PLANNER" column.

(7) Total weight and volume of space suits and support equipment may be obtained by adding down the "FOR USE BY PLANNER" columns after adjustments for the number of EVAs and spares are made.

TABLE 5-1: SPACE SUITS & SUPPORT EQUIPMENT

PARAMETER / SPACE SUIT HARDWARE	NUMBER OF CREWMEN EVA												NUMBER OF SPARES REQUIRED	REMARKS	FOR USE BY PLANNER			
	1				2				3						TOTAL ITEM WEIGHT		TOTAL ITEM VOLUME	
	WEIGHT		VOLUME		WEIGHT		VOLUME		WEIGHT		VOLUME							
	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3			lbs.	kg.	ft.^{3}	m^3
Pressure Garment Assembly (3.75 psi)	46.3		10.8		92.6		21.6		138.9		32.4			1 Per Crewman per Flight				
- Helmet	2.7				5.4				8.1									
- Gloves (EV)	2.7				5.4				8.1									
- Gloves (IV)	2.1				4.2				6.3									
Advanced Pressure Garment (8 psi)														1 Per Crewman per Flight				
- Helmet	TBD																	
- Gloves (EV)																		
- Gloves (IV)																		
Urine Collection Transfer Assy	.5		2		1.0		4		1.5		6			1 Per Crewman per EVA (Skylab)				
Operational Bioinstrumentation System	1.1				2.2				3.3									
- Bio-Belt Assy	.3		.04		.6		.08		.9		.12							
- Suit Harness	.5				1.0				1.5									
Communications Carrier Assy	1.6		.18		3.2		.36		4.8		.54							
- Eartube	.2				.4				.6									
- Earmold	.2				.4				.6									
Fecal Containment System	.5		.08		1.0		.16		1.5		.24			1 Per Crewman per EVA (Skylab)				
Extravehicular Visor Assy	4.9		.7		9.8		1.4		14.7		2.1			1 Per Crewman per Flight				
Liquid Cooling Garment (LCG)	4.4		.25		8.8		.5		13.2		.75			1 Per Crewman per EVA (Skylab)				
Checklist Pocket	.4		.01		.8		.02		1.2		.03							
Data List Pocket	.8		.13		1.6		.26		2.4		.39							
Scissors Pocket	.1		.001		.2		.001		.3		.001							
Passive (Radiation) Dosimeter	.1				.2				.3									

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TABLE 5-1: SPACE SUITS & SUPPORT EQUIPMENT (CONT.)

SPACE SUIT HARDWARE / PARAMETER	NUMBER OF CREWMEN EVA												NUMBER OF SPARES REQUIRED	REMARKS	FOR USE BY PLANNER			
	1				2				3						TOTAL ITEM WEIGHT		TOTAL ITEM VOLUME	
	WEIGHT		VOLUME		WEIGHT		VOLUME		WEIGHT		VOLUME							
	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3			lbs.	kg.	ft.^{3}	m^3
Personal Radiation Dosimeter	-		.003		-		.006		-		.009							
Wristlets	.1		-		.2		-		.3		-			Crewman Preference				
Comfort Gloves	.1		-		.2		-		.3		-			Crewman Preference				
Watchband	.1		-		.2		-		.3		-							
Chronograph	.1		-		.2		-		.3		-							
In-Suit Drinking Device	.3		.1		.6		.2		.9		.3			1 Per Crewman per EVA (Skylab)				
Penlights	.3		.002		.6		.004		.9		.006			1 Per Crewman per EVA (Skylab)				
Scissors	.5		-		1.0		-		1.5		-							
Data Recording Pens	.1		.001		.2		.002		.3		.003							
Pencil	.1		.001		.2		.002		.3		.003							
Marker Pen	.1		.001		.2		.002		.3		.003							
EVA Wrist Tether	.6		-		1.2		-		1.8									
Constant Wear Garments (CWG)	.8		.1		1.6		.2		2.4		.3							

5.2 STOWAGE SUPPORT EQUIPMENT

On previous space programs several pieces of supporting hardware associated with the pressure suits and EVA life support systems have required special protective or stowage devices (e.g., containers, bags, straps) when handled or stowed on-orbit. Depending on the stowage provisions available on the Space Shuttle, an assortment of such protective items will be required for future EVAs. The protective items will vary in configuration with the EVA hardware specified for the Shuttle.

Table 5-2 provides data on several miscellaneous stowage support items. The items listed are generally small and lightweight but are necessary to prevent damage to the EVA equipment. The weights and volumes quoted in the table are based on Apollo and Skylab hardware and are considered within the state-of-the-art for future missions.

To use the table,

(1) Establish the number of crewmen required to be EVA to accomplish the selected task(s).

(2) Establish the number of EVAs required to accomplish the selected task(s).

(3) Identify the column which corresponds to the number of crewmen EVA established above.

(4) Obtain component weights and volumes by descending the appropriate column to the row containing the component.

(5) Establish the number of spare components required.

(6) Adjust component weights and volumes by multiplying values given by the number of EVAs according to notes in the Spares and Remarks

columns. Other adjustments may also be required on the basis of notes in the Remarks column. Record in "FOR USE BY PLANNER" columns.

(7) Obtain total weight and volume by scanning down the "PLANNER" column after adjustments are made.

TABLE 5-2: STOWAGE SUPPORT EQUIPMENT

STOWAGE SUPPORT EQUIPMENT / PARAMETER	NUMBER OF CREWMEN EVA												NUMBER OF SPARES REQUIRED	REMARKS	FOR USE BY PLANNER			
	1				2				3						TOTAL ITEM WEIGHT		TOTAL ITEM VOLUME	
	WEIGHT		VOLUME		WEIGHT		VOLUME		WEIGHT		VOLUME							
	lbs.	kg.	$ft.^3$	m^3	lbs.	kg.	$ft.^3$	m^3	lbs.	kg.	$ft.^3$	m^3			lbs.	kg.	$ft.^3$	m^3
PGA Container	1.5		4.8		3.0		9.6		4.5		14.4							
In-Flight Helmet Stowage Bag	.7		-		1.4		-		2.1		-							
Extravehicular Visor Stowage Bag	2.9		-		5.8		-		8.7		-							
Earmold/Eartube Bag	.1		-		.1		-		.1		-							
Temporary Stowage Bag	5.1		.33		10.2		.66		15.3		.99			Based on 3 per EVA Crewman				
Accessory Bag	.3		-		.6		-		.9		-							
Utility Strap	.1		-		.2		-		.3					Approximately 48 used on Skylab				
LCG Retention/Retaining Strap	.4		-		.4		-		.4		-			2 Per Program per LCG				
PGA Tie-Down Strap	.1		-		.2		-		.3		-							
EMU Kit Strap Assy	.3		-		.3		-		.3		-			3 Per Program				

5.3 MAINTENANCE, DON/DOFF AND DRYING SUPPORT ITEMS

Several items are required to support functions such as pressure suit donning/doffing, drying after use, and maintenance in the event of damage or deterioration while on orbit. Maintenance kits, suit drying hoses, connectors and interior stabilization aids are among the most frequently required support articles. Each iteration in the development of advanced EVA equipment will require a complement of support items to ensure timely and efficient operation of the hardware. The weight and volume of each supporting item required will be charged to the payload utilizing EVA. Many of the items are small and light-weight and might best be integrated into generic packages based on frequency of use, rapid accessibility, stowage configuration/availability, etc. Each EVA mission is studied individually to determine the type and quantity of support items required.

Table 5-3 provides information on the costs of a variety of EVA systems support items required for the Apollo and Skylab programs. Many of these or similar items are likely to be required on Shuttle-based EVA missions.

To use the table,

(1) Establish the number of crewmen that must be EVA to perform the task.

(2) Establish the number of EVAs that must be performed to accomplish the selected task(s).

(3) Locate the column which corresponds to the number of crewmen EVA determined above.

(4) Obtain weights and volumes of individual components by descending the selected column.

(5) Establish the number of spare components required.

(6) Adjust individual item weights and volumes by multiplying entries in the table after considering the number of EVAs and the number of EVA suits (i.e., the number of crewman EVA) according to notes in the Spares and Remarks columns.

(7) Add individual entries down the "PLANNER" column to obtain totals.

TABLE 5-3: MAINTENANCE, DON/DOFF AND DRYING SUPPORT ITEMS

MAINTENANCE ITEMS \ PARAMETER	NUMBER OF CREWMEN EVA												NUMBER OF SPARES REQUIRED	REMARKS	FOR USE BY PLANNER			
	1				2				3						TOTAL ITEM WEIGHT		TOTAL ITEM VOLUME	
	WEIGHT		VOLUME		WEIGHT		VOLUME		WEIGHT		VOLUME							
	lbs.	kg.	$ft.^3$	m^3	lbs.	kg.	$ft.^3$	m^3	lbs.	kg.	$ft.^3$	m^3			lbs.	kg.	$ft.^3$	m^3
PGA OWS Maintenance Kit	4.7		.24		4.7		.24		4.7		.24							
EMU Maintenance Kit	.6		-		.6		-		.6		-							
OBS Electrode Assembly Kit	1		.04		1		.04		1		.04							
Electrical Connector Cap	.1		-		.2		-		.3		-							
UCTA Clamp	.1		.002		.2		.004		.3		.006			1 Per Crewman per EVA				
Electrical Connector Cover	.1		.002		.2		-		.3		-							
Desiccant Bags (Reusable)	4.4		.08		8.8		.16		13.2		.24			2 Per Suit				
Dryer (Blower Motor)	18.3		-		18.3		-		18.3		-							
Drying Hoses																		
Foot Restraints																		

5.4 LIFE SUPPORT SYSTEMS

According to current guidelines, the EVA Life Support Systems (LSS) used on the Space Shuttle will consist of a self-contained, back-mounted portable LSS and/or an umbilical LSS with consumable stowage integrated into the total spacecraft environmental control system (ECS). Present studies favor the portable type system used on the Apollo lunar surface exploration missions. The portable LSS will require modification to meet the requirements of the Space Shuttle Orbiter and payloads.

The development of new LSS or modification of existing designs will allow selection -- by the Space Shuttle Program -- of basic LSS units/equipment for use on all EVA missions. Similar to pressure suit selection responsibilities, a choice of primary EVA life support systems will not be available to the payload planner -- other than perhaps a choice between portable LSS or umbilical LSS. Designation of the quantity of life support systems, inflight component spares, expendables, etc. required will be the responsibility of the payload planning/designing teams of NASA and experimenters based on the specific payload requirements. The total weight and volume impact of the LSS to the experiment is of primary interest to the Shuttle user. As a minimum, the following life support system components are required when more than one EVA is conducted during a mission:

- Portable Life Support System
  - 1 primary LSS unit
  - 1 secondary (emergency) LSS unit
  - 1 spare CO_2 adsorbant for each LSS operation
  - recharge water
  - recharge oxygen (O_2)
  - battery recharge
- Umbilical Life Support System

- 1 EVA umbilical assembly
- 1 pressure control unit
- 1 secondary (emergency) LSS unit

Table 5-4 provides data for estimating the weight and volume costs of the EVA life support systems. The values quoted in this table are based on Apollo and Skylab systems with provisions for advanced life support systems data.

Table 5-4 is presented in two parts: (1) Portable Life Support Systems, and (2) Umbilical Life Support Systems. Since present concepts for Shuttle EVA are emphasizing portable systems, the portable systems receive primary emphasis in this model. Umbilical systems are described in Table 5-4 as supporting information in the event these systems are included in some tasks or as backups to portable systems.

To use the table,

(1) Establish the number of crewmen required to be EVA to accomplish the selected task(s).

(2) Establish the number of EVAs required to accomplish the selected task(s).

(3) Identify the column in either the portable or umbilical systems table which corresponds to the number of crewmen EVA established above.

(4) Obtain component weights and volumes by descending the selected column to the row of the individual item.

(5) Establish the number of spare components required.

(6) Adjust component weights and volumes by multiplying the values given by the number of EVAs required according to the Spares and Remarks columns. Other adjustments may also be required according to notes in the Remarks column. Record in "FOR USE BY PLANNER" column.

(7) Obtain total weight and volume of Life Support Systems by scanning down the "FOR USE BY PLANNER" column after making adjustments as required by the Remarks column.

TABLE 5-4: LIFE SUPPORT SYSTEMS (PORTABLE SYSTEMS)

LIFE SUPPORT SYSTEM HARDWARE (PORTABLE LSS) / PARAMETER	NUMBER OF CREWMEN EVA												NUMBER OF SPARES REQUIRED	REMARKS	FOR USE BY PLANNER			
	1				2				3						TOTAL ITEM WEIGHT		TOTAL ITEM VOLUME	
	WEIGHT		VOLUME		WEIGHT		VOLUME		WEIGHT		VOLUME							
	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3			lbs.	kg.	ft.^{3}	m^3
PLSS/EVCS Assy	94.5	42.9	-		189		-		283.5		-							
- Battery	8.2	3.7	-		16.4		-		24.6		-			One per Crewman per EVA				
- LiOH Cartridge	4.6	2.1	-		9.2		-		13.8		-							
Oxygen Purge System	34	15.4	-		68		-		102		-			One per Crewman per EVA				
Buddy SLSS Assy	7.1	3.2	-		14.2		-		21.3		-							
PLSS Remote Control Unit	5.3	2.4	-		10.6		-		15.9		-			One per Crewman				
Buddy SLSS Assy Stowage Container	3.0	1.4			3.0	1.4			3.0	1.4				One per Pair of Crewmen				
Umbilical/Tether Container	1.6	.7			1.6	.7			1.6	.7								
PLSS/LiOH Cartridge Container Assy																		
PLSS/LiOH (Protective) Container Assy	6.8	3.1			TBD				TBD									
OPS Antenna Repair Kit	.6	.3			.6	.3			.6	.3								
PLSS Oxygen Vent Cap	.1	.05			.1		.05		.1	.05				Unique to Apollo Program				

TABLE 5-4 (CONT.): LIFE SUPPORT SYSTEMS (UMBILICAL SYSTEMS)

LIFE SUPPORT SYSTEM HARDWARE (UMBILICAL) / PARAMETER	NUMBER OF CREWMEN EVA												NUMBER OF SPARES REQUIRED	REMARKS	FOR USE BY PLANNER			
	1				2				3						TOTAL ITEM WEIGHT		TOTAL ITEM VOLUME	
	WEIGHT		VOLUME		WEIGHT		VOLUME		WEIGHT		VOLUME							
	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3			lbs.	kg.	ft.^{3}	m^3
Oxygen Umbilical														Apollo Lunar Surface -- One Per Crewman				
- Left	7.8	3.5	-	-	15.6		-	-	23.4		-	-						
- Center	8.1	3.7	-	-	16.2		-	-	24.3		-	-						
- Right	11.8	5.4	-	-	23.6		-	-	35.4		-	-						
Apollo EVA Umbilical Assy	14.3	6.5	-	-	28.6		-	-	42.9		-	-		Apollo Transearth				
Life Support Umbilical -- Skylab														60 ft. (18.3 m) long				
- Wet	54.5	24.7			109				163.5									
- Dry	48.7	22.1			97.4				146.1									
Oxygen Umbilical Hose Clamp	.1				.2				.3									
Secondary Oxygen Pack	44	20	.55		88		1.1		132		1.65							
Pressure Control Unit																		
- Wet	26.7	12.1	-	-	53.4		-	-	80.1		-	-						
- Dry	26.2	11.9	-	-	52.4		-	-	78.6		-	-						
Pressure Control Unit Container	8.0	3.6			8.0	3.6			8.0	3.6				2 Per Flight (Skylab)				
Secondary Oxygen Pack Container	9.3	4.2			9.3	4.2			9.3	4.2				2 Per Flight (Skylab)				
MDA Umbilical Container	.3	.14	.73		.3	.14	.73		.3	.14	.73			1 Per Flight (Skylab)				

TABLE 5-4: LIFE SUPPORT SYSTEMS (ADVANCED) (CONT.)

LIFE SUPPORT SYSTEM HARDWARE (ADVANCED LSS) / PARAMETER	NUMBER OF CREWMEN EVA												NUMBER OF SPARES REQUIRED	REMARKS	FOR USE BY PLANNER			
	1				2				3									
	WEIGHT		VOLUME		WEIGHT		VOLUME		WEIGHT		VOLUME				TOTAL ITEM WEIGHT		TOTAL ITEM VOLUME	
	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3	lbs.	kg.	ft.^{3}	m^3			lbs.	kg.	ft.^{3}	m^3
NOTE: No entries are presently available for this chart																		

5.5 CREWMAN TRANSLATION AND PACKAGE TRANSPORTATION AIDS

Numerous crewman translation and cargo transportation devices and systems were proposed during previous spaceflight programs for assisting the crewman in his transfer tasks. Of the many transfer/transport systems conceived/ developed, only a limited number remain as candidates for future space missions. These consist primarily of proven systems or those in the development/qualification stages for the Skylab and Space Shuttle Programs. Single and dual handrails of a specified cross section, compatible to the space suit gloves, have been efficiently used on previous EVA missions. Cargo transfer booms (i.e., electrically powered extendible booms with manual backup) will be used during the Skylab EVA mission to retrieve scientific data inside film magazine containers. An Astronaut Maneuvering Unit (AMU) and a Foot Controlled Maneuvering Unit (FCMU), to be evaluated on Skylab, offer potential free-flying systems for transferring man and cargo on the Space Shuttle and future programs. It is anticipated that the crewman translation and package transportation aids will not vary considerably from those currently available. The Space Shuttle Orbiter payload bay may, however, require some innovative concepts in order to service the wide range of payload configurations and payload arrangements inside the Orbiter bay. Only the weight of the EVA transfer/transportation systems above those required for normal EVA crewman translation inside the payload bay will be charged to the payload utilizing EVA. The Shuttle Orbiter will provide mobility aids for EVA translation through the payload bay.

Table 5-5 provides weight and volume values for available crewman translation and cargo transportation aids/devices. The crewman-only translation portion of the chart appears in the column where the package mass/volume entry is 0/0. The 0/0 entry implies that the crewman transports only himself and his attached support equipment.

Four major package size levels in terms of mass and a corresponding volume are established by the columns in the table. The 0/0; $\leq$160/$\leq$10; 160-1600/10-140; and >1600/>140 package mass/volume (in lbs./ft.^{3} and kilogram/meter^3) levels have been demonstrated to be meaningful dividing points. The translation/

transportation aids which are considered appropriate for each package mass/volume region are designated with a check mark (✓). The aids considered inadequate for each region are designated with an (X). The assignments of translation/transportation aids to each region were made on the basis of demonstrated in-flight and simulation results.

To use the table,

(1) Establish the mass and volume of the package (item) that must be transferred.

(2) Identify the column heading within which the selected package falls.

(3) Obtain the least complex and least expensive translation/transportation aid by identifying the first ✓ mark as the selected column is descended.

(4) Obtain weight and volume estimates from the weight and volume columns of the row containing the selected translation/transportation aid.

Since the translation/transportation aid table is only a planning tool, extreme cases are not accommodated. Consequently, extremely cumbersome objects and objects with small mass and/or small volume having awkward shapes cannot be transported by the same aid as more standardized packages. In such cases the next most complex transportation aid should be selected.

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TABLE 5-5: CREWMAN TRANSLATION & PACKAGE TRANSPORTATION AIDS

TRANSLATION/TRANSPORTATION AID	WEIGHT lbs.	WEIGHT kgs.	VOLUME $ft.^3$	VOLUME m^3	0/0	PACKAGE MASS/VOLUME LBS/$FEET^3$ -- KILOGRAMS/$METERS^3$: lbs./$ft.^3$ $\leq 160/\leq 10$; kg./m^3 $\leq 73/\leq .3$	lbs./$ft.^3$ 160-1600/10-140 ; kg./m^3 73-730/.3-3.9	lbs./$ft.^3$ > 1600/>140 ; kg./m^3 > 730/>3.9	REMARKS/APPLICATIONS
No Aids					✓	X	X	X	IVA only - Short distances
Existing Equipment					✓	X	X	X	*IVA only - Equipment dependent*
Handholds					✓	✓	X	X	Package Tethered to Crewman
Single Rail					✓	✓	X	X	Baselined Cross Sections
Dual Rail					✓	✓	✓	X	Baselined Configuration
Endless Clothesline					✓	✓	X	X	Manually Actuated
Extendible Booms					X	✓	✓	X	Electrically Actuated
Shuttle Manipulator Arms					X	✓	✓	✓	*Remotely Actuated*
Dedicated Devices/Systems					X	✓	✓	✓	Powered Equipment, Trolleys, etc.
Free-Flying Transporters • HHMU					✓	✓	X	X	Package Tethered to Crewman
• AMU					✓	✓	X	X	Package Attached to AMU
• MWP					✓	✓	✓	X	Package Stowed on Unit
FOR USE BY PLANNERS									
TOTALS									

5.6 WORKSITE FORCE REQUIREMENTS VS. RESTRAINTS

The ability of the EVA crewman to exert the necessary forces in weightlessness to perform required tasks is dependent upon the type of restraints and stabilization aids provided at the worksite. In the zero-gravity environment, the EVA crewman must have a means of reacting all forces he imparts to the workpiece. Simple inspection, monitoring, and switch actuation (e.g., toggle switches, rotary switches, push buttons) can normally be performed using existing (surrounding) equipment or with no restraints under conditions of low force (<1.0 lb.-<.45 kg.) and time (<4.5 sec.). Surrounding equipment frequently provides a quasi-grip area/protrusion satisfactory for the low force/time tasks; however, this equipment should be used as a restraint only after qualifying exercises (ref. 3.10).

The forces that must be applied to perform a required task can generally be used to determine the type of restraint needed for that task. Table 5-6 presents major force levels at which different restraint concepts have been shown to be effective. However, if the crewman is required to perform activities (regardless of forces) at a worksite for a period of time, foot restraints must be provided. This will allow the crewman to function at the worksite with minimal energy expenditure for extended periods.

The accompanying table makes no allowance for the direction in which forces are to be exerted. This is based on the fact that the force values given are conservative. Consequently, the crewman should be able to apply the force level specified at the top of the column selected in virtually any direction, given that the task location is compatible with the worksite orientation and crewman reach capabilities.

To use the table,

(1) Establish the level of force (lb. or kg.) that must be applied to accomplish a selected task(s).

(2) Locate the column which corresponds to the force level determined above.

(3) To obtain the least complex, least expensive system, identify the first (✓) mark reached as the column is descended.

(4) Obtain weight and volume estimates for the identified restraint system by locating the values quoted in the weight and volumes columns of the row selected, making adjustments as noted in the "Remarks" column.

TABLE 5-6: WORKSITE FORCE REQUIREMENTS VS. RESTRAINTS

RESTRAINT SYSTEM	WEIGHT		VOLUME		FORCE APPLIED				REMARKS/APPLICATIONS
	lb.	kg.	ft.^{3}	m^3	lb. <10 / kg. <4.5	lb. < 25 / kg. <11.4	lb. < 50 / kg. < 22.7	lb. <100 / kg. <45.4	
Existing Equipment	0	0	0	0	X	X	X	X	Applicable for IVA/EVA inspection only (no forces applied)
No Restraints	0	0	0	0	(See REMARKS)	X	X	X	Not recommended for EVA/IVA tasks where applying 10 lb. (4.5 kg.) for 1.5 sec. 5 lb. (2.3 kg.) for 2.0 sec. 1 lb. (.45 kg.) for 4.5 sec.
Handholds					✓	X	X	X	Short duration tasks
Foot Restraints					✓	✓	X	X	Two-handed tasks
Foot Restraints and Handholds					✓	✓	✓	✓	One-handed push/pull type forces
Foot Restraints and Waist Tethers					✓	✓	✓	✓	Two-handed tasks, long duration, large forces
Foot Restraints, Handholds and Waist Tethers					✓	✓	✓	✓	Tasks requiring upper limits of crewman's force capability
FOR USE BY PLANNERS									
TOTAL									

5.7 PRE-EVA CREW TIME

The time required for the crewmen to prepare the spacecraft systems and the EVA support hardware for external activities is directly related to the efficient design of the man/system interface, the number of manual operations required, the location of the items used in the preparation functions, etc. The preparation time required for EVA on previous missions has acted somewhat as a deterrent in selecting EVA for future missions. The donning of the EVA gear is only a moderate fraction of the time required as compared to vehicle and EVA systems checkout and preparation. The incorporation of smaller air-locks, advanced EVA support systems (e.g., life support system, pressure suits), and collocation of EVA associated items and functions on future missions is designed to reduce the preparation and termination time. Crewman prebreathing (pure oxygen to prevent dysbarism) time will be eliminated, according to current guidelines, through the use of high pressure (8 psi - .56 kg./cm.^{2}) suits. Prebreathing time has been a significant factor on previous EVAs. The number of crewmen required to participate in EVA, the number assisting in EVA preparation, and the duration of each EVA will affect the total preparation time.

Table 5-7 is provided to allow an <u>estimate</u> of crew time required for EVA preparation. Values are given for facility preparation, suit donning, life support system donning, airlock depressurization, etc. The values given are for the A7L-B, PLSS, and umbilical systems (unshaded areas) used on Apollo and Skylab, as well as the advanced extravehicular suit (8 psi) and the advanced life support system (shaded areas). The times shown in the unshaded areas are based on simulation time associated only with the item listed and contain no other concurrent vehicle or systems functions. The shaded areas contain gross estimated times of EVA systems in the advanced development stage without having been verified through simulations or space flight.

To use the table:

(1) Establish the duration of the EVA required to accomplish the selected task(s).

(2) Establish the number of crewmen that must be EVA to perform the task and number of supporting crewmen.

(3) Locate the column which corresponds to the EVA duration, number of crewmen EVA, and number of crewmen assisting, established above.

(4) Add pre-EVA times proceeding down the appropriate column.

(5) Add times for each major activity to obtain total pre-EVA time.

Pre-EVA time includes all operations from the time the crewman begins EVA preparation until the airlock hatch is egressed. It should again be noted that the times included in the table are estimates based on previous EVA missions and simulations for Skylab, then "projected" to future missions.

TABLE 5-7: PRE-EVA CREW TIME (HRS.)

	EVA DURATION (hrs.)		2						4						6						8						REMARKS
	NUMBER OF CREWMEN EVA		1		2		3		1		2		3		1		2		3		1		2		3		
	NUMBER OF SUPPORTING CREWMEN		1	2	0	1	0	1	1	2	0	1	0	1	1	2	0	1	0	1	1	2	0	1	0	1	
	FACILITY PREPARATION																										
SUIT DONNING	Prepare Suit for Donning	A7L-B																									
		AES																									
	Don Suit	A7L-B																									
		AES																									
	Checkout Suit	A7L-B																									
		AES																									
LIFE SUPPORT SYSTEM DONNING	Prepare Life Support System for Donning	PLSS																									
		UMB																									
		ALSS																									
	Don LSS	PLSS																									
		UMB																									
		ALSS																									
	Checkout LSS	PLSS																									
		UMB																									
		ALSS																									
AIRLOCK DEPRESS	Prepare A/L																										
	Depress A/L																										
	Open Hatch																										
FOR USE BY PLANNER	TOTALS																										

5.8 POST-EVA CREW TIME

The factors which determine EVA termination time (i.e., post-EVA time) include EVA equipment doffing, EVA support systems recharging/drying, equipment stowage, and vehicle systems post-EVA operations. The equipment and systems are serviced as quickly as practical following EVA in order to have operational hardware available for contingency circumstances and future scheduled EVAs. As in the preparation for EVA, the number of crewmen required in EVA functions, the number assisting in EVA termination, and the duration of each EVA will affect the total termination time.

Table 5-8 is provided to allow an <u>estimate</u> to be made of the crew time required after EVA tasks are complete. Values are given for airlock pressurization, suit doffing, equipment servicing, etc. The times given in the table are specified for the A7L-B and the advanced suit (8 psi); times in the shaded/unshaded areas are explained in Section 5.7, p. 40.

To use the table:

(1) Establish the duration of the EVA required to accomplish the selected task(s).

(2) Establish the number of crewmen that must be EVA to perform the task and the number of supporting crewmen.

(3) Locate the column which corresponds to the EVA duration, number of crewmen EVA, and number of supporting crewmen established above.

(4) Add post-EVA times proceeding down the appropriate column.

(5) Add times for each major activity to obtain total post-EVA time.

Post-EVA time includes all activities from the time the exterior airlock hatch is ingressed until the crewman is prepared to start another type of activity. It should be noted that the times included in the table are estimates based on previous EVA missions and simulations for Skylab, then "projected" to future missions. Many options are available for efficiently performing other tasks during post-EVA functions and should be considered relative to the total space mission.

TABLE 5-8: POST-EVA CREW TIME (HRS.)

EVA DURATION (hrs.)			2						4						6						8						REMARKS
NUMBER OF CREWMEN EVA			1		2		3		1		2		3		1		2		3		1		2		3		
NUMBER OF SUPPORTING CREWMEN			1	2	0	1	0	1	1	2	0	1	0	1	1	2	0	1	0	1	1	2	0	1	0	1	
SUIT DOFFING	Prepare Suit and Equipment for Doffing and Doff Suit	A7L-B																									
		AES																									
	Service Suit for Next Use	A7L-B																									
		AES																									
	Stow Suit and Equipment	A7L-B																									
		AES																									
LIFE SUPPORT SYSTEM DOFFING	Prepare LSS for Doffing	PLSS																									
		UMB																									
		ALSS																									
	Doff LSS	PLSS																									
		UMB																									
		ALSS																									
	Service LSS for Next Use and Stow	PLSS																									
		UMB																									
		ALSS																									
AIRLOCK PRESS	Prepare Airlock																										
	Pressurize Airlock																										
	Secure Airlock																										
FOR USE BY PLANNER																											
TOTALS																											

5.9 CONSUMABLES AND EXPENDABLES

The expendables required by the EVA life support system (LSS) and pressure suit, and the consumables used by the crewmen must be considered when deriving the total cost of EVA to a space program. The design of systems to supply stowage (e.g., tankage, containers, plumbing) of the consumables and expendables is normally the responsibility of the primary vehicle designers, while the elements being used are considered part of the total EVA supporting requirements. The consumables required by the EVA crewman include oxygen (O_2) for breathing and drinking water for long duration EVAs. The expendables required for the current LSS include cooling water for the Liquid Cooling Garment (LCG), lithium hydroxide (LiOH) for carbon dioxide (CO_2) control, and charcoal for trace contamination control. Advanced LSS may require a variety of expendables or refurbishables such as ice packs, chlorate candles, magnesium hydroxide, zinc oxide, etc. The pressure suits also have a small percentage O_2 loss from leakage that is considered in the expendable calculations. The quantity of expendables and consumables for EVA are, of course, based upon the EVA duration and number of crewmen required.

Table 5-9 provides data on the weight and volume of consumables and expendables that must be provided for EVA. The values given in the table are based on Apollo and Skylab systems with provisions for including the weight and volumes of advanced systems.

To use this table:

(1) Establish the duration of the EVA required to accomplish the selected task(s).

(2) Establish the number of crewmen that must be EVA to perform the task.

(3) Locate the column which corresponds to the EVA duration and number of crewmen EVA established above.

(4) Obtain individual consumable or expendable weights and volumes by descending the selected column. Data shown is for one unit and must be multiplied by the number of units required. Total consumable and expendable weights and volumes are calculated at the bottom of the selected column by the user.

TABLE 5-9: CONSUMABLES & EXPENDABLES

EVA DURATION (hrs.)				2			4			6			8			REMARKS
NUMBER OF CREWMEN EVA				1	2	3	1	2	3	1	2	3	1	2	3	
CONSUMABLES	OXYGEN (O_2)	WEIGHT	lb.													
			kg.													
		VOLUME	$ft.^3$													
			m^3													
	WATER (DRINKING)	WEIGHT	lb.													
			kg.													
		VOLUME	$ft.^3$													
			m^3													
EXPENDABLES	WATER (COOLING)	WEIGHT	lb.													
			kg.													
		VOLUME	$ft.^3$													
			m^3													
	LITHIUM HYDROXIDE (LiOH) NO. CANISTERS ___	WEIGHT	lb.													
			kg.													
		VOLUME	$ft.^3$													
			m^3													
REFURBISHABLES	ICE PACK (ADVANCED LSS) NO. PACKS ___	WEIGHT	lb.													
			kg.													
		VOLUME	$ft.^3$													
			m^3													
FOR USE BY PLANNER TOTALS																

5.10 SPECIAL TOOLS

A variety of tools may be required to perform vehicle and payload tasks while EVA. Several special "zero" and reduced reaction power tools have been designed and tested for use on previous orbital missions. Only a minimum of these tools were flown, but they may have application on future missions in their present configuration or through slight modification. However, experience from previous orbital EVA missions indicates that if the crewman is properly restrained, most EVA tasks can be accomplished with hand tools. Further, many off-the-shelf industrial/consumer tools can be used with minor modifications to enhance handling/gripping and to prevent loss by "floating" away.

A representative small tools listing is provided in Table 5-10 to assist in estimating the weight, volume, and power cost to the vehicle/payload. Many of the tools listed in Table 5-10 are of the types used on previous orbital missions or scheduled for Skylab intravehicular activities (IVA). The many powered and special application tools are not included in the listing. Sufficient space is included in the table for listing of dedicated tools. Each EVA man/system interface task must be studied to determine the following: (1) are tools required, (2) are off-the-shelf tools adequate, and (3) if special power tools are required, can existing units be used to avoid research and development costs.

Using Table 5-10 requires only that the planner identify the type and quantity of tools needed, and record the total in the space provided.

TABLE 5-10: SPECIAL TOOLS

TOOL ITEM / FUNCTION		WEIGHT lb.	WEIGHT kg.	VOLUME ft.^{3}	VOLUME m^3	POWER WATTS	MODIFICATION YES/NO	REMARKS
SCREWDRIVING AND TORQUING TOOLS								
Wrench, Adjustable	6 in. (15.2 cm)							
	8 in. (20.3 cm)							
	10 in. (25.4 cm)							
Wrench, Socket Set	6 pc. set							
	8 pc. set							
	10 pc. set							
Pliers	Slip Joint							
	Connector							
	Needlenose							
	Channel Lock							
	Vise Grip							
Screwdrivers (Standard or Phillips)	4 in. (10.2 cm)							
	6 in. (15.2 cm)							
	8 in. (20.3 cm)							
FOR USE BY PLANNER TOTAL								

TABLE 5-10: SPECIAL TOOLS (CONT.)

TOOL ITEM	FUNCTION	WEIGHT lb.	WEIGHT kg.	VOLUME ft.^{3}	VOLUME m^3	POWER WATTS	MODIFICATION YES/NO	REMARKS
SCREWDRIVING AND TORQUING TOOLS (Cont.)								
Screwdrivers (Standard or Phillips) (Cont.)	10 in. (25.4 cm)							
	12 in. (30.5 cm)							
Allen Wrenches	3 pc. set							
	5 pc. set							
	7 pc. set							
Wrench, Open/Box End	3 pc. set							
	5 pc. set							
	7 pc. set							
	9 pc. set							
	12 pc. set							
Pry Bar	30 in. (.76 m)							
Inertia Wheel								
FOR USE BY PLANNER TOTAL								

TABLE 5-10: SPECIAL TOOLS (CONT.)

TOOL ITEM / FUNCTION		WEIGHT		VOLUME		POWER	MODIFICATION	REMARKS
		lb.	kg.	$ft.^3$	m^3	WATTS	YES/NO	
CUTTING TOOLS								
Diagonal Cutters								
Scissors								
Knives								
Wire Cutters								
Bolt Cutters								
Power Drill								
Power Saw								
IMPACT TOOLS								
Hammer	Ball-Peen							
	Dead Blow							
BONDING AND ELECTROADHESOR TOOLS								
Hand Model (Electroadhesor)								
Bonding (Restraint)								
FOR USE BY PLANNER								
TOTAL								

TABLE 5-10: SPECIAL TOOLS (CONT.)

FUNCTION / TOOL ITEM	WEIGHT		VOLUME		POWER	MODIFICATION	REMARKS
	lb.	kg.	$ft.^3$	m^3	WATTS	YES/NO	
ELECTRICAL/ELECTRONIC TOOLS							
Multipurpose "Wiring" Tool							
Multipurpose Electrical Meter							
INSPECTION/MONITORING TOOLS							
Mirror							
Mechanical Fingers							
DEDICATED TOOLS							
FOR USE BY PLANNER							
TOTAL							

5.11 EVA CREWMAN OPERATIONAL ENVELOPES

Considerations given to the envelopes required for the crewmen with EVA equipment to translate, ingress/egress, maneuver, etc. are important in the location and arrangement of equipment involving EVA operations. The location of EVA airlocks and hatches with respect to surrounding equipment, or vice versa, must allow sufficient room for ingress/egress with EVA equipment. The arrangement of payloads in the Shuttle Orbiter bay requires study if EVA is used for payload servicing. The translation route to the worksites and sufficient working volume at the sites are also factors in "designing for EVA". The area required for package transfer is, of course, based on the overall package dimensions. Simulations indicate that the passageway should be a minimum of TBD% over that of the package being transferred.

Table 5-11 provides an estimate of the envelopes necessary for the crewman to effectively and efficiently perform EVA functions. Table 5-11 should be referenced during the early phases of vehicle design and payload arrangement.

TABLE 5-11: EVA CREWMAN OPERATIONAL ENVELOPES

OPERATION PERFORMED / PARAMETER		SIZE in.	SIZE m	AREA ft.^{2}	AREA m^2	VOLUME ft.^{3}	VOLUME m^3	REMARKS
HATCH INGRESS/EGRESS	PLSS							
	UMB							
HATCH ENTRY CLEARANCE VOLUME (40 in. - 1.0 m dia. hatch)	PLSS							Based on a 39.4 in. (1.0 m) hatch.
	UMB							
AIRLOCK VOLUME *(2 Crewmen)*	PLSS							Based on minimum volume required.
	UMB							
CREWMEN TRANSFER (Parallel to Crewman's Longitudinal Axis)	PLSS							
	UMB							
WORKSTATION INGRESS/EGRESS	PLSS							Sufficient mobility/ingress aids provided.
	UMB							
WORKSTATION WORKING VOLUME	PLSS							
	UMB							
PACKAGE TRANSFER (Parallel to Crewman's Longitudinal Axis)			See Remarks - Based on package size. Consider each case individually.					Same as crewman transfer for packages sizes equal to or less than the crewman longitudinal projected area.

5.12 EVA SUPPORTING EQUIPMENT

The major systems (e.g., life support system, pressure suits) which provide direct support to the EVA crewmen will themselves require a complement of equipment for checkout, monitoring, and servicing. The portable life support systems used will require a means of verifying operational status prior to EVA, minor repair in the event of component malfunction, and servicing (i.e., replenishing expendables) operations following EVA. The pressure suits will require provisions for repairing suit components and for drying/servicing the suit following EVA/IVA operations.

A number of critical body functions and equipment performance parameters will be monitored and recorded during EVA for the safety of the crewman. Functions monitored will normally include heart rate, CO_2 status, O_2 flow rate, O_2 pressure, time, voice, etc. An EVA monitoring station/console will be required inside the vehicle to perform these operations. The weight, volume, and numerous systems interfaces will impact the vehicle and payloads.

Supporting equipment for "servicing" advanced EVA systems may include hardware such as ice pack refreeze systems (refrigerator) for life support systems, checkout system for pressure suit outer contamination garment, servicing hardware for regenerable LSS, etc. Systems of the above nature are not currently available for future EVA missions; however, preliminary studies have been conducted in many areas involving EVA support systems. Some spin-offs of these type studies may be incorporated into the Shuttle Orbiter EVA systems and should be closely followed to determine possible vehicle and payload impacts.

Table 5-12 provides estimates of the weight, volume, and power required to include several of the EVA supporting equipment items aboard a vehicle. The "cost" estimates are given for the total supporting unit but are subject to subsystem breakdown in future studies. The required supporting items are identified and the cost (e.g., weight, volume) multiplied by the number of units needed to arrive at a total cost.

TABLE 5-12: EVA SUPPORTING EQUIPMENT

EQUIPMENT/ITEM \ PARAMETER		WEIGHT		VOLUME		POWER	NUMBER OF UNITS REQUIRED	REMARKS
		lb.	kg.	ft.^{3}	m^3	WATTS		
EVA Monitoring Console								
PLSS Recharge System								
Suit Drying System								
Lighting	Fixed							
	Portable							
Workstations	Basic							
	Inter-mediate							
	Complete							
Power	Camera							
	Battery Charger							
Ice Pack Refreeze System (Advanced EVA LSS)								
FOR USE BY PLANNER								
TOTAL								

5.13 EVA COSTS SUMMARY

A summary chart/master worksheet is provided to allow the user to record and obtain a total estimated cost of EVA to a future program. Each of the major costs in terms of weight, volume, crew time, power, etc. can be summarized individually on the master worksheet. The individual worksheets can be used as a checklist for identifying a complement of necessary EVA systems/hardware.

The EVA tasks and number of EVAs needed are identified from the user vehicle and payload requirements. These requirements are compared to the EVA crewman's capabilities from the information contained in Section 4.0 of this report and other pertinent documentation. From this information the number of EVA crewmen required, the EVA duration, and the EVA equipment needed are estimated. The individual EVA equipment Cost Model sheets are then used to estimate the cost of each item or operation associated with EVA.

The EVA time (i.e., the total amount of time required to perform the tasks and translate to and from the worksite) must be estimated. This time is then added to the pre- and post-EVA times to derive a total EVA crew time estimate.

The summary chart is subdivided into two (2) sets of cost elements. Set one contains those EVA systems/elements which have a weight, volume, power, or crewman time impact to the mission, vehicle, or payload. The set two elements have either a crewman time or dimensional impact.

TABLE 5-13: EVA COST SUMMARY

TASK DESCRIPTION ______________________________

NUMBER CREWMEN REQUIRED ___ ___ ESTIMATED TASK DURATION ______ (HOURS) NUMBER OF EVA'S ______

COST ELEMENTS (SET 1)	WEIGHT		VOLUME		POWER	TOTAL TIME	REMARKS
	lbs.	kg.	$ft.^3$	m^3	WATTS	Hours	
SPACE SUITS No. ______ Type ______							
HELMETS & VISORS No. ______ Type ______							
GLOVES							
IVA No.							
EVA No.							
STOWAGE SUPPORT EQUIPMENT (All Equipment)							
MAINTENANCE, DON/DOFF AND DRYING EQUIPMENT (All Equipment)							
LIFE SUPPORT SYSTEMS							
PLSS No.							
LSU No.							
CONSUMABLES AND EXPENDABLES							
Crewman							
Systems							

TABLE 5-13: EVA COST SUMMARY (CONT.)

COST ELEMENTS (SET 1)	WEIGHT		VOLUME		POWER	TOTAL TIME	REMARKS
	lbs.	kg.	$ft.^3$	m^3	WATTS	HOURS	
CREWMAN TRANSLATION AND CARGO TRANSFER AIDS							
Handrails No.							
Handholds No.							
Powered: Type							
No.							
Free-Flying: Type							
No.							
SPECIAL TOOLS							
Power							
Hand							
EVA SUPPORTING EQUIPMENT							
EVA Monitoring Console							
PLSS Recharge System							
Suit Drying System							
Workstations							
Lighting							
Others							
RESTRAINTS							
Tethers No.							
Foot No.							
TOTAL							

TABLE 5-13: EVA COST SUMMARY (CONT.)

COST ELEMENTS (SET 2)	DIMENSIONS		AREA		VOLUME		TOTAL TIME	REMARKS
	in.	m	ft.^{2}	m^2	ft.^{3}	m^3	HOURS	
CREWMAN OPERATIONAL ENVELOPE PLSS ______ LSU ______								
Airlock Volume								
Translation								
Package Transfer								
Hatch Ingress/Egress								
Hatch Entry Clearance								
Workstation Ingress/Egress								
Workstation Working Volume								
______								
______								
PRE-EVA CREW TIME No. CREWMEN ______								
POST-EVA CREW TIME No. CREWMEN ______								

TOTAL SYSTEMS COST:

WEIGHT ______ (lbs.) VOLUME ______ (ft.^{3}) POWER ______ (Watts) CREW TIME ______ (Hours)

______ (kg.) ______ (m^3)

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