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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

Space Station Program Cost Analysis

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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PREFACE

The McDonnell Douglas Astronautics Company has been engaged in a study for the National Aeronautics and Space Administration to determine Space Station needs, attributes, and architecture. The study, which emphasized mission validation by potential users, and the benefits a Space Station would provide to its users, was divided into the following three tasks:

Task 1: Mission Requirements

Task 2: Mission Implementation Concepts

Task 3: Cost and Programmatics Analysis

In Task 1, missions and potential users were identified; the degree of interest on the part of potential users was ascertained, especially for commercial missions; benefits to users were quantified; and mission requirements were defined.

In Task 2, a range of system and architectural alternatives encompassing the needs of all missions identified in Task 1 were developed. Functions, resources, support, and transportation necessary to accomplish the missions were described.

Task 3 examined the programmatic options and the impact of alternative program strategies on cost, schedule and mission accommodation.

This report, which discusses Space Station Program cost analysis, was prepared for the National Aeronautics and Space Administration under contract NASw-3687 as part of the Task 3 activities.

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CONTENTS

Section 1

INTRODUCTION AND SUMMARY

This report documents the principal cost results (Task 3) derived from the Space Station Needs, Attributes, and Architectural Options study conducted for the NASA by the McDonnell Douglas Astronautics Company. The determined costs were those of Architectural Options (Task 2) defined to satisfy Mission Requirements (Task 1) developed within the study (see Figure 1-1).

A major feature of this part of the study was the consideration of realistic NASA budget constraints on the recommended architecture. Thus, the

FIGURE 1-1

MDAC'S STUDY APPROACH

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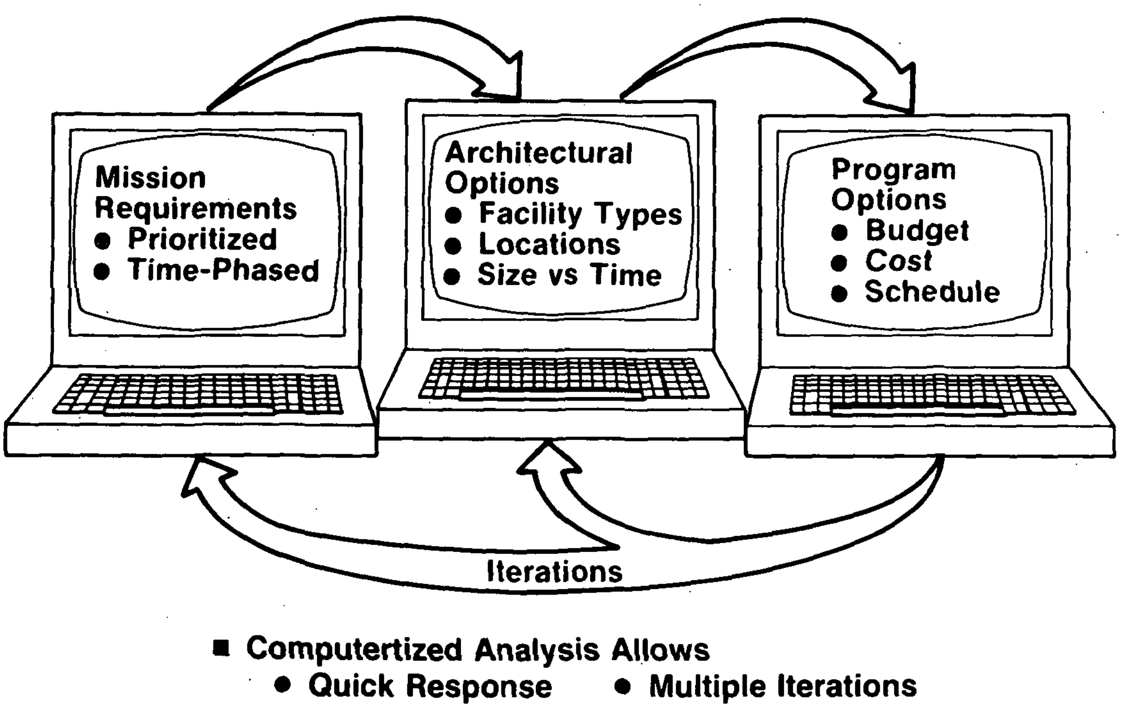

space station funding requirements were adjusted by altering schedule until they were consistent with current NASA budget trends. The program (architecture) resulting from the study analysis includes an initial station (4-man, 25-KW mission power) estimated to cost $5.2 billion, with a maximum annual funding requirement less than $1.4 billion. The costs of expanded capability were also identified.

The identified funding requirements include consideration of non-contractor costs such as NASA program support, contingency (30 percent), and operations. Thus they can be viewed as NASA line-item values (see Figure 1-2).

The MDAC Program Definition Cost Model (Figure 1-3) was the primary tool for determining program cost. This computerized model is described herein.

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FIGURE 1-2

SPACE STATION SYSTEM COST ESTIMATING METHODOLOGY

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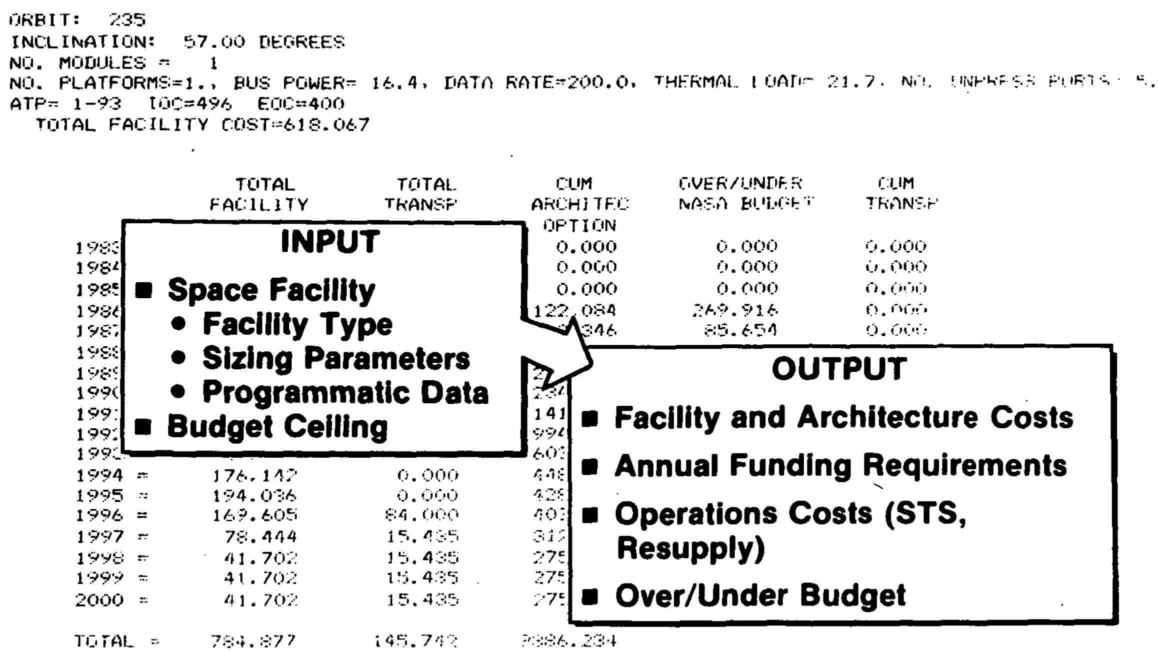
CATEGORY	SPACE FACILITIES	MISSION EQUIPMENT
Flight Hardware ■ GSE, Systems Test, SE&I Initial Spares, Proj Mgmt ■ NASA Integ/Mgmt, Contingency	MDAC Cost Model	Rough Sizing W/ Aerospace Cost Model
Operations ■ Logistics — Transportation (STS) — Materials, Spares		Factored From Flight Hardware
■ Ground Support — Equipment — Operations	Estimated Independently	Estimated Independently

FIGURE 1-3 VGB499

PROGRAM DEFINITION COST MODEL



An illustration of how a Space Station User Charge Model might be constructed is included, giving quantitative examples of rates for different cost philosophies.

Section 2

PROGRAM COST AND FUNDING MODEL

The primary tool for determining Space Station program cost and funding requirements is the MDAC computerized space facility cost model. This model was developed with company discretionary funds, but was tailored to provide the type of cost data needed by this study. This section describes this model, its purpose, and capabilities. The nomenclature used is defined here.

- Element: Lowest cost category. Largest group of hardware items that can be defined as unit without imposing restrictions on the design concept (e.g., ACS, EC&LS, etc.)
- Facility: One or more elements forming an autonomous unit (e.g., Space Station, OTV, Platform, etc.).
- Architectural Option: One or more facilities.

2.1 PURPOSE

The purpose of the cost model is to provide an efficient tool for estimating the cost of space facilities (e.g., Space Station, platforms, and TMS) and determining the aggregate annual funding requirements for program architecture alternatives. In the case of the Space Station facility, it was desired that cost estimates be built up from the element level.

2.2 CAPABILITIES

The cost model capabilities are summarized in Figure 2-1. Development, production, and operational costs are calculated for the specified facilities. Program costs are accumulated for the combined facilities, and annual funding requirements are determined according to the scheduled sequence of facility starts. These requirements are tested against input budget allowances and discrepancies may be rectified by redistributing the annual funding level. The level of commonality between succeeding facilities/elements may be specified. Provision is made for altering technology levels at the element level.

Figure 2-2 indicates the various calculations that are made and funding options that are available to the operator during run time. Figure 2-3 shows the level of cost accumulation, which is at the element level. Element costs are estimated by way of algorithms, or cost estimating relationships (CERs),

FIGURE 2-1

COST MODEL CAPABILITIES

- LANGUAGE - FORTRAN
- COMPUTER - CDC
- ESTIMATES FACILITY COSTS (DEVELOPMENT, PRODUCTION, OPERATIONS)
  - SPACE STATION
  - PLATFORM
  - "OTHER EQUIPMENT"(OTV, TMS, DOCKING MODULE, ETC.)
- PROGRAMMATIC FEATURES
  - TIME SEQUENCING OF EACH FACILITY START, IOC, ETC.
  - VARIABLE TECHNOLOGY LEVELS FOR EACH ELEMENT
  - REFLECTS BENEFITS OF EXISTING HARDWARE AND COMMONALITY (ENGINEERING, SIMULATOR)
  - TESTS FUNDING REQUIREMENT AGAINST BUDGET CEILING; PROVIDES ALTERNATIVE FIXES.
  - ABILITY TO CHANGE INPUTS ON-LINE

FIGURE 2-2

CALCULATIONS

- FOR EACH ELEMENT
  - DETAIL COST
  - FUNDING
  - CUM COST
  - CUM FUNDING REQUIREMENT
- OPTIONS AVAILABLE DURING RUN TIME
  - CHANGE FUNDING REQUIREMENTS START
  - CHANGE FUNDING REQUIREMENTS DURATION
  - SHIFT FUNDING REQUIREMENTS EARLIER OR LATER
  - FORCE FUNDING REQUIREMENTS TO BUDGET CEILING
  - ASSIGN DESIRED FUNDING TO ANY YEAR
- COMPAPE TO BUDGET (OVER - UNDER)

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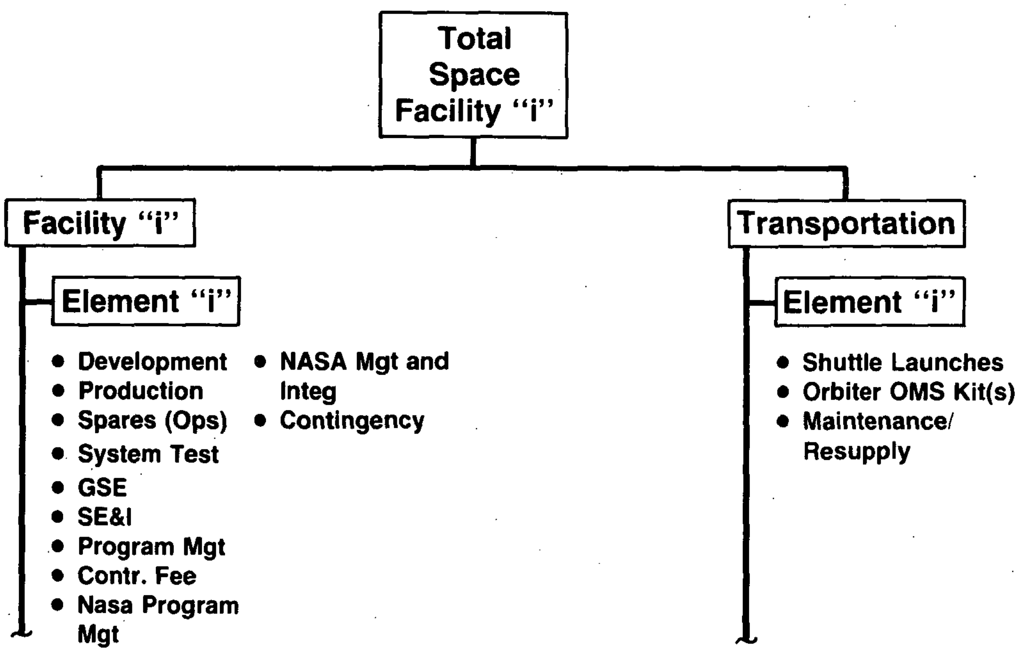
FIGURE 2-3

COST ACCUMULATION SPACE FACILITY



for each designated element. CERs presently in the model are listed in Tables 2-1 and 2-2 along with the principal source of data providing the basis for the CER and the respective independent variables. Items included in the CERs are listed in Tables 2-3 and 2-4.

Table 2-1. COST MODEL DATA SOURCES AND INDEPENDENT VARIABLES FOR MANNED SPACE STATION

ELEMENT	PRINCIPAL SOURCE	INDEPENDENT VARIABLE
1. 2 DIA. SHELL AND UTILITY SERVICES	MOSC STUDY	LENGTH (FT)
2. CONSTANT DIA. SHELL AND UTILITY SERVICES	MOSC STUDY	LENGTH (FT)
3. LOGISTICS MODULE	MOSC STUDY	LENGTH (FT)
4. LAB SHELL AND UTILITY SERVICES	MOSC STUDY	LENGTH (FT)
5. SOLAR ARRAY	LOCKHEED	POWER AT ARRAY (KW)
6. ELECTRICAL CONTROLS	25 KW POWER SYSTEM STUDY	POWER AT BUS (KW)
7. CREW ACCOMMODATIONS	MOSC STUDY	CREW SIZE
8. ENVIRONMENTAL LIFE SUPPORT SYSTEM	HAMILTON STANDARD	CREW SIZE
9. THERMAL SYSTEM - NO RADIATORS	HAMILTON STANDARD	HEAT REJECTION (KW)
10. COMMUNICATIONS AND DATA MANAGEMENT	NASA AND AF COST DATA	DATA RATE (MBPS)
11. ATTITUDE CONTROL	SSSAS STUDY, PART 3	NUMBER OF MODULES
12. LAB EQUIPMENT	SSSAS STUDY, PART 3	LENGTH (FT)
13. STATION DOCKING MODULE	MOSC STUDY	CONSTANT
14. PAYLOAD SUPPORT STRUCTURE	MANNED SASP STUDY	CONSTANT
15. EQUIPMENT RACKS	NASA SPACELAB DATA	CONSTANT
16. SHORT MODULE	NASA SPACELAB DATA	CONSTANT
17. DEPLOYABLE RADIATOR	25 KW POWER SYSTEM STUDY	HEAT REJECTION (KW)
18. PROPULSION MODULE	25 KW POWER SYSTEM STUDY	TOTAL LENGTH ALL MODULES (FT)
19. SOFTWARE (TOTAL FACILITY)	MDAC HISTORICAL DATA	MACHINE LANGUAGE INSTRUCTIONS
20. FRAMEWORK & UTILITY SERVICES	25 KW POWER SYSTEM STUDY	POWER AT BUS (KW)
ORBITER DOCKING MODULE	MOSC STUDY	CONSTANT
TMS	VOUGHT	CONSTANT
TMS REFUELING AND SERVICE	MDAC OTV STUDY	CONSTANT
OTV	NASA AND CONTRACTOR STUDIES	CONSTANT
OTV REFUELING AND SERVICE	MDAC OTV STUDY	CONSTANT
100 FT RMS	SPAR	CONSTANT
MMU	NASA	CONSTANT
EMU	NASA	CONSTANT

Table 2-2. COST MODEL DATA SOURCES AND INDEPENDENT VARIABLES FOR UNMANNED PLATFORMS

ELEMENT	PRINCIPAL SOURCE	INDEPENDENT VARIABLE
1. FRAMEWORK AND UTILITY SERVICES	25 KW POWER SYSTEM STUDY	POWER AT BUS (KW)
2. ACS/PROPULSION - RBM	25 KW POWER SYSTEM STUDY	POWER AT BUS (KW)
3. SOLAR ARRAY	LOCKHEED	POWER AT ARRAY (KW)
4. ELECTRICAL CONTROLS	25 KW POWER SYSTEM STUDY	POWER AT BUS (KW)
5. COMMUNICATIONS AND DATA MANAGEMENT	NASA AND AF COST DATA	DATA RATE (MBPS)
6. THERMAL SYSTEM - NO RADIATORS	25 KW POWER SYSTEM STUDY	HEAT REJECTION (KW)
7. UNPRESSURIZED PORTS/ARM	MANNED SASP STUDY	CONSTANT
8. PROPULSION MODULE	25 KW POWER SYSTEM STUDY	CONSTANT
9. ATTITUDE CONTROL	25 KW POWER SYSTEM STUDY	CONSTANT
10. SOFTWARE (TOTAL FACILITY)	MDAC HISTORICAL DATA	MACHINE LANGUAGE INSTRUCTIONS
11. DEPLOYABLE RADIATOR	25 KW POWER SYSTEM STUDY	HEAT REJECTION (KW)

Table 2-3. MANNED SPACE STATION PARAMETRIC PREDICTOR METHODOLOGY DEFINITION OF ITEMS INCLUDED IN CER's

Two Different Diameter Pressurizable Manned Shells and Utility Services

Structure (Cylinder, Floor, Racks, Domes, Attach Fittings, Hatches, Hatch Adapters, Docking Adapters)
Environment Protection (Radiation/Meteor Shield, External Insulation)
Electrical Distribution
Lighting
Atmospheric Circulation, Vent, Fans
Gimbals & Support For Solar Array

One Constant Diameter Pressurizable Manned Shell and Utility Services

Structure (Cylinder, Floor, Racks, Domes, Attach Fittings, Hatches, Hatch Adapters, Docking Adapters)
Environment Protection (Radiation/Meteor Shield, External Insulation)
Electrical Distribution
Lighting
Atmospheric Circulation, Vent, Fans

Table 2-3. MANNED SPACE STATION PARAMETRIC PREDICTOR METHODOLOGY DEFINITION OF ITEMS INCLUDED IN CER's (Continued)

Logistics Module

Pressurized Section

- Structure (Cylinder, Floor, Racks, Domes, Hatches, Docking Adapters, Stowage Compartments)
- Environment Protection (Meteoroid Shield, Insulation)
- Electrical Distribution
- Lighting

Unpressurized Cylinder
Tunnel
Intercom and Control Panel
O_2 and N_2 Storage Tanks
H_2O Storage Tanks

Electrical Power - Array

Solar Cells, Blankets and Connections
Supporting Hardware
Solar Mast
Array Linkage
Cannisters, Containers & Covers

Electrical Power - Regulation and Control

Batteries/Fuel Cells
Power Processor
Battery Protection Circuit
Power Distributors
Regulators
Diodes
Wiring

Table 2-3. MANNED SPACE STATION PARAMETRIC PREDICTOR METHODOLOGY DEFINITION OF ITEMS INCLUDED IN CER's (Continued)

Crew Accommodations

Crew Quarters
Crew Gear
Restraints
Flight Operations Equipment
Food Management
Hygiene
Trash Management Without Compactor
Water Management

ECLS (Open Loop)

Ventilation Control
Temperature Control
Humidity Control
Pressure Control
Emergency O_2 and N_2
Trace Contaminant Control
Regenerable CO_2 Removal
Humidity Condensate Recovery
Wash Water Recovery
Hot and Cold Water Supply
Emergency Water Storage
Waste Collection and Storage
Hand Wash Hygiene
Oven

ECLS (Partial Closed Loop)

All of Open Loop Above Plus:
Shower
Clothes Washer
Trash Compactor
Airlock Pump
Refrigerator/Freezer
Added Wash Water Recovery From Shower
Water Quality Monitor and Control

ECLS (Closed Loop)

All of Open Loop and Partial Closed Loop Above Plus:
Dishwasher
Oxygen Generation System
CO_2 Reduction System
Water Recovery from Urine

Table 2-3. MANNED SPACE STATION PARAMETRIC PREDICTOR METHODOLOGY DEFINITION OF ITEMS INCLUDED IN CER's (Continued)

Thermal Control

Water Pump Package
Freon Pump Package
Water/Freon Interface Heat Exchanges
Controls

Communications and Data Management

Antennas
Transponders
Amplifiers
Transmitters
Signal Processors
Internal Communications
Electronics Assemblies
Data Processing Equipment
Instrumentation
Display/Control Equipment

Attitude Control/Propulsion/RCS

RCS (Tankage and Thrusters)
Control Electronics
Telemetry
Optical Reference Assembly
Intertial Reference Assembly
Guidance Electronics

Lab Equipment

Atmosphere Control
Thermal Control
Data Management
Communications
Facility Control Equipment
Processing Work Station
Medical/Biological Mission Equipment

Pressurized Ports - Docking Module

Active Ports(4 side ports, 2 end ports)
Hatches
Cylindrical Structure Section and End Domes
Environment Protection
Electrical Distribution
Lighting
Wiring and Fluid Lines & Interconnects

Table 2-3. MANNED SPACE STATION PARAMETRIC PREDICTOR METHODOLOGY DEFINITION OF ITEMS INCLUDED IN CER's (Continued)

Unpressurized Port (Payload Support Structure)

Payload Ports (12)
Extension Arm Truss
Interface Umbilicals at Both Ends of Arm
Wiring and Fluid Lines

Equipment Racks

Spacelab Experiment Segment Rack Including Thermal Ducts & Wiring

Short Module

Modified Spacelab Core Segment Including:
- Structure
- Electrical Power Distribution
- Communications/Data Management
- Life Support Distribution
- Thermal Control
- Viewpoint

Deployable Radiator

Radiator Assembly (3 panels total 829 sq. ft.)
Radiator Deployment Mechanism
Plumbing and Fittings
Flex Hoses

Spacelab Pallet

Pallet Assembly with Thermal Lines & Electrical Wiring

Orbiter Docking Module

Structure (Cylinder, Floor, Domes, Hatches, Docking Adapters)
Environment Protection
Electrical Distribution
Lighting
Airlock and Controls

Table 2-4. UNMANNED PLATFORM PARAMETRIC PREDICTOR METHODOLOGY DEFINITON OF ITEMS INCLUDED IN CER's

Frame

- Deployable Radiator Panels and Mechanical Support/Deployment
- Ku Antenna Structure
- Low Fidelity Mockup
- Equipment Housing Assembly
- Support Beam Assembly
- Solar Array Support Assembly
- Crew Accommodations (EVA Restraints)
- Interface Pivot Assembly
- Adapter Housing Assembly

Attitude Control/Propulsion

- Control Electronics
- Guidance Electronics
- CMG's
- Magnetometer
- Electromagnet
- Rate Sensor
- Sun Sensor
- Horizon Sensor
- Electrical Power (Wiring and Controls)
- Thermal Control (Insulation and Heaters)
- RCS (Tankage, Thrusters, Valves, Lines, Instrumentation)
- Structure

Electrical Power - Array

- Solar Cells, Blankets and Connections
- Supporting Hardware
- Solar Mast
- Array Linkage
- Cannisters & Container Box/Covers

Electrical Power - Regulation and Control

- Batteries/Fuel Cells
- Power Processor
- Battery Protection Circuit
- Power Distributors
- Regulators
- Diodes
- Wiring Associated with Above Items Only

Table 2-4. UNMANNED PLATFORM PARAMETRIC PREDICTOR METHODOLOGY DEFINITION OF ITEMS INCLUDED IN CER's (Continued)

Communications and Data Management

Antennas
Transponders
Amplifiers
Transmitters
Signal Conditioners
Data Processing Equipment
Instrumentation
TV Camera

Thermal Control

Insulation
Coolant
Radiator and Control Assembly
Cold Plate Assembly
Pump and Payload Cooling Package

2.3 INPUT REQUIREMENTS

Model inputs are categorized as either Architectural Option, Facility, or Element inputs:

- Architectural Option Inputs
  - Data file name
  - NASA budget file
  - Ancillary equipment file
- Facility Inputs
  - Orbit data
  - Schedule data
  - Support flights per year

- Element Inputs
  - Quantity
  - Value of estimating parameter
  - Percent new design and new simulator/test
  - Spares parameters
  - Technology level

An example input file is shown in Figure 2-4.

2.4 OUTPUT

Two categories of output data are developed: element costs and facility funding requirements (Figure 2-5). Element costs are calculated at the contractor (excluding fee) and NASA line item level. T2 designates the first

---

FIGURE 2-4

PROGRAM DEFINITION COST MODEL INPUT

```
                         CONFIGURATION DATA FOR SPACE STATION:
 #       VARIABLE NUMBERS =       2                3                        4                       5
 1. 2 DIA EQU  : # OF UNITS= 0.0, LENGTH(FT)= 32.2, % NEW ENGR= 100.000, % NEW GDH= 100.000,
 2. 1 DIA EQU1: # OF UNITS= 1.0, LENGTH(FT)= 27.0, % NEW ENGR=  10.000, % NEW GDH=  10.000,
 3. LOG MOD   : # OF UNITS= 2.0, LENGTH(FT)= 27.0, % NEW ENGR=  50.000, % NEW GDH=  18.000,
 4. 1 DIA EQU2: # OF UNITS= 1.0, LENGTH(FT)= 44.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
 5. ARRAY     : # OF SETS = 1.0, TOT STA KW=100.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
 6. ELECT CNTR: # OF SETS = 1.0, TOT BUS KW= 38.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
 7. CREW ACCOM: # CREW MOD= 1.0, TOT STA CR=  4.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
 8. LIFE SUPPT: # OF SETS = 1.0, TOT STA CR=  4.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
 9. THERMAL SY: # OF SETS = 1.0, STA THM LD= 51.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
10. COM & DM  : # OF SETS = 1.0,  RATE MBPS= 80.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
11. ATT CONTRL: # OF SETS = 1.0, # OF MODS =  7.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
12. LAB EQUIP : # OF SETS = 0.0, TOT LAB FT= 31.7, % NEW ENGR= 100.000, % NEW GDH= 100.000,
13. 4/6 DOCK  : # OF UNITS= 1.0,  (NULL)    =  0.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
14. P/L SUPT S: # OF UNITS= 1.0,  (NULL)    =  0.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
15. EOP RACKS : # OF UNITS= 9.0,  (NULL)    =  0.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
16. SHRT MOD  : # OF UNITS= 0.0,  (NULL)    =  0.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
17. DEPLY RAD: # OF …            … DY KW = 23.0, % NEW ENGR= 100.000, % NEW GDH= 100.000,
18. PROP SECT : # …                                            … % NEW GDH= 100.000,
19. SOFTWARE  : …                                                   …= 100.000,
20. FRAME+SERV: …                                                     …00.000,
```

- ELEMENT INPUTS
  - QUANTITY
  - VALUE OF ESTIMATING PARAMETER
  - PERCENT NEW DESIGN AND NEW GROUND DEVELOPMENT HARDWARE
  - SPARES PARAMETERS
  - TECHNOLOGY LEVEL

FIGURE 2-4 (Continued)

PROGRAM DEFINITION COST MODEL
INPUT

- ARCHITECTURAL OPTION INPUTS
  - DATA FILE NAME
  - NASA BUDGET FILE
  - ANCILLARY EQUIPMENT FILE

```
  FILE NAME=SS4F    D/T= 83/03/30.      19.26.35.
FACILITY NO.(1)= 1.
TYPE(2)=SPACE STA.
USER(3)=NASA         INCLINATION(4)=  28.5, ALTITUDE(5)=235 NA. MI., IOC(6)=192, EOC(7)=400
# SUP FLTS/YR(8)=10, # SPEC ELEMENTS(9)= 1, START TO LAUNCH PER MODULE=22.
```

- FACILITY INPUTS
  - ORBIT DATA
  - SCHEDULE DATA
  - SUPPORT FLIGHTS PER YEAR

```
SPECIAL EQUIPMENT NO.=  1 EQUIPMENT NAME=ORB DM       1.000
SPECIAL EQUIPMENT NO.=  1 EQUIPMENT NAME=EMU          2.000
SPECIAL EQUIPMENT NO.=  1 EQUIPMENT NAME=MMU          2.000
```

FIGURE 2-5

```
**********      COST MODEL**********
83/03/31.       16.53.23.

ARCH OPTION: SS4F1
ARCH TITLE: SPACE STATION SYSTEM ARCHITECTURE,4,8,8
FACILITY NUMBER: 1.
FACILITY NAME: SP STATION
  FUNDING DURATION=22. SPAN=25.
  RESUPPLY FLIGHTS PER YEAR=10.

ORBIT:  235
INCLINATION:  28.50 DEGREES
NO. MODULES =   4
NO. 2 DIA MODS=0., NO. 1 DIA MODS#1=1., NO. 1 DIA MODS#2=1., CREW SIZE= 4.
 THERMAL LOAD= 51.0, DATA RATE= 80.0, NO. DOCK MODS= 1.
NO. PAYLD SUPPORT STRUCT= 1., NO. SHRT MODS= 0., BUS POWER= 38.0
ATP= 1-86  IOC=192  EOC=400
  TOTAL FACILITY COST=5214.683852907
```

	TOTAL FACILITY	TOTAL TRANSP	CUM ARCHITEC OPTION	OVER/UNDER NASA BUDGET	CUM TRANSP
1983 =	0.000	0.000	0.000	0.000	0.000
1984 =	0.000	0.000	0.000	0.000	0.000
1985 =	0.000	0.000	0.000	0.000	0.000
1986 =	392.000	0.000	392.000	.000	0.000
1987 =	646.000	0.000	646.000	.000	0.000
1988 =	1219.000	0.000	1219.000	.000	0.000
1989 =	1293.515	0.000	1293.515	78.485	0.000
1990 =	1004.694	0.000	1004.694	367.306	0.000
1991 =	602.895	252.300	602.895	769.105	252.300
1992 =	56.580	84.100	56.580	1315.420	84.100
1993 =	185.148	48.597	185.148	1186.852	48.597
1994 =	185.148	48.597	185.148	1186.852	48.597
1995 =	185.148	48.597	185.148	1186.852	48.597
1996 =	185.148	48.597	185.148	1186.852	48.597
1997 =	185.148	48.597	185.148	1186.852	48.597
1998 =	185.148	48.597	185.148	1186.852	48.597
1999 =	185.148	48.597	185.148	1186.852	48.597
2000 =	185.148	48.597	185.148	1186.852	48.597
TOTAL =	6695.868	725.176	6695.868		

article production cost and PROD designates the total production cost according to the quantity of units (PROD = QUANTITY x T2).

Design and tooling (DES & TLNG) costs are printed out and are a component of development costs (DEVELOPMENT). Cumulative values (CUM) are calculated, including the preceding elements. The cost of spares and their associated weight are printed out, the latter providing the basis for calculating STS transportation cost.

Facility annual funding requirements are output, presenting costs for the facility and a cost accumulation including preceding facilities in the architecture. The accumulated funding is tested against input budget limitations and the difference printed out. The cost of spares is accumulated under the facility. Transportation costs are shown separately and not charged against the budget.

Section 3

PROGRAM COSTS

Program costs have been estimated which make allowance for all major categories necessary to define total costs to NASA for the required space facilities. This section presents the results of the cost analysis.

3.1 ESTIMATING METHODOLOGY

Figure 3-1 identifies the categories of cost considered. The MDAC cost model accounted for all areas of space facilities cost except operational ground support and associated support equipment.

FIGURE 3-1

SPACE FACILITY COST ELEMENTS

- CONTRACTOR

  HARDWARE, GSE, SYSTEMS TEST, SE&I, INITIAL SPARES, PROJECT MANAGEMENT, FEE

  CONTINGENCY (30%)

- NASA

  PROGRAM SUPPORT, MANAGEMENT & INTEGRATION, LAUNCH & LANDING

- OPERATIONS

  TRANSPORTATION, EXPENDABLES, SPARES, GROUND SUPPORT AND SUPPORT EQUIPMENT

These costs were estimated independently. An allowance for contractor fee (10 percent) was included. NASA costs traditionally identified as Program Support, Management and Integration, and Launch and Landing were accounted for by factors. A contingency equal to 30 percent of the contractor program price (fee included) was assumed.

Where the cost of mission equipment was estimated, flight hardware cost was calculated by use of an algorithm developed by Aerospace Corporation*. Operations costs were estimated independently, with the logistics costs calculated as a fraction of hardware costs.

Key assumptions are noted in Figure 3-2.

3.2 PROGRAM FUNDING REQUIREMENTS

Program funding requirements were determined for the study baseline architecture (see Figure 3-3).

FIGURE 3-2
COST AND SCHEDULE ASSUMPTIONS

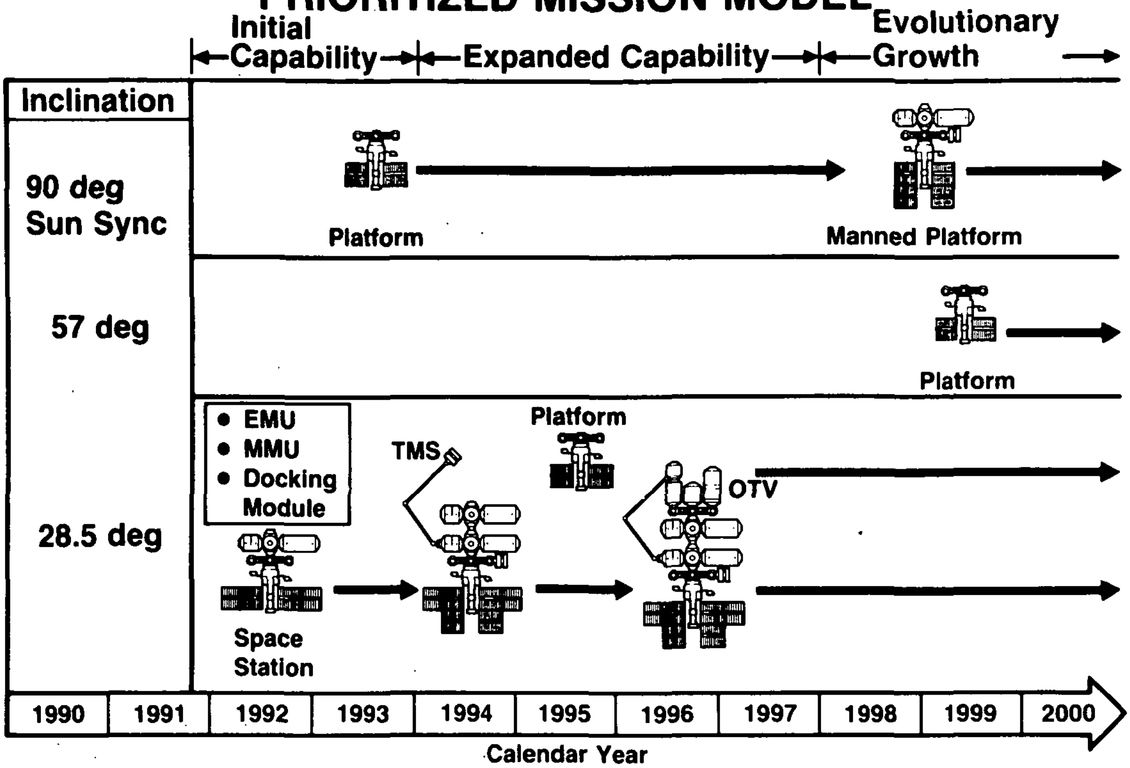
- $1984 (FISCAL YEAR)
- TOTAL PROGRAM COSTS INCLUDE CONTRACTOR FEE, NASA COSTS, CONTINGENCY
- SHUTTLE
  - FUNDED FROM OSTS "SHUTTLE OPERATIONS" BUDGET
  - $84M/LAUNCH
- MOST COST-EFFECTIVE PROCUREMENT CONCEPT
  - MAXIMUM COMMONALITY
  - SINGLE NASA CENTER PROGRAM MANAGEMENT
  - PRIME CONTRACTOR DOES SYSTEM ENGINEERING

*Spacecraft System Cost Model, Aerospace Resource Cost Analysis Office, March 1981.

FIGURE 3-3

SPACE STATION SYSTEM ARCHITECTURE PRIORITIZED MISSION MODEL

VGB553A



The baseline architecture's buildup is accomplished through seven separate steps which either add new facilities or expand facilities already deployed. Standard sized modules and elements are used in these steps as indicated below.

1. Space Station at 28°
   - 4-man crew (3 for missions)
   - 25-kW mission power
2. Platform at 97°
   - 15-kW mission power
   - 300-Mbps data rate
3. Expand Space Station
   - 8-man crew
   - 40-kW mission power
   - Add TMS operations

4. Platform at 28.5°

   - 15-kW mission power

5. Expand Space Station at 28°

   - Add ROTV operations

6. Expand platform at 97° (evolutionary growth)

   - 4-man capability
   - 25-kW mission power

7. Add platform at 57° (evolutionary growth)

8. Continuous logistics and assembly-level upgrade.

Program funding requirements for this architecture are shown in Figure 3-4. The annual funding is constrained to a maximum of $1.37 billion (1984 dollars). Cumulative facility costs are shown, with factors to account for

FIGURE 3-4
SPACE STATION PROGRAM FUNDING
PRIORITIZED MISSION MODEL

VGB818

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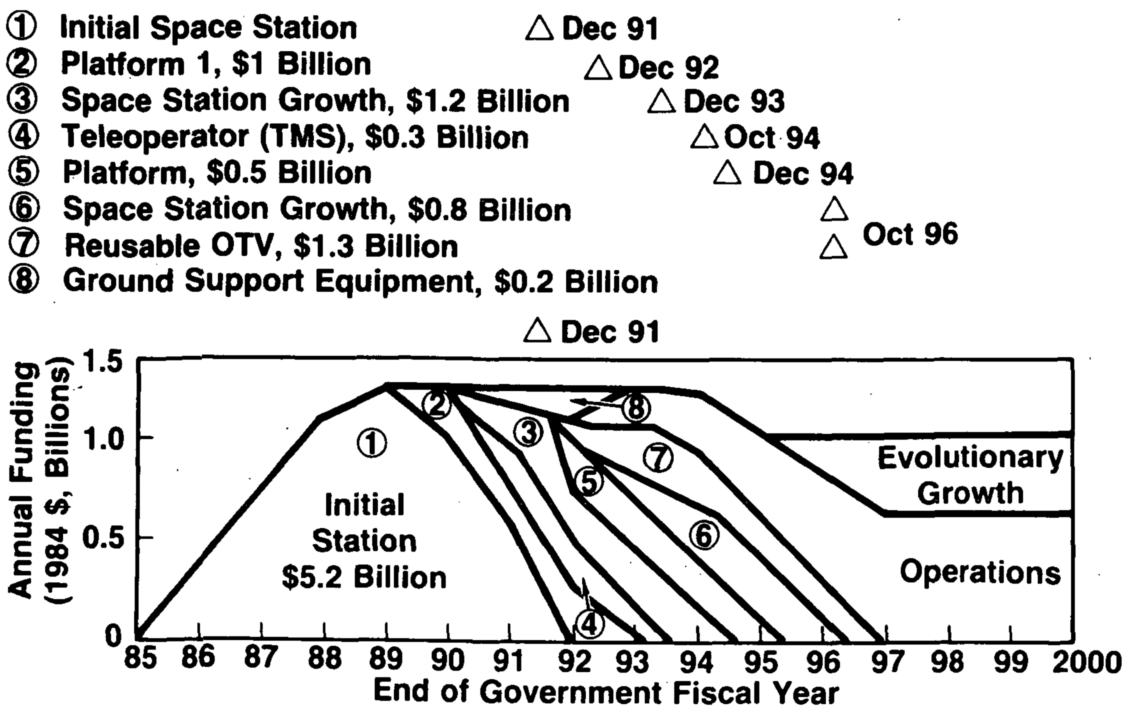

NASA management and a 30 percent contingency included. An initial capability station, sized to accommodate four crew persons, is estimated to cost $5.2 billion. An expanded capability would include station growth from four to eight persons and introduction of TMS operations. Total cost for these additions is $1.2 billion. If ROTV development and operations were introduced, an added cost of $0.8 billion would be incurred. Funding for operations is overlaid, including consideration of the costs of spares, ground support, and the associated equipment. The cost of STS operations is excluded.

The architecture discussed above results in maximum accommodation of the prioritized mission model. Figure 3-5 shows the relative cost impact of reduced levels of mission capture as caused by elimination of selected architectural elements. The architecture which captures 50 percent of the mission model consists of a Space Station at 28^{0} inclination and a platform

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FIGURE 3-5

VGB681

ARCHITECTURAL OPTIONS

Mission Model		ARCHITECTURAL ELEMENTS							COST VS CAPTURE		
		Space Station	Platform	TMS	OTV	RMS	Ku Comm	Subsys Growth	50%	75%	95%
Prioritized Missions	50%	●	●	●			●		0.65		
	75%	●	●	●		●	●	●		0.70	
	95%	●	● ●	●	●	●	●	●			1.00(1)

(1) 1.00 Represents Total Program Cost — Prioritized Mission Model

at 90^{0} inclination and employs a TMS for satellite servicing and Ku band communications as required by some high priority Science and Applications missions.

In order to capture the 75 percent model, missions of lower priority are added. Growth subsystems and an RMS are required to capture this model.

Capture of the 95 percent model (maximum capture) requires the addition of another 28^{0} inclination platform and an OTV to satisfy operations missions launching payloads to geosynchronous orbits.

The costs show that the 50 percent capture costs a factor of 0.65 compared to a factor of 1.00 for 95 percent capture. This means that the cost is greater per mission captured for facilities with reduced capture. Also, a smaller increase in cost occurs between the 50 percent and 75 percent than between the 75 percent and 100 percent capture. This is primarily due to the need for the OTV for the 95 percent capture version.

3.3 SPACE STATION COST BREAKDOWN

A breakdown of costs for the initial space station is shown in Table 3-1. Costs are identified at the hardware, project (i.e., contractor), and program (i.e., NASA line item) levels. An allocation for contractor fee (10 percent) is included within the item designated NASA Program Support, Contingency.

3.4 GROUND OPERATIONS COST

Cost elements and their associated costs for the category of ground operations and equipment are shown in Table 3-2. The cost designated

Table 3-1. SPACE STATION COST BREAKDOWN ($M 1984)

4-15-83

	INITIAL STA ($)	GROWTH ($)	GROWTH ($)
MISSION EQUIPMENT SHELL AND UTILITY SERVICES*	114	25	
LOGISTICS MODULES (2)	69		
CREW SHELL & UTILITY SERVICES	19	15	
UTILITIES FRAMEWORK	52		
ORBITER DOCKING MODULE	76		18
DOCKING PORT MODULE	60	21	
MISCELLANEOUS SUPPORT STRUCTURE	39	18	13
SOLAR ARRAY (100 kW)	128	65	
ELECTRICAL CONTROLS (38 kW)	122	39	
CREW ACCOMMODATIONS (4 MEN)	90	19	
LIFE SUPPORT SYSTEM (OPEN GAS/CLOSED FLUID)	217	59	
THERMAL SYSTEM/RADIATORS	49	18	
COMM/DATA MANAGEMENT	406		
SOFTWARE	181	10	10
ATTITUDE CONTROL/PROPULSION/G&N	105	10	
100 RMS		170	
HYPERGOLIC TANKS		54	
CRYO TANKS & FUEL TRN. SYS.			187
■ TOTAL HARDWARE	1727	523	228
GSE, SYSTEM TEST, SE&I INITIAL SPARES, PROJECT MANAGEMENT	1497	248	203
■ PROJECT COST	3224	771	431
NASA PROGRAM SUPPORT, CONTINGENCY	1990	401	282
■ TOTAL PROGRAM COST	5214 +	1172 +	713

*INCLUDES COMMON NON-RECURRING COSTS FOR ALL PRESSURIZED SHELLS.

Table 3-2. GROUND SUPPORT OPERATIONS - SPACE STATION SYSTEMS ($M, 1984)

FACILITY ITEM	INVESTMENT COST	ANNUAL OPERATIONS COST
SPACE STATION CONTROL CONSOLES (SSCC)	$ 74.6	25.9
PLATFORM CONTROL CONSOLE (SPCC) #1 (90^{o})	24.9	8.6
SPCC #2 (28.5^{o})	12.4	8.6
SPCC #3 (57^{o})	12.4	8.6
DATA HANDLING FACILITY (DHF)	54.4	13.4
NON-SEPARABLE	8.4	23.5
	$187.2M	$88.6M/YR

INVESTMENT COST: DEVELOPMENT AND PRODUCTION OF HARDWARE AND SOFTWARE.

OPERATIONS COST: HARDWARE AND SOFTWARE MAINTENANCE, FACILITY STAFFING, TRAINING AND MANAGEMENT.

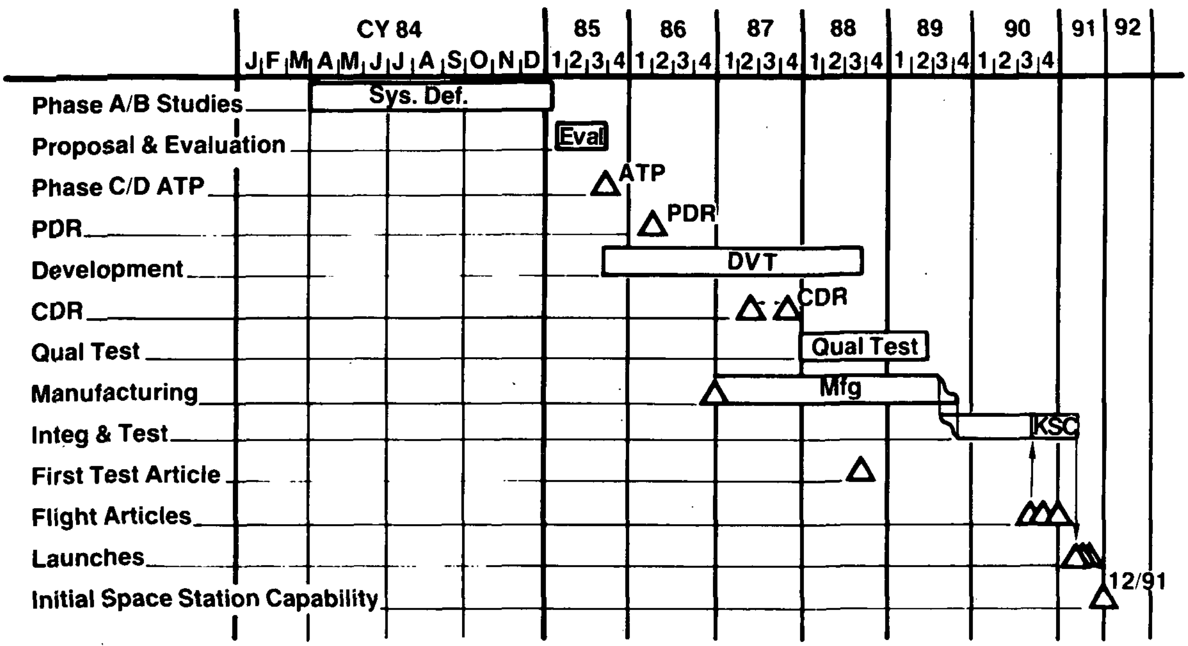
Investment Cost corresponds to the Ground Support Equipment item shown in Figure 3-4. The source of these data was the Space Platform Study (June 1982). Costs were escalated at 9 percent per annum and tripled (as appropriate) to reflect the increased complexity of the Space Station.

A program schedule, showing major program milestones is shown in Figure 3-6. The Phase C/D ATP and initial station IOC correspond to the funding profile shown in Figure 3-4.

FIGURE 3-6

VGC228

SPACE STATION PROGRAM SCHEDULE



Section 4

USER CHARGE MODEL

A NASA objective is to ultimately commercialize the Space Station. One important aspect of this process would be to establish a user charge model. This section presents examples of how this might be done and representative rates.

4.1 COST ELEMENTS

User charges should reflect all station costs, whether they are direct or indirect (see Figure 4-1). Direct costs are those directly relating to user

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FIGURE 4-1
USER CHARGE MODEL COST ELEMENTS

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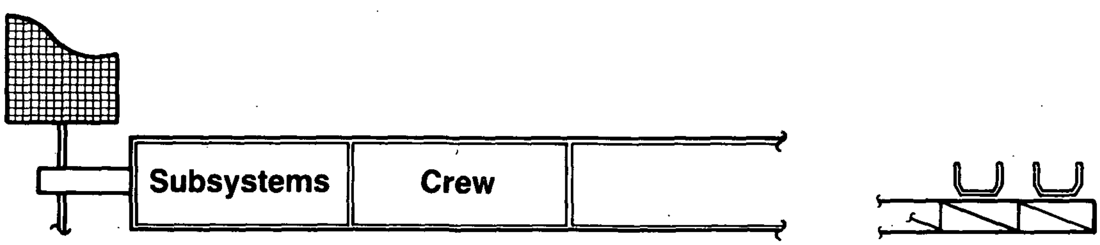

HOUSEKEEPING UTILITIES	HABITATION	MISSION SERVICES
• Power • ACS • Thermal	• Quarters • Resupply • EC&LS	• Power* • Data/Comm* • Labor* • Equipment Accommodation* (Internal, External) • Lab Facilities • Resupply • Ground Support • Training

*Direct Charges;
All Other Costs Allocated

services, such as electrical power, data handling, crew labor, and mission equipment accommodation (internal pressurized volume or external mounts). Indirect costs are all other costs necessary for the operation of the station.

4.2 ALLOCATION OF FACILITY COSTS

In establishing user charges, it is necessary to first assign or allocate costs against the services to be sold. An example of how this might be done is shown in Figure 4-2.

Figure 4-3 shows the accumulation of all costs which are prorated across user services. The station is assumed to be written off over a 10-year program. Development costs are included in this illustration. The figures designated Available Resource represent a quantification of the service that

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FIGURE 4-2

VGB820

ALLOCATION OF STATION FACILITY COSTS
(PERCENT)

Allocated Element	Mission Service				
	Power	Data Mgt/ Comm	Labor	Internal Volume	External Mount
Crew Shell, Accom	—	—	100	—	—
Mission Module	—	—	—	100	—
Utilities Framework	60	14	18	4	4
Logistics Module	10	—	80	5	5
Array/Elec Control	50	13	14	12	11
Thermal Control	13	6	14	67	—
ECLS	—	—	80	20	—
ACS/Propulsion	16	17	17	25	25
Comm/Data Mgt	33	17	33	9	8
Software	33	17	33	9	8
Unpress Ports	—	—	—	—	100

FIGURE 4-3

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PRORATING OF STATION COSTS

VGB821

10-YEAR MISSION
ALL-UP PROGRAM COSTS

Cost Element ($ Millions/Year)	Total	Power	Data/ Comm	Labor	Internal Volume	External Mount
Space Facility	508††	111	48	223	94	32
Resupply*	220	48	21	96	41	14
Ground Support**	100	22	9	44	19	6
Training, Duplicate Crews			(Assumed Small)			
Total Cost Base	828	181	78	363	154	52
Available Resource Units (Annual)	—	201K · KWh	2.5^9 Mb	8,800 Hr	$12kft^3$	20† Ports
Annual Rate ($/Units)						
Gross	—	900	0.031	41K	12.8K	2.6M
(Load Factor)	—	(50%)	(20%)	(80%)	(80%)	(80%)
Net	—	1800	0.156	52K	16K	3.25M

*Includes STS and Cost of Spares (Excludes Payload Spares)
**Excludes Payload Support (i.e., Only Space Facility Support Included)
†External Ports
††Based on a $5.08B Station (Early Iteration Concept) With 3-Man Crew, 35 kW Power.

is assumed available for sale. In the case of labor, it was assumed that 2.4 persons of a 3-person crew were available 10 hours a day, 365 days a year. Load factors are applied on the assumption that 100 percent utilization of services could not be achieved.

4.3 USER CHARGES

User charges are summarized in Figure 4-4, showing the relative apportionment of costs to the various services. The impact of only amortizing production costs is shown in Figure 4-5. The potential reimbursement for these two scenarios, based on the commercial mission demand for services, is shown in Figure 4-6.

FIGURE 4-4

SPACE STATION USER CHARGE MODEL

ALL-UP PROGRAM COSTS

3 Men, 35 kW

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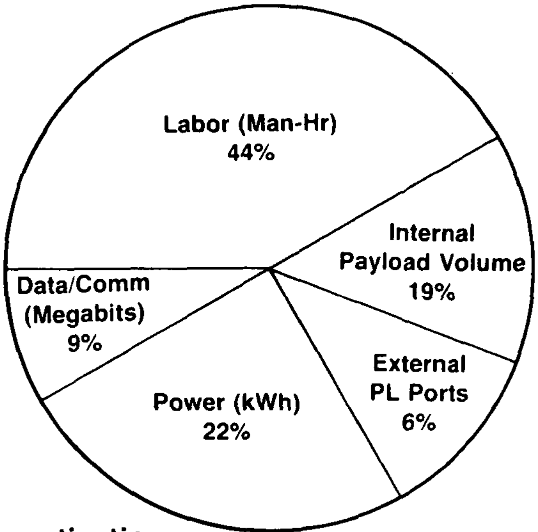


Amortization of Costs

USER CHARGES

- Labor $52,000/Man-Hr
- Data/Comm $0.156/Megabit
- Power $1800/kWh
- Payload
  - Internal Volume $16,000/ft^3/yr
  - External Mount $3.3 Million/Port/yr

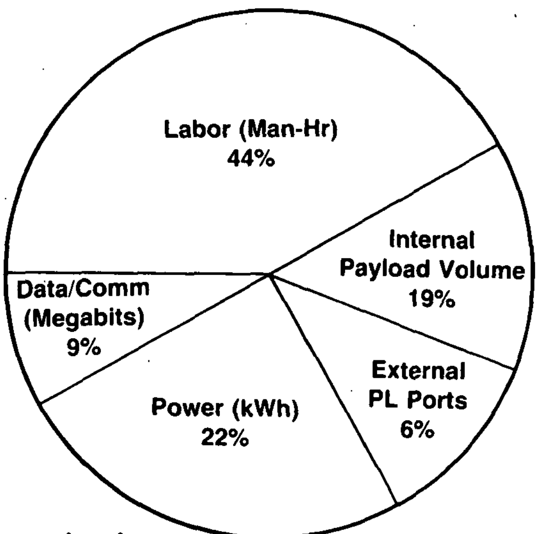
FIGURE 4-5

SPACE STATION USER CHARGE MODEL

PRODUCTION COSTS ONLY

3 Men, 35 kW

VGB819-1



Amortization of Costs

USER CHARGES

- Labor $26,000/Man-Hr
- Data/Comm $0.08/Megabit
- Power $965/kWh
- Payload
  - Internal Volume $8,200/ft^3/yr
  - External Mount $1.8 Million/Port/yr

FIGURE 4-6

REIMBURSIBLE FRACTION OF SPACE STATION RESOURCES

VGC236

COMMERCIAL MISSIONS

Resource	Reimbursible Fraction (%)	Average (10 Year) Annual Reimbursement ($M/Yr)	
		All-Up(1)	Production(2)
Power	53	96	51
Data	5	4(3)	2(3)
Labor	37	134	68
Interal Volume	62	95	49
External Mounts	14	7	4
Total	—	$336M̄/Yr	$174M̄/Yr

Notes:
(1) All Costs, Including Development, Prorated Over 10 Years
(2) All Costs, Excluding Development, Prorated Over 10 Years
(3) Excludes TDRSS Lease Charges
Excludes STS Charges
Space Station Cost Assumed $5.2 Billion

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