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MCDONNELL DOUGLAS

CONTRACT NAS8-15140
MSFC-DPD-235/DR NO. MA-06

MODULAR SPACE STATION PROGRAM OPTION SUMMARY REPORT

JANUARY 1972

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PREFACE

The work described in this document was performed under the Space Station Phase B Extension Period Study (Contract NAS8-25140). The purpose of the extension period has been to develop the Phase B definition of the Modular Space Station. The modular approach selected during the option period (characterized by low initial cost and incremental manning) was evaluated, requirements were defined, and program definition and design were accomplished to the depth necessary for departure from Phase B.

The initial 2-1/2-month effort of the extension period was used for analyses of the requirements associated with Modular Space Station Program options. During this time, a baseline, incrementally manned program and attendant experiment program options were derived. In addition, the features of the program that significantly affect initial development and early operating costs were identified, and their impacts on the program were assessed. This assessment, together with a recommended program, was submitted for NASA review and approval on 15 April 1971.

The second phase of the study (15 April to 3 December 1971) consists of the program definition and preliminary design of the approved Modular Space Station configuration.

A subject reference matrix is included on page v to indicate the relationship of the study tasks to the documentation.

This report is submitted as Data Requirement MA-06.

DATA REQUIREMENTS (DR's)
MSFC-DPD-235/DR NOs.
(contract NAS8-25140)

Category	Designation	DR Number	Title
Configuration Management	CM	CM-01	Space Station Program (Modular) Specification
		CM-02	Space Station Project (Modular) Specification
		CM-03	Modular Space Station Project Part 1 CEI Specification
		CM-04	Interface and Support Requirements Document
Program Management	MA	MA-01	Space Stations Phase B Extension Study Plan
		MA-02	Performance Review Documentation
		MA-03	Letter Progress and Status Report
		MA-04	Executive Summary Report
		MA-05	Phase C/D Program Development Plan
		MA-06	Program Option Summary Report
Manning and Financial	MF	MF-01	Space Station Program (modular) Cost Estimates Document
		MF-02	Financial Management Report
Mission Operations	MP	MP-01	Space Station Program (Modular) Mission Analysis Document
		MP-02	Space Station Program (Modular) Crew Operations Document
		MP-03	Integrated Mission Management Operations Document
System Engineering and Technical Description	SE	SE-01	Modular Space Station Concept
		SE-02	Information Management System Study Results Documentation
		SE-03	Technical Summary
		SE-04	Modular Space Station Detailed Preliminary Design
		SE-06	Crew/Cargo Module Definition Document
		SE-07	Modular Space Station Mass Properties Document
		SE-08	User's Handbook
		SE-10	Supporting Research and Technology Document
		SE-11	Alternate Bay Sizes

FOLDOUT FRAME 1

FOLDOUT FRAME 2

SUBJECT REFERENCE MATRIX

LEGEND:

- CM Configuration Management
- MA Program Management
- MF Manning and Financial
- MP Mission Operations
- SE System Engineering and Technical Description

	CM				MA		MF	MP			SE								
	CM-01 Space Station Program (Modular) Specification	CM-02 Space Station Project (Modular) Specification	CM-03 Modular Space Station Project Part I CEI Spec	CM-04 Interface and Support Requirement Document	MA-05 Phase C/D Program Development Plan	MA-06 Program Option Summary Report	MF-01 Space Station Program (Modular) Cost Estimates Document	MP-01 Space Station Program (Modular) Mission Analysis Document	MP-02 Space Station Program (Modular) Crew Operations Document	MP-03 Integrated Mission Management Operations Document	SE-01 Modular Space Station Concept	SE-02 Information Management System Study Results	SE-03 Technical Summary	SE-04 Modular SS Detailed Preliminary Design	SE-06 Crew/Cargo Module Definition Document	SE-07 Modular Space Station Mass Properties Document	SE-08 User's Handbook	SE-10 Supporting Research and Technology	SE-11 Alternate Bay Sizes
2.0 Contractor Tasks																			
2.1 Develop Study Plan and Review Past Effort (MA-01)																			
2.2 Space Station Program (Modular) Mission Analysis								●											
2.3 Modular Space Station Configuration and Subsystems Definition														●					
2.4 Technical and Cost Tradeoff Studies							●												
2.4.4 Modular Space Station Option Summary											●								
2.5 Modular Space Station Detailed Preliminary Design														●					
Mass Properties																●			
2.6 Crew Operational Analysis									●										
2.7 Crew Cargo Module															●				
Mass Properties																●			
2.8 Integrated Mission Management Operations										●									
2.9 Hardware Commonality Assessment													●						
2.10 Program Support					●														
2.11 Requirements Definition																			
Space Station Program (Modular)	●																		
Space Station Project (Modular)		●																	
Modular Space Station Project–Part 1 CEI			●																
Interface and Support Requirements				●															
2.12 Plans					●														
2.13 Costs and Schedules							●												
2.14 Special Emphasis Task Information Management (IMS)												●							
Modular Space Station Mass Properties																●			
User's Handbook																	●		
Supporting Research and Technology																		●	
Technical Summary													●						
MOD 29																			●
MOD 40						●													

V. 1

V. 2

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FIGURES

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TABLES

Section 1
INTRODUCTION

1.1 BACKGROUND

With the advent of the Space Shuttle in the late 1970's, a long-term manned scientific laboratory in Earth orbit will become feasible. Using the Shuttle for orbital buildup, logistics delivery, and return of scientific data, this laboratory will provide many advantages to the scientific community and will make available to the United States a platform for application to the solution of national problems associated with ecology research, weather observation and prediction, and research in medicine and the life sciences. It will be ideally situated for Earth and space observation, and its location above the atmosphere will be of great benefit to the field of astronomy.

This orbiting laboratory can take many forms and can be configured to house a crew of up to 12 men. The initial study of the 33-foot-diameter Space Station, launched by the Saturn INT-21 and supporting a complement of 12, has been completed to the Phase B level and documented in the DRL-160 series. Recently completed studies are centered around a Space Station comprised of smaller, shuttle-launched modules. These modules could ultimately be configured to provide for a crew of the same size as that of the 33-foot-diameter Space Station, but buildup would be gradual, beginning with a small initial crew and progressing toward greater capability by adding modules and crewmen on a flexible schedule.

The Modular Space Station Phase A-level study results are documented in the DRL-231 series. Recent Modular Space Station Phase B study results are documented in the DPD-235 series, of which this is a volume.

The Space Station will provide laboratory areas which, like similar facilities on Earth, will be designed for flexible, efficient changeover as research and experimental programs proceed. Provisions will be included for such functions as data processing and evaluation, astronomy support, and test and calibration of optics. Zero gravity, which is desirable for the conduct of experiments, will be the normal mode of operation. In addition to experiments carried out within the station, the laboratories will support operation of experiments in separate modules that are either docked to the Space Station or free-flying.

Following launch and activation, Space Station operations will be largely autonomous, and an extensive ground support complex will be unnecessary. Ground activities will ordinarily be limited to long-range planning, control of logistics, and support of the experiment program.

The Initial Space Station (ISS) will be delivered to orbit by three Space Shuttle launches and will be assembled in space. A crew in the Shuttle orbiter will accompany the modules to assemble them and check interfacing functions.

ISS resupply and crew rotation will be carried out via round-trip Shuttle flights using Logistics Modules (LM's) for transport and on-orbit storage of cargo. Of the four modules required, one will remain on orbit at all times.

Experiment modules will be delivered to the Space Station by the Shuttle as required by the experiment program. On return flights, the Shuttle will transport data from the experiment program, returning crewmen, and wastes.

The ISS configuration is shown in the frontispiece. The Power/Subsystems Module will be launched first, followed at 30-day intervals by the Crew/Operations Module and the General Purpose Laboratory Module. This configuration will provide for a crew of six. Subsequently, two additional modules (duplicate Crew/Operations and Power/Subsystems Modules) will be mated to the ISS to form the Growth Space Station (GSS), also shown in the frontispiece, which will house a crew of 12 and provide a capability equivalent to that of the 33-foot INT-21-launched Space Station. GSS logistics support will use a Crew/Cargo Module capable of transporting a crew of six.

During ISS operations, five Research and Applications Modules will be assembled to the Space Station. Three of these will be returned to Earth prior to completion of the GSS. In the GSS configuration, 12 additional RAM's will augment the two remaining from the ISS phase. Three of the RAM's delivered to the GSS will be free-flying modules.

During the baseline 10-year program, the Space Station will be serviced by Shuttle-supported Logistics Module or Crew/Cargo Module flights.

1.2 SCOPE OF THIS VOLUME

A special task was introduced into the Space Station Study during the last quarter. The objective of this supplemental study was to determine whether a viable Space Station Experiment program of 5 to 10 years' duration could be defined that would reduce the total program cost significantly below the projected $6 billion cost of developing the Initial and Growth Space Stations. This task entailed the definition of four experiment program options, all of which were smaller in scope than the experiment program previously defined for the ISS/GSS. Each option was defined for a Space Station limited to a six-man capability. Two of the options were programs whose durations were limited to five years. The other two extended through 10 years of operation. Six hundred hours were authorized to:

A. Identify and provide technical descriptions for each of the experiment program options.
B. Define the design, development, and operational impacts on the Baseline Space Station (ISS/GSS) that would occur as a result of each option.
C. Define the total program, costs, and schedules for each option.

This document summarizes the results of this task, including the identification and description of the options, the impact assessment of these options on the Space Station design, and the costs and schedules for programs encompassing each option.

The option descriptions and their assessments are defined and presented in Sections 2 and 3 of this document. The ISS/GSS Baseline Experiment Program, which is summarized for comparison purposes in Section 1.4, was the source for the derivative programs that are described in Options 1 through 4.

1.3 OBJECTIVES AND GROUNDRULES

As a result of Preliminary Modular Space Station Program Data (experiment costs, and Space Station costs) presented in August 1971, NASA directed the examination of alternative programs that would permit substantial reductions in total program costs. These included evaluation of an ISS designed for a six-man 5-year operation to determine modifications that might be necessary to extend its life to 10 years.

The seven scientific and technical experiment disciplines were combined in different mixes for each of the four experiment program options. This was done in order to permit the evaluation of any effects that the different discipline combinations might have on the Space Station's design characteristics, and to determine whether any of these combinations would significantly affect either costs to achieve initial operating capability (IOC) or total program costs.

In accomplishing the definition of the four program options, five major groundrules were established:

A. Assure that overall development costs for the initial experiments (to IOC) were limited to a value no greater than the baseline program (about $475 million).

B. Assure that the total experiment program cost would be significantly lower than the $3 billion cost of the baseline program.

C. Exclude free-flying modules and their associated experiments because of the high costs associated with; the experiment equipment (astronomy instruments); and development of the relatively sophisticated free-flying modules in which they are flown. Parenthetically, though not specifically requested by NASA, MDAC defined a program option which included two free-flying Functional Program Elements (FPE's) in order to assess program and design impacts of this type of experiment program. This option (2A) is described in Section 2.2.

D. Assure that the composition and size of the six-man ISS crew complement would be effectively utilized for any of the program options.

E. Evaluate the modular Space Station six-man configuration and its associated system and subsystem design concepts to establish potential changes that might be required to accommodate any of the program options.

Utilizing these groundrules, MDAC defined and scheduled the experiment programs comprising each of the four options. These schedules were then applied to the ISS concept to derive the Space Station resource requirements (power, crew time, logistics support, etc.) for each option within the groundrules noted above. These resource requirements were then applied to each system and subsystem design to determine the degree to which that design met the requirements. In the event the Space Station design required modification, the modification was to be identified and the cost defined.

1.4 BASELINE PROGRAM SUMMARY

Figure 1-1 identifies the seven experiment disciplines and corresponding experiments that constitute the Baseline Experiment Program for the ISS/GSS. Each of these experiment areas (i.e., Communication Navigation—Initial) consists of an FPE or subgroups of experiment equipment from that FPE. These subgroups have been designated as partial FPE's. The NASA Experiment Blue Book issued in January 1971 provided the FPE definitions and descriptions. Detail descriptions of the partial FPE's and their experiment hardware are contained in DPD-235, MP-01, Volume I, Section 2.

The 10-year operating schedule illustrated is the period of on-orbit operation defined for the ISS/GSS program. The first five years of operations are conducted by a six-man Space Station crew. In the second half of the decade, operations are conducted by a 12-man crew. The schedule bars associated with each experiment area define its period of on-orbit operation, and its mode of accommodation, e.g., integral to the station's General Purpose Laboratory (GPL) Module or in Research and Applications Modules (RAM's) that are attached (A) to the station or operate as free flyers (FF).

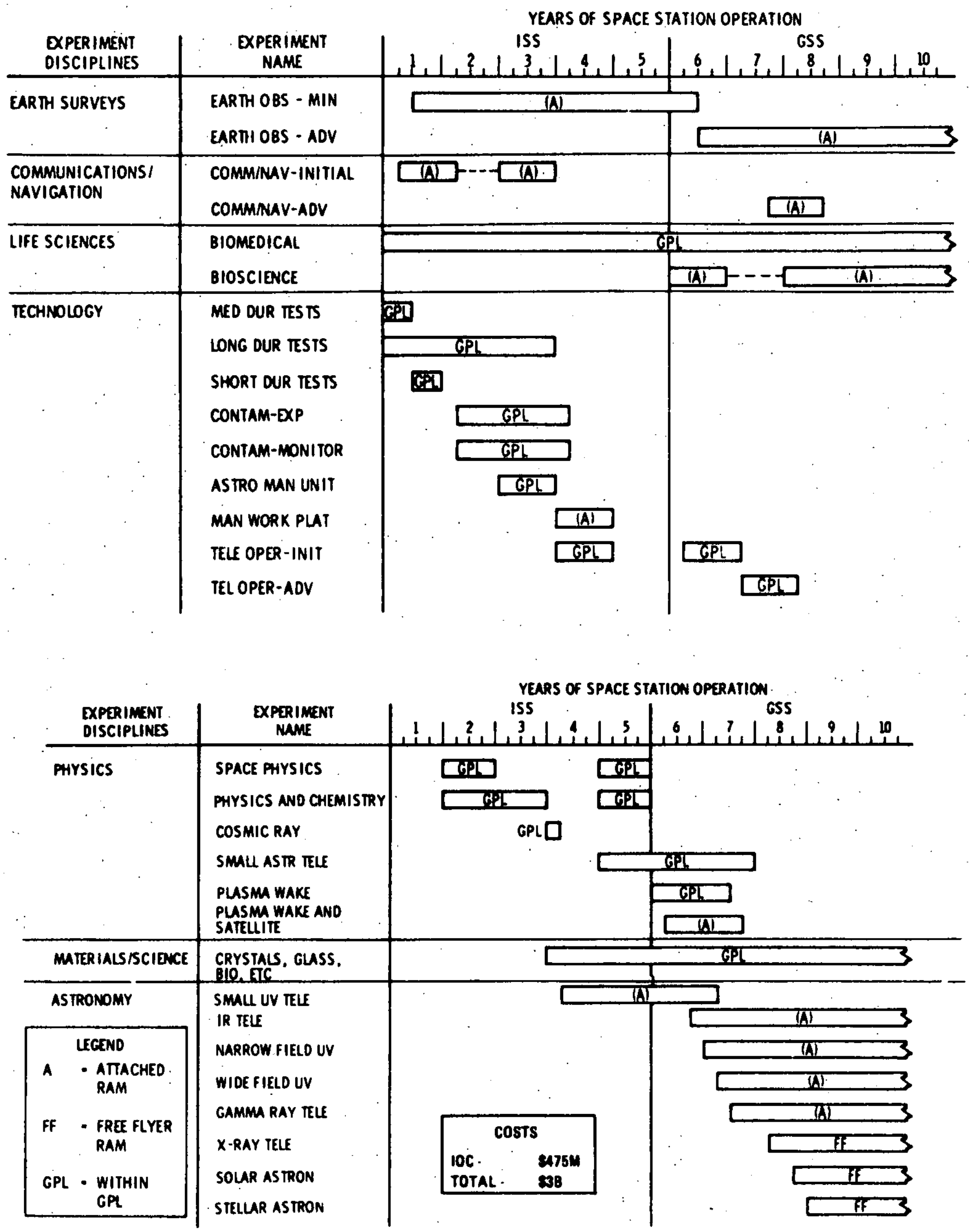

Figure 1-1. Baseline Research and Applications Program

The modes of accommodation, the sequence of experiments, and the duration of their operations were the products of a series of analyses in which low initial costs (for total program to IOC) and low total program costs served as guidelines in the experiment program definition. These guidelines were then factored into a worth analysis which quantified the potential benefits derivable from each experiment area. This analysis assisted in defining which experiments should be flown early. Where precursor experiments were required, the schedule was modified to permit the necessary sequencing.

Figure 1-1 also identifies the experiment development costs required by this program to attain an IOC ($475 million) and the total experiment program costs including the costs for experiment operations ($3 billion). Cost and funding data were furnished by NASA for each FPE defined in the Blue Book. These data were augmented with cost and schedule data for the development and fabrication of the RAM's that would house those FPE's flown either as attached or free flyers.

It will be noted that the majority of the astronomy experiments are flown in the last five years, and that all are flown in either attached or free-flying modules. The principal reason for deferring their activation is the cost associated with the development of each astronomy FPE, and the attendant costs for free-flying modules.

Section 2

OPTION DESCRIPTIONS

The options that have been examined in order to establish the costs of various six-man, 5- and 10-year Space Station programs are summarized in Figure 2-1.

Options 1 and 4 were programs envisioned to be complete at the end of five years of operation. Option 1 contains the same experiments identified in the baseline program for the first five years of operation. Option 4 had a limitation of $100 million per year for experiment funding.

Options 2 and 3 are 10-year programs. The former consists of experiments representing the seven major disciplines and, as such, provides balanced support for all of the scientific disciplines. The latter emphasizes the

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OPTION	5 YEAR ISS	10 YEAR ISS	BALANCED PROGRAM	APPLICATION PROGRAM	REMARKS
1	X		X		1ST 5 YRS OF BASELINE
2		X	X		NO FREE FLYERS
2A		X	X		WITH FREE FLYERS
3		X		X	APPLICATIONS FPE'S: EARTH SURVEYS, MATERIALS SCIENCE, TECHNOLOGY, COMM/NAVIGATION
4	X		X		COST CONSTRAINT OF $100 M/YR

Figure 2-1. Optional Experiment Programs Definition

applications areas (e.g., Earth surveys, material sciences, communications/ navigation, etc.) and thereby provides direct socio-economic benefits to man.

Option 2A was injected by MDAC in order to assess the cost and Space Station design impacts resulting from the addition of free flyers.

2.1 OPTION 1

Option 1 (a 5-year program of balanced disciplines with no free flyers) was extracted directly from the ISS/GSS Baseline Experiment Program. Figure 2-2 summarizes the experiment schedule and associated costs for this option. The integral experiments within this program are denoted by the (I) within the schedule block, and the costs for their development and operation are $455 million. The remaining experiments are housed in attached modules (A), and will require about $600 million for development and operation, thus bringing the total experiment costs for this option to about $1.1 billion. It will be noted that costs to IOC are less than $500 million.

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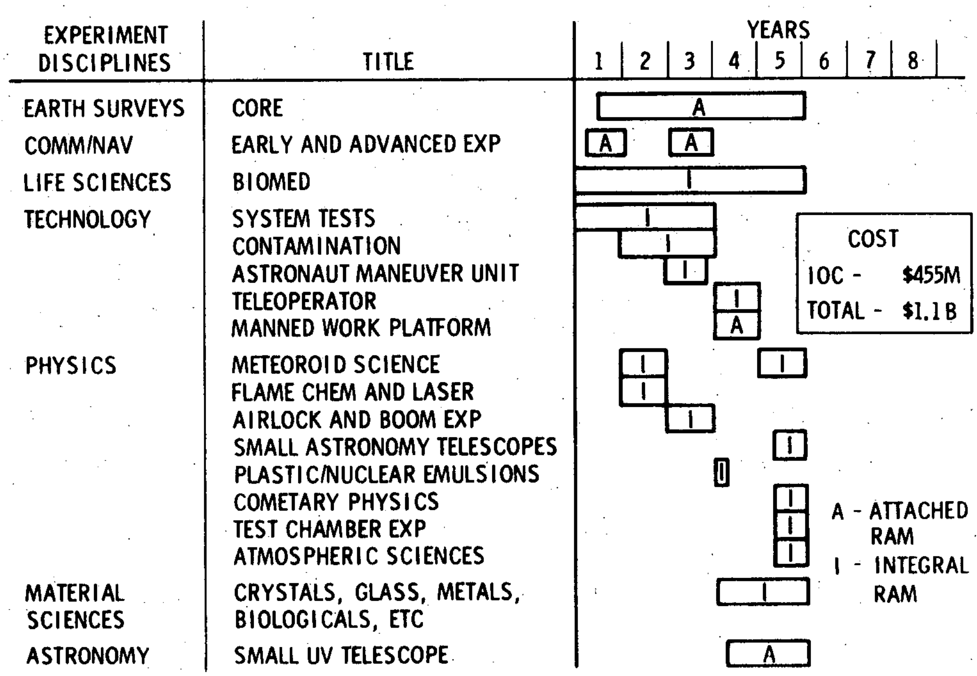


Figure 2-2. Experiment Schedule, Option 1

2.1.1 Experiment Program Description (Option 1)

As noted in Figure 2-2, experiments are flown in each of the seven scientific and technical disciplines. The program defined for this option is limited to five years' operation and as such contains none of the experiments that were originally scheduled for the second five years of the 10-year ISS/GSS program. Early experiments (first five years) were flown because they were either necessary precursor experiments or because their accomplishment would add significantly to man's technological understanding of space operations and the use of space to exploit the Earth's resources. Thus, the major emphasis in this program option is on Earth surveys, communications/navigation, and material sciences, with a lesser effort devoted to astronomy, technology, physics, and life sciences.

2.1.2 Option 1 Program Schedule

Option 1 is basically the ISS portion of the baseline Modular Space Station Program. The flight operations phase extends through December 1985 and includes a total of 65 launches; three Space Station Modules (SSM's), five attached Research Application Modules (RAM's), 33 Logistics Modules (LM's), and 24 Shuttle flights for crew rotation. Module manufacturing requirements remain the same for the ISS program; three SSM's, four RAM's and four LM's. Figure 2-3 illustrates this total program schedule.

2.1.3 Option 1 Costs and Funding

Space Station project costs and funding are identical with those developed for the Baseline Space Station—Initial Space Station only, as reported in the Costs and Schedules Document, MF-01. The Ground Rules, Assumptions and Rationale in MF-01 are assumed, where appropriate. Experiment costs and funding are those for the Initial Space Station. Major elements of hardware comprising the Space Station project include the following:

A. Power/Subsystems Module - one each
B. Crew/Operations Module - one each
C. General Purpose Laboratory Module - one each
D. Logistics Modules - four each
E. Test articles
F. Integral experiments
G. GSE

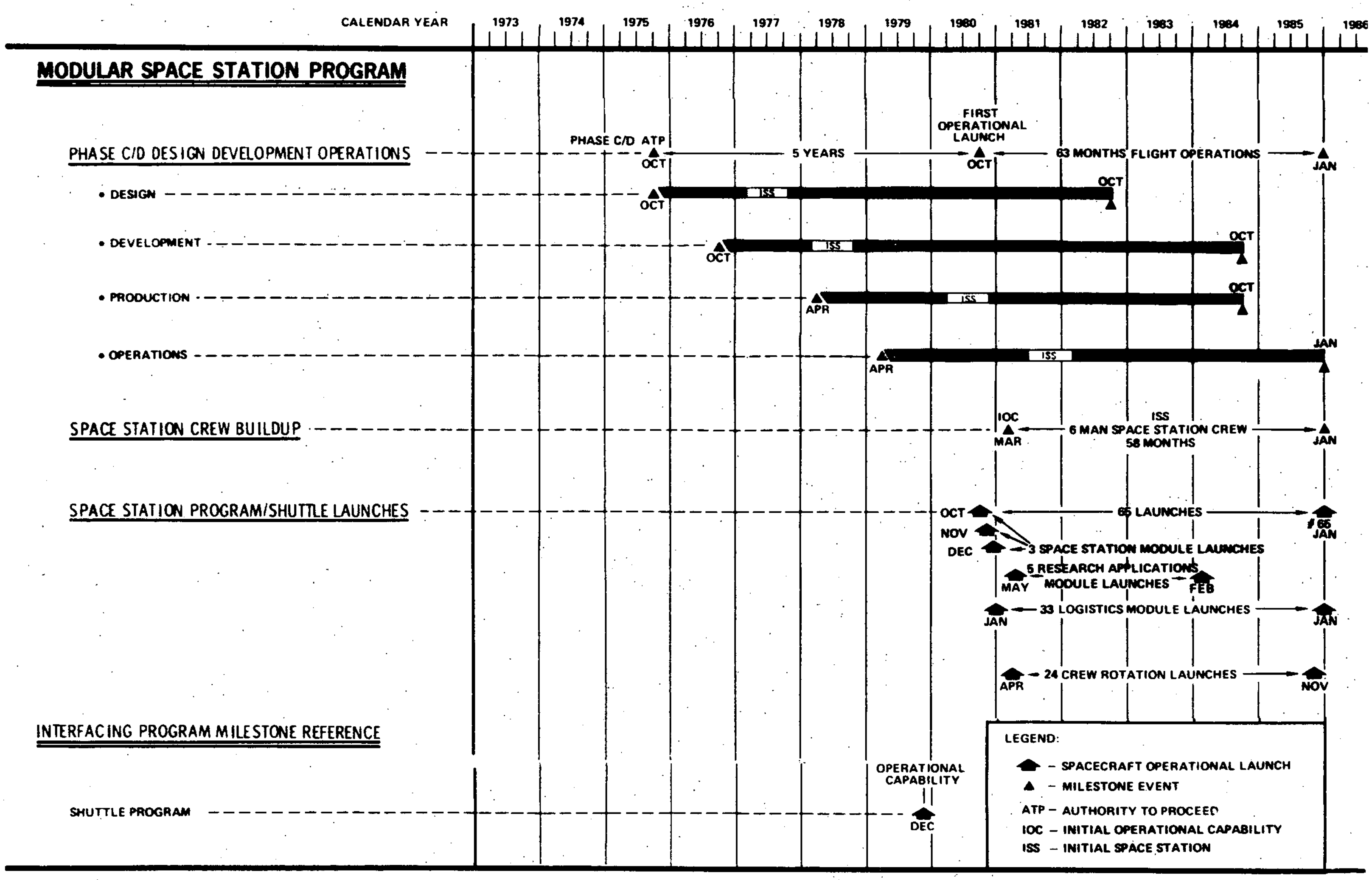
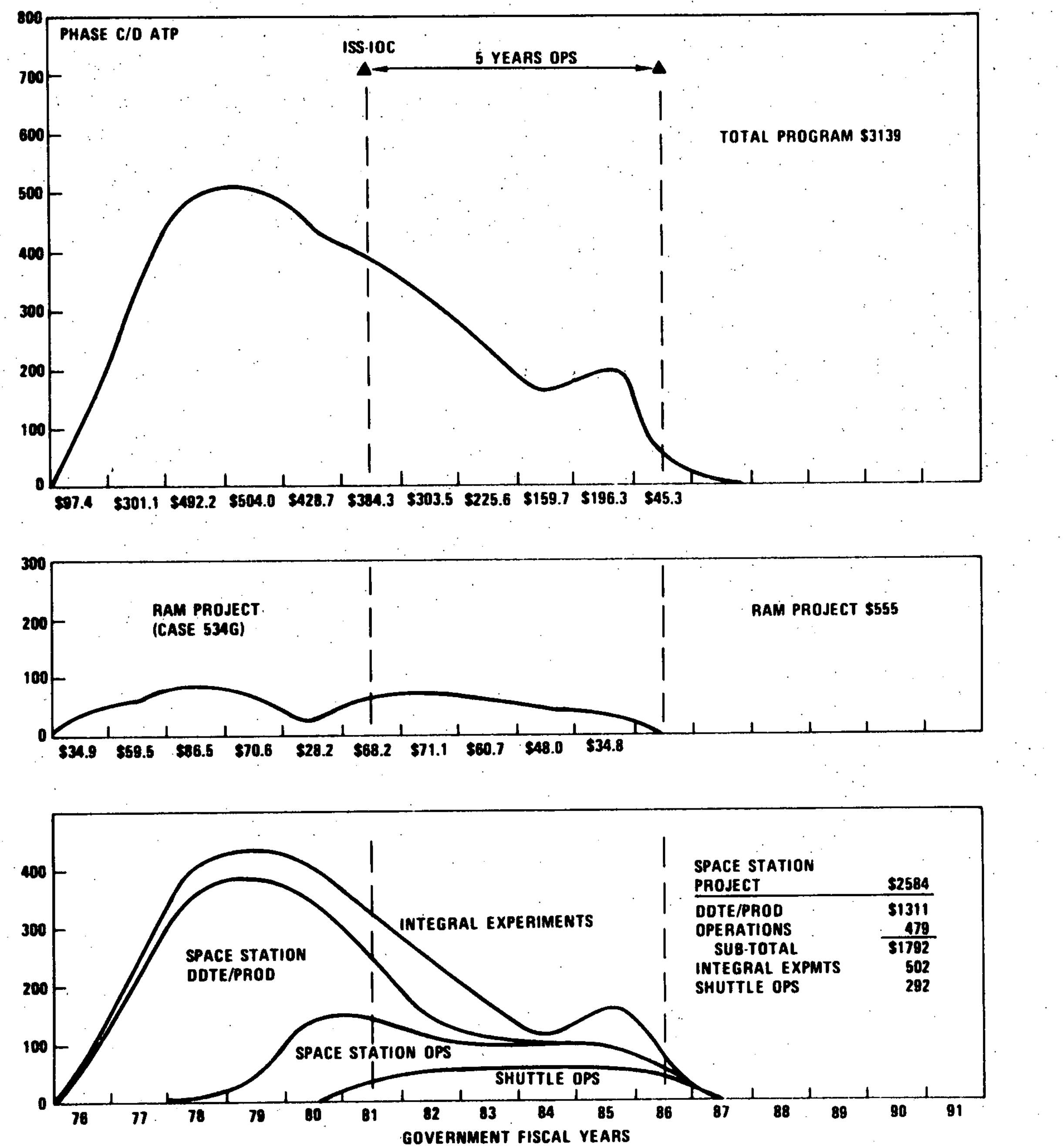


Figure 2-3. Modular Space Station Program Schedule, Option 1



																	PROJECT TOTAL
DDTE/PROD	$63.8	$222.8	$361.8	$347.0	$190.6	$ 92.9	$ 27.8	$ 7.5	$	$	$						$1311
OPS			4.2	33.2	148.1	101.6	58.9	42.4	42.4	38.7	9.3						479
SUB-TOTAL	53.8	222.8	366.1	382.2	338.7	194.5	86.7	49.9	42.4	38.7	9.3						1790
INTEGRAL EXPMTS	3.7	18.8	39.6	51.2	61.8	81.6	91.7	61.0	22.3	68.8							502
SHUTTLE OPS						40.0	54.0	54.0	54.0	54.0	36.0						292
TOTAL	62.5	241.6	405.7	433.4	400.5	316.1	232.4	164.9	119.7	161.5	45.3						2534

(MF-01 COSTS – SPACE STATION PROJECT)

Figure 2-4. Option 1 Funding Summary 1972 Dollars In Millions

The development schedule results in a peak funding of $504 million for the Space Station Program in GFY 1979. The major element of this peak is Space Station Project DDTE/Production, which must be accomplished in consonance with an initial launch in October 1980 (GFY 1981).

Costs and funding are summarized in Figure 2-4.

2.2 OPTIONS 2 AND 2A

Option 1 was envisioned for a six-man Space Station whose operational life would be limited to five years after IOC. Options 2 and 2A are defined for a six-man Space Station that would operate for 10 years.

Option 2, identified and scheduled in Figure 2-5, describes a program that has representative experiments from each of the seven experiment disciplines. In comparing this experiment program with the baseline program described in Section 1.4, it will be noted that several experiments have been eliminated from the astronomy category. One or two experiments have also been dropped in the areas of technology, physics, life sciences, and communications/navigation.

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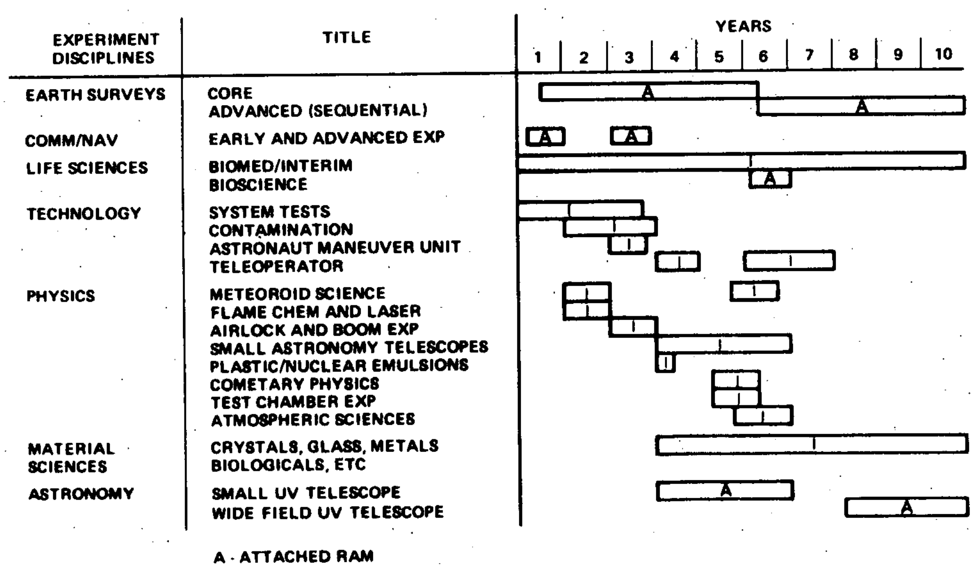

Figure 2-5. Experiment Schedule, Option 2

Results provided a substantial reduction in total experiment program costs ($1.6 billion vs $3 billion). However, the costs to IOC remained essentially the same.

An alternative to the balanced Option 2 was established to assess the impact on the program of free flyers. For this option, MDAC selected two of the free flyers that were to be flown as a part of the ISS/GSS baseline. These free flyers (an advanced ATM and an x-ray stellar telescope) were substituted for a life science experiment and the wide-field ultraviolet telescope. In other respects, this option is essentially identical to Option 2. The cost to IOC remains at about $450 million; however, even with the elimination of the two experiments, the addition of the two astronomy free flyers increases the total experiment costs (over Option 2) by about $500 million. Figure 2-6 illustrates this variation of Option 2.

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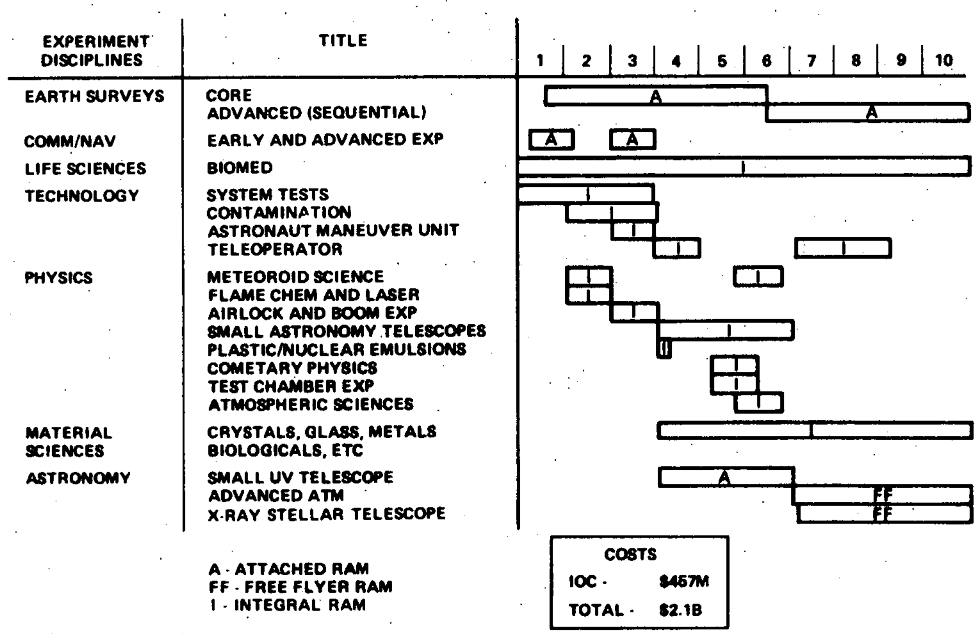

Figure 2-6. Experiment Schedule, Option 2A

2.2.1 Experiment Program Description (Option 2)

Option 2 was defined as a program in which a balanced effort would be expended in all of the seven disciplines. The 10-year duration permits significant additional experimentation in each discipline area. For example, the Earth surveys discipline has been expanded to include advanced experiments. Additionally, this option augments the astronomy discipline by adding a wide-field ultraviolet telescope, and supplements the life sciences area with experiments in the bioscience field.

Comparison of this experiment program option with the ISS/GSS Baseline Experiments program shows that, with the exception of several free-flying astronomy experiments (whose costs are significant), this option achieves virtually the same results as the baseline.

2.2.2 Option 2 Program Schedule

The Option 2 schedule represents an ISS program with a six-man crew capability extended through December 1990. Flight operations include a total of 126 Shuttle launches.

Option 2 requires one additional Space Station Module to augment the three modules deployed during initial IOC buildup. A second Power/Subsystems Module is planned for launch in August 1985. The rationale supporting the addition of this module is presented in detail in Section 3.2. RAM modules to be flown attached to the Space Station are scheduled for launch commencing in May 1981 with the last launch in January 1988. The experiment program requires no free-flying RAM's. Four Logistics Modules are required, as in the baseline program, and a total of 47 LM launches are planned. Option 2 requires 68 Shuttle launches for crew rotation. Figure 2-7 illustrates the program schedule for Option 2.

2.2.3 Experiment/Space Station Costs and Funding (Option 2)

Space Station project costs and funding for the initial Space Station portion—GFY 1976 through GFY 1980—are identical with those of the baseline. Additional hardware is required in order to continue Space Station operations for another five years. The cost of this additional hardware and the five additional years of operation combine to increase Space Station project costs.

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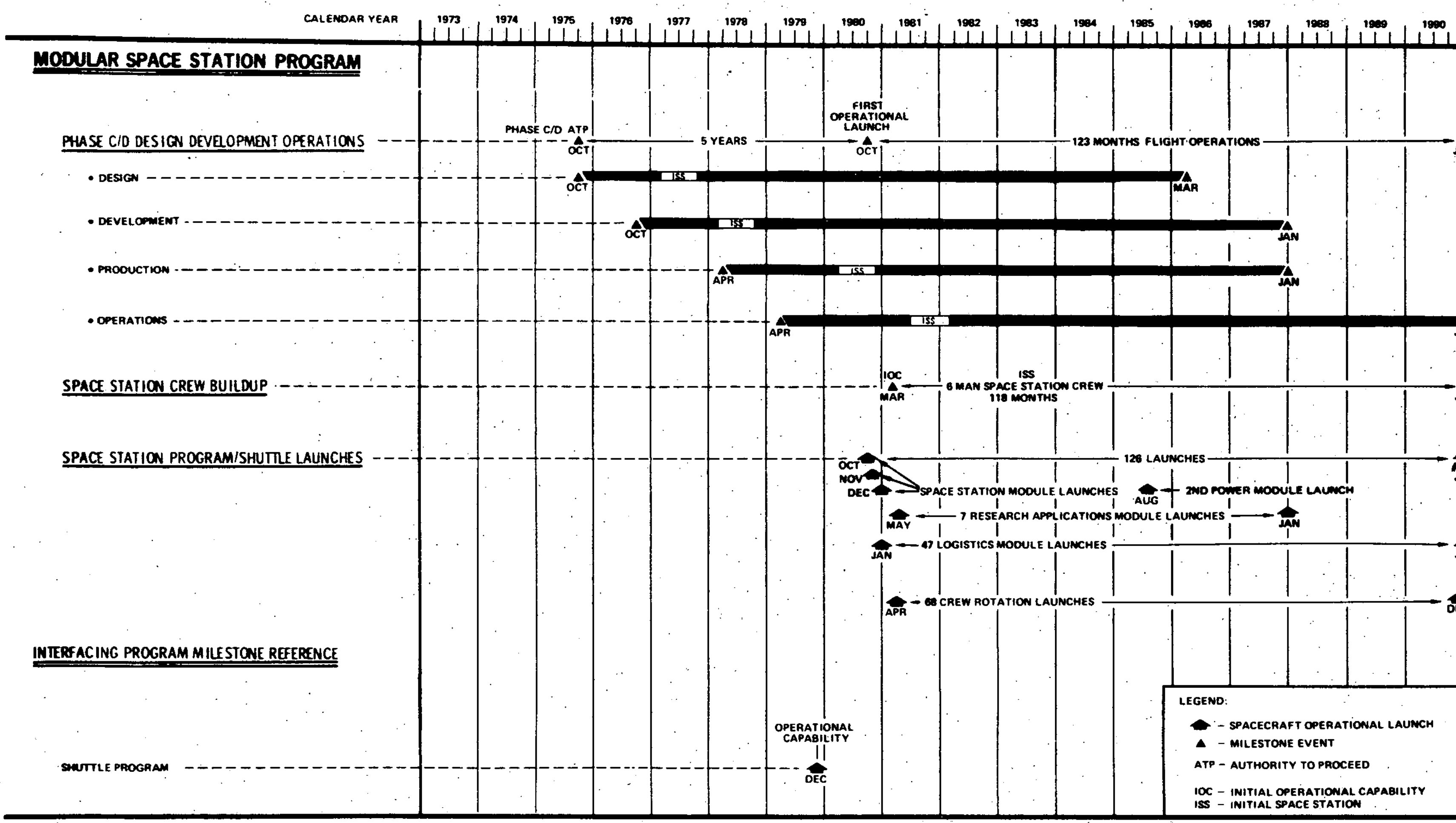


Figure 2-7. Modular Space Station Program Schedule, Option 2

The additional hardware includes one Power/Subsystems Module and the additional replenishment spares for the second five years of operations. The costs include the assumption that replenishment spares requirements can be reduced, because of the availability of a portion of the spares from the initial Power/Subsystems Module remaining in orbit.

Experiment costs for both Integral and RAM's are identical to those of the baseline program, but do not include any free-flying modules.

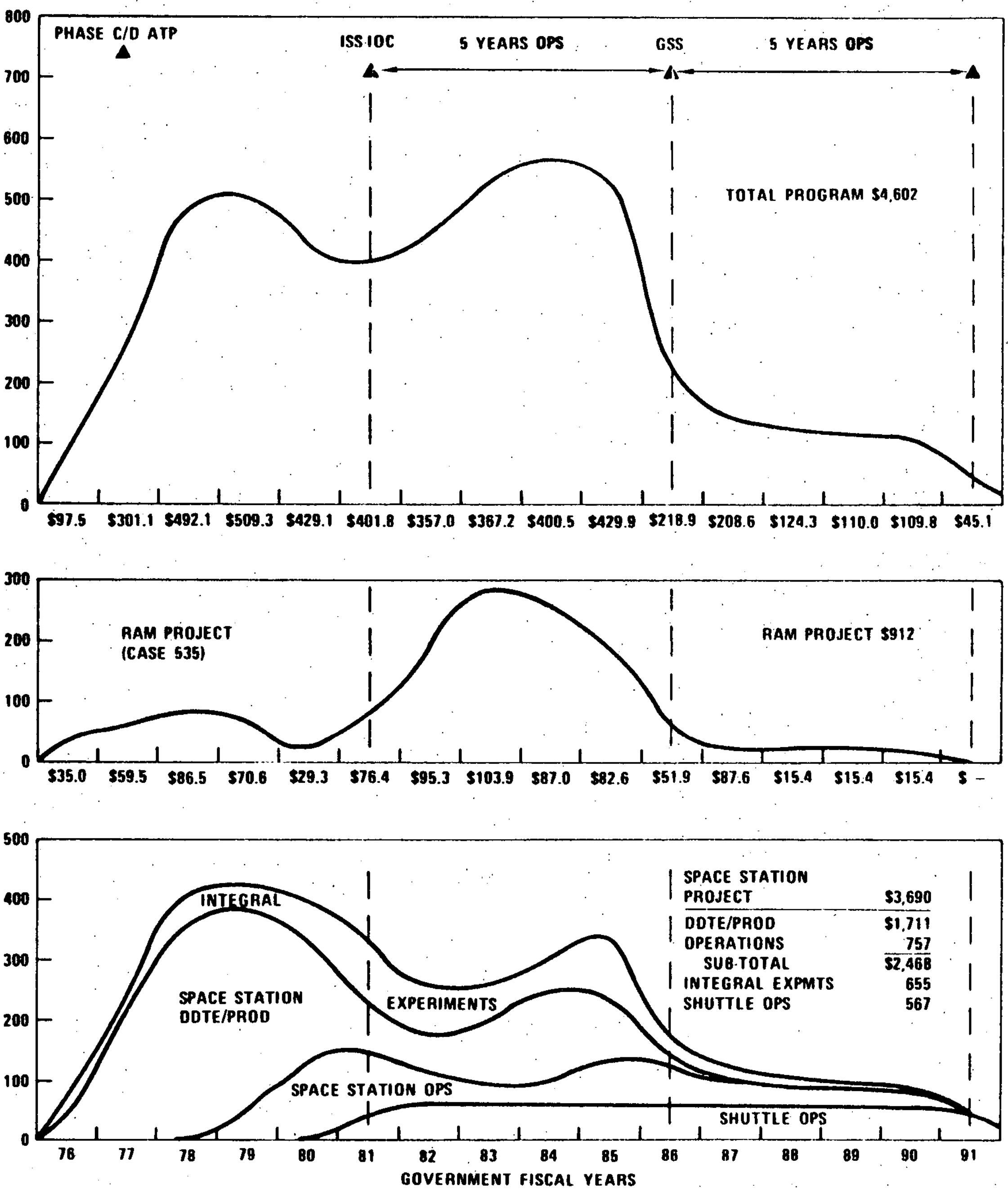
Costs and funding are summarized in Figure 2-8. Peak funding of the Space Station Program occurs in GFY 1979 at $509 million, most of which is for Space Station Project DDTE/Production. The additional hardware required for the second five years of operations contributes to the secondary peak of $430 million in GFY 1985. RAM funding is held to a relatively even level throughout most of the program.

2.2.4 Experiment Program Description (Option 2A)

As noted earlier, this variation to Option 2 was examined in order to determine the impact on program/system costs and design of including free-flying RAM's in a low-cost total program. To accommodate the addition of free flyers without materially augmenting the costs of Option 2, the Bioscience Module and experiments were deleted in the life sciences area, and the wide-field ultraviolet telescope was eliminated from the astronomy area. In their place, MDAC substituted free-flying modules for advanced and x-ray stellar astronomy. The remaining scientific and technical disciplines are identical to those of Option 2.

2.2.5 Program Schedules (Option 2A)

Option 2A differs from Option 2 in the RAM experiment program area. The last two Space Station-attached RAM's in Option 2 are replaced in Option 2A with free-flying experiments. The attached module requirement to support the experiment program is reduced to four modules, with one scheduled to be reconfigured and reused. The total number of program Shuttle launches remains the same as in Option 2—4 SSM's, 7 RAM/s, 46 LM's and 69 crew-rotation launches. Flight operations include a total of 126 flights. Figure 2-9 is the program schedule for Option 2A.



																	PROJECT TOTAL
DDTE/PROD	$58.8	$222.8	$361.8	$349.0	$190.6	$101.7	$58.7	$103.3	$154.4	$100.8	$6.7	$3.0	$ –	$ –	$ –	$ –	$1,711
OPS		–	4.2	33.2	148.1	101.6	58.9	42.4	49.9	87.0	66.1	47.8	43.7	34.6	34.4	5.1	757
SUB-TOTAL	58.8	222.8	366.0	382.2	338.7	203.3	117.6	145.7	204.3	187.8	72.8	50.8	43.7	34.6	34.4	5.1	2,468
INTEGRAL EXPMTS	3.7	18.8	39.6	56.5	61.1	81.1	90.1	63.6	55.2	105.5	40.2	16.2	11.2	6.0	6.0		655
SHUTTLE OPS	–	–	–	–	–	41	54	54	54	54	54	54	54	54	54	40	567
TOTAL	62.5	241.6	405.6	438.7	399.8	325.4	261.7	263.3	313.5	347.3	167.1	121.0	108.9	94.6	94.4	45.1	3,690

(MF-01 COSTS – SPACE STATION PROJECT)

Figure 2-8. Option 2 Funding Summary 1972 Dollars in Millions

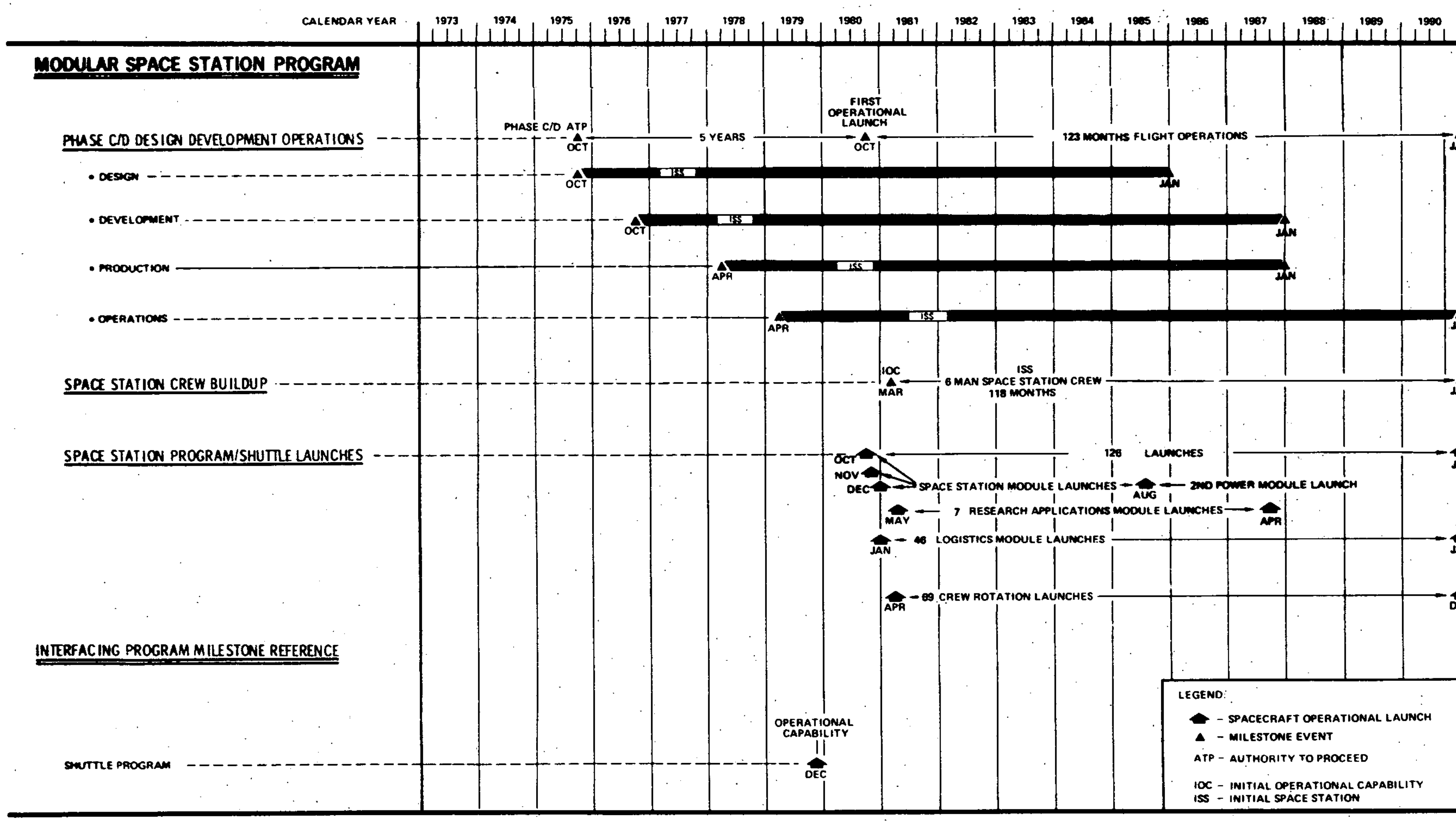


Figure 2-9. Modular Space Station Program Schedule, Option 2A

2.2.6 Program Costs and Funding (Option 2A)

Space Station project costs are the same as those for Option 2. Experiment costs are those resulting from the Case 537 definition, which includes two free-flying RAM's. Experiment costs, therefore, are $525 million, or 33 percent greater than those for Option 2.

Figure 2-10 summarizes the costs and funding for Option 2A. An initial peak funding at the program level takes place in GFY 1979 at $509 million, the major portion of which is the cost of Space Station Project DDTE/ Production. A second funding peak occurs in GFY 1984 and amounts to $578 million. The Space Station project accounts for $313 million of this peak, and the remaining $265 million is RAM project cost. RAM project peak funding occurs a year earlier in GFY 1983 and amounts to $283 million. Space Station project integral experiments funding peaks in GFY 1985 at $105 million.

2.3 OPTION 3

Option 3 (see Figure 2-11) is an experiment program designed to emphasize the applications area, i.e., those disciplines that have measurable socio-

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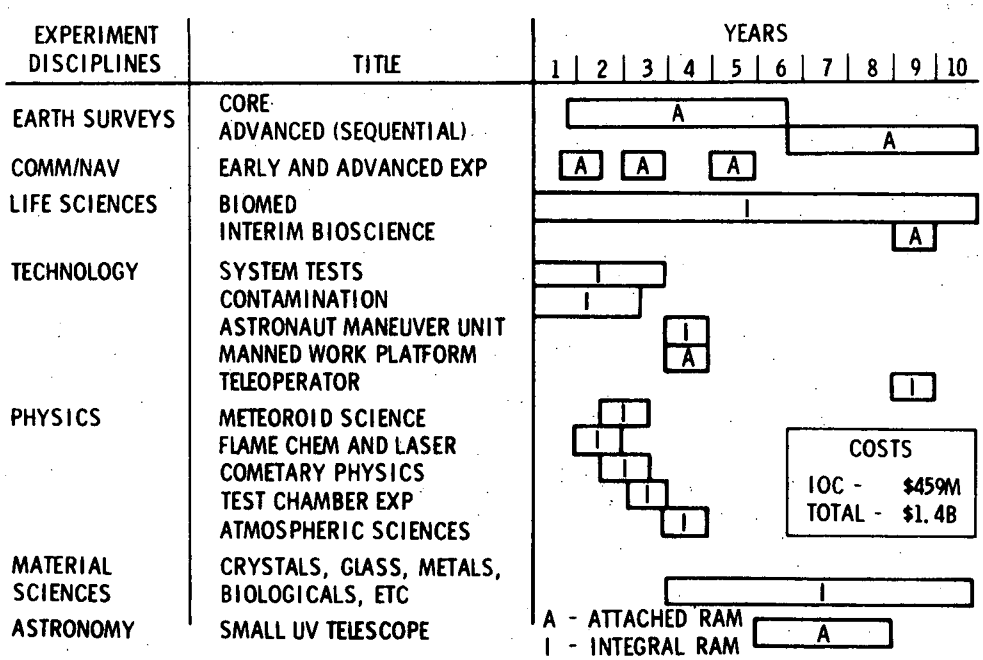
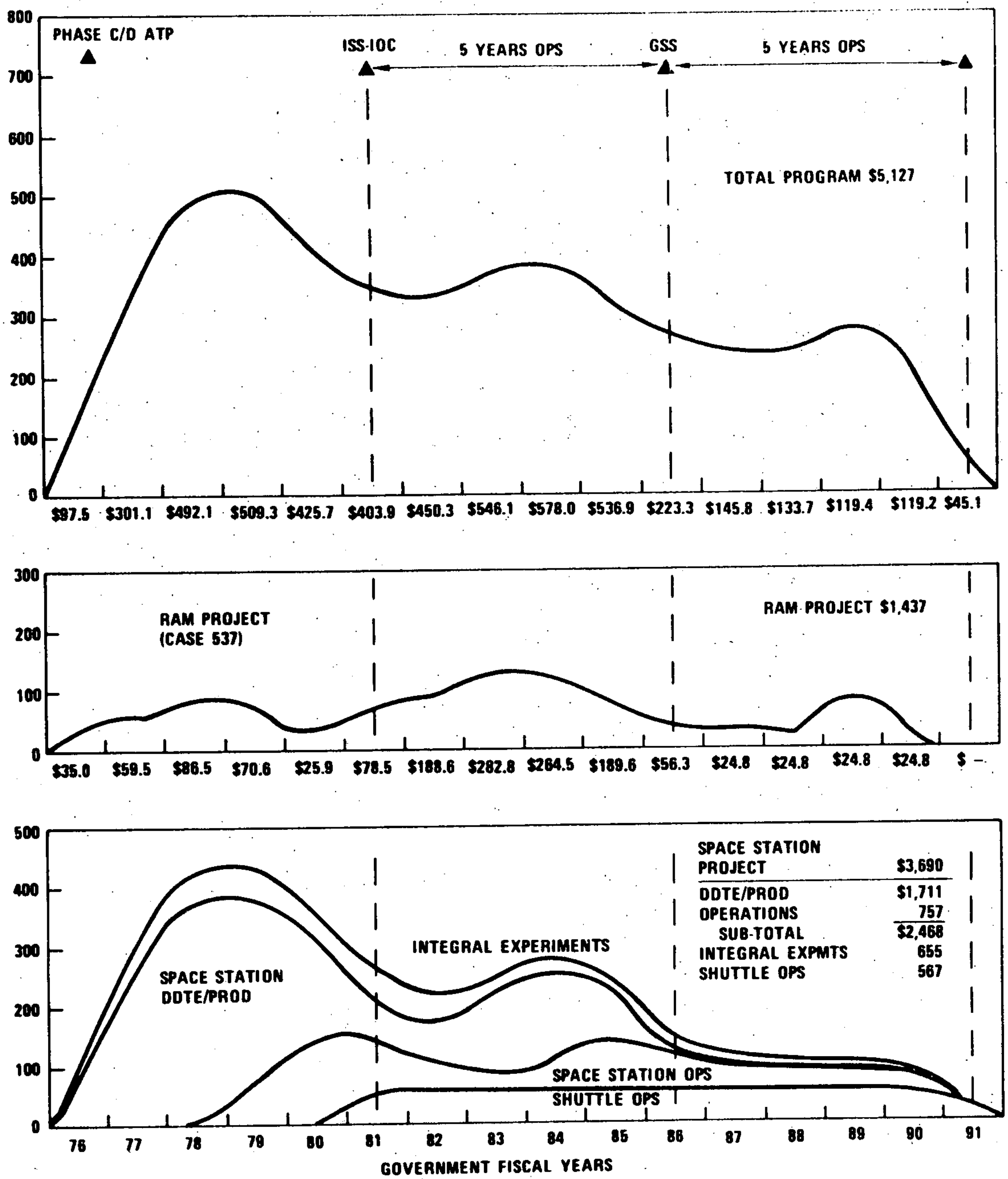


Figure 2-11. Experiment Schedule, Option 3



																	PROJECT TOTAL
DDTE/PROD	$58.8	$222.8	$361.8	$349.0	$190.6	$101.7	$58.7	$103.3	$154.4	$100.8	$6.7	$3.0	$ –	$ –	$ –	$ –	$1,711
OPS	–	–	4.2	33.2	148.1	101.6	58.9	42.4	49.9	87.0	66.1	48.8	43.7	34.6	34.4	5.1	757
SUB-TOTAL	58.8	222.8	366.0	382.2	338.7	203.3	117.6	145.7	204.3	187.8	72.8	50.8	43.7	34.6	34.4	5.1	2,463
INTEGRAL EXPMTS	3.7	18.8	39.6	56.5	61.1	81.1	90.1	63.6	55.2	105.5	40.2	16.2	11.2	6.0	6.0	–	655
SHUTTLE OPS	–	–	–	–	–	41	54	54	54	54	54	54	54	54	54	40	567
TOTAL	62.5	241.6	405.6	438.7	399.8	325.4	261.7	263.3	313.5	347.3	167.0	121.0	108.9	94.6	94.4	45.1	3,690

(MF-01 COSTS – SPACE STATION PROJECT)

Figure 2-10: Option 2A Funding Summary 1972 Dollars in Millions

logical or economic benefits to man. Although all seven disciplines are still represented, the physics and astronomy experiments are limited. The resulting program is very attractive in that it provides a significant return with the lowest experiment cost ($1.4 billion) for the 10 years of operation of any 10-year option considered.

2.3.1 Experiment Program Definition

As in the two options described earlier, this program is a derivative of the ISS/GSS Baseline Experiment Program. The disciplines receiving major emphasis within this option are Earth surveys, communications/navigation, material sciences, and life sciences. Decreased activity in the remaining disciplines results in a reduction of about $200 million in experiment costs.

2.3.2 Schedules

The Option 3 schedule represents an ISS program with a six-man crew capability extended through December 1990. Flight operations include a total of 126 Shuttle launches.

The number of integral experiments is reduced from 26 to 18 and RAM experiments total 8 compared to 7 in Options 2 and 2A. The program has a prime emphasis on applications activities. All RAM's are Space Station-attached modules and the last experiment to be deployed is launched in January 1989, one year later than the last in Options 2 and 2A. Six RAM's will be manufactured with one module being reconfigured and reused for two subsequent missions.

The flight operations summary includes four Space Station Module launches, eight RAM launches, 47 Logistics Module flights utilizing four LM's, and 67 crew rotation launches.

Figure 2-12 is the program schedule for Option 3.

2.3.3 Program Costs and Funding (Option 3)

Space Station project costs are the same as those for Option 2. Experiment costs are those resulting from the applications emphasis. Integral experiments costs are $222 million less than those for Option 2

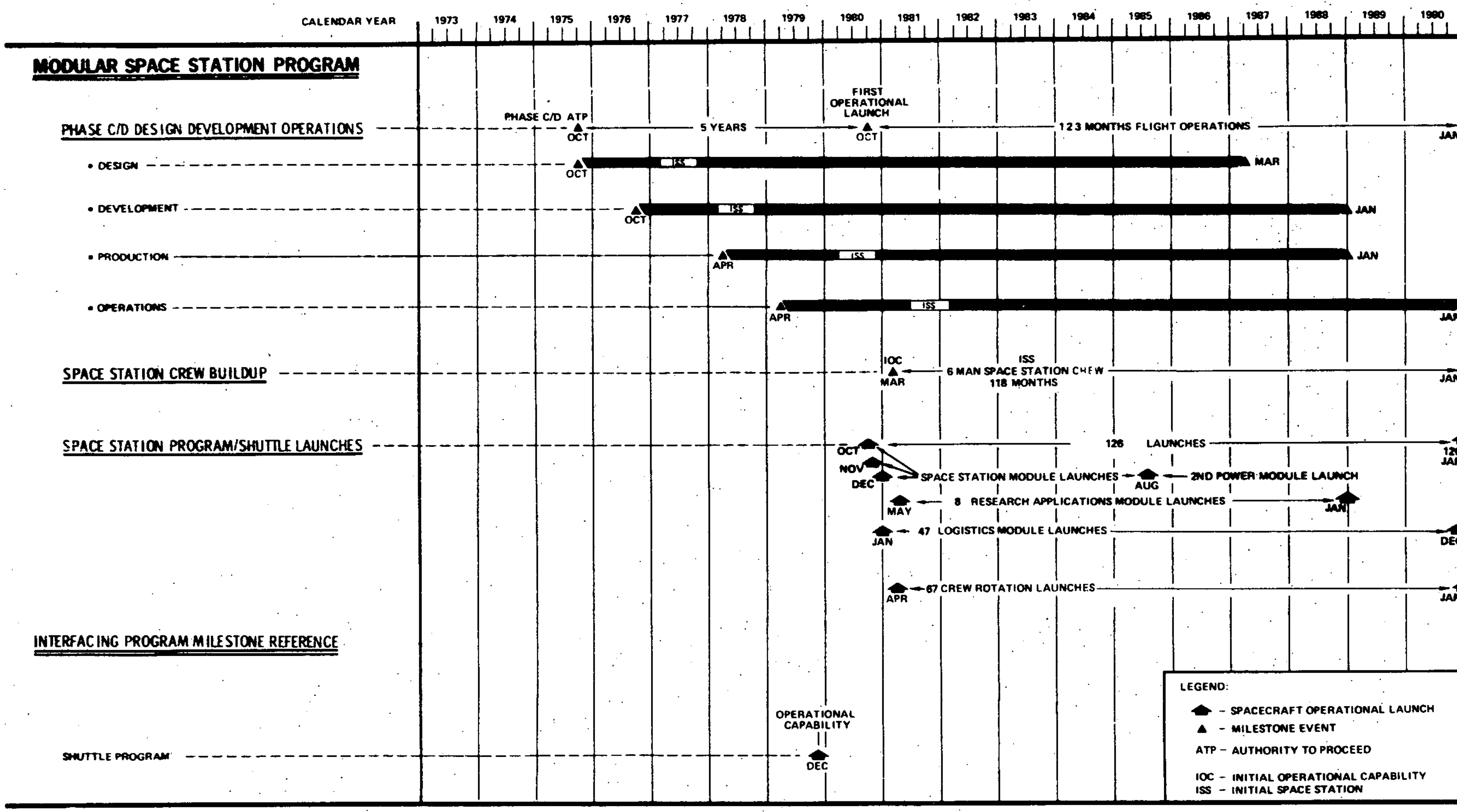


Figure 2-12. Modular Space Station Program Schedule, Option 3

($433 million vs $655 million), while RAM Project costs are $21 million greater than those for Option 2 ($933 million vs $912 million). Option 3 experiments costs total $1,366 million, which is $201 million less than the experiment costs for Option 2.

Costs and funding are summarized in Figure 2-13. Peak program funding is in GFY 1979 and amounts to $511 million, $440 million of which is for the Space Station project and $71 million for the RAM project. RAM project funding peaks in GFY 1983 at $126 million, while the $440 million in GFY 1979 is the peak for the Space Station project. A secondary program funding peak appears in GFY 1984 and results from the additional Space Station project hardware and operations, along with the RAM project experiment definition. This secondary peak amounts to $392 million, of which $279 is for the Space Station project and $113 is for the RAM project.

2.4 OPTION 4

Option 4 was defined as a 5-year experiment program whose annual experiment funds were limited to $100 million per year.

2.4.1 Experiment Program Definition (Option 4)

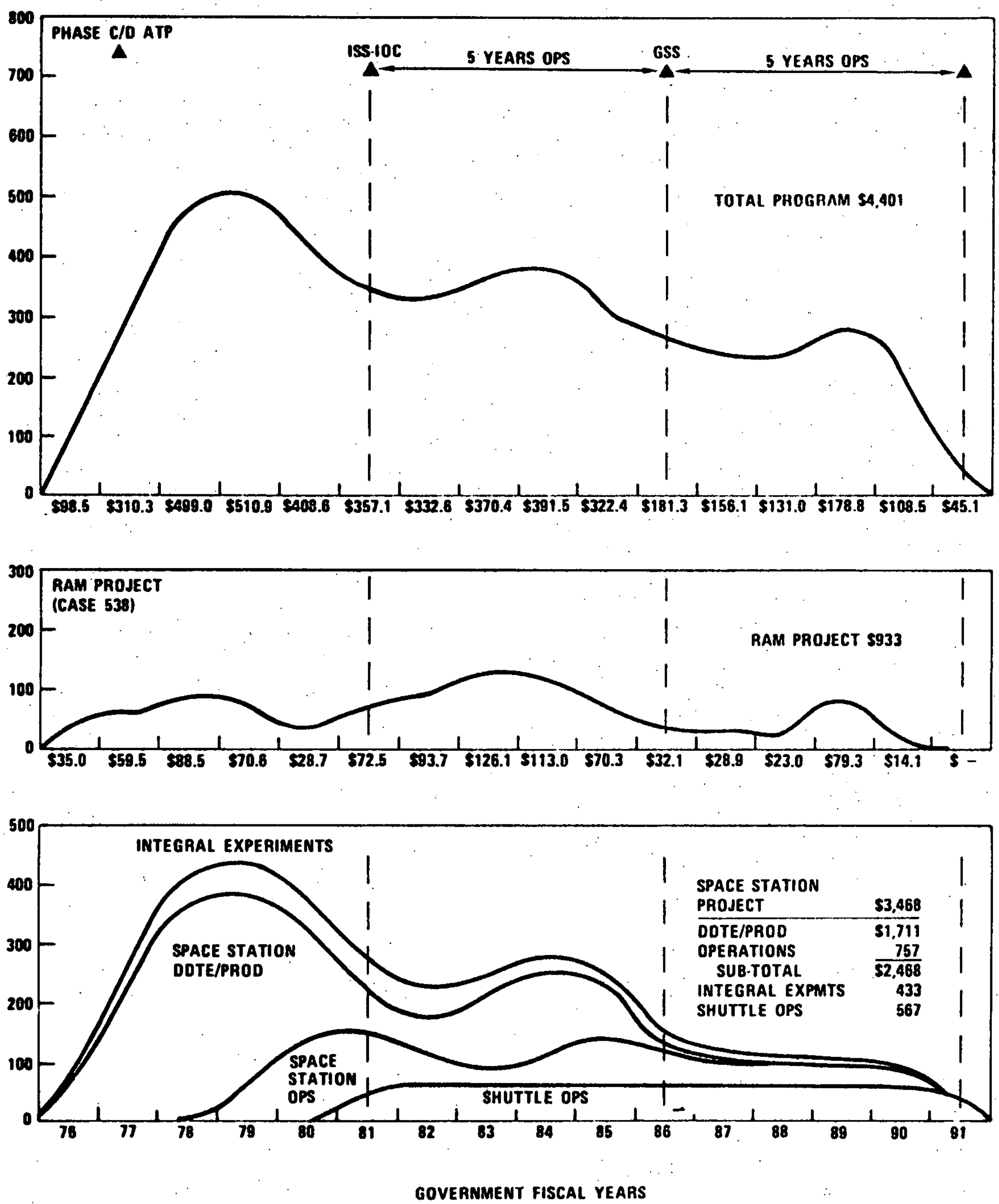
This program differs from Option 1 in three areas:

A. A reduction in the technology area by elimination of the teleoperator and manned work platform experiments.

B. Elimination of the test chamber and atmospheric sciences experiments in the physics area.

C. Deletion of all astronomy experiments.

The major reason for these deletions was the $100 million limitation. Resulting costs were $400 million to IOC, and a total experiment investment of $800 million for five years of operation. Figure 2-14 summarizes this program.



																	PROJECT TOTAL
DDTE/PROD	$58.8	$222.8	$361.8	$349.0	$190.6	$101.7	$58.7	$103.3	$154.4	$100.8	$6.7	$3.0	$ –	$ –	$ –	$ –	$1,711
OPS			4.2	33.2	148.5	101.6	58.9	42.4	49.9	87.0	66.1	47.8	43.7	34.6	34.4	5.1	757
SUB-TOTAL	58.8	222.8	366.0	382.2	338.7	203.3	117.6	145.7	204.3	187.8	72.8	50.8	43.7	34.6	34.4	5.1	2,468
INTEGRAL EXPMTS	4.7	28.0	46.5	58.1	41.2	40.3	67.3	44.6	20.2	10.3	22.4	22.4	10.3	10.9	6.0		433
SHUTTLE OPS						41	54	54	54	54	54	54	54	54	54	40	567
TOTAL	63.5	250.8	412.5	440.3	379.9	284.6	238.9	244.3	278.5	262.1	149.2	127.2	108.0	99.5	94.4	45.1	3,468

(MF-01 COSTS – SPACE STATION PROJECT)

Figure 2-13. Option 3 Funding Summary 1972 Dollars in Millions

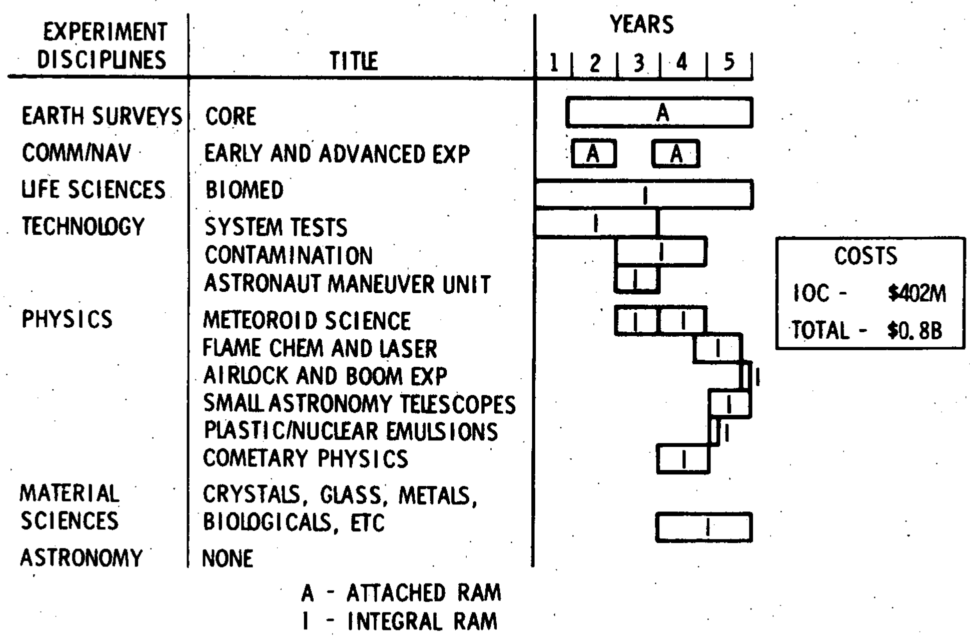


Figure 2-14. Funding Summary, Option 4

2.4.2 Option 4 Schedules

The flight operations phase of Option 4, as in Option 1, is terminated in December 1985, 58 months after IOC. The experiment program for Option 4 is reduced to 22 flights—19 integral and 3 attached RAM's—as compared to 27 flights—22 integral and 5 attached RAM's—in the baseline ISS program and Option 1.

Two RAM-attached modules are required to accomplish three scheduled experiments, the second and third experiments using the same module with a reconfiguration period scheduled between flights. Four Logistics Modules are required, as in the baseline ISS program and all options.

The flight operations program includes 66 launches: 3 SSM's, 3 Space Station-attached RAM's, 24 Logistics Module flights, and 36 launches for crew rotation.

Figure 2-15 is the program schedule for Option 4.

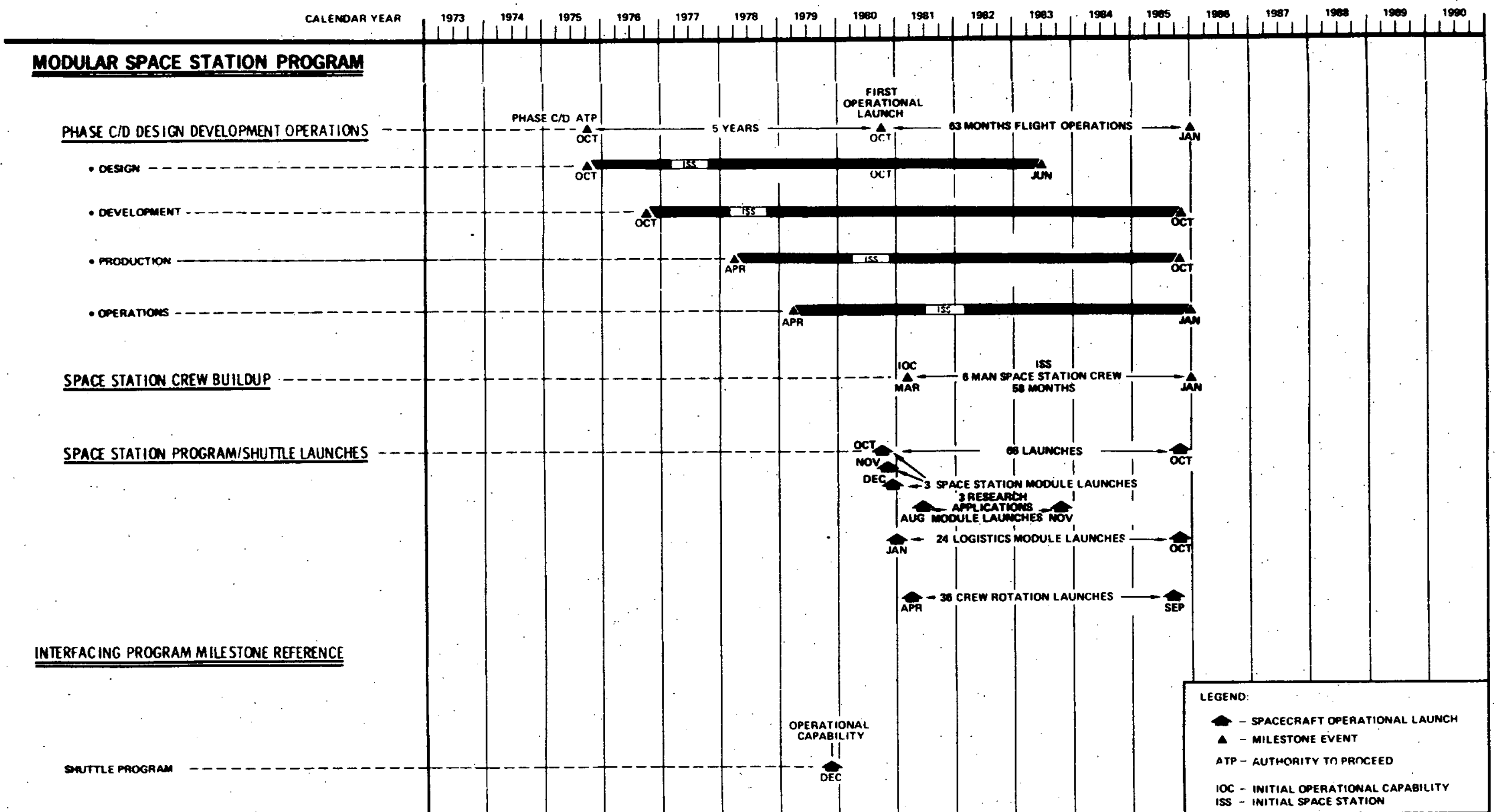
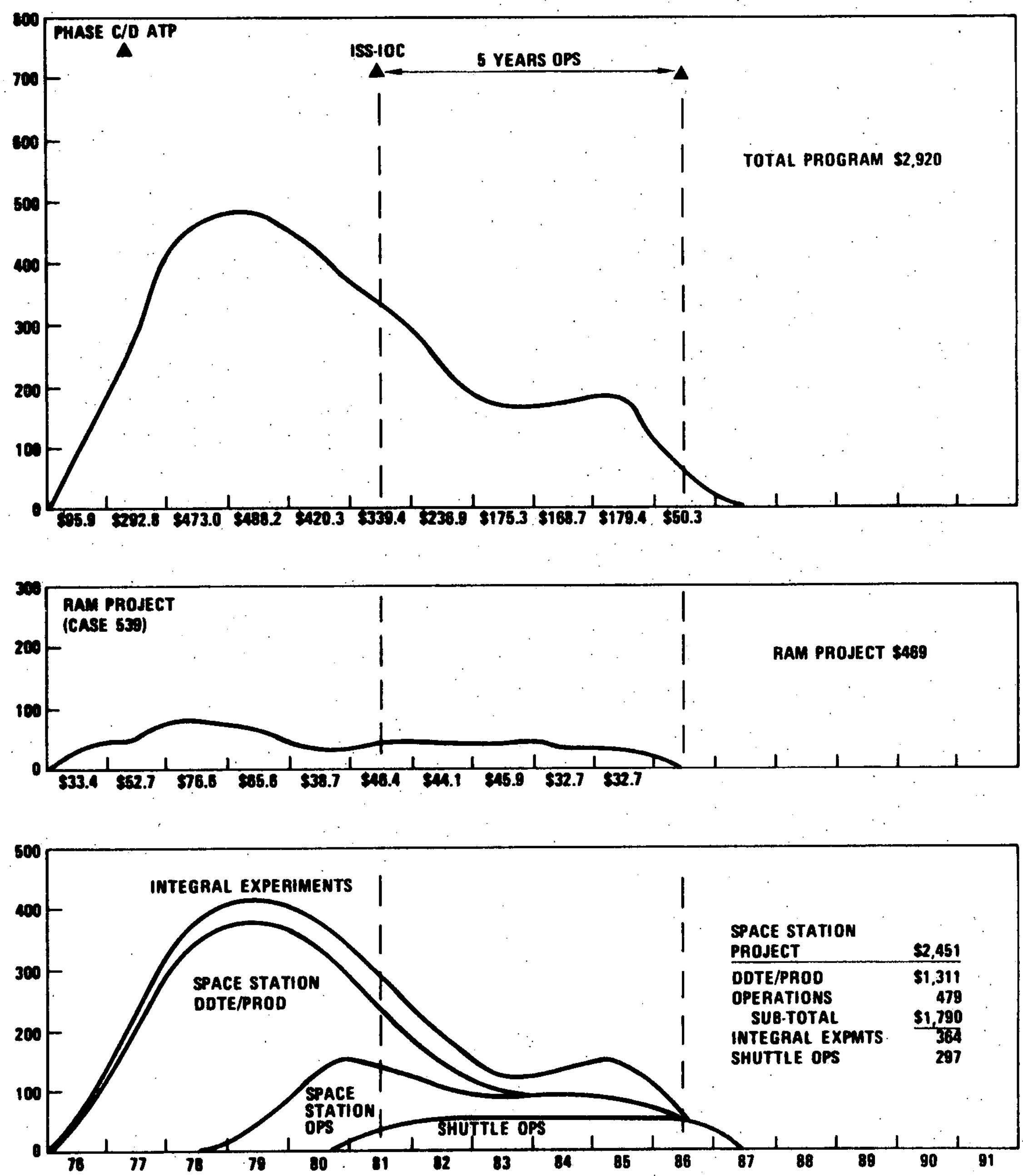


Figure 2-15. Modular Space Station Program Schedule, Option 4

2.4.3 Option 4 Experiment/Space Station Costs and Funding

Space Station project costs and funding are the same as those for Option 1. The costs for experiments are different, however, and result from the $100 million per year funding limitation imposed by this option. Total experiment costs for Option 4 at $833 million are $224 million less than those for Option 1, which required $1, 057 million. Integral experiments account for $138 million of the $224 million reduction ($364 million vs $502 million), while the remaining $86 million reduction is in the RAM project ($469 million vs $555 million).

Figure 2-16 summarizes the costs and funding for Option 4. Peak program funding is in GFY 1979 and amounts to $488 million, of which $422 million is Space Station project cost and $66 million is RAM project cost. The funding limitation results in fairly level funding for the RAM project and for the Integral Experiments portion of the Space Station project.



GOVERNMENT FISCAL YEARS

																PROJECT TOTAL
DDTE/PROD	$58.8	$222.8	$361.5	$349.0	$190.8	$92.9	$27.8	$7.5	$–	$–	$–					$1,311
OPS			4.2	33.2	148.1	101.6	58.9	42.4	42.4	38.7	9.3					479
SUB-TOTAL	56.8	222.8	366.1	382.2	338.7	194.5	86.7	49.9	42.4	38.7	9.3					1,790
INTEGRAL EXPMTS	3.7	17.3	30.3	40.4	42.9	58.5	52.1	25.5	39.6	54.0						364
SHUTTLE OPS						40	54	54	54	54	41					297
TOTAL	62.5	240.1	396.4	422.6	381.6	293.0	192.8	129.4	136.0	146.7	50.3					2,451

(MP-01 COSTS – SPACE STATION PROJECT)

Figure 2-16. Option 4 Funding Summary 1972 Dollars in Millions

Section 3
OPTION COMPARISONS

3.1 EXPERIMENT RESOURCE UTILIZATION

In order to establish the impact of each of the options on the design of the MDAC six-man Space Station, the power and crew time required to perform each option was determined. These requirements were established using the schedules and data presented in Section 2 for each option, and resource (crew and power) timelines were prepared. For the ISS/GSS Baseline Experiment Program, 4.6 of the six-man crew were required to conduct the experiment program. As shown in Figure 3-1, utilization of this 4.6-man experiment crew for the various options ranges from 65 to 85 percent. Thus, the six-man crew size appears to be about optimum, and provides some flexibility (about 25 percent) for accommodating experiment

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OPTION	CREW (4.6 MEN)	POWER (4.8 KWe)
1	73%	80%
2	79%	95%
2A	85%	90%
3	72%	95%
4	66%	75%

Figure 3-1. Optional Experiment Programs Resource Utilization Comparison

changes. The 4.8 kwe baselined for the ISS/GSS program experiments was assessed in order to establish the degree of power utilization for each of the experiment options. Power utilization for the family of options considered ranges from 75 to 95 percent. This relatively high utilization rate is logical when consideration is given to the fact that the 4.8 kwe was derived for an experiment program (the ISS/GSS baseline) that was then modified to establish the options. These modifications in a general sense eliminated free-flying modules which did not utilize a significant portion of the Space Station's power.

Figure 3-1 information showed that the 4.8-kwe power level for the baseline would not be exceeded, and that nominal power utilization for any option was about 90 percent. The conclusion to be drawn from this is that the power system size and design should remain the same as that defined for the ISS/GSS Baseline Experiment Program. However, the three modules required for the six-man Space Station will require some power augmentation to accommodate the second five years of operation.

3.2 DESIGN/OPERATIONS IMPACTS

The Facility Concept for experiment support that is inherent in the MDAC modular Growth Space Station (GSS) design has been analyzed to determine whether significant design changes or cost savings would accrue should the Baseline Experiment Program be modified to any one of the options described previously. These analyses indicate that the Initial Space Station (ISS) currently defined will efficiently accommodate any of the variations noted. Design modifications to the ISS might be appropriate if the program were limited to five years of operations; however, reductions in cost to IOC would be insignificant.

As noted in Section 3.1, the 5-year operation of the three-module ISS configuration can be extended to 10 years, with no degradation in performance, by adding a second Power/Subsystems Module that is identical to the first. Alternative methods for power augmentation were considered; however, the second Power/Subsystems Module approach offered the greatest advantage since it also provides additional docking ports for accommodation of attached or free-flying RAM's.

The GPL is inherently capable of accommodating any experiment program. Space is available within the ISS design envelope to permit the ISS configuration to support any reasonable combination of RAM's merely through the addition of carry-on equipment, e.g., experiment consoles and their support communications.

Sustained operation at the ISS level can be accomplished in most subsystem areas by continuing the on-orbit maintenance and component replacement cycle, the only impact being a recurring requirement for spares and allocation for maintenance activities. The notable exception to this capability is the solar array which, due to anticipated degradation resulting from numerous factors such as ultraviolet radiation, high-energy protons, electrons, thermal cycling, contamination, meteoroid erosion, etc., has a decreasing power output with time. The baseline array is sized to compensate for this degradation so that sufficient power capacity remains to support the ISS load requirements at the end of five years of operation. Figure 3-2 illustrates the baseline power capability provided by the initial 5,300-ft^2 array and shows the increased power available when the second

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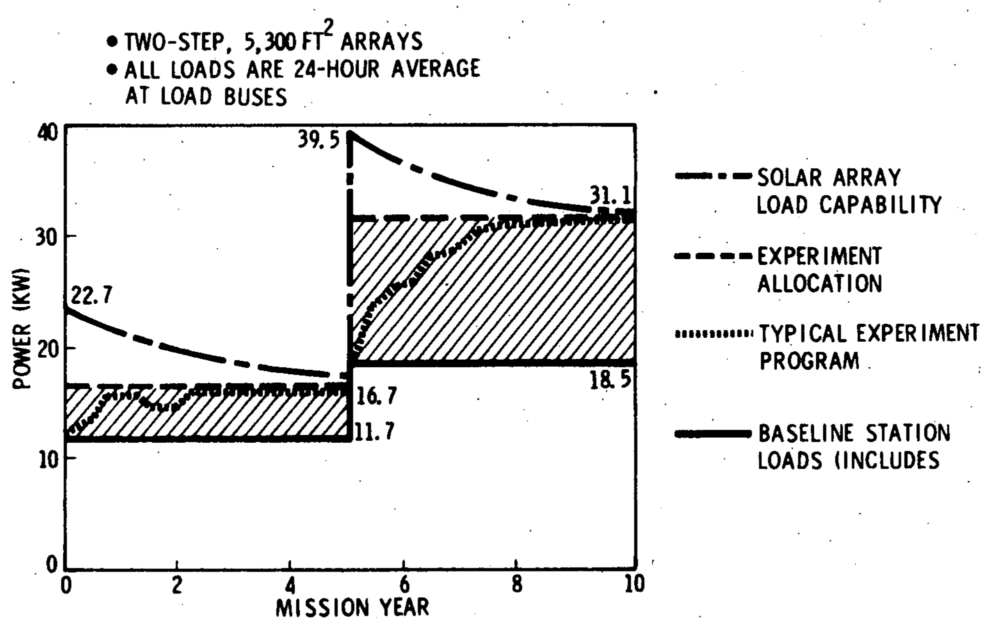

Figure 3-2. Power Buildup

5,300-ft^2 array is added at the GSS step. As illustrated, the ISS array is initially capable of producing 22.7 kw which degrades to slightly more than the load requirement of 16.7 kw at the end of five years. This capability accommodates the basic station requirements plus an allocation of 5 kw for experiments. The second array compensates for degradation in the first array and adds sufficient power to meet the increased demands of the GSS growth step with its larger crew size and expanded experiment program. Cost-effectiveness and performance studies on array modularity (number of arrays to meet a given power profile) indicate a two-step configuration of this type is superior to other options.

Analysis of the Experiment Program power requirements for sustained operation at the ISS level (e.g., to 10 years) indicates that 5 kw is sufficient for planning purposes and, since no increase in the station loads is anticipated beyond the first five years of ISS operation, the minimum power required for the second five years of ISS remains at the 16.7-kw level. However, if the initial array is used during the second five years, the additional degradation anticipated is 2.4 kw which results in a total capacity of only 14.3 kw after 10 years. As a minimum, this amount of degradation must be compensated for by supplementing the initial array.

A number of candidates are available for making up this deficit in power capacity. The six primary ones are:

A. Use a larger initial array with a 10-year degradation to 16.7 kw.
B. Replace solar panel segments by EVA as necessary to maintain 16.7 kw.
C. Return the initial array after five years via Shuttle; refurbish to original capacity and return to orbit.
D. Replace the original Power/Subsystems Module with a new one after five years.
E. Add a second Power/Subsystems Module after five years, as planned for the GSS step.
F. Add a small supplementary power system (solar array, fuel cells, or isotope/Brayton) after five years.

Although several variations on these alternates are available, the ones listed represent the six basic candidates.

3.2.1 Discussion of Alternate Approaches

In evaluating methods of maintaining the ISS beyond five years (e.g., to 10 years) the same basic program constraints used in the Modular Space Station study influence the selection.

A. Meet necessary performance requirements
B. Minimize initial cost
C. Minimize total cost
D. Maximize crew effectiveness for mission and experiment operations.

Potentially, all candidates can meet the first requirement—performance—with the exception that performance is interrupted in Candidate 3 while the module is down for refurbishment and is interrupted briefly in most other candidates while retrofit or replacement operations are in progress.

Candidate 1 avoids power interrupts but has the disadvantage that costs are incurred initially to support a need 5 to 10 years later in the program. It also adds significant weight to the initial power module launch, which is undesirable, and has a fixed lifetime with no growth features.

Candidate 2 requires an additional design feature not needed by the baseline configuration, namely, provisions for manually or automatically adding or removing and replacing array segments. This involves adding an automatic docking/attachment mechanism, a remotely controlled manipulator, or manual attachment/interconnect provisions with associated EVA activity. Again, the cost for implementing one of these approaches must be absorbed in initial design and development although usage may not occur until after five years of operation. The current solar array concept under development at MSC does incorporate EVA segment replacement features which, if proved feasible, could enhance the desirability of Candidate 2.

In Candidate 3, the primary disadvantage is the loss of Space Station operating time while the Power/Subsystems Module is down for refurbishment. There also is the risk associated with leaving the remaining cluster of station modules in a dormant, unattended mode for the refurbishment time period. Further, it is not clear that the cost of refurbishing the array will be less than the cost of a new array.

With Candidate 4, the downtime disadvantage of Candidate 3 is avoided, but at a substantial cost penalty in midprogram. There are no additional cost penalties at the start of the program, however, since the second module is a duplicate of the first.

Candidate 5 has cost impacts similar to those of Candidate 4. Since the baseline design already includes provisions for later addition of a second array as part of the second power module, a second power module identical to the first can be attached to the crew module opposite the first power module with no new development required. Some cost savings relative to Candidate 4 are possible since the power module contains numerous equipment not associated with the power subsystem (such as propulsion tankage and engines, cargos, attitude reference components, airlock pumps and tanks, etc.) and this equipment may be omitted. If both power modules are to remain attached to the station cluster, the increase in mass characteristics will require additional control impulse capacity, and retention of the CMG's and propulsion equipment is preferred. The additional components will only be utilized as required to provide additional redundancy over original equipment in the first power module. If retained for this purpose, the spares that would otherwise be needed may be omitted. This reduces the effective cost of adding the second power module. If identical arrays are used, the second module will add more power than necessary to sustain the ISS level. This increase may be used to support additional or higher power experiments not presently planned. Unless such a need is projected, the second array should contain fewer segments to further reduce cost.

The last alternate listed, Candidate 6, is similar to Candidate 5 except that the power supply is tailored to meet the specific delta capability (i.e., 2.4 kw) required. The selected power source could be another small solar array or consist of a fuel cell assembly or a source based on a newer technology. Unless the selection of this approach is identified at the start of the Space Station Program, and appropriate installation provisions and interfaces are incorporated, it is probable that a small module will have to be developed to house the supplementary power supply which would then occupy one of the docking ports in the station cluster. One of the Logistics Modules may be readily adaptable for this purpose. The primary disadvantages of Candidate 6 are the added development cost for the module installation, the potential costs for a second type of power source, and the impact on initial design and costs if integration into one of the basic station core modules is preferred. Table 3-1 is a matrix which summarizes the candidates discussed above.

3.2.2 Additional Considerations

Another item which is subject to deterioration with time, but in a less predictable manner, is the radiator surface. In the event deterioration of the heat rejection properties exceeds current design estimates, the supplemental radiator of the second power module could be used to restore capacity as well as reject necessary heat losses from the increased power output. Based on this rationale, Candidate 5, in which a second power module is added to sustain the ISS capability, provides an additional advantage. In addition, if solar array performance on-orbit exceeds predictions (which are based on worst-case analyses), the addition of the second power module and the associated costs may be deferred correspondingly.

In terms of programmatic considerations, the impact of continued ISS operation on other subsystems is negligible. The maintenance/replacement techniques applied during initial years of operation will be applicable indefinitely as in current aircraft maintenance operations. The major effect anticipated is an increase in the rate of spares usage which should not significantly impact cost.

Table 3-1

POWER SYSTEM SELECTION 10 YEAR ISS

Candidate	Features	Evaluation
1. Larger Initial Array	Low total cost impact Adds to initial cost Adds to power module weight No growth potential Below required power after 10 years	Good solution if no growth is anticipated.
2. Replace Panels by EVA	Low total cost impact Some initial cost impact Adds EVA risk/complexity No growth potential Can continue beyond 10 years	Best solution if no growth is needed and if EVA risks are acceptable.
3. Return Array and Refurbish	Shuttle return and reorbit Requires extended dormant operation No initial cost impact Significant total cost impact	Undesirable due to cost and downtime
4. Replace Power Module	High total cost No initial cost impact Extend beyond 10 years by replacing module every 5 years May involve unnecessary replacement of other subsystems	Acceptable solution but no major advantage for the high cost involved.
5. Add Second Power Module	High total cost No initial cost impact Same technique as GSS step Large increase in power capacity Adds subsystem redundancy or can off-load to reduce cost	Best solution. Defers cost and increases power capacity and redundancy.
6. Add Small Power Source	Significant initial and total cost Requires additional development Requires installation provisions or small dedicated module	Not cost effective compared with other options.

3.3 PROGRAMMATIC COMPARISONS

In order to assess the cost effectiveness of the various options and compare them to the baseline program, major effectiveness parameters were identified and interrelated as shown in the formula in Figure 3-3. Since the number of dollars expended per man-quarter on-orbit is a significant measure of overall program efficiency, each of the programs was analyzed using this parameter.

Using the baseline as a point of departure and comparing each of the options in man-quarters results in the following:

A. Crew utilization in man-quarters as shown in Column 4 ranges from 55 to 65 percent for the 10-year experiment options. This indicates a near-optimum crew size with inherent flexibility for experiment changes.

B. The costs for experiments for the 10-year options are about 45 to 70 percent of those for the baseline. This produces a significant reduction in program costs as requested by NASA.

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OPTION/CASE	RAMS A	RAMS FF	MANQUARTERS (MQ) (% OF BASELINE)	$EXP (% OF BASELINE)	$M/MQ*
BASELINE	14	3	100	100	24
1	5	0	28	40	46
2	7	0	60	52	28
2A	5	2	63	70	29
3	8	0	55	46	29
4	3	0	25	28	48

$$*\$M/MQ = \frac{\$\text{SPACE STATION} + \$\text{SHUTTLE} + \$\text{EXPERIMENT}}{\text{MANQUARTERS WORK DONE}}$$

Figure 3-3. Comparison of Optional Experiment Programs

Coupling these items with the added factors noted in the formula results in an effectiveness measure for each option, as noted in the last column of the figure. The lower the value, the more effective the program. Thus, it will be seen that any of the 10-year options compare favorably with the baseline in total cost per man-quarter on-orbit. As expected, the effectiveness of the five-year options (Options 2 and 4) offers a significantly lower rate of return. This reflects the fact that the return for a Space Station as an experiment facility is considerably enhanced as its life is extended.

Figure 3-4 compares the costs associated with several options that might be selected for a manned Earth-orbiting Space Station Program. For a six-man Initial Space Station, the costs to IOC are relatively constant regardless of the magnitude of subsequent activities. NASA can anticipate the expenditure of about $2.0 billion (about $1.6 billion for station development and activation and about $500 million for experiments) over a 5-year period in order to achieve this capability. Assuming a development time of about five years, the average annual expenditure for this total development is

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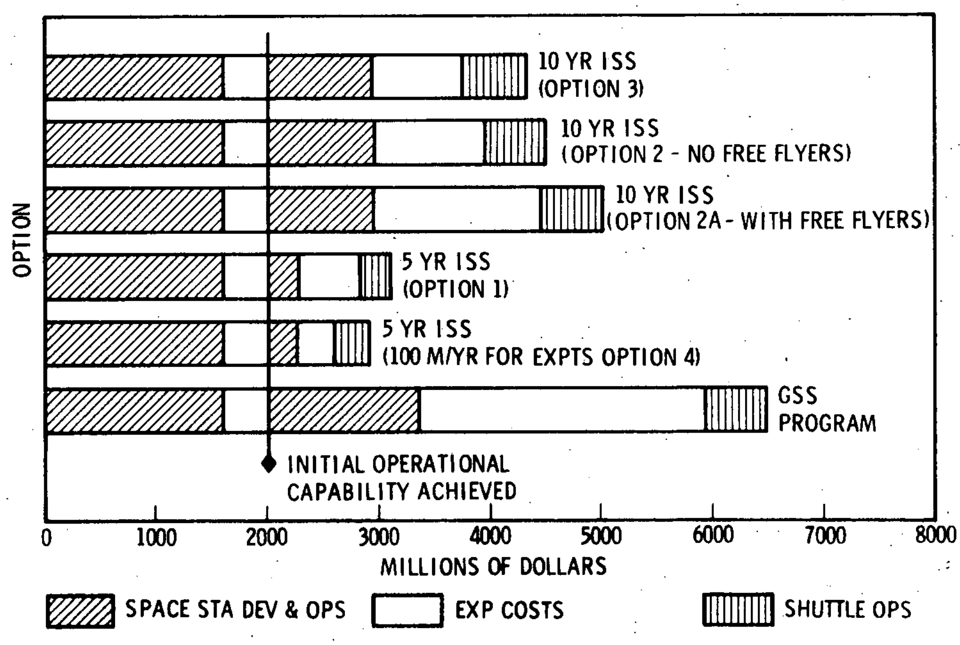

Figure 3-4. Program Option Costs (1972 Dollars)

about $400 million. Since the program is structured to incorporate growth capability, any of the options illustrated may be accomplished.

An attractive 10-year ISS (six-man) program has been identified (Option 3) that will provide significant return for the investment. This Applications Program would achieve a measureable return for an average annual expenditure during the 10-year operation of about $225 million. The more ambitious GSS program, which encompasses the entire Blue Book of experiments, could be attained with an annual expenditure during the same 10-year time period of about $450 million.

Figure 3-5 tabulates the data presented on the previous chart in a manner that permits another comparison. The total expenditure necessary to achieve a 5-year operating capability (Option 1) is about 70 percent ($3,139 vs $4,401 million) of that required to operate for ten years in an Option 3 mode. Thus, a 100-percent increase in station operating capability (10 years vs 5) can be attained through an added expenditure of about 30 percent of the costs for the first five years.

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	SPACE STATION DDTE/PROD	SPACE STATION SHUTTLE OPERATIONS	INTEGRAL EXPERIMENTS	RAM PROJECT	TOTAL
BASELINE	1,972	1,519	614	2,381	6,486
OPTION 2	1,711	1,324	655	912	4,602
OPTION 3	1,711	1,324	433	933	4,401
OPTION 2A	1,711	1,324	655	1,437	5,127
OPTION 1	1,311	771	502	555	3,139
OPTION 4	1,311	776	364	469	2,920

Figure 3-5. Modular Space Station Program Costs (1972 Dollars in Millions)

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Section 4
CONCLUSIONS

Figure 4-1 summarizes a set of conclusions that have emerged from MDAC's option study. Viable Space Station programs of either 5 or 10 years' duration are attainable; however, the 10-year program offers a significantly greater return on the investment. This is in part due to the fact that the initial investment costs are insensitive to the eventual mission duration, thus permitting lower annual amortization as the life of the program is extended.

The facility design concept established by MDAC during its Modular Space Station Study has the inherent flexibility with no significant design changes to accommodate virtually any combination of disciplines and experiments.

An Experiment Program whose total cost from ATP through 10 years of operation is limited to $1.5 billion will very effectively utilize a six-man Space Station's resources and facilities.

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- 10-YEAR EXPERIMENT PROGRAMS AT APPROXIMATELY $1.5 B EFFECTIVELY UTILIZE 6-MAN SPACE STATION RESOURCES AND FACILITIES
- APPLICATIONS DISCIPLINES DOMINATE ALL EXPERIMENT PROGRAM OPTIONS
- INITIAL DEVELOPMENT COSTS ARE INSENSITIVE TO:
    - EVENTUAL MISSION DURATION (5 TO 10 YEARS)
    - EXPERIMENT PROGRAM EMPHASIS
    - GROWTH SPACE STATION (12 MEN) IMPLEMENTATION
- SPACE STATION GENERAL FACILITY DESIGN CONCEPT IS INSENSITIVE TO EXPERIMENT PROGRAM EMPHASIS

Figure 4-1. Optional Experiment Programs – Comparison Conclusions

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