AEROSPACE REPORT NO.
ATR-77(7379-01)-1

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Advanced Space Program Studies

Overall Executive Summary

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30 June 1977

Prepared for

OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-2884

Systems Engineering Operations
THE AEROSPACE CORPORATION

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Prepared by

Advanced Mission Analysis Directorate
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Overall Executive Summary

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CONTENTS

CONTENTS (Cont.)

TABLES

FIGURES

1. INTRODUCTION

This document is an Overall Executive Summary of work accomplished from 1 September 1976 through 30 June 1977 on the seven Advanced Space Program Studies covered by NASA contract NASW-2884. Table 1-1 lists the studies, their funding, The Aerospace Corporation MTS deliveries, and the names of the personnel responsible for managing and monitoring each individual effort.

Table 1-1. Advanced Space Program Studies

STUDY	TITLE	STUDY MANAGERS			FUNDING $ K	MTS MAN MONTHS
		AEROSPACE	NASA			
2.1	Advanced Space Planning and Conceptual Analysis	B. H. Campbell	M. E. Goodhart F. S. Roberts	JSC Hq	206.3	31.0
2.2	Shuttle User Studies	E. I. Pritchard	W. F. Moore	Hq	225.4	28.3
2.3	Technology Assessment and New Opportunities	D. G. Aviv	S. R. Sadin	Hq	120.0	18.0
2.4	Standardization and Program Practice	T. Shiokari	M. L. Spruill A. T. Diamond	Hq Hq	313.4	48.1
2.5	Integrated STS Operations Planning Study	R. R. Wolfe	J. M. Smith	Hq	126.9	16.9
2.6	Solid Spinning Upper Stage	W. A. Knittle	A. G. Orillion J. W. Wild	MSFC Hq	495.2	51.3
2.7	Integrated Planning Support Functions	I. Bekey	R. W. Johnson	Hq	99.9	7.7
	Total				1587.1	201.3

The objectives of these studies were to provide NASA with multidisciplined advanced planning studies that involved space operations and the associated system elements (including man), identification of potential low cost system approaches, vehicle design, cost synthesis techniques, technology forecasting and opportunities for DoD technology transfer, and the development of near-, mid-, and far-term space initiatives and development plans with emphasis on domestic and military use commonality. All of the studies involved consideration of both NASA and DoD requirements and planning data.

The Advanced Space Program Studies have been performed by The Aerospace Corporation since FY 1970, primarily for the NASA Office of Space Flight. In FY 1975 the support base was expanded to include the Low Cost Systems Office and the Office of Space Technology.

Every attempt was made to integrate the studies. For instance, the selection of initiatives used in Study 2.1 - Advanced Space Planning and Conceptual Analysis - was strongly influenced by the FY 76 work which preceded Study 2.7 - Integrated Planning Support Functions. A primary objective of the Aerospace studies is to ensure integration of DoD and NASA activities wherever possible. Study 2.3 - Technology Assessment and New Opportunities - proved to be very successful in furthering this objective, and the DoD data bank generated in this study has been widely disseminated and received with deep interest throughout the NASA user community.

The operational management of STS will present a significant problem to which no clear solution is likely to become apparent. The unique decision-making techniques employed in Study 2.5 - Integrated STS Operations Planning - offer an attractive approach to resolving this very important issue.

A particularly important contribution was made by Study 2.6 - Spinning Solid Upper Stage (SSUS) for Delta and Atlas/Centaur class missions. It was concluded that the SSUS concept is feasible and the study was able to be carried to such a depth of detail to permit bypassing a Phase A definition contract and direct committal to Phase B hardware development.

2. REPORTS ISSUED

The results of the studies performed under Contract NASW-2884 are documented in the following reports:

ATR-76(7371)-1	Advanced Space Planning and Conceptual Analysis (Study 2.1) Final Report Volume I - Executive Summary Volume II - Initiative Transportation Analysis Volume III - Assessment of Man in Space	15 April 1977
ATR-76(7372-01)-1	On-Orbit Checkout Study (Study 2.2) Final Report	13 January 1977
ATR-77(7372)-1	Shuttle User Studies (Study 2.2) Final Report, Executive Summary	30 June 1977
ATR-77(7373-01)-1	Spacelab Utility for DoD (Study 2.2) Final Report	30 June 1977
ATR-77(7373-01)-1	Spacelab Utility for DoD (Study 2.2) Final Report, Appendix (Classified)	30 June 1977
ATR-77(7373-02)-1	STS Ancillary Equipment Study (Study 2.2) Final Report	30 June 1977
ATR-77(7373-02)-2	STS Ancillary Equipment Study (Study 2.2) User Reference Book	30 June 1977
ATR-77(7629)-1	On-Orbit Checkout of Satellites (Study 2.2) Final Report (Part 2 of On-Orbit Checkout Study)	30 June 1977
ATR-76(7374-01)-1	Technology Assessment and Forecast (Study 2.3) (Sensor portion only)	13 October 1976

ATR-76(7374)-2	Technology Assessment and New Opportunities (Study 2.3) Final Report Volume I - Executive Summary Volume II, Part 1 - Strategic and Tactical Systems and Near-Term Technology Programs Volume II, Part 2 - Technology Assessment for DoD Space Programs Volume II, Part 3 - Technology Assessment for DoD Space Programs (cont'd)	15 December 1976
ATR-77(7375-01)-1	Standardization and Program Practices Analysis (Study 2.4) Final Report Volume I - Executive Summary Volume II, Part 1 - Program Practices Evaluation Volume II, Part 2 - Appendixes Volume III - Auxiliary Propulsion Components Compendium	15 December 1976
ATR-75(7364)-1, Revision 1	Volume IV - Equipment Compendium Part A. Stabilization and Control Subsystem Part C. Electrical Power Subsystem Part D. Communication and Data Processing	September 1976
ATR-76(7376)-1	Manned Earth Science Observations (Study 2.5)	February 1976
ATR-76(7376)-2	Integrated STS Operations Planning (Study 2.5) Final Report Volume I - Executive Summary STS Operational Management Concepts Volume II - STS Operational Management Assessment Volume III - Phase 2 STS Operational Management Assessment	16 July 1976

ATR-76(7377-01)-1	Spinning Solid Upper Stage for Delta and Atlas/Centaur Class Missions (Study 2.6) Final Report Volume I - Executive Summary Volume II - Technical Report Volume II - Appendix A Volume II - Appendix A Drawings	30 November 1976
ATR-77(7378)-1	Integrated Planning Support Functions (Study 2.7) Final Report Volume I - Executive Summary Volume II - Study Report	30 June 1977

3. ADVANCED SPACE PLANNING AND CONCEPTUAL ANALYSIS (STUDY 2.1)

The Space Shuttle and the Interim Upper Stage (IUS) will support most space mission objectives through the early 1980s. However, a number of candidate payloads for the post-1985 era could exceed the expected capability, including any nominal uprating of the baseline STS. In this study, The Aerospace Corporation defined potential transportation requirements and operational modes for a selected group of space initiatives which are intended to represent NASA and DoD space programs for the period 1985-2000.

3.1 OBJECTIVE

The primary objective of this study was to define potential transportation requirements and operational modes for the 1985-2000 time period and to construct project plans based on an evolutionary Space Transportation System (STS), defining the associated vehicle elements and operational options required to support each of a number of selected initiatives. Further objectives were: to identify those functions that man could profitably perform in space; and to recommend areas being investigated by the DoD that should be evaluated by NASA.

3.2 RESULTS

The selected initiatives are listed in Table 3-1, together with the Outlook for Space* themes which they represent. Payload weights range from 11,360 to 1.8 million kg; orbits range from 926 km to geosynchronous and also include L3. It was assumed that each initiative was independent of the other. A graphical portrayal of the transportation recommendations to support the NASA initiatives listed in Table 3-1 is given in Figure 3-1. The small Orbit Transfer Vehicle (OTV) weighs about 42,200 kg; the large OTV weighs about 65,000 kg.

The study identified in a preliminary way those functions which man could profitably perform in space. The conclusions are:

*"Outlook for Space," NASA Report NASA SP-386, January 1976

a. Manned support for many of the initiatives will be needed.

b. Refurbishment and repair is cost effective.

c. Remote manipulators and robotics have limited capability but should be evaluated in greater depth.

d. Interactive man/machine systems have great potential.

e. Multipurpose missions appear inevitable.

f. Very sophisticated initiatives will require specialized crew complements.

Table 3-1. Relationship of Selected Payloads to Original NASA Initiatives

Theme 01	Production and Management of Food and Fibre Resources
	- Advanced Resources/Pollution Observatory
Theme 02	Prediction and Protection of the Environment
	- Synchronous Meteorological Satellite
Theme 03	Protection of Life and Property
	- Nuclear Fuel Location - Fire Detection - Coastal Passive Radar
Theme 04	Mineral Exploration and Energy
	- Nuclear Waste Disposal
Theme 05	Transfer of Information
	- Personal Communications
Theme 08, 10, and 11	The Nature of the Universe, the Life Cycle of Stars, and Evolution of the Solar System
	- Large Telescope Facility
Theme 12	Origins and Future of Life
	- Interstellar Search System

3.3 RECOMMENDATIONS

An area which should also be evaluated is that of manually-controlled remote teleoperators, robotics, and software/hardware interactive command and control systems (artificial intelligence) which are being examined by the DoD. Studies should:

a. Assess the present and planned capabilities of these devices for the 1985-2000 time period

b. Determine the applicability of these devices to selected initiatives

c. Identify areas where development or modification could lead to significant improvements in operational capability.

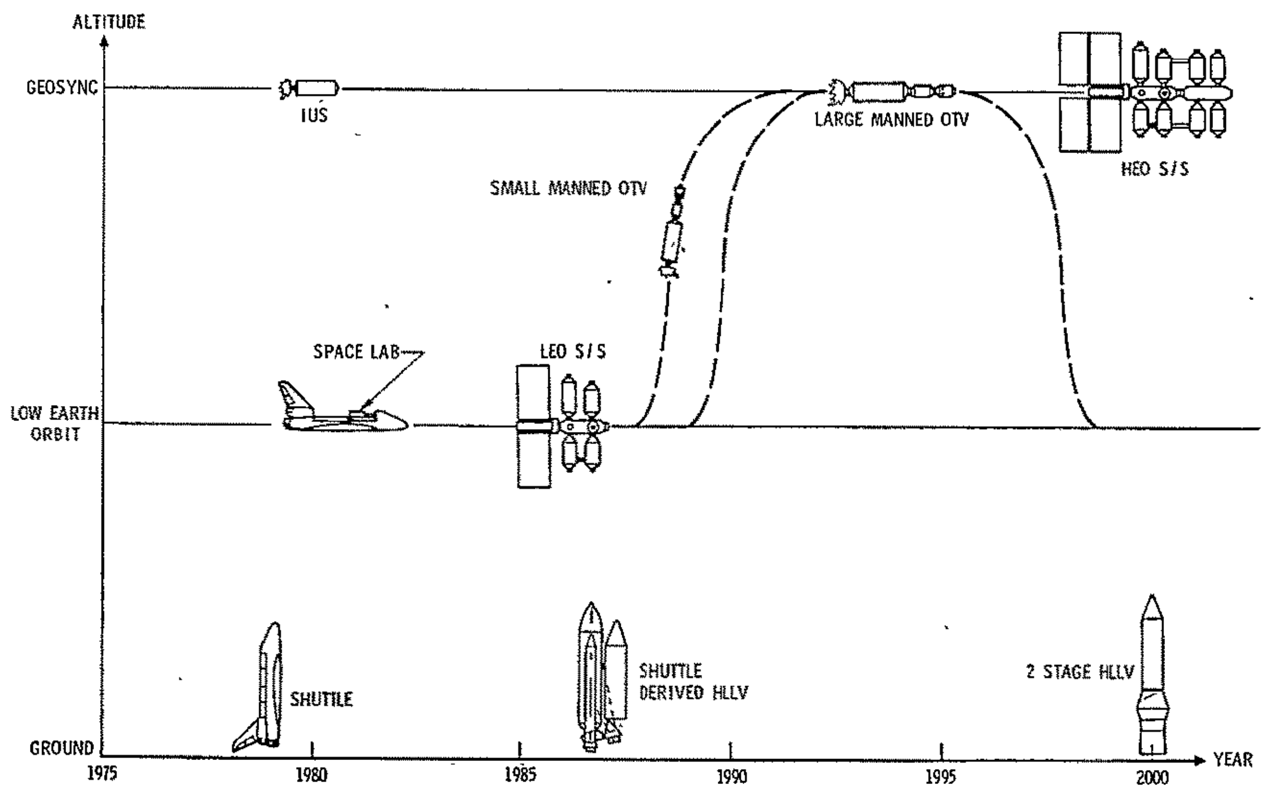


Figure 3-1. Transportation System Plan

4. SHUTTLE USER STUDIES (STUDY 2.2)

4.1 ON-ORBIT CHECKOUT STUDY

Major decisions must be made before orbital separation of the payload, and checkout on orbit is needed to make these decisions. Furthermore, checkout is needed: (1) during space servicing and resupply, (2) for checkout of zero-g devices, (3) to forestall the loss of a nonreturnable STS payload suffering early degradation or failure, (4) to avoid ground refurbishment of returnable payloads when adjustment or repair in space is possible, (5) to avoid an extra flight for retrieving a faulty returnable payload, and (6) to decrease the elapsed time for satellite initiation.

Several potential checkout modes were identified by The Aerospace Corporation. For example, checkout can be supported, controlled, and sequenced from the ground, either through the Orbiter communications system or by communicating directly with the payload. Alternatively, use can be made of on-board, in-flight, automated equipments. It seems expedient to support payload checkout with the same equipment used for factory and launch site testing and to utilize support equipment and software which could be applied to many STS users. The potential utility of the TDRS (Tracking and Data Relay Satellite) must also be considered.

4.1.1 Objective

The objective of this study was to investigate the feasibility and effectiveness of on-orbit checkout of advanced STS payloads.

The feasibility of on-orbit checkout by equipment which remains attached to the Orbiter was considered, in addition to checkout by equipment at the payload operational control center. The study was restricted to consideration of checkout at low altitude Shuttle orbits.

4.1.2 Results

Data were obtained on 18 candidate satellites which are representative of the different types on which on-orbit checkout would be applicable. Three of these were selected for analysis: Technology Demonstration Satellite, Stormsat, and Synchronous Meteorological Satellite/GOES). The Technology Demonstration Satellite studied had an air quality instrument package and synthetic aperture radar mounted on a Multimission Modular Spacecraft [MMS, see Figure 4-1(a)]. The other two satellites are illustrated in Figure 4-1 (b) and (c).

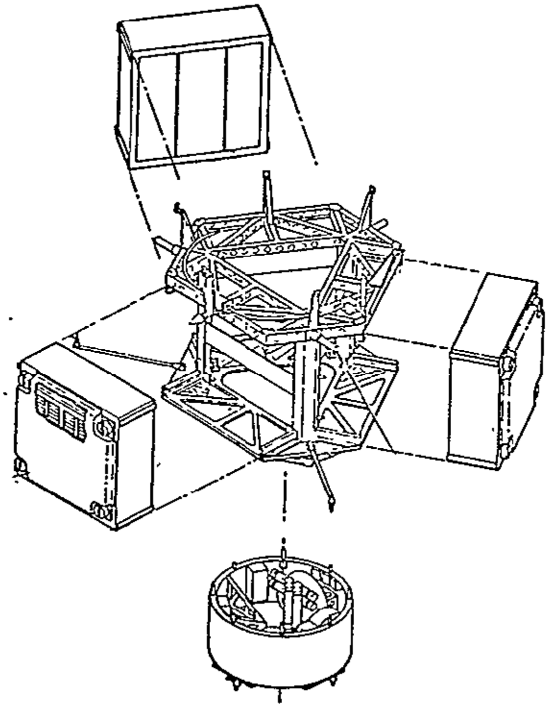
Tables 4-1, 4-2, and 4-3 show comparisons of on-orbit checkout costs per launch for the development, procurement, and use of on-orbit checkout equipment for the three selected examples. Three ground-based and three space-based test sequencing modes of operation were considered. In each case, RF tests made directly with the ground terminal are cost competitive with the other approaches. Ground-based test sequencing costs less than space-based test sequencing.

4.1.3 Conclusions

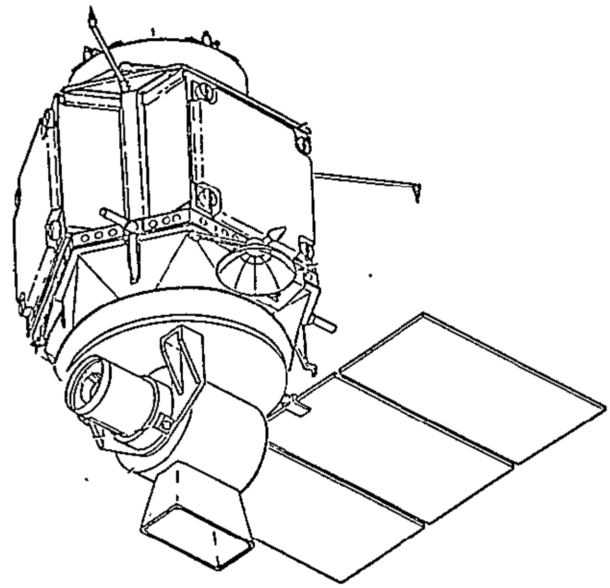
Table 4-4 gives a summary of on-orbit checkout cost benefit data. The data show that on-orbit checkout of the Technology Demonstration Satellite (a low earth orbit satellite) is justified although cost benefits are modest at two to three hundred thousand dollars per launch. These benefits can increase substantially if either: (1) the Orbiter or avionics could support on-orbit checkout with a lower charge, or (2) some of the on-orbit checkout equipment replaces ground support equipment used for prelaunch checkout. Each of these alternatives is possible.

On-orbit checkout of Stormsat (a synchronous equatorial orbit satellite) does not appear to be justified on a cost/benefit basis unless the upper stage is also checked out on orbit. This could prevent upper stage early failure and hence loss of the upper stage and the payload.

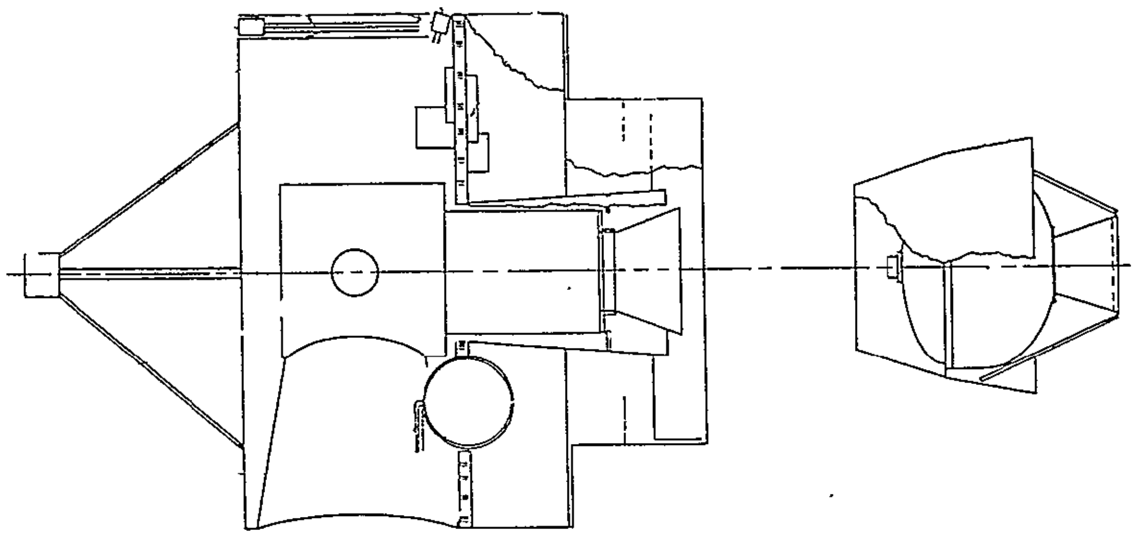
On-orbit checkout of the SMS/GOES satellite does not appear to be justified on a cost/benefit basis unless: (1) the Shuttle parking orbit



(a) MMS Baseline Structure



(b) Stormsat Configuration



(c) SMS Spacecraft Configuration

Figure 4-1. Candidate Payloads

Table 4-1. TDS On-Orbit Checkout Costs Per Launch, $M Equipment and Software (1)

Tests	Spaceborne Equipment: General Purpose	Spaceborne Equipment: Special Purpose	Ground Equipment	Software	Total (2)
GROUND-BASED TEST SEQUENCING					
RF Tests (3) Thru Checkout Equipment/Spacecraft Link	0.157	0.129	0.021	0.125	0.432 (0.234)
RF Tests (3) Thru Orbiter/Spacecraft RF Link	0.157	-0-	0.021	0.125	0.303 (0.218)
RF Tests (3) Direct With Ground Terminal	0.157	-0-	0.021	0.125	0.303 (0.218)
SPACE-BASED TEST SEQUENCING					
RF Tests (3) Thru Checkout Equipment/Spacecraft Link	0.234	0.129	0.019	0.125	0.507 (0.309)
RF Tests (3) Thru Orbiter/Spacecraft RF Link	0.234	-0-	0.019	0.125	0.378 (0.293)
RF Tests (3) Direct With Ground Terminal	0.234	-0-	0.019	0.125	0.378 (0.293)

(1) Equipment and software can also be applied to launch site payload testing.
(2) Costs in parentheses assume 8 TDS satellites are launched, without parentheses assume 1 TDS satellite launched.
(3) Test of satellite TT&C RF equipment.

Table 4-2. Stormsat On-Orbit Checkout Costs Per Launch (1), $M Equipment and Software (2)

Alternative Testing Concepts For On-Orbit Checkout	Spaceborne Equipment: General Purpose	Spaceborne Equipment: Special Purpose	Ground Equipment	Software	Total
GROUND-BASED TEST SEQUENCING					
RF Tests (3) Thru Checkout Equipment/Spacecraft Link	0.157	0.547	0.021	0.075	0.800
RF Tests (4) Thru Orbiter/Spacecraft RF Link	0.157	0.483	0.021	0.075	0.736
RF Tests (5) Direct With Ground Terminal	0.157	0.150	0.021	0.075	0.403
SPACE-BASED TEST SEQUENCING					
RF Tests (3) Thru Checkout Equipment/Spacecraft Link	0.234	0.547	0.019	0.075	0.875
RF Tests (4) Thru Orbiter/Spacecraft RF Link	0.234	0.483	0.019	0.075	0.811
RF Tests (5) Direct With Ground Terminal	0.234	0.150	0.019	0.075	0.478

(1) Two Stormsats assumed launched
(2) Equipment and software can also be applied to launch site payload testing
(3) Test of satellite TT&C RF equipment and wideband data system RF equipment
(4) Test of satellite TT&C RF equipment through orbiter link, wideband data system through checkout equipment link
(5) Test of satellite TT&C RF equipment through orbiter link or directly with the ground terminus. Wideband data system R.F. link is checked out directly with ground terminal.

Table 4-3. SMS/GOES On-Orbit Checkout Costs Per Launch(1), $M Equipment and Software(2)

Tests	Spaceborne Equipment: General Purpose	Spaceborne Equipment: Special Purpose	Ground Equipment	Software	Total
GROUND-BASED TEST SEQUENCING					
RF Tests Thru Checkout Equipment/Spacecraft Link	0.157	1.121	0.021	0.050	1.349
S-Band RF Tests Thru Orbiter/Spacecraft RF Link	0.157	0.887	0.021	0.050	1.110
RF Tests Direct With Ground Terminal(3)	0.157	0.663	0.021	0.050	0.891
SPACE-BASED TEST SEQUENCING					
RF Tests Thru Checkout Equipment/Spacecraft Link	0.234	1.121	0.019	0.050	1.424
S-Band RF Tests Thru Orbiter/Spacecraft RF Link	0.234	0.887	0.019	0.050	1.190
RF Tests Direct With Ground Terminal(3)	0.234	0.663	0.019	0.050	0.966

(1) Four SMS/GOES satellites assumed launched

(2) Equipment and software can also be applied to launch site payload testing

(3) Data collection system only, Wallops Island ground station outside of line-of-sight unless high inclination parking orbit is used.

Table 4-4. Summary of On-Orbit Checkout Cost/Benefit Data

Satellite Project	Upper Stage: Identification	Upper Stage: On-Orbit Checkout Of Stage	Potential Savings(1)	Checkout Cost: Equipment(2)	Checkout Cost: Maintenance(3)	Potential Loss(4)	Potential Benefit(5)
TDS							
Launch 1	---	---	0.7	0.3	0.1	0.1	0.2
Launch 8	---	---	0.7	0.2	0.1	0.1	0.3
STORMSAT	IUS	No	0.5/0.8(6)	0.4	0.1	0.1	-0.1
"	IUS	Yes	0.8/1.2(6)	0.4(7)	0.1	0.1	0.2
SMS/GOES	IUS	No	0.2/0.4(6)	0.9	0.1	0.1	-1.0
"	IUS	Yes	0.4/0.5(6)	0.9(7)	0.1	0.1	-0.7(8)
"	SSUS	Yes	0.3/0.4(6)	0.9(7)	0.1	0.1	-0.8

(1) From returning satellites suffering early failures (infant mortality).

(2) Assuming sequencing of checkout at POCC and RF checkout with ground terminal. This covers equipment plus software [DDT&E and procurement (non-recurring) costs].

(3) Maintenance of checkout equipment.

(4) Returning good satellites because of false alarm.

(5) Assumes infant mortality split before and after upper stage burn.

(6) Higher number assumes all satellite infant mortality occurs before upper stage burn; lower number assumes an even split before and after.

(7) Assumes satellite and upper stage are checked out using same general-purpose equipment.

(8) Negative benefit reduced (to approximately -0.2M$) if high inclination parking orbit is used.

inclination is increased so that RF communications between SMS and Wallops Island is possible from the parking orbit, (2) the upper stage is checked out on orbit as well as the satellite, and (3) the SMS upper stage shares the payload bay with other satellites which are also tested on orbit using the multipurpose on-orbit checkout equipment. Even then, the economic benefits for SMS/GOES satellite on-orbit checkout are marginal.

4.2 STS ANCILLARY EQUIPMENT STUDY

Over the past several years, STS ancillary equipment requirements have been studied by JSC, KSC, MSFC, and a number of NASA and DoD contractors. These studies covered ground support equipment and spaceborne equipment. Both program-unique and multi-mission equipment were studied. The mass of information available was organized and catalogued into a single document by The Aerospace Corporation.

4.2.1 Objective

The objective of this study was to provide a current record describing what is known about STS ancillary equipments and their current status.

Information was drawn from as many sources as possible, but no new data was originated. The emphasis is on ancillary equipments which could be applied to more than one STS user's project.

4.2.2 Results

The output of the effort was an Ancillary Equipment Reference Data Book. It was designed to (eventually) contain sufficient information so that an STS user would be able to evaluate whether the described ancillary equipment could be used for a specific project or whether payload-unique items would have to be designed and fabricated.

4.3 SPACELAB UTILITY FOR DOD

The Skylab Program demonstrated the unique contributions man can make to meet space mission objectives. Throughout the mission, man was crucial in assessing and repairing damage, calibrating and operating equipment, and obtaining and analyzing data. But for the participation of man, few of the objectives of the mission would have been realized.

Manned operations have special significance for future DoD research, development, and test space programs which require advanced and complex instrumentation and new and untested operational modes.

4.3.1 Objective

The objective of this study was to identify and characterize specific manned operations which are applicable to DoD space missions.

4.3.2 Manned Spacelab Activities

Specific Spacelab manned operations which are applicable to DoD space missions are:

a. Setup and assembly of equipment
b. Pre-operations tests of experimental equipment
c. Man/machine interactive operation
d. Malfunction diagnosis
e. Maintenance, repair, and instrument modification
f. Ground/space cooperative tests
g. Visual observations
h. Analysis, interpretation, and reduction of data
i. Test program management and "work around" decision making
j. Recovery of film.

4.3.3 Results

Fifteen Air Force FY 77 Technical Objective Documents (TODs) were reviewed during the course of this study in a search for activities described by the various laboratories and centers which are or could be related to future Spacelab activities. Two activities (shortwave infrared interferometer and ultraviolet spectrometer) in the Geophysics Laboratory TOD could be Shuttle-attached or Spacelab payloads. It is not surprising that only two activities were identified since most of DoD's planning is normally done for a five-year period, which ends just about the time Spacelab flights start. It was found that, in addition to the Air Force Geophysics Laboratory, several other laboratories may have requirements for Spacelab flight in FY 1982 and beyond if a logical extension of their current activities is made.

The Aerospace task of generating ideas, concepts, and uses of Spacelab appropriate for DoD produced potential uses for test and demonstration and some concepts for operation uses. This task considered longer term DoD needs extending out through the early 1990s.

The DoD use concepts are summarized in Table 4-5. About half of the 17 discipline areas represented would prefer launches from WTR; other areas are primarily interested in ETR launches. Only a relatively small number of uses are identified. However, the results should be interpreted in terms of areas of activity, any one of which may fly more than one sensor or set of equipment and more than one flight on Spacelab. Potential operational uses are listed in the classified appendix of report ATR-77(7373-01)-2, Spacelab Utility for DoD Final Report (Study 2.2).

For military terrestrial operations there are testing grounds, i.e., rifle ranges; mortar, bomb, and artillery ranges; road test, off-road test areas; flight test areas; etc. Spacelab could be very useful to the military in this sense as the key element in a low altitude earth orbit test range for space-based equipment.

Table 4-5. Spacelab Use Concepts for DoD in the Test and Demonstration Area - Summary of Number of Uses

	Number of Uses	
Use of NASA Spacelab Facility for DoD Experiments	9	Facilities are AMPS (possible FY 79 start), Space Processing (possible FY 80 start).
Use of Spacelab Primarily Because of Man's Presence (Excluding Spacelab Facilities Above)	23	Man erects, operates, selects, coordinates, compares, points, conducts surveys, establishes patterns, tracks, programs, monitors.
Use of Spacelab Primarily Because of Shuttle Payload Bay Size and Payload Weight	9	Many could use Shuttle with or without Spacelab.
Use of Spacelab Primarily Because of its Return Capability	2	(1) Measurements during orbiter reentry. (2) Bring back film and recorded data.
Possible Use of Spacelab for "Economic" Reasons	23	Most economies are expected to be due to man's abilities, return and reflight of experiments/instruments, elimination of experiment supporting spacecraft.

5. TECHNOLOGY ASSESSMENT AND NEW OPPORTUNITIES (STUDY 2.3)

Many space technology programs serve to satisfy both DoD and NASA requirements, and it is important to maintain close coordination between the two government agencies to avoid duplication of effort. A detailed DoD technology assessment (up to and including a classification of secret) was made by The Aerospace Corporation to determine which DoD advanced technology programs have application to NASA needs.

5.1 OBJECTIVE

The objective of this study was to survey and assess DoD-supported technology programs through the year 2000.

The results enable NASA to review (and possible modify and/or enhance) its own future programs in the light of knowledge of DoD programs. They also help to reduce duplication of effort between military and civilian agencies.

5.2 SCOPE

The primary output of the study was an exhaustive collation of DoD technology data up to and including a classification of secret, covering the fields of strategic and tactical surveillance, navigation, meteorology, communications, and various special-purpose space applications. A list of the near-term technology programs that were covered is given in Table 5-1. Table 5-2 lists the far-term programs. Both passive and active sensor systems were considered. The technologies covered in these two groups are outlined in Figure 5-1 and 5-2, respectively.

5.3 RESULTS

The trend to increase passive sensor resolution is towards the multimega element focal plane array, using advanced CCD (Charge Coupled Device) technology.

Table 5-1. Near-Term (1975-1985) DoD Technology Programs

SURVEILLANCE

- DSP Follow on
- Optical System Development
- Focal Plane Development
- Sensor Concept and Component Development

LWIR

- CCD at LWIR
- Low Noise Detector/Amplifier
- Multi-Band Technology
- Sensor Out-of-FOV Rejection

SPACE SURVEILLANCE AND DEFENSE

- Solid-State Detector
- Cryocooler
- Satellite Attack Warning
- System Development
- Phenomenology and Advanced Technology

SPACE SYSTEM SURVIVABILITY

- Optical Warning Sensor
- Radiation Sensor
- Countermeasures
- Hardened Electronics
- Laser Vulnerability and Hardening
- Survivability Satellite Airborne Control Facility
- Satellite Observable Control

S/C GUIDANCE, PROPULSION, CONTROL

- Autonomous Navigation Technology for Low/High Altitude
- UV Radiometer
- Precision Attitude Gyro
- Electrostatically Suspended Accelerometer

METEOROLOGICAL SATELLITE TECHNOLOGY

- Cloud Composition Analyzer
- Ionosonde Antenna
- Microwave Technology
- Sea-State Monitor
- Ionosonde Data Processing
- Nuclear Survivability

SPACECRAFT SUPPORT AND SYSTEMS

- Improved Solar Cells
- Secondary Battery
- Fuel Cell
- Spacecraft Charging (Scatha)

COMMUNICATION

- Laser Communication
- EHF Communication
- Narrow Beamwidth
- Multibeam Antenna
- Variable Beamwidth Antenna
- Solid-State Amplifiers and Oscillators

INFORMATION PROCESSING AND TRANSFER

- High Speed Data Buffer and processor
- Fault Tolerant Spacecraft Computer
- Computer Program Verification and validation
- Improved Magnetic Bubble Storage
- Tape Recorders

Table 5-2. Far-Term (Through CY 2000) Technology Projections

- Data Rate Projections and Associated Signal Processing/ Compression Techniques*
- Computer Technology*
- Software*
- Visible, NWIR, MWIR, LWIR, FIR Sensor Technology*
- Cryogenic Cooling*
- Adaptive Optics*
- Microwave Sensor Systems and Components*
- Guidance, Attitude Determination and Control*
- Material Technology (Contamination Control, Heat Shields, Ablation Sensors)*
- Solid-State RF Devices (All Solid-State Radar)*
- High Power Microwave Devices (Intense Relativistic Electron Beam)*
- Multifunctional Space-Based Radar*
- Super-Schottky Diode and Low Noise 10-60 GHz Receiver
- Far-Infrared Heterodyne Radiometer*
- Far-Infrared Lasers
- Single and Multiple Resonant Distributed Feedback Semi-Conductor Laser*
- Solid-State Space-Based Lasers*
- Trace Gas Determination
- Visible Chemical Lasers*
- Efficient UV Lasers*
- Millimeter Wave Radiometric Imaging*
- Mode Locked Lasers (Laser Fusion, Laser Plasma Diagnostics, X-Ray Laser)
- GPS Technology (Atomic Clocks, Surface Acoustic Wave Devices, Null Steering Antennas)

*Techniques are Applicable to Sensor Design and Deployment

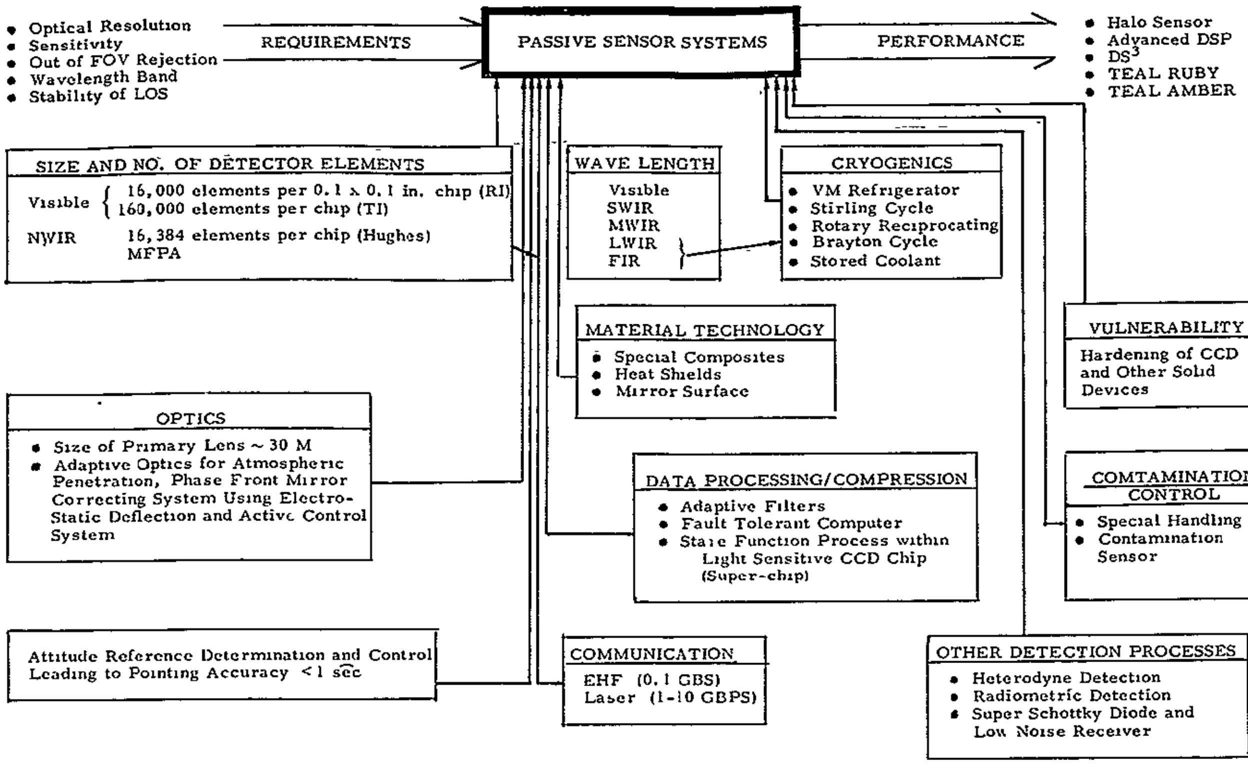


Figure 5-1. Passive Sensor Systems and Associated Technology

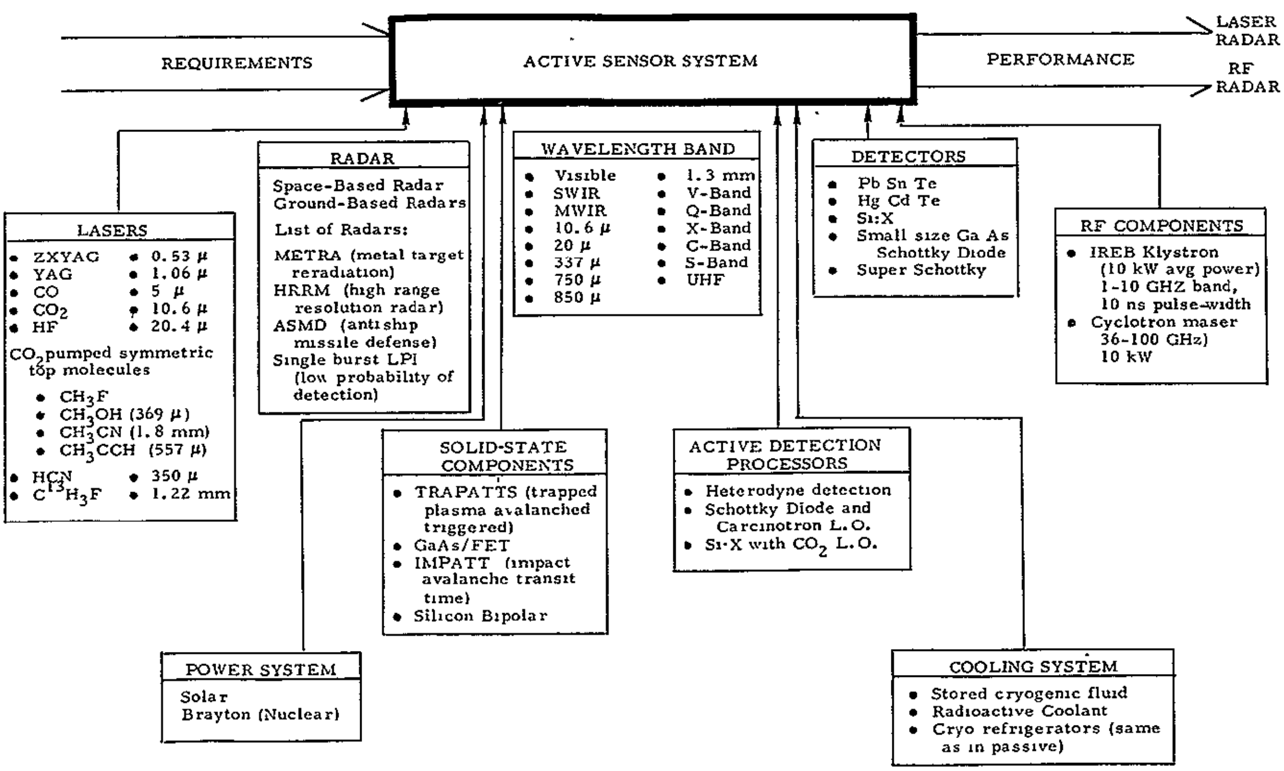


Figure 5-2. Active Sensor Subsystems and Associated Technology

Spectral selectivity can be increased by using acousto-optic and electro-optic tunable filters. The major trend in active sensors is towards adaptive optics enabling large optics (30 to 100 meters) of high figure quality to be designed.

The development of lasers capable of generating lines in the 20-μ to 1-mm spectral region and corresponding receivers using Schottky barrier diode mixers to achieve high sensitivity over wide bandwidths will permit all-weather imaging and communication. Table 5-3 gives the characteristics of a multi-line system. Laser and RF radar are expected to be viable techniques within a period of 10 to 20 years.

On-board data processing and data compaction is being actively pursued by DoD. Another important area of emphasis is the technology associated with achieving accurate attitude reference and Figure 5-3 lists the attitude reference requirements for a number of potential DoD future missions.

MISSION	ORBIT	REFERENCE ACCURACY	TIME PERIOD
S-A	Sync. Equatorial	5-8 sec	1980-1985
S-B	Sync. Equatorial	0.4-0.6 sec	1980-1985
S-C	Sync. Equatorial	0.5-1.5 sec	1980
S-E	1 K nmi	7-11 sec	1980-1985
S-F	Sync. Equatorial	0.2-0.4 sec	1980-1985
S-G	Sync. Equatorial	80-100 sec	1980-1985
S-H	Sync. Equatorial	5-7 sec	1985-1990
C-B	5 X Sync. Equatorial	50-60 sec	1985-1990
C-D	Sync. 30 deg Inclined	20-28 sec	1980-1985
C-E	Sync. Equatorial	18-20 sec	1980-1985
C-F	Sync. Equatorial	2-3 sec	1985-1990
M-C	Sync. Equatorial	60-90 sec	1980
M-E	Sync. Equatorial	1-2 sec	1985-1990
M-G	Sync. Equatorial	0.02-0.04 sec	1990-1995

Space sextant high altitude navigation and attitude reference system

ADVANCED COMPONENTS

- Precision attitude gyros
- Electrostatically suspended accelerometer
- UV Radiometer
- Magnetically suspended reaction wheel

- On-Board computer capable of supporting multiple navigation subsystems and associated sensors

Figure 5-3. High Attitude Reference Technology Programs

Table 5-3. LWIR and FIR Imaging Sensor Performance

OPERATION:	LWIR and FIR radiation emitted in narrow beam scanning target area in two-dimensional raster: reflected radiation impressed upon imaging display.
10.6 μ	Efficient CO_2 with HgCdTe detectors available at $77^{\circ}K$; atmospheric turbulence will limit maximum aperture to about 15 cm; effective in rain (5 dB/nmi; 25 mm/hr; 0.06 gm/m^3). However, in fog, range is under 1 km for median fog droplets of $\sim 5\,\mu$ (0.1 gm/m^3 density; 50 dB/nmi)
20 μ:	HF laser with $Hg_{0.82}\,Cd_{0.18}Te$ detector; less satisfactory than the 10.6 μ system because of increased attenuation in clear weather; slightly better ability to penetrate fog but range still unsatisfactory
337 μ:	HCN laser with small area GaAs Schottky diode at room temperature; least desirable system because of large atmospheric attenuation; the range is < 1 km even in clear weather
750 μ:	CH_3CCH laser and small area Schottky diode; attenuation in clear weather and fog improves dramatically over 337 μ; same as 10.6 μ system in rain
850 μ:	$C_2H_2F_2$ laser and Schottky diode mixer with carcinotron local oscillator can operate in the six bands
1.3 mm:	Penetration through clear weather and fog exceedingly good; penetration through rain slightly better than 850 μ/$C^{13}H_3F$ laser or small area InSb electron bolometer or small area Schottky diode
CONCLUSIONS:	Use multiband system: for rain and snow, the six bands are nearly independent of wavelength; the 1.3 mm system is best in fog.

6. STANDARDIZATION AND PROGRAM PRACTICES ANALYSIS (STUDY 2.4)

Program Practices are defined as the non-hardware related activities within a project. The activities support the development, production and operation of the flight hardware (program management, system engineering, quality assurance and testing). This study quantifies such activities in order to examine the effectiveness of these accepted practices. The effort evaluates each program practice by determining its function, effect and cost. These attributes are quantified by examining a large sample of spacecraft representing DoD and NASA programs. In addition to the non-hardware activities, the study examines the use of previously developed and qualified components.

6.1 OBJECTIVE

The objective of this study was to assist the NASA Low Cost Systems Office to reduce satellite program cost by: (1) the identification of cost-effective program practices; and (2) the analysis of the use of previously developed programs.

6.2 SCOPE

The program practices task was performed by: (1) collecting spacecraft cost and technical data, (2) reducing and categorizing data into a uniform format, and (3) statistically analyzing the data to identify effective practices. The cost data analysis developed a common work breakdown structure (WBS) to assure consistency in content of each program practice activity and separated the cost of each program into common WBS categories. Adjustments were made for variations in production quantities, program start dates and prime contractor scope.

Technical data were quantified by establishing the complexity and program success index. The complexity index consists of an aggregate of parameters that, when combined, describe a spacecraft design. Quantified parameters with appropriate weightings were summed to derive an aggregate complexity index for each spacecraft program shown in Table 6-1. Program success index was determined for each spacecraft by considering its performance in orbital operation and in meeting planned schedule and cost objectives. These performance measures were weighted before they were summed to determine an aggregate program success index. Orbital performance was measured by both number and severity of flight anomalies. Schedule and cost performance were measured by a ratio of planned to actual outcomes.

Table 6-1. Program Practices Data Base

PROGRAM	AGENCY	TYPE	MISSION	FIRST LAUNCH	CONTRACTOR
Pioneer F/G	NASA	Scientific	Jupiter Explorer	1972	TRW
ATS-F	NASA	Scientific	Communication	1974	Fairchild
Nimbus E/F	NASA	Operational	Meteorology	1972	GE
OSO-I	NASA	Scientific	Solar Observ.	1975	Hughes
ITOS-1	NASA	Operational	Meteorology	1970	RCA
SMS	NASA	Operational	Meteorology	1975	Philco Ford
STP (P72-1)	DoD	Scientific	Experiments	1972	Boeing
STP(S-3)	DoD	Scientific	Experiments	1974	Boeing
DSP Phase I	DoD	Operational	Earth Observ.	1970	TRW
DSCS II	DoD	Operational	Communication	1971	TRW
STP (P72-2)	DoD	Scientific	Experiments	1975	RI

Cost data, spacecraft complexity indexes and performance measures were used to identify cost reducing and success improving program practices. Linear regression analysis was applied to a sample size of eight to nine data points for each program practice to determine the existence of any correlation.

Analysis of the use of previously developed components was accomplished by: (1) cataloging housekeeping components from DoD, NASA and commercial programs in an equipment compendium, and (2) applying the cataloged components to NASA new starts. The developed components analysis was a continuation of work performed over a two-year span and dealt with cataloging qualified components from the 27 current or recent satellite programs listed in Table 6-2 and the analysis of six new starts.

6.3 RESULTS

The activities that comprise program practices represent about 34 percent of spacecraft cost. Spacecraft cost for this analysis is defined as total development plus first unit production. The distribution of average cost of activities is: 8 percent for program management, 7 percent each for system engineering and quality assurance, and 12 percent for testing. The balance (66 percent) is attributable to hardware cost.

The correlation between spacecraft cost and spacecraft complexity index is shown in Figure 6-1. The upper shaded area encompasses all of the NASA and operational DoD programs. The lower shaded area covers only DoD space test programs. The cost trend shows that substantial savings can be achieved by designing spacecraft for low complexity. Data point identifications are deleted from the figure to keep the report non-proprietary.

Development phase program management is related to program success in Figure 6-2. Increasing management improves program success. Data points outside the shaded area of Figure 6-2 are programs having special situations, such as a follow-on to an existing spacecraft design or an abnormally large amount of subcontracted effort. Program success did not correlate during the production phase, which suggests that if production management is reduced, there is little likelihood that program success will be adversely affected.

A reduction in flight anomalies was observed with increasing quality assurance effort and test thoroughness during the production phase. Test thoroughness is an index that reflects the sum of the relative importance of each phase of a total test program, that is, development, qualification, acceptance and launch site testing. Flight anomalies also decreased

Table 6-2. Equipment Compendium Data Base

NASA		
N1	Orbiting Solar Observation	OSO-1
N2	Atmosphere Explorer	AE-C
N3	Small Astronomy Satellite	SAS-C
N4	Improved TIROS Operations System	ITOS-D
N5	Synchronous Meteorological Satellite	SMS
N6	Application Technology Satellite	ATS-F
N7	Nimbus F	Nim
	Earth Resources Technology Satellite	ERTS
N8 (*)	International Ultraviolet Explorer	IUE
N9 (*)	High Energy Astronomy Observatory	HEAO
N10(*)	Viking 75 Project Lander	MV 75
N11(*)	Pioneer F/G	
DoD		
D1	Fleet Satellite Communications	FSC
D2	Space Test Program, Flight 72-1	P72-1
D3	Space Test Program, Flight 72-2	P72-2
D4	Space Test Program, Flight S3	S3
D5	Defense Satellite Communication System	DSCS-II
D6	NATO Phase III	NATO-III
D7	Defense Meteorological Satellite Program, Block 5	DMSP
D8	Defense Space Program, Model 35	DSP
D9	Space Test Program, Flight 71-2	P71-2
D10(*)	NAVSTAR Global Positioning System	GPS
D11(*)	Navy Technology Satellite	NTS-2
Commercial		
C1(*)	Westar	
C2(*)	Anik	
C3(*)	Intelsat IVA	
C4(*)	Comstar	
C5(*)	Geosynchronous Meteorological Satellite	GMS

*Cataloged in FY 76 NASA Study (Contract No. NASW-2727)

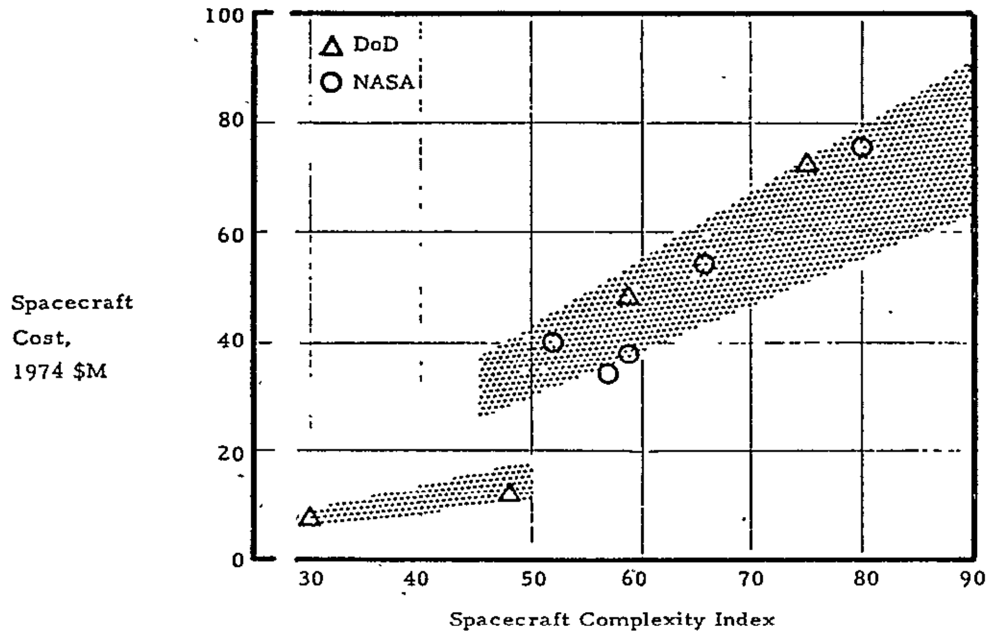


Figure 6-1 Spacecraft Cost as a Function of Complexity

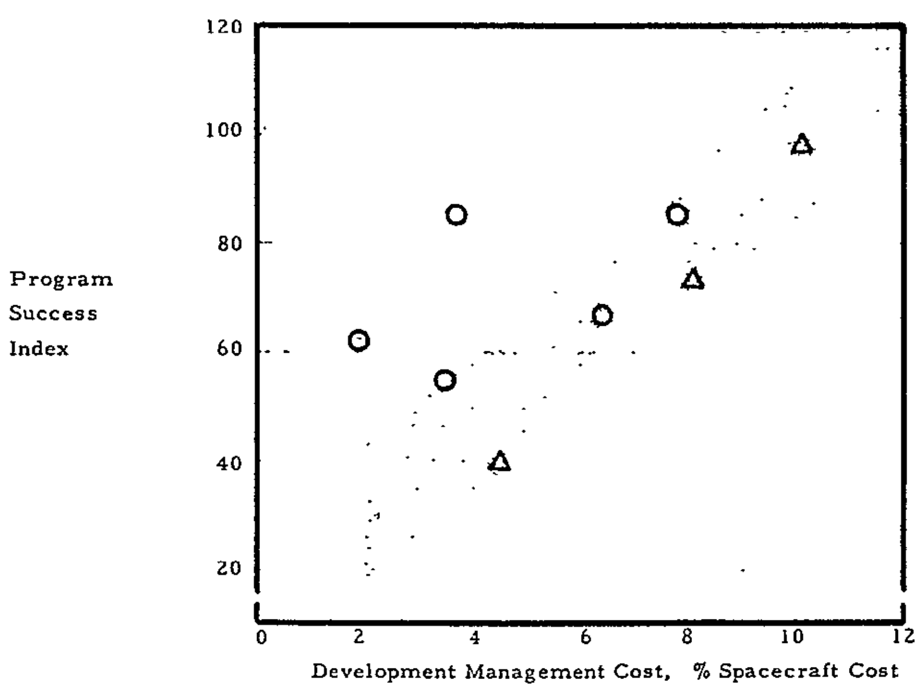


Figure 6-2 Program Success vs Percent Development Management

with increasing acceptance test cost. In addition, it was observed that programs employing the protoflight test concept produced comparable flight performance with programs using the prototype test concept.

In the Equipment Compendium, over 600 developed and qualified components that are producible or available as spares are cataloged. The compendium is designed to provide concise developed components technical information in one document. Technical information for each component consists of key design characteristics, environmental capability, and component application.

The analysis of previously developed components for application to new starts indicated that over 50 percent of the components can use units listed in the catalog. In order to increase the number of developed components, it was necessary to investigate alternative subsystem concepts that were used in past spacecraft and, therefore, could use more components from the catalog. In the case of the Jupiter Orbiter Probe, the baseline Data Handling design is based on microprocessor technology. By employing a centralized computer, which is available as standard NASA equipment, the use of developed components can be increased from 58 percent to 76 percent. Analysis of the Multimission Modular Spacecraft resulted in a similar conclusion. The baseline electrical power design is a direct power transfer system which charges batteries in parallel and is not the type of power control that has been widely used on other spacecraft. An alternate design, which charges each battery individually, reflects common practice and therefore has more components available from the catalog.

6.4 CONCLUSIONS

Based on empirical and statistical evidence, cost effective spacecraft program practices have been identified. Those practices leading to improved program success are:

a. Program Management - Program success improves as the relative proportion of total cost devoted to management during the development phase is increased. An acceptable range is 8 to 10 percent of spacecraft cost.

b. Quality Assurance - Flight anomalies decrease as spacecraft production quality assurance efforts increase. The resources applied should be 2 to 4 percent of spacecraft cost.

c. Acceptance Testing - System acceptance testing is an effective way to reduce flight hardware anomalies. Flight anomalies decrease as the resources applied to acceptance testing are increased.

The practices that result in cost reduction without affecting program success are:

a. Spacecraft Design - Substantial reductions in spacecraft cost can be achieved by reducing spacecraft complexity. However, payload requirement needs must be analyzed and screened to assure that a low complexity spacecraft design will provide required capability.

b. Program Management - Management activities should be reduced significantly during the production phase from the level used during development to between 2 and 3 percent of spacecraft cost.

c. Protoflight Concept - System qualification tests should be performed on the first flight spacecraft. Flight hardware anomalies tend to be associated with the prototype concept.

d. Developed Component - Use of developed components should be encouraged. The equipment compendium provides a standard reference source of DoD and NASA developed components.

7. INTEGRATED STS OPERATIONS PLANNING (STUDY 2.5)

The STS offers a unique capability for exploiting the benefits of space, and its effective use is an important consideration in any future planning of STS operations. It is therefore important to consider the options available to manage this resource for the benefit of all users.

It is assumed that NASA will retain its management responsibility for STS through the developmental period and subsequent transition to steady-state operations. It is the next step that is of interest: establishment of an operational management concept that best achieves the overall program objectives. An assessment of the operational management options was made by The Aerospace Corporation.

7.1 OBJECTIVE

The objective of this study was to develop a technique for assessing the merits of each STS operational management option relative to a complete option set.

The problem is complex and typical of issues that must be resolved by top level management. The decision process involves values of the decision maker that are not always obvious to others. These values may also change quite rapidly (depending on such factors as the prevailing political environment) and therefore the decision process is, under most conditions, very subjective. In spite of this, the decision process visibility must be maintained along with consistency in ranking the various options. Also it is desirable to provide, to the greatest extent possible, a quantifiable measure of the likes and dislikes of the decision maker.

7.2 MANAGEMENT OPTIONS

Seven candidate management options were identified and their primary characteristics are listed in Table 7-1. Assessment of the options requires consideration of the principal parties involved in STS operations viz; NASA, DoD, and Congress, and also of the STS program objectives interpreted as:

a. Reduce cost of future space operations by more efficient use of resources.

b. Expand horizons to include larger segment of society and generate potential for increased public benefits.

c. Provide capability to stay at the forefront of space exploration and maintain leadership in the field.

d. Support international policies and goals by cooperation in the peaceful use of space.

Table 7-1. Management Alternatives

STS MANAGEMENT CONCEPTS		PRINCIPLE FEATURES				
OPTIONS	DEFINITION	EASE OF TRANSITION	AVAILABLE RESOURCES	REDUCED NASA BURDEN	RESPONSE TO NAT'L EMERGENCY	RESPONSE TO USERS
1. NASA (CURRENT)	• EVOLVES FROM R&D TO OPERATIONAL ORGANIZATION	✓	✓			
2. NASA (MODIFIED)	• SEPARATE STS OPERATIONS DIVISION		✓			✓
3 NASA - CONTRACTOR/OPERATOR	• SMALL NASA MANAGEMENT ORGANIZATION - CONTRACTOR OPERATES STS SYSTEM			✓		✓
4 NASA/DoD	• MANAGEMENT BOARD WITH SHARED OPERATIONS RESPONSIBILITY				✓	
5. SEPARATE AGENCY	• NATIONAL SPACE TRANSPORTATION AGENCY			✓		✓
6. COMMERCIAL OPERATIONS - "A"	• AMTRAK QUASI-PUBLIC AGENCY			✓		✓
7. COMMERCIAL OPERATIONS - "B"	• COMSAT QUASI-PUBLIC AGENCY			✓		✓

7.3 RESULTS

The values used in the assessment were established by a NASA study team. The analysis was performed by The Aerospace Corporation. Intuitive feelings towards a given option are not necessarily borne out by analysis, as outlined in Table 7-2.

Table 7-2. Intuitive vs. Counter Intuitive Findings

INTUITIVE	OPTION	COUNTER/INTUITIVE
• HIGHLY QUALIFIED AND MOTIVATED ORGANIZATIONS	NASA (CURRENT) NASA (MODIFIED)	• BURDEN ON NASA BUDGETS AND MANPOWER • DILUTES R&D EFFORTS • TOP HEAVY ORGANIZATION
• LOSS OF CONTROL • INEFFICIENT OPERATIONS	NASA-CONTRACTOR	• RETAINS POLICY RESPONSIBILITIES • PROFIT MOTIVE INCREASES RESPONSE TO USERS
• EQUAL RESPONSIBILITIES • NASA BUDGET RELIEF	NASA-DoD	• CUMBERSOME ORGANIZATION UNDER MOST SCENARIOS • UNORIENTED TO PROGRAM OBJECTIVES
• DEDICATED TO PROGRAM OBJECTIVES	SEPARATE AGENCY	• CONGRESSIONAL PREFERENCE IS TO RESTRAIN FEDERAL BUREAUCRACY
• INVESTMENT TOO GREAT TO HAND OVER TO PRIVATE ENTERPRISE	COMMERCIAL "A" AMTRAK COMMERCIAL "B" COMSAT	• PROFIT MOTIVE LEADS TO INCREASED EFFICIENCY FOR ALL USERS • OPERATIONS vs DEVELOPMENT

The results of the analysis indicate that Option 3 (NASA-Contractor/Operator) is the preferred approach. However, it is not possible to rationalize the significance of this choice without a quantitative ranking of the remaining options. The ranking is shown in Figure 7-1 for five different scenarios where the maximum achievable value is 1000 points.

The NASA personnel who participated in the final evaluation are listed in Table 7-3. In each instance the participant was expected to express what was best for the program, not what was best for NASA, or DoD, or any other agency. The most significant result is that a strong preference exists within NASA middle management to minimize the involvement of NASA in day-to-day operations while still retaining executive management control.

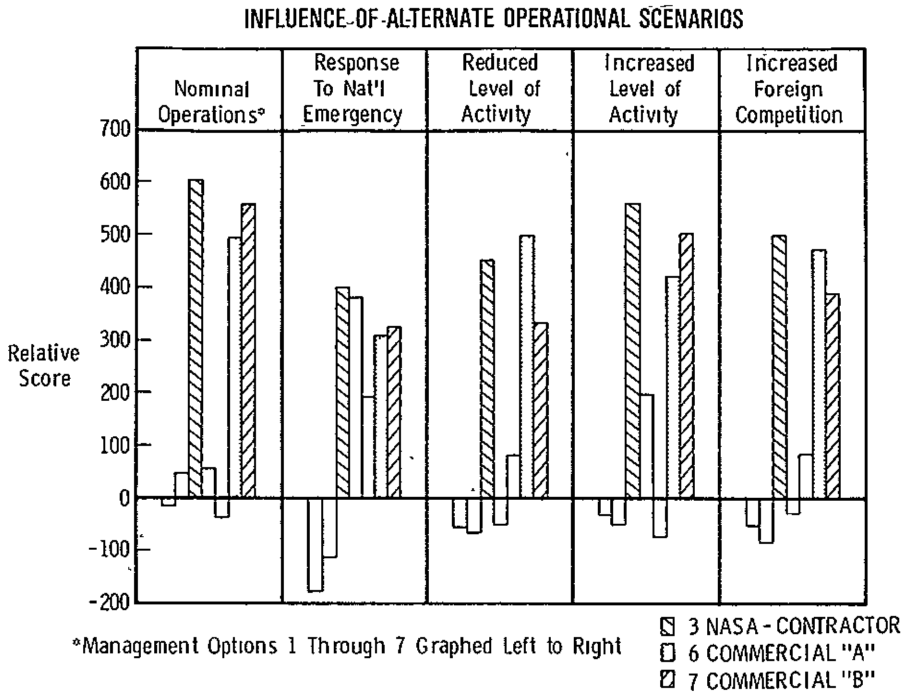


Figure 7-1. Study Results

Table 7-3. Participating NASA Personnel

NASA Participant (Judge)	Position
C. M. Lee	Director - STS Operations
R. O. Aller	Dep. Director - STS Operations
J. M. Smith	Study Director - Phase I
R. F. Heuser	Study Director - Phase II
M. S. Malkin	Director - Space Shuttle
D. R. Lord	Director - Spacelab
W. C. Schneider	Dep. Assoc. Adm. - Office of Space Flight

7.4 CONCLUSION

Ranking of the seven management concepts occurs in two distinct groups for each of the five scenarios. The first group consists of Options 3, 6, and 7.

Although Option 3 consistently ranks first, the point spread is sufficiently small that discrimination between the three concepts is difficult without further work. The following summarizes the value judgments expressed by those participating in the assessment process:

a. NASA should utilize its resources for research and scientific endeavors and minimize the burden of routine operational support.

b. Selection of any one of the three highest ranking options represents a rational compromise for supporting DoD operations. NASA would not be directly involved with classified operations.

c. The profit motive is a strong incentive to achieve efficient operations and reduce user costs.

d. The profit motive provides an inducement to treat users in a fair and impartial manner, since loss of a customer immediately reflects loss of revenue and profit.

e. The profit motive enhances the competitive posture of STS operations relative to terrestrial alternatives.

f. The three preferred concepts are less sensitive to annual budget fluctuations and therefore could effectively provide continuity of planning and commitments.

8. SPINNING SOLID UPPER STAGE (SSUS) FOR DELTA AND ATLAS/CENTAUR CLASS MISSIONS (STUDY 2.6)

The spin-stabilized Shuttle upper stage was proposed in 1974 and resulted in an Aerospace Corporation and a Hughes Aircraft study in FY 75. These studies addressed the feasibility of spin stabilizing a stage deployed from the Orbiter. Various methods of obtaining the stabilization, injection accuracy, satellite modifications, and design characteristics associated with the use of a spin-stabilized stage were examined.

It was concluded that the SSUS concept was feasible and appeared to be a cost-effective alternative to the interim upper stage (IUS) and to the full capability Tug, particularly for the Delta and Atlas/Centaur class missions which represent a high proportion of the NASA and commercial satellite traffic. More detailed analysis was recommended and The Aerospace Corporation was contracted to conduct a follow-on effort with emphasis on the Delta and Atlas/Centaur class missions.

8.1 OBJECTIVES

The objectives of this study were:

a. Provide planning data to support NASA feasibility and economic assessment of the SSUS

b. Recommend the most promising SSUS concept for Delta and Atlas/Centaur class payloads

c. Define the potential economic and technical advantages of having the SSUS augment the IUS system

d. Establish the SSUS relationship to the IUS system/components with emphasis on commonality

e. Determine the major impacts on spacecraft programs that utilize the SSUS

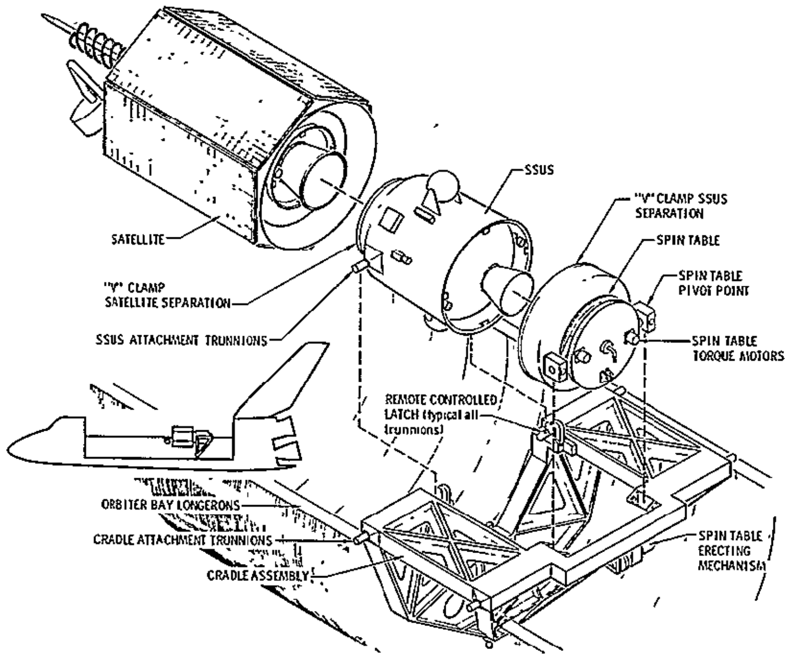
f. Provide an early assessment (75 days) of an Intelsat V SSUS system.

8.2 RESULTS

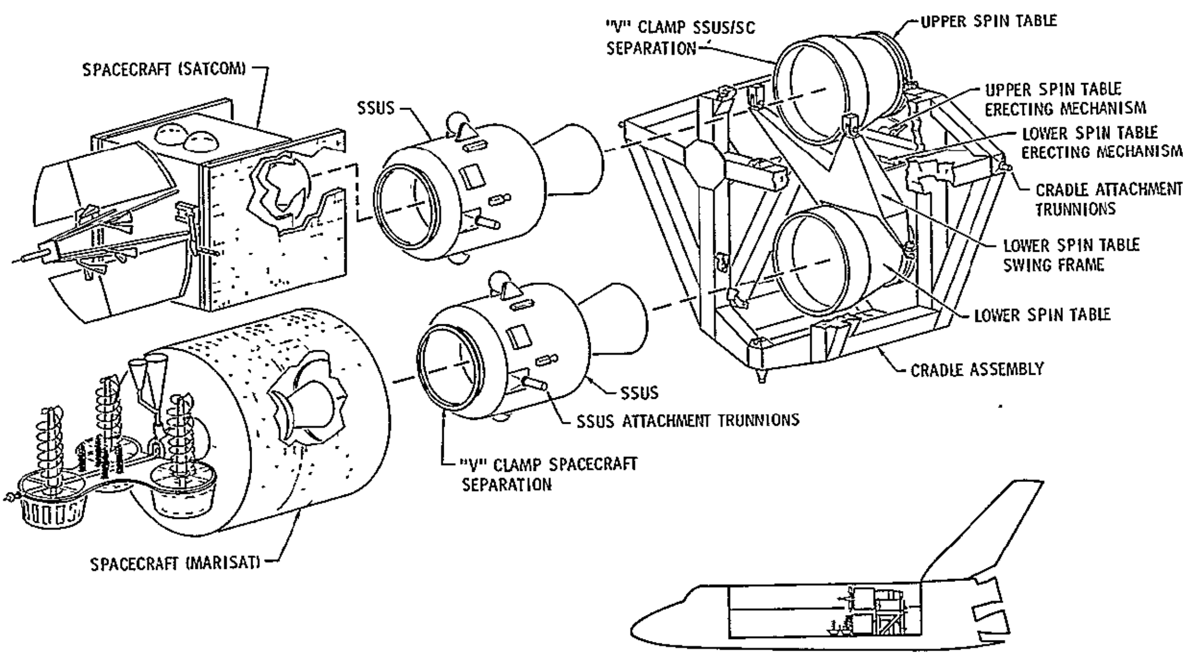
The SSUS concepts which resulted from the study are illustrated in Figures 8-1 (a) and 8-1 (b). They both utilize single solid rocket perigee kick motors (PKM), one of about 3300-kg mass for the Atlas/Centaur class and one of about 1630-kg mass for the Delta class. These motors, with attached spacecraft and SSUS subsystems, are spin stabilized to a maximum of 60 and 100 rpm, respectively, using a tilting spin table driven by redundant electric motors. The same spin table was used for both concepts. The satellite, SSUS, and spin table are mounted on a one-piece cradle having two attach points on each Orbiter longeron and a single keel fitting attachment. The SSUS-A (Atlas/Centaur class) mounts a single system in the cradle while the SSUS-D (Delta class) mounts two systems (one above the other on the cradle).

A single cylindrical structure of aluminum skin and stringer construction surrounds the SRM and interfaces with the spin table and spacecraft. The cradle mating trunnions and other subsystems are mounted on this structure. Avionics consist of a redundant sequence timer, batteries, separation systems, and an ANC (active nutation control - kitable option) system. The stage mechanical system consists of a small GN_2 sphere, regulator, control valve, and nozzle for the ANC and a YO-weight destabilization system. The ANC system is a necessary option kit for spacecraft having high energy dissipation rates and consequently high nutation during the coast period prior to SSUS motor firing, while the YO-weight device is used to destabilize the burnt out SSUS after spacecraft separation.

SSUS injection accuracy studies for both SSUS-A and -D indicated final orbit injection accuracies [after spacecraft apogee kick motor (AKM) burn out] equivalent to present Atlas/Centaur and Delta experience. Pointing errors during the AKM burn are determined by the satellite, while those during the SSUS PKM burn are determined by the Orbiter pointing of the SSUS cradle and SSUS stability during coast after



(a) Atlas Centaur Class Payloads, SSUS-A



(b) Dual Delta Class Payloads, SSUS-D

Figure 8-1. Spinning Solid Upper Stage/Spacecraft System deployment. Studies of the Orbiter pointing indicated that as long as a maximum 2-deg error in Orbiter payload bay to Orbiter navigation base alignment is achieved excellent accuracy is achievable. Greater errors could require an auxiliary star tracker mounted on the SSUS cradle.

The two SSUS designs provide interfaces which exactly duplicate the standard Atlas/Centaur and Delta interfaces. The SSUS interfaces with the Orbiter are limited to the cradle mechanical attachments, simple electrical controls for elevating and powering the spin table motors, and a minimum electric power and monitoring interface with the SSUS. No fluid connections are required. The SSUS sequence timer system is initiated by the Orbiter-generated separation signal routed through redundant SSUS separation switches on the spin table interface.

For the contamination levels assumed, safe separation distances of approximately 7 km for SSUS-A and 4.2 km for SSUS-D with angles of 25-30 deg between the Orbiter slant range vector and the plume axis are required. These distances can be achieved in 1/2 revolution of the parking operation (45-min coast) with a 0.3-mps SSUS separation velocity and additional Orbiter velocity maneuvering of about 0.5 mps. The sequence timer primary timing signal thus consists of a 45-min SSUS separation to SRM firing signal interval. This time becomes an important parameter for nutation studies, ANC, and operational timelines. Operations both in flight and on the ground were found to be very simple and low cost.

The SSUS study resulted in sufficient information to permit bypassing a Phase A definition contract and direct committal to Phase B hardware development. However, several space system contractors have offered to develop and build the SSUS as commercially funded ventures. Currently, both the McDonnell Douglas Corporation and the Boeing Company have signed agreements with NASA on the terms of such developments.

The first 75 days of the SSUS study were directed at achieving a detailed preliminary design suitable for the Intelsat V communication satellite. This goal was achieved and the Comsat Corporation and Intelsat Consortium subsequently committed the Intelsat V spacecraft to transition from the Atlas/Centaur expendable launch vehicle to the STS using the SSUS-A.

8.3 CONCLUSIONS

The study achieved its objectives and surpassed the expectations of the study team by clearly identifying two simple, low cost, highly reliable upper stage systems for the STS. NASA mission model capture analyses resulted in 173 SSUS flights and 19 IUS missions (16 escape missions) for the 1980-1991 time period. The SSUS system is ideally suited to the transition of Delta and Atlas/Centaur class satellites from expendable launch vehicles to the STS with minimum technical risk and cost impact.

9. INTEGRATED PLANNING SUPPORT FUNCTIONS (STUDY 2.7)

A large number of space initiative concepts have been identified in the recent past. Though their general impact on needed transportation and support vehicles is understood, additional and specific planning information on the earliest need dates for each type of initiative is needed.

9.1 OBJECTIVE

The objective of this study was to define requirements for space transportation and orbital support facilities based on time-phased development plan milestone data generated for logically grouped sets of initiative system concepts. The data were to be prepared in a form suitable for NASA to use in defining programs in space industrialization. At least two alternative program plan options were to be treated and the categories of space processing, communication, and space power included as a minimum.

9.2 APPROACH

All the initiatives identified in previous studies were grouped into the eleven functional groups listed in Table 9-1 to enable a time-phased development to be generated for each functional grouping. Examples of the time-phased developments for three of the groupings are given in Figures 9-1, 9-2, and 9-3. The corresponding time-phased needs for transportation and orbital support facilities were then identified for each group and examined to derive the study output. The study output includes: (1) the earliest date on which a support element is needed; (2) identification of those initiative groupings which would require a Space Construction Base or other permanent manned facility as opposed to Sortie operations supported by the Shuttle; and (3) identification of those initiative groupings which would require more advanced transportation systems and support facilities.

Table 9-1. Initiatives in Groups

GROUPS	TYPICAL INITIATIVES INCORPORATED			
	NASA 5-YR PLAN	OFS[1]	AEROSPACE[2]	NASA STUDIES
1 Public Service Systems Using Microwave Multibeam Antennas	- Search and Rescue - Public Service Broadcast	- Domestic/Mobile Communications - Personal Communications	- Personal Communications - Electronic Mail - Military-Communications	---
2 Public Service Systems Using Long Microwave Antennas with Stationkept Subarrays	---	---	- Vehicle/Package Locator - Border Surveillance - Military Logistics Locator	---
3 Active/Passive Radar and Power Distribution Systems	- Seasat A, B	- Long Wavelength Microwave Systems - Large Scale Weather Survey	- Coastal Radar - Hi Resolution Microwave - Military Observation	---
4 Observation and Designation Systems Using Low Altitude Optics	- Radiation Budget Satellite - Large Telescope	- Tropospheric Monitor Sat - Very High Resolution Survey	- Atmospheric Profile Sat - Ocean Resources System - Military Observation	---
5 High Altitude Navigation and Location Systems	- Search and Rescue Satellite - VLBI	- Advanced Navigation and Communication System	- Personal Navigation - Package Locator	---
6 Observation Systems Using Synchronous Optics	---	- Large Scale Weather Survey - Synchronous Earth Observatory	- Forest Fire Detection - Earthquake Prediction Laser - Military Observation	---
7 Space Processing and Manufacturing	- Sounding Rocket Experiments - Spacelab Tests of Integrated Facilities	- Spacelab Facilities - Space Station Facilities	---	Hq MSFC Space Industrialization Materials Processing
8 Large Scale, High Energy, Far-Term Systems	- SPS Technology Advancement - SPS Subscale Orbital Verification	- SPS Test Activity - Power Relay Testing	- Power Distribution - Nuclear Waste Disposal - Military Devices	Hq MSFC JSC Studies on SPS Definition, Large Structures, HLLV etc
9 National Operations Facilities	---	- SETI - High Energy Observatories	- Microwave Detection Facility - Space Observatory	- SETI
10. Planetary Missions	- Jupiter/Saturn - Venus Orbiting Imager	- Mars Lander - Comet Sample Return	---	---
11. Scientific and Research Experiments	- Solar Maximum Mission - Gravity Wave Detector	- Fotsos Effects - UV Telescope	- Astronomical Super-telescope - Picosecond Laser	- Biological Research Life Sciences

(1) Outlook for Space NASA Report SP-386, January 1976.
(2) Advanced Space Concepts and Their Orbital Support Needs (1980-2000), Aerospace Report ATR-76(7365)-1, April 1977.

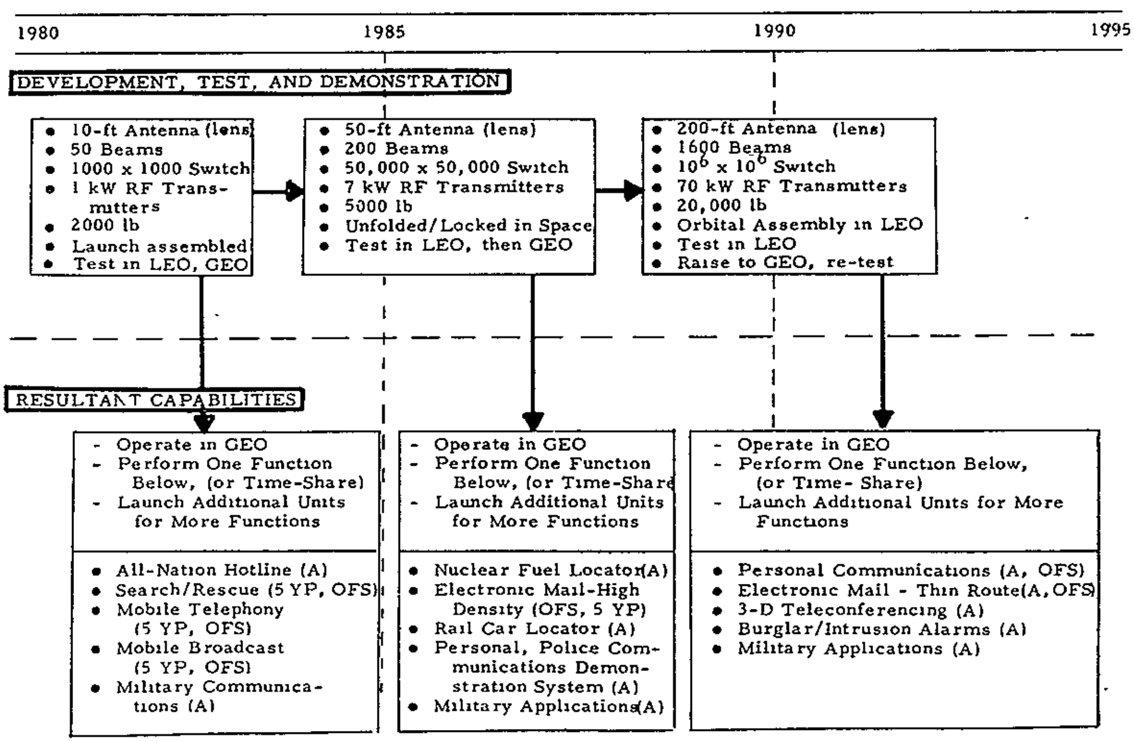


Figure 9-1. Development Plan, Group 1 Initiatives (Public Service Platforms Using Microwave Multibeam Antennas)

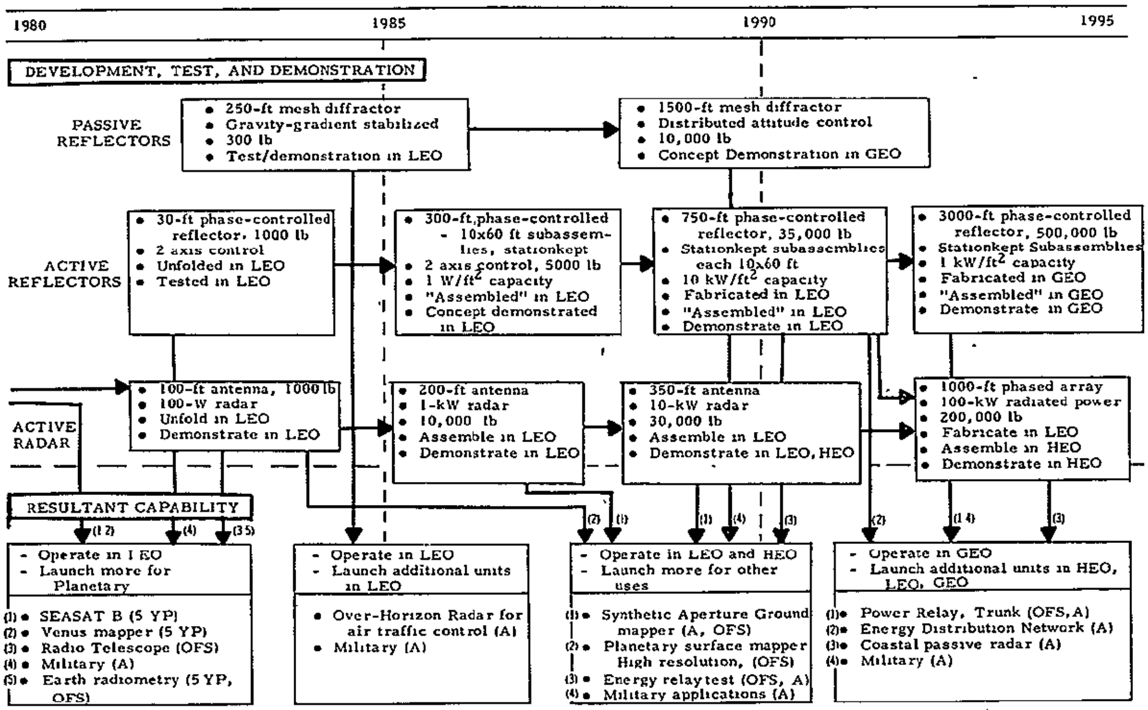


Figure 9-2. Development Plan, Group 3 Initiatives (Active/Passive Radar, and Power Distribution Systems)

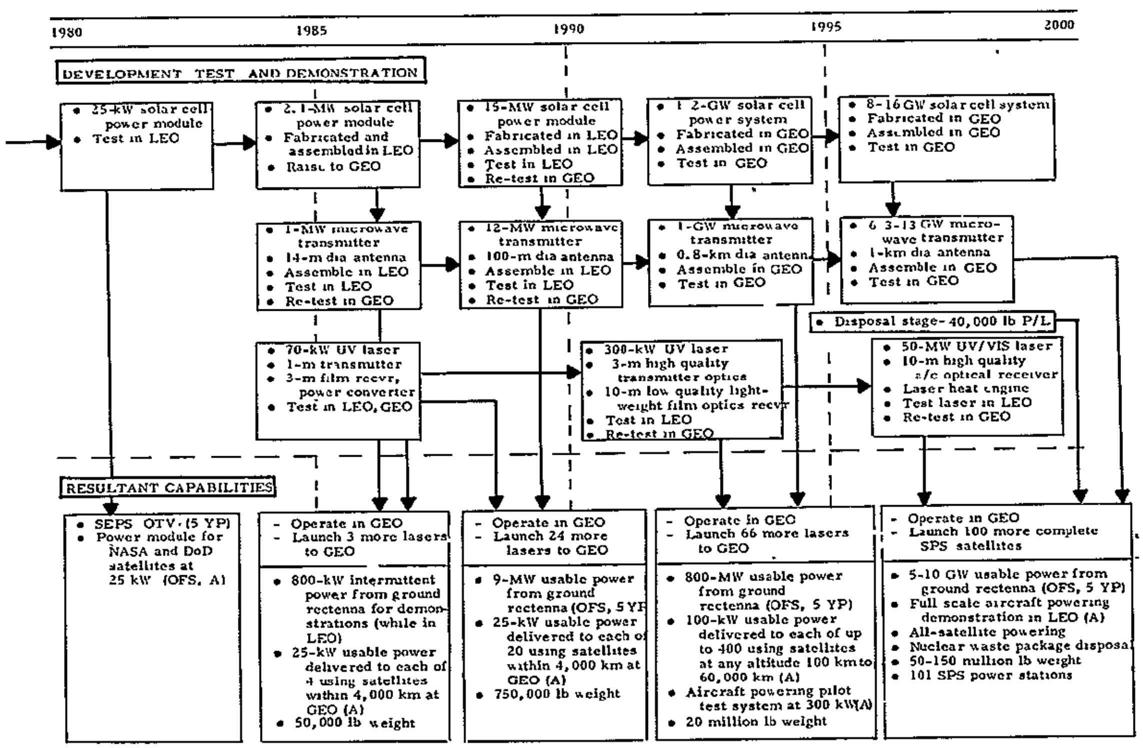


Figure 9-3. Development Plan, Group 8 Initiatives (Large Scale, High Energy, Far-Term Systems)

9.3 RESULTS

The study resulted in two forms of study output. The first, illustrated in Figures 9-4 and 9-5, presents two extremes of the earliest needs for transportation and support. Figure 9-4 represents the condition where all space initiative areas are developed except the Satellite Power Station (SPS) and very large space radars, and none are carried beyond the demonstration phase. Figure 9-5 represents the condition where all initiatives (including the large, high power devices) are developed and operated.

Figures 9-4 and 9-5 indicate that the need for large boosters, very large OTVs, and some full capability space facilities is dependent on very large scale projects such as the SPS. However, the need for laboratories, manned habitats, medium capability and low thrust OTVs, test/start up/ assembly/servicing devices, and some space facilities is independent of any decisions made concerning the SPS.

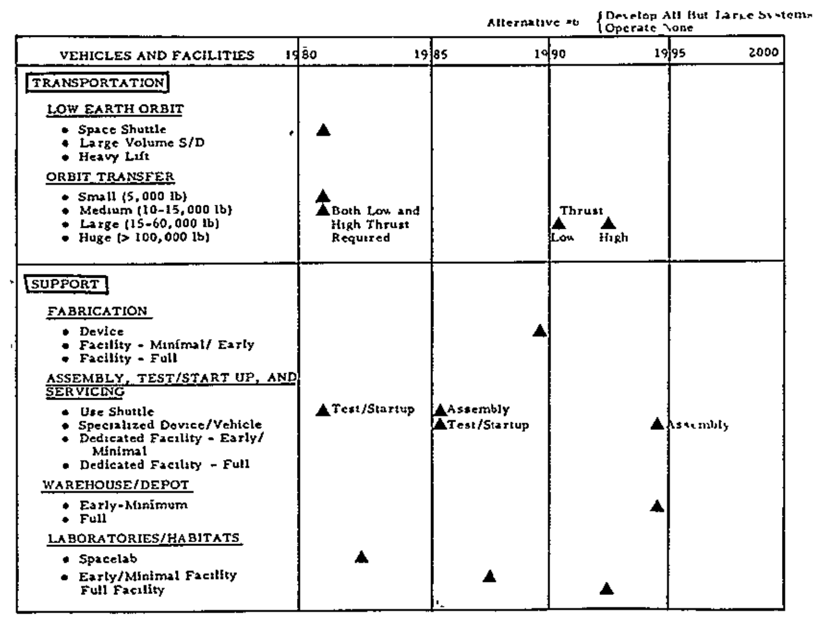


Figure 9-4. Composite Plan - Earliest Needs for Transportation and Support (Alternative #6)

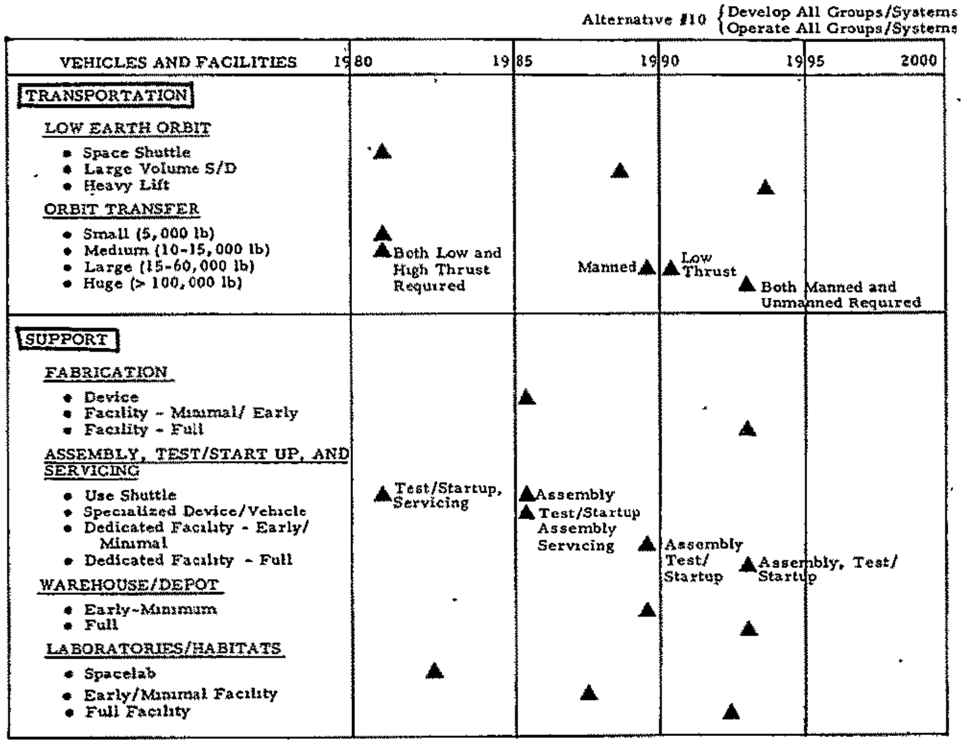


Figure 9-5. Composite Plan - Earliest Needs for Transportation and Support (Alternative #10)

The second form of display is illustrated in Figures 9-6, 9-7, and 9-8. Four levels of increasing capability are postulated, as shown in Figure 9-6. The earliest time at which each level is required by various space initiative groups is shown in Figure 9-7 for development and demonstration programs only, and in Figure 9-8 for development, demonstration, and operational programs. The figures indicate that: (1) the planetary programs require the earliest augmentation of the Shuttle/Spacelab/IUS combination, (2) all programs require such augmentation in the mid-1980s, (3) large OTVs, early permanent facilities, and manned habitats will be needed around 1990, and (4) large boosters and large permanent facilities are needed by operational large information and energy systems in the 1995 time period (but only by the energy system if demonstration is the only goal).

FUNCTION				CAPABILITY LEVEL I	II	III	IV
TRANSPORTATION	Low Orbit Boost	Shuttle		√	√	√	√
		Large Volume-Shuttle - Derived - Unmanned				√	√
		Heavy Lift - Manned/Unmanned					√
	Orbit Transfer/Escape	Small (5000 lb in GEO) - Unmanned, Chemical		√	√	√	√
		Medium (10-15,000 lb in GEO) - Low Thrust, Crew Modules Optional			√	√	√
		Large (15-60,000 lb in GEO) - Low Thrust, Crew Modules Optional				√	√
		Huge (> 100,000 lb in GEO) - Low Thrust, Crew Modules Optional					√
SUPPORT	Fabrication, Assembly, Test, Start Up, Servicing in Orbit	Use Capability of Shuttle		√	√	√	√
		Specialized Device/Vehicle/Stage			√	√	√
		Dedicated Facility, Warehouse	Early, Minimal			√	√
			Full				√
	Research Laboratories, Processing Factories	Use of Spacelab		√	√	√	√
		Dedicated Facility	Early, Minimal			√	√
			Full				√
	Habitat	Early, Minimal				√	√
		Full					√

Figure 9-6. Capability Levels

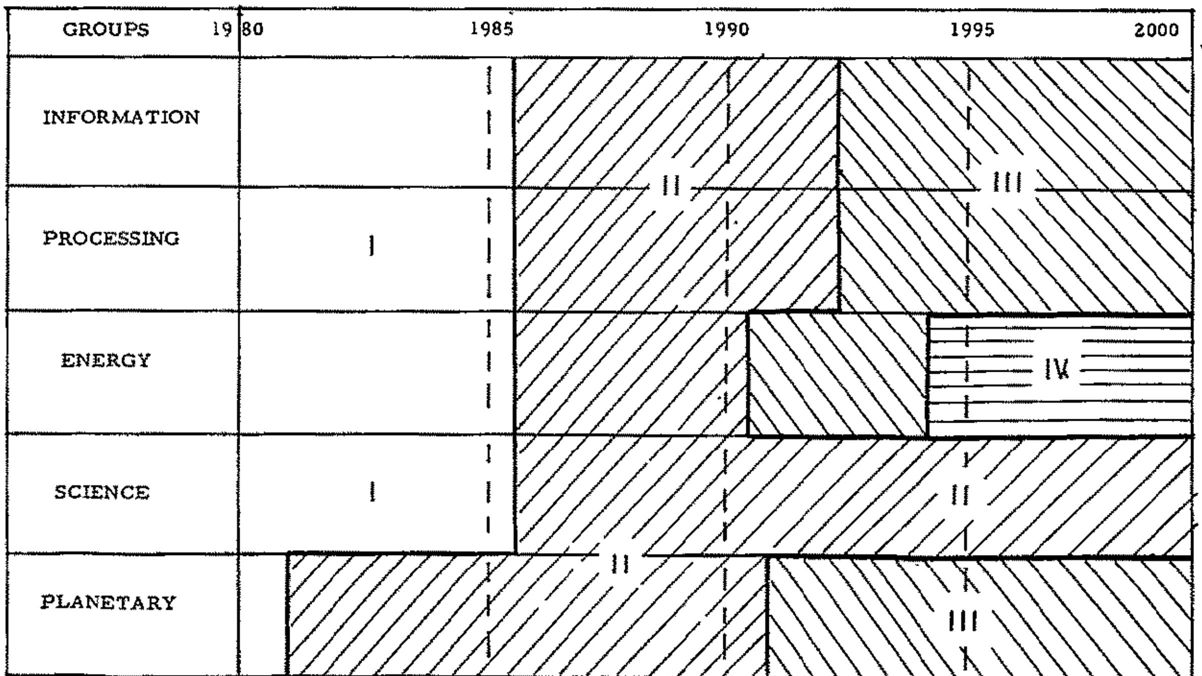


Figure 9-7. Approximate Earliest Capability Needs, Development and Demonstration Programs

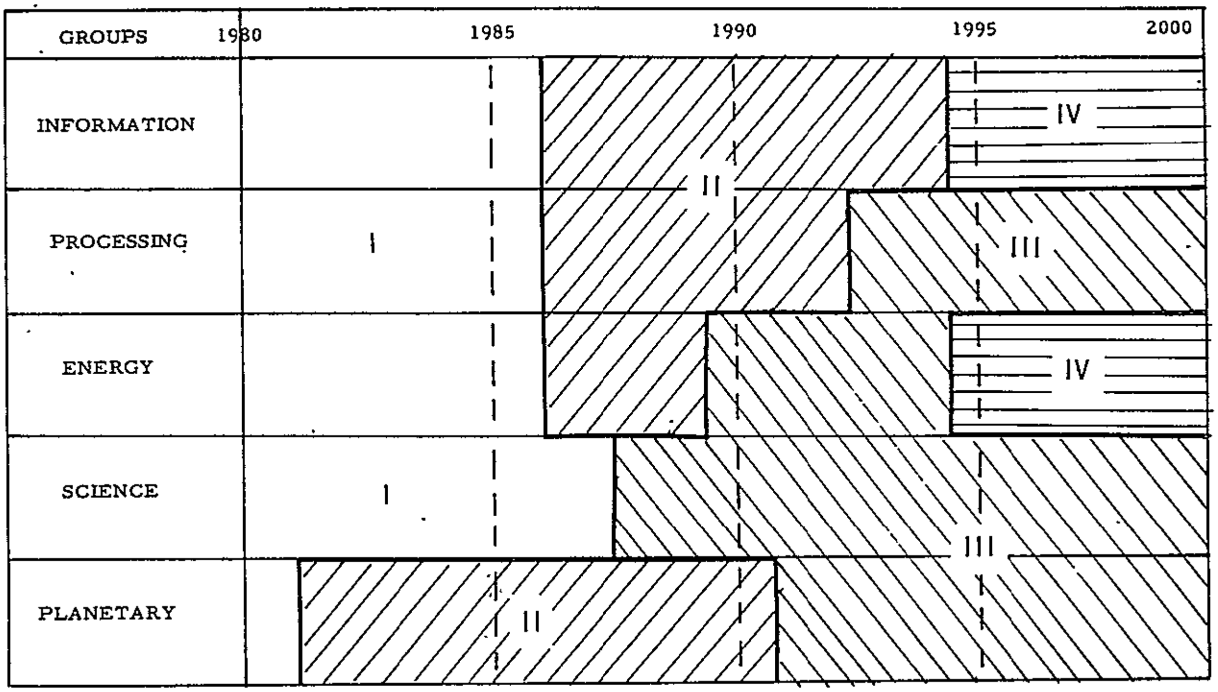


Figure 9-8. Approximate Earliest Capability Needs, Operational Programs

9.4 CONCLUSIONS*

The following general conclusions may be drawn:

a. Except for some planetary missions, Shuttle, IUS, and Skylab will support most initiatives through the mid-1990s, and many through the early 1990s.

b. Larger OTVs (chemical and low thrust), specialized vehicles and devices for orbital fabrication, assembly, test, start up and servicing, and crew capsules for manned operations will be required, beginning in the mid-to-late 1980s.

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*It must be noted that many of the specific transportation and support devices are clearly impacted by questions such as manned versus automated versus teleoperator operations, assembly in GEO versus LEO, orbital fabrication versus use of large-volume payload boosters, etc., which were outside the scope of this study.

c. Shuttle-derived unmanned boosters designed for large volume, low density payloads, even larger OTVs (chemical and low thrust), early minimal dedicated facilities for warehousing, fabrication, assembly, test, start up, servicing, and crew capsules and habitats will be required, beginning in the late 1980s or early 1990s.

d. A new heavy lift booster (manned and unmanned), huge OTVs, and full, manned facilities for warehousing, fabrication, assembly, test, start up, and servicing will be required, beginning in the mid-1990s. However, these requirements are dependent on the pursuit of very large scale projects such as energy delivery or distribution and the larger space radars.

e. Space fabrication, assembly, and servicing are needed by most of the initiatives in their fully evolved form, but many early demonstrations do not require such capability.

f. Shuttle-derived advanced boosters should strive for two options: one with much larger payload volume, rather than larger payload weight, and a second option which maximizes weight.

g. If a balanced and ambitious program is followed in all other areas of space activity, all but the largest of the transportation and orbital support needs in the 1990s are independent of any decisions made on the SPS.

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