FOREWORD

The Space Operations Center System Analysis Study (Contract NAS9-16151) was initiated in June of 1980 and completed in May of 1981. A separately funded Technology Assessment and Advancement Plan study was conducted in parallel with the System Analysis Study. The study was conducted by the Boeing Aerospace Company with Hamilton Standard as the subcontractor. These studies were documented in 5 final reports:

Vol. I - Executive Summary
Vol. II - Requirements (NASA CR-160944)
Vol. III - SOC System Definition Report
Vol. IV - SOC System Analysis Report (2 volumes)

The System Analysis Study was extended by a Study Extension contract (Contract NAS9-16151, Exhibit B) that was initiated in August of 1981 and completed in January 1982. The study was conducted by the Boeing Aerospace Company with Hamilton Standard and Grumman Aerospace Company as subcontractors. The study extension results are reported in 6 final reports (eight books total):

Vol. I - Executive Summary
Vol. II - Programmatics
Vol. III - Final Briefing
Vol. IV - System Analysis Report (two books)
Vol. V - SOC System Requirements
Vol. VI - SOC System Definition Report (two books)

*These documents are Revision A of the documents published at the end of the previous study. These revisions include requirements and configuration additions and modifications that resulted from the study extension analyses.

These studies were managed by the Lyndon B. Johnson Space Center. The Contracting Officer's Representative and Study Technical Manager is Sam Nassiff.
The Boeing study manager is Gordon R. Woodcock. The Hamilton Standard study manager is Harlan Brose. The Grumman study manager is Ron McCaffrey.

For convenience to the reader, a complete listing of all of the known Space Operations Center documentation is included in the Reference section of each document. This includes NASA, Boeing, and Rockwell documentation.
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</tr>
<tr>
<td>REM</td>
<td>Reoentgen Equivalent Man</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>RFI</td>
<td>Radio Frequency Interference</td>
</tr>
<tr>
<td>RMS</td>
<td>Remote Manipulator System</td>
</tr>
<tr>
<td>RPM</td>
<td>Revolutions Per Minute</td>
</tr>
<tr>
<td>SAF</td>
<td>Systems Assembly Facility</td>
</tr>
<tr>
<td>SAWD</td>
<td>Solid Amine Water Desorbed</td>
</tr>
<tr>
<td>scfm</td>
<td>Standard Cubic Feet per Minute</td>
</tr>
<tr>
<td>SCS</td>
<td>Stability and Control System</td>
</tr>
<tr>
<td>SCU</td>
<td>Service and Cooling Umbilical</td>
</tr>
<tr>
<td>SDV</td>
<td>Shuttle - Derived Vehicle</td>
</tr>
<tr>
<td>SDHLV</td>
<td>Shuttle - Derived Heavy Lift Vehicle</td>
</tr>
<tr>
<td>SEPS</td>
<td>Solar Electric Propulsion System</td>
</tr>
<tr>
<td>SF</td>
<td>Storage Facility</td>
</tr>
<tr>
<td>SM</td>
<td>Service Module</td>
</tr>
<tr>
<td>SOC</td>
<td>Space Operations Center</td>
</tr>
<tr>
<td>SOP</td>
<td>Secondary Oxygen Pack</td>
</tr>
<tr>
<td>SSA</td>
<td>Space Suit Assembly</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>SSTS</td>
<td>Space Shuttle Transportation System</td>
</tr>
<tr>
<td>SSP</td>
<td>Space Station Prototype</td>
</tr>
<tr>
<td>STAR</td>
<td>Shuttle Turnaround Analysis Report</td>
</tr>
<tr>
<td>STDN</td>
<td>Spaceflight Tracking and Data Network</td>
</tr>
<tr>
<td>STE</td>
<td>Standard Test Equipment</td>
</tr>
<tr>
<td>TBD</td>
<td>To Be Determined</td>
</tr>
<tr>
<td>TDRSS</td>
<td>Tracking and Data Relay Satellite System</td>
</tr>
<tr>
<td>TFU</td>
<td>Theoretical First Unit</td>
</tr>
<tr>
<td>TGA</td>
<td>Trace Gas Analyzer</td>
</tr>
<tr>
<td>TIMES</td>
<td>Thermoelectric Integrated Membrane Evaporation System</td>
</tr>
<tr>
<td>TLM</td>
<td>Telemetry</td>
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<tr>
<td>TM</td>
<td>Telemetry</td>
</tr>
<tr>
<td>TMS</td>
<td>Teleoperator Maneuvering System</td>
</tr>
<tr>
<td>TT</td>
<td>Turntable/Tilttable</td>
</tr>
<tr>
<td>TV</td>
<td>Television</td>
</tr>
<tr>
<td>UCD</td>
<td>Urine Collection Device</td>
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<tr>
<td>VCD</td>
<td>Vapor Compression Distillation</td>
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<tr>
<td>VDC</td>
<td>Volts Direct Current</td>
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<tr>
<td>VSS</td>
<td>Versatile Servicing Stage</td>
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<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
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<tr>
<td>WMS</td>
<td>Waste Management System</td>
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</table>
1.0 INTRODUCTION

This volume of the SOC System Analysis Study Extension Final Project provides the documentation of the analyses conducted during this study.

Section 2.0 summarizes the study objectives and gives a cross-reference matrix showing where the study task outputs are documented in Sections 3.0 thru 9.0 of this document. Requirements and configuration updates that were products of this study were incorporated into the SOC Requirements Document (Boeing-18) and the SOC System Definition Document (Boeing-19) as Revision A to each of these books.

The programmatic and cost analyses conducted during this study have been documented in Vol. II of the Final Report (D180-26785-2).
2.0 SUMMARY OF STUDY EXTENSION TASKS

The study tasks are listed on the left axis of Figure 2.0-1. The location of the documentation and results of these task analyses are given by the matrix. Given below are capsule summaries of the key objectives of the various tasks. Complete descriptions of the task objectives will be found in the referenced subsection reports.

TASK 1.0 SATELLITE SERVICING, TEST, AND CHECKOUT

Subtask 1.1: Define Servicing Requirements and Approaches - Analyze the test and checkout requirements for attached and co-orbiting satellites to identify tasks, procedures, equipment, and timelines for accomplishing these functions from the SOC.

Subtask 1.2: Construction and Satellite Servicing Equipment Requirements - Analyze equipment requirements established for space construction and satellite servicing in the SOC system analysis study and the GAC and LMSC satellite servicing studies to identify common satellite servicing and construction requirements and equipment.

Subtask 1.3: Define Servicing Mission Needs and Benefits - Survey and analyze user mission needs for satellite servicing at LEO and GEO. Based on user inputs and historical and projected failure rate data, develop a forecast of servicing needs. Identify specific benefits derived by servicing satellites using SOC.

Subtask 1.4: Differential Drag Considerations of Co-orbiting Satellites - Analyze the effects of unequal ballistic coefficients on the relative orbital positions of the SOC and co-orbiting satellites.

Subtask 1.5: Transportation Considerations - Analyze the potential relative orbital positions of the SOC and serviceable satellites. Determine preferred transportation modes as a function of SOC - satellite separation and associated propellant requirements.
**Figure 2.0-1 Study Tasks vs. Documentation Matrix**

<table>
<thead>
<tr>
<th>Task 1.0 Satellite Servicing, Test and Checkout</th>
<th>Study Tasks</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Define Servicing Requirements</td>
<td>Study Task 1</td>
<td>X</td>
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<tr>
<td>1.2 Configuration and Satellite Servicing Equipment</td>
<td>Study Task 2</td>
<td>X</td>
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<tr>
<td>1.3 Define Satellite Servicing Test and Checkout</td>
<td>Study Task 3</td>
<td>X</td>
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<tr>
<td>1.4 Differential Drag Characteristic of Co-orbiting Satellites</td>
<td>Study Task 4</td>
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</tr>
<tr>
<td>1.5 Satellite Servicing Transport Considerations</td>
<td>Study Task 5</td>
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<table>
<thead>
<tr>
<th>Task 2.0 SOC Research and Applications</th>
<th>Study Tasks</th>
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</thead>
<tbody>
<tr>
<td>2.1 SOC RAQ Support Analysis</td>
<td>Study Task 6</td>
<td>X</td>
</tr>
<tr>
<td>2.2 Operational Requirements</td>
<td>Study Task 7</td>
<td>X</td>
</tr>
<tr>
<td>2.3 Environmental Capabilities</td>
<td>Study Task 8</td>
<td>X</td>
</tr>
<tr>
<td>2.4 Materials Processing and Life Support Missions</td>
<td>Study Task 9</td>
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<thead>
<tr>
<th>Task 3.0 Crew Requirements Integration</th>
<th>Study Tasks</th>
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<tbody>
<tr>
<td>3.1 Integrated Crew Requirements</td>
<td>Study Task 10</td>
<td>X</td>
</tr>
<tr>
<td>3.2 Crew Labor Estimating Relationships</td>
<td>Study Task 11</td>
<td>X</td>
</tr>
<tr>
<td>3.3 Define Range of Requirements</td>
<td>Study Task 12</td>
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<table>
<thead>
<tr>
<th>Task 4.0 SOC/External Tank</th>
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<tr>
<td>4.1 Propellant Tank Options</td>
<td>Study Task 13</td>
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<td>4.2 Flight Control</td>
<td>Study Task 14</td>
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<td>4.3 Hangar Options</td>
<td>Study Task 15</td>
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<table>
<thead>
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<th>Task 5.0 SOC Digital Ops</th>
<th>Study Tasks</th>
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<tr>
<td>5.1 Define Operational Scenarios</td>
<td>Study Task 16</td>
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<tr>
<td>5.2 Identify Special Requirements</td>
<td>Study Task 17</td>
<td>X</td>
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<tr>
<td>5.3 Assess SOC Capability Limits</td>
<td>Study Task 18</td>
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<tr>
<th>Task 6.0 Flight Support</th>
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<tr>
<td>6.1 SOC/Shuttle Ops</td>
<td>Study Task 19</td>
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<tr>
<td>6.2 SOC/Shuttle Derived Vehicle Ops</td>
<td>Study Task 20</td>
<td>X</td>
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<tr>
<td>6.3 SOC/OTV Ops</td>
<td>Study Task 21</td>
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<table>
<thead>
<tr>
<th>Task 7.0 SOC Ops to GEO</th>
<th>Study Tasks</th>
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<tr>
<td>7.1 Define Requirements</td>
<td>Study Task 22</td>
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<tr>
<td>7.2 Identify Design Notes</td>
<td>Study Task 23</td>
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<thead>
<tr>
<th>Task 8.0 Mission Needs and Modeling Analysis</th>
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<td>8.1 Mission Model Forecast</td>
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<tr>
<td>8.2 DnB Traffic Model</td>
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<td>8.3 Economic and Budget Forecast</td>
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<th>Task 9.0 SOC Requirements and Update Configuration</th>
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<tbody>
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<td>9.1 Update Requirements and Configuration</td>
<td>Study Task 27</td>
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<tr>
<td>9.2 Define Range of Requirements</td>
<td>Study Task 28</td>
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<th>Task 10.0 Programmatic</th>
<th>Study Tasks</th>
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<tr>
<td>10.1 Update Development Plan</td>
<td>Study Task 29</td>
<td>X</td>
</tr>
<tr>
<td>10.2 Define Planning Options</td>
<td>Study Task 30</td>
<td>X</td>
</tr>
<tr>
<td>10.3 Develop Users Charge Plan</td>
<td>Study Task 31</td>
<td>X</td>
</tr>
</tbody>
</table>
TASK 2.0: SOC/RESEARCH AND APPLICATIONS INTEGRATION

Subtask 2.1: SOC R&D Support Analysis - Analyze the potential of the basic SOC concept to support R&D through pilot plant operations leading to operational commercial, applications and scientific space systems.

Subtask 2.2: Operational Requirements for R&D and Applications Missions - Assess the changes in operating requirements for the operational phase of these systems, including any requirements for continuous manned presence or periodic manned presence. Determine whether the systems should be attached to the SOC, co-orbiting or completely independent in their operational phase.

Subtask 2.3: Environmental Capabilities Evaluations - Evaluate the requirements for the research and application activities against the capabilities and environment of an operational SOC. Identify areas of compatibility and incompatibility. Define any additional capabilities that a station configuration assembled from basic SOC modules and subsystem would need to support research, applications, and science objectives.

Subtask 2.4: Materials Processing and Life Sciences Research Capability Analysis - Survey and analyze available plans for materials processing and life sciences research. Estimate the number and duration of experiments and the SOC accommodations required. Determine how the SOC could be used as a test bed and/or development facility for science/applications, materials processing, manufacturing, etc. Forecast the expected evolution to production facilities for materials processing, manufacturing, etc., and related SOC involvement.

TASK 3.0: CREW REQUIREMENTS

Subtask 3.1: Integrated Crew Operations Requirements - Summarize, on a yearly basis, the crew requirements, i.e., number of man-months and crew skills, to perform construction work, orbiter transfer vehicle (OTV) support, satellite servicing, science and applications, and SOC housekeeping and control duties.
Subtask 3.2: Develop Crew Labor Estimating Relationships - This data should be presented in a format with suitable estimating relationships that allow the analysis of subsequent parametric variations of the mission model.

Subtask 3.3: Define Range of Crew Requirements - Define the range of crew requirements corresponding to the range of mission models.

TASK 4.0 SOC/EXTERNAL TANK (ET) CONFIGURATION

Subtask 4.1: Configuration Options - Assess the feasibility of operating the SOC with an ET attached and used as a propellant storage and propellant transfer depot.

Subtask 4.2: Flight Control - Determine attitude stabilization and control, and orbit makeup requirements for the SOC with the ET attached.

Subtask 4.3: Evaluate Other ET Uses - Evaluate ET use as a hangar for OTVs.

TASK 5.0 SOC ORBITAL OPERATIONS

Subtask 5.1: Define Operations Scenario - Analyze the capability of the SOC to support multiple, simultaneous operations such as space construction, satellite servicing, test, and checkout, flight support for orbital transfer vehicles and operations with the Shuttle.

Subtask 5.2: Identify Special Requirements - Identify special requirements and impacts on the SOC configuration and operations concepts to provide the capability to handle the simultaneous operations.

Subtask 5.3: Assess SOC Operational Capability Limits - Assess the capability of the SOC to conduct the simulations operations required by the range of mission models.
TASK 6.0  FLIGHT SUPPORT

Subtask 6.1: Develop SOC-Shuttle Operational Interfaces - Analyze and further develop SOC operational interfaces with the Space Shuttle.

Subtask 6.2: Develop SOC/SDV Operational Interfaces - Analyze and further develop SOC operational interfaces with projected Shuttle-derived vehicles (SDVs).

Subtask 6.3: Develop SOC-OTV Operational Interfaces - Analyze and further develop SOC operational interfaces with OTVs to (1) assess the impact of OTV aerobraking, and, (2) compare SOC support provisions and launch operations required for reusable single-stage, two-stage, and one-and-a-half stage OTVs.

TASK 7.0  SOC OPERATIONS TO GEOSYNCHRONOUS ORBIT (GEO)

Subtask 7.1: Define Requirements - Determine the requirements and impacts on SOC elements for potential growth missions operating at GEO.

Subtask 7.2: Identify Design Modifications - Identify any hardware or software design modifications that are required to support a SOC growth mission operating at GEO.

TASK 8.0  CONDUCT MISSION NEEDS AND MODELING ANALYSIS

Subtask 8.1: Mission Model Forecasting - Survey and analyze existing mission models. Develop a range of forecasts for mission evolution in the following two functional area groups:

- Earth sensing, Earth and space sciences, space testing of developmental systems and subsystems.
- Communications, materials processing, life sciences.

Subtask 8.2: DoD Traffic Model Update - Update the DoD traffic model based on current available DoD information.
**Subtask 8.3: Economic and Budget Forecasting** - Employ economic and budget forecasting methods to rationalize mission model projections based on plausible growth patterns and budgetary limitations.

**TASK 9.0: SOC REQUIREMENTS AND CONFIGURATION UPDATE**

**Subtask 9.1: Update Requirements Document and Configuration** - The SOC requirements document and SOC configuration elements shall be updated to reflect results of the subcontract extension.

**Subtask 9.2: Assess and Document Ranges of Requirements** - Assess the impact of the variations in mission and traffic models on the SOC requirements and on the initial, operational and growth configurations. Develop an updated set of SOC growth options to reflect ranges of requirements derived from the mission and traffic models.

**TASK 10: PROGRAMMATICS**

**Subtask 10.1: Update Development Plan** - Update the development plan produced in the SOC Systems Analysis Study to incorporate schedule and cost revisions and any possible alternatives resulting from the task analyses of the contract extension. SOC modular approach, buildup, commonality of modules (primary and secondary structures, subsystems, etc.) and associated effects on DDT&E and manufacturing costs will be analyzed.

**Subtask 10.2: Define Planning Options** - Assess the impact of mission and traffic model variations on SOC development planning, buildup, evolution, and costs. Develop and describe a strategy for development that is adaptive to mission needs evolution.

**Subtask 10.3: Develop User Charge Plan** - Develop a rationale and plan for SOC user charges, based on amortization of SOC flight hardware, costs of facilities and services, operations costs, and resupply costs. Compare the projected user charges to estimated value of services and make any adjustments that would increase the utility of SOC services to the user community.
3.0 MISSION MODELING AND MISSION NEEDS

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3.2 Telecommunications Mission Model .................................... 3-2
3.3 Space Science, Earth Sensing, and Space Testing Missions ........... 3-77
3.4 Research and Applications Missions .................................... 3-138
3.5 DoD Mission Model .................................................. 3-145
3.6 Satellite Servicing Missions ........................................... 3-153
### 3.1 MISSION ANALYSIS OVERVIEW

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<td>Summary of Mission Model Development</td>
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<td>Research and Applications On-Board SOC</td>
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<td>3.1.4.1</td>
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<tr>
<td>3.1.5</td>
<td>Conclusions</td>
<td>3-49</td>
</tr>
</tbody>
</table>
3.0 MISSION MODELING AND MISSION NEEDS

This section of the report presents results of several related tasks in an integrated fashion. These tasks were concerned with SOC mission models, mission needs, satellite servicing, transportation interrelationships, orbital operations, and crew skills and manlevels. The presentation here is organized to present continuity from derivation of mission models through SOC utilization and crew size. The integrated discussion is followed by more detailed discussion of individual segments of the mission models.

3.1 MISSION ANALYSIS OVERVIEW

3.1.1 OBJECTIVES OF MISSION MODELING

One of the principal issues involved in design and program planning for a manned Space Operations Center is determination of mission needs, and the derivation of appropriate system requirements and program planning. Accordingly, as a major part of this Phase A study extension, a mission modeling and analysis task was conducted. A part of this task was to develop a fresh approach to mission modeling, one founded on economic principles rather than the survey methods that have been used in prior mission modeling activities. The objectives of this mission modeling activity are described in Table 3.1-1.

3.1.2 MISSION MODELING APPROACH

Past attempts at mission modeling have relied largely on survey methods. These have been historically unsuccessful. The reasons for lack of success differ in the different sectors of the space economy. (These sectors are discussed on subsequent pages.)

In the NASA Research and Application sector, past mission models have been generally based on lists of payloads for which some scientific or applications rationale exists, but lists that do not consider representative budget realities that will constrain the number of payloads developed and flown.
Table 3.1-1

OBJECTIVES OF MISSION MODELING

- Understand and characterize the fundamental determining forces that shape the future utilization of space systems
- Develop a range of specific mission event predictions encompassing the credible range of determining forces
- Provide a quantitative basis for evaluating the utility of manned space platforms and their relationships to space operations, research, and applications
- Create an overall future scenario within which the benefits of manned space platforms can be quantified and compared with costs.
If a permanently-manned station exists in low Earth orbit, this station can be used as a research facility for science and applications projects. Since no such facility presently exists, there is no well-organized user constituency to survey. The life sciences community is planning primarily Spacelab applications. There is some literature for utilization of a permanently-manned facility, and these were used in this study as a source. Materials processing science is presently considering mainly shuttle sortie flights and free fliers. The substantial opportunities that would exist with a manned platform have not been well represented in the available literature.

In the commercial sectors, the planning horizon is relatively short, commensurate with the emphasis on near-term profitability and cash flow that always exists in a commercial organization. Further, such long-term plans as may exist are generally treated as business secrets and are not revealed to anyone who surveys these organizations.

The defense sector exhibits some of the wish list syndrome but far less than the NASA sector, inasmuch as the planning process in DOD is more inclined to take into account budget realities. The defense sector also tends towards a planning horizon of about 10 years. Dealing with the defense sector in an unclassified study is confounded by classification of specific projects and the sensitivity of revealing potential evolutions of policy through forecasting of specific missions.

The first sector considered in our analysis was the NASA Research and Applications spacecraft sector. This sector represents institutionalized research and applications areas, including astrophysics and solar terrestrial physics, planetary exploration, etc. This sector is characterized by budget levels that have become generally institutionalized. These levels are subject to variation depending upon political trends and problems with Federal deficits. Presently, this sector is under considerable budget pressure, but a long-range forecast must presume that current budget pressure will not necessarily permanently reduce the institutionalized levels of research.

The second sector is represented by that category of research that would be carried out on a permanently-occupied manned platform, should one become available. A review of many potential lines of research indicated that the ones
most likely to be implemented on a manned platform would be life sciences and materials processing, with some additional activity in space technology testing. There is no well-organized constituency for this kind of research on a manned platform since no research facility has been available. The constituency that existed in the early 1970s has generally dissolved.

This sector is characterized by latent demand. Budget levels for such research are not institutionalized and present levels of funding for life sciences and materials processing within NASA are quite small. It is plausible to anticipate some increase in budget levels in these areas with the availability of a manned platform, but because of continuing pressure on the Federal budget it is not expected that these areas will become funded to the same degree as existing research areas presently carrying out major flight projects. Private sector funding is available for materials research. The amount is not known, but is potentially large given the general economic character of the sectors of the economy that could benefit from breakthroughs in materials processing in the microgravity environment.

The commercial sector for space utilization exploits those operations using space that are profitable. Presently, this amounts to space communications, using communications satellites. A future potential exists for materials processing commercial production if suitable process candidates are developed. Commercial sectors are characterized by exponential growth. In the case of space communications, this growth has historically been quite rapid.

The final sector is the defense sector. This sector is driven by estimates of the military threat, and to some degree by perceived military opportunities. Historically, this sector has exhibited a continued gradual increase in budget. A projection of present trends would suggest a budget doubling by about the year 2000.

In accordance with the characteristics of the sectors presented above, the philosophy for construction of the mission model is presented in Table 3.1-2.

The present study has tended to be somewhat more conservative in satellite servicing than related studies. We have assumed that only high-value payloads
Table 3.1-2
MISSION MODEL PHILOSOPHY

<table>
<thead>
<tr>
<th>Model Type</th>
<th>NASA Research Description</th>
<th>Commercial Description</th>
<th>DoD Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Model - Highly Conservative Projections</td>
<td>Continued Gradual Decline in Real Budget Authority</td>
<td>Less Growth Than Present</td>
<td>Cessation of Historical Growth Trends</td>
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<tr>
<td>Median Model - Most Likely Projections</td>
<td>Roughly Constant Real Budget Authority</td>
<td>Continuation of Present Trends</td>
<td>Continuation of Present Trends</td>
</tr>
<tr>
<td>High Model - Optimistic Projections</td>
<td>Gradual Increase in Real Budget Authority</td>
<td>Modest Increase in Present Growth Rate</td>
<td>Increase in Present Growth Rate</td>
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</table>
will be serviced inasmuch as low-cost payloads are of a nature not requiring service, and at any rate may not have sufficient value to warrant a servicing mission.

GEO servicing missions are deferred in this model until they are warranted by the total value of assets in geosynchronous orbit. We arrived at timing by taking an insurance approach: When the value of the GEO assets exceeds $10 billion, then the creation of a servicing capability is justified as insurance; if a high-value payload at GEO fails, the capability will exist to go there and restore it to service. This judgment was based on the premise that the basic upper-stage technology for a GEO servicing mission would exist in the form of orbit transfer vehicles for payload placement and that the added investment to create a manned orbit transfer vehicle capability for satellite servicing would be on the order of a billion dollars.

Servicing rates were estimated on the premise that a typical spacecraft has a 3% chance of failure in each year of service. This corresponds to a 20-year mean-time-between-failure for spacecraft. This is somewhat better than present experience, but trends in spacecraft life indicate that in the timeframe of interest a 20-year mean-time-between-failure is realistic. Finally, we assumed that the typical GEO servicing mission will service two to four spacecraft. Some failures at GEO will be so serious as to need immediate servicing. However, many will be of a nature that the spacecraft owner will elect to wait until he can cost-share with another owner needing service before he services his system.

3.1.3 SUMMARY OF MISSION MODEL DEVELOPMENT

The following discussion describes the development of the mission model, sector by sector.

3.1.3.1 NASA Research and Applications Spacecraft

The NASA Research and Applications sector mission model was rationalized beginning with the available models created by a survey approach. These available models were assumed to represent scientifically-justifiable missions. The principal premises and method of analysis are described in Figure 3.1-1.
- Mission projections based on living within historical budget trends

- High-Level Cost Model
  - Spacecraft Development $80,000/KG
  - Spacecraft Production $20,000/KG
  - Spacecraft Reuse after Recovery $10,000/KG
  - Spacecraft Revisit $5,000/KG

Figure 3.1-1. Budget Rationalization Approach
The basic premise was that each subsector of the NASA Research and Applications sector would have to live within historical budget levels. A high-level cost model was employed to derive budgetary estimates based on the cost of spacecraft development, production, reuse, and servicing. This high-level cost model was also derived from historical experience. It is presumed that the cost of spacecraft development and production will dominate the cost such that the simplification of ignoring launch services will not lead to major errors in the model. The iteration procedure presented in the figure was used to arrive at final models. The funding spread routine simply takes the costs estimated for spacecraft and spreads them over a reasonable development period for the development of the spacecraft, to present a funding projection for the subsectors.

The funding, spreading and plotting program utilized for this analysis accepts a maximum of 25 cost elements for each chart presented. The number of cost elements for the astrophysics program as presented in NASA planning documents was approximately 40. Consequently this program was divided into near-term and far-term programs. Figure 3.1-2 presents the estimated funding requirements for the near-term programs as presented in NASA planning documents. These programs were characterized by multiple simultaneous development of observatory class payloads, and generally resulted in budget level estimates that exceed the present budget level by factors approaching 10.

The funding estimates for the long range programs reached even higher total values than the near-term program with a funding peak in the mid 1990s of roughly $1½ billion as shown in Figure 3.1-3. These models must be regarded as unrealistic inasmuch as the present level of funding for the astrophysics programs is on the order of $200 million. Consequently, the rationalization approach was used to eliminate or defer cost events until a program funding projection similar to historical budget trends was accomplished.

The astrophysics model, after being rationalized, exhibits the funding trend illustrated in Figure 3.1-4. This funding trend, although perhaps slightly ambitious, was used as the median traffic model. The low traffic model had fewer payloads and the high traffic model slightly more. In general for the NASA sector, the differences between the low and high models were not great inasmuch
Figure 3.1-2. Astrophysics Funding Levels
(Near-Term Programs
as Presented in NASA Planning Documents)
Figure 3.1-3. Astrophysics Funding (Long-Range Programs as Presented in NASA Planning Documents)
Figure 3.1-4. Rationalized Astrophysics Model (Based on Medium Traffic Model)
as the institutionalized nature of these sectors would suggest that large fluctuations in historical funding trends should not be expected.

Figure 3.1-5 presents a summary of the median traffic model for all of the NASA Research and Applications spacecraft payloads. Although there are a large number of individual payloads represented in this portion of the model, the total number of equivalent Shuttle flights is relatively small.

3.1.3.2 Research and Applications On Board SOC

Three representative mission categories were analyzed in this sector. These are life sciences, materials processing, and DoD and technology space testing of subsystems, instruments and technologies.

A review of the so-called "Blue Books" from the space station studies of the early 1970s suggested that mission activities in other areas such as space physics and communications would be relatively insignificant and not worth the investment of time and effort to create mission models. These kinds of activities can generally be aggregated under the DoD and technology category.

Only very limited life sciences research can be conducted on short duration space missions. The existence of a manned platform would permit research on the various long-term exposure effects for meaningful time periods. The flexibility of a permanently-occupied station would permit a diversity of research carried out over a long sustained period. It would also provide collection of medical data for 90 days or more on human beings. Operation in a laboratory mode would provide flexibility of in-situ modifications of experiment protocols and the introduction of new and varied experiments as the research was conducted. This would also provide the opportunity for fixing things if malfunctions occur and the experiment is put in jeopardy. The relative flexibility of timelines and operations in a permanently-manned station will allow the accomplishment of research at considerably less cost than would be required for operations in which detailed advanced plans must be prepared and followed meticulously.

Three models were created for life sciences research, as was the case for the other sectors. In life sciences, the low model was designed to satisfy those
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Figure 3.1-5 Median NASA Payloads Mission Model
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Figure 3.1-5 Median NASA Payloads Mission Model (Con't)
research objectives most essential to routine long-term manned space operations. These research objectives would be essential to a long-term program intended to eventually use manned systems for military purposes. These systems will require routine and highly effective operations with long crew stay times.

The median model included some additional research objectives of a more academic nature; objectives related to understanding the effects of microgravity, and other aspects of the space environment, on a variety of living organisms. These research objectives may also have a practical application inasmuch as the well being of other living organisms in space may eventually be of importance to permanent human settlements in space.

The high model was designed to satisfy all presently identified microgravity life sciences objectives, excepting those requiring a human centrifuge. (The human centrifuge was considered to be an unreasonable requirement to impose on a space station in the SOC class.) Note that even the high model does not address research objectives that might be identified in the future. It may be presumed that some such objectives of high priority would displace objectives presently recognized, but of lower priority.

Figure 3.1-6 presents the life sciences mission models that were developed as a result of the life sciences investigation.

The field of microgravity materials processing is presently in an early experimental research stage. This activity has been carried out on past space missions as well as in aircraft, drop towers and sounding rockets. A number of such experiments are planned for Shuttle and Spacelab flights in the 1980s. Figure 3.1-7 illustrates the evolution of this present phase of research into phases of process development toward commercially-viable processes, and finally commercial manufacturing of products for the free marketplace. The main characteristics of these phases of development are also indicated in the figure.

Process development represents a venture of commercial risk capital, to develop a proprietary process from which returns will be obtained when the process is fully developed, automated and commercialized. Accordingly, time is of the essence. It is very important that the process development be expected to reach
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*CREW INVOLVEMENT BASED ON 1 SHUTTLE/LS SPACELAB MISSION PER YEAR.

Figure 3.1-6. *Life Sciences Mission Model*  
(Crew Involvement in Manyyears/Year)
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*Figure 3.1-7. Materials Processing Evolution*
a successful conclusion in relatively few years. Otherwise, the commercial return on investment will not be sufficiently attractive to merit a risk capital investment. The presence of a continuously-manned platform can be expected to reduce the process development time from one likely to be unattractive commercially to one probably attractive commercially. The process development time on a permanently manned platform would be not greatly more than a comparable process development on Earth.

The low model for materials processing is an extrapolation of Spacelab research plans presently in existence. It was estimated that a process development activity would begin in 1994, aimed at eventual commercialization.

The median model assumes that the existence of a permanently-manned platform would stimulate additional research activity over that planned for Spacelab, and that process development could begin in 1992.

The high model represents a moderately aggressive program to develop commercial processes. Process development begins in 1991, about as early as could be expected with a space station launched in 1989 or 1990. It assumes that four parallel process development activities are in progress by 1995, and that the first commercial production free-flyer is launched in 1998.

Figure 3.1-8 presents the principal statistics for the low, median and high models in terms of the number of processes and development, as well as the space station man level dedicated to research and to process development.

Figure 3.1-9 presents a summary of the DoD and technology space testing models. These represent continuations of present trends in space testing. It is assumed that the Space Operations Center would provide those services now provided by spacecraft busses or shuttle. Crew involvement would be primarily for experiment tending. These experiments would generally be mounted on pallets and berthed to a Space Operations Center berthing port. The required crew involvement is relatively minimal since most of the testing would simply be accomplished by relaying data to the ground.
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Figure 3.1-8. Materials Processing Mission Model
- Continuation of present trends in space testing

- SOC provides those services now provided by spacecraft bus or shuttle

- Experiment-tending operations

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*Figure 3.1-9. DoD and Technology Space Testing*
3.1.3.3 Commercial Communications

The commercial communications sector model was derived from an economic-technical rationale based on historical experience and technological projections.

New technologies introduced to the marketplace often generate a very high rate of economic growth over a substantial number of years. Rapid economic growth occurs, as lower costs made possible by the new technology cause rapid acquisition of a significant market sector for whatever service or product is offered. Examination of historical data suggests that the process begins with an infancy period in which the growth is erratic and often at very high rates. Then an adolescent period occurs, in which the growth rate is more predictable but still quite rapid. This is followed by a period in which the new industry has reached maturity and its growth generally parallels the gross national product. Many industries eventually reach an old age period when growth subsides and decline takes place, even in some instances, entirely phasing out an industry. The trending concept illustrated in Figure 3.1-10 represents this rationale and is based on an examination of historical development of market sectors.

Figure 3.1-11 presents the space telecommunications model created as a part of this study. The economic trending concepts described earlier were used. This model presumes that space communications will acquire a larger and larger sector of the entire telecommunications marketplace until it reaches market saturation sometime in the future. In consonance with the idea of creating low, median and high models, three growth rate levels were presumed. The data on the chart represent the values actually used in the model.

The structure of the model projects economic developments in terms of investment in the industry, and technical trends in terms of technological improvements. These two sets of assumptions then allow derivation of the number and type of satellites launched. Information shown on the chart includes the following model elements: (1) Growth of total telecommunications, representing a ceiling for acquisition of market share by space telecommunications. (2) Growth rates for the space telecommunications sectors of the market. (3) The value of the space segment part of the space telecommunications system, this representing the actual value of assets placed in space. It is important to recognize that as the
Figure 3.1-10. The Economic Trending Concept
Figure 3.1-11. Space Telecommunications Model Concept
marketplace matures the fraction of the total investment in space telecommunication systems actually launched in space will decline. This is already taking place with the proliferation of ground receivers for television distribution. (4) The cost of spacecraft and space transportation, both expected to gradually decline on a unit mass basis over the next 20 years. The figures used for space transportation costs in the year 2000 are appropriate to a Shuttle with a reusable, aerobraked, high-energy orbit transfer vehicle. (Projections utilized in this study did not presume radical advances in space transportation such as fully reusable heavy lift systems or advanced technology propulsion.) (5) Payload mass per representative transponder based on results of the General Dynamics study of space platforms. (6) The spacecraft bus to payload ratio, also as estimated by the General Dynamics study, is expected to improve as size increases. (7) The representative spacecraft mass is expected to increase to the platform class by the year 2000. The size of the platform was varied as a function of the traffic models. (8) The representative spacecraft life is expected to gradually increase to 15 years. (9) Since this model is for U.S. space operations, a projection was made that the U.S. market share for total telecommunications launches would decrease from the present near 100% market share to about 50%.

The final telecommunications models shown in Figure 3.1-12 were completed by making the parametric economic model results specific in terms of numbers of spacecraft of different sizes to be launched every year. The progression to larger and larger spacecraft was forecast to be gradual with a new, larger size of spacecraft introduced every two to five years, such as has been true in the past. The high model is forecast to grow to bigger spacecraft than the median or low models. Overlap was forecast to occur with as many as three different classes of spacecraft being launched simultaneously in some years. This also is typical of present systems.

The number of communications satellites actually launched in 1981 will be eight, and about five of those will be one-ton class with the other somewhat smaller. Launches of a two-ton class will begin with the initial launches of TDRSS. Section 3.2 of this report presents additional details of the communications model.
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*Figure 3.1-12. Telecommunications Models*
3.1.3.4 Military Mission Model

In the creation of an unclassified military mission model, the available DoD sources cannot be utilized because they are classified, with even some names of payloads classified. Almost all of the size and mass data necessary for a specific analysis were also classified. Finally, these plans do not generally predict far enough into the future to be very useful for a SOC mission model in which payload activity would begin about 1990. Unclassified sources permit projection of general types of missions.

Because we could not use classified models, we developed a budget-driven model that we feel is realistic. Again, three levels were developed: low, median and high.

We employed a simplification of not considering the WTR launches excepting in our projection of the total demand for space transportation. These launches are presumed to use 40% of the available launches and represent 70% of the launched spacecraft mass inasmuch as WTR launches generally are destined for relatively low Earth orbits, whereas ETR launches are typically destined for geosynchronous orbit: the spacecraft mass that can be launched with a Shuttle flight is substantially less than that for WTR. Finally, for purposes of analysis it was assumed that all ETR launches go to geosynchronous orbit. Even though some may go to other orbits, all of the high energy orbits represent approximately the same transportation challenge.

Figure 3.1-13 presents the budgetary assumptions used in the military model. The low model assumes a cessation of historical growth in military space spending, the median model projects a continuation of historical trends, and the high model presumes that space utilization increases with new classes of military missions.

The derived mission models for the three military model levels are presented in Figure 3.1-14. These models do not include WTR launches nor do they include space testing at SOC as the latter was included in an earlier sector. Section 3.5 of this report presents additional details of the military mission model.
- LOW MODEL
  - NO SIGNIFICANT CHANGE IN USES OF SPACE
  - GRADUAL GROWTH OF AVERAGE SPACECRAFT MASS TO 5000KG BY END OF CENTURY

- MEDIAN MODEL
  - ASAT THREAT LEADS TO BUDGET GROWTH FOR SPACE DEFENSE
  - SPACECRAFT MASS GROWTH SAME AS LOW MODEL
  - MANNED ACTIVITY ONLY FOR SPACE TESTING AT A NATIONAL SPACE STATION

- HIGH MODEL
  - SPACE EVOLVES TO THEATER OF CONFLICT
  - SPACECRAFT AVERAGE MASS GROWTH TO 10,000 KG
  - SMALL MILITARY MANNED

Figure 3.1-13. Military Mission Model Budgetary Assumptions
## Figure 3.1-14. Military Mission Models

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**NOTE:** Space testing at SOC not included in these payloads.
3.1.4 SOC UTILIZATION ANALYSIS

3.1.4.1 Analysis Procedure

The mission models described above provide forecasts of mission events to be accomplished each year in a U.S. space program. Before the SOC operations analysis could be conducted, it was necessary to convert the mission models into traffic models. Since one of the functions of SOC is to serve as an element of space transportation systems, it is necessary to understand the space transportation requirements imposed by the mission models.

Traffic models were created by determining the space transportation traffic needed to accomplish each of the mission models. With the transportation traffic models created, the SOC operations analysis was then conducted to determine what SOC operations must take place, and what crew skills and man levels are required for a variety of mission models and transportation options. The general logic is shown in Figure 3.1-15.

Because the analysis is quite tedious and highly repetitive, an automated system was created to conduct the SOC utilization analysis. This automated system consists of four modular software units that communicate through data files, as diagrammed in Figure 3.1-16.

The first software element is a file-handling code which reads a sequential mission description file and converts this file into random-access format files for the transportation manifesting analysis and for the crew activities and facility utilization analysis.

The second element of the program is a manifesting code which organizes the payload and traffic model data for actual manifesting analysis. This code creates mission traffic listings and also has the capability to generate plots of payload mass versus calendar time.

The actual manifesting analysis is done by the third element of this modular system. It reads the files created by the other elements and provides a manifesting results listing. It also provides a year-by-year file that is the principal input to the crew activities and facility utilization analysis.
MISSION MODELS (LOW, MEDIAN, HIGH)

FORECASTS OF MISSION EVENTS TO BE ACCOMPLISHED EACH YEAR

TRAFFIC MODELS

DETERMINATION OF SPACE TRANSPORTATION FLIGHT TRAFFIC REQUIRED TO ACCOMPLISH A PARTICULAR MISSION MODEL, GIVEN ASSUMPTIONS OF SPACE TRANSPORTATION MODES AND CAPABILITIES

SOC OPERATIONS MODELS

DETERMINATION OF SOC OPERATIONS, CREW SKILLS, AND MANNING LEVELS, GIVEN A PARTICULAR MISSION MODEL AND SET OF SPACE TRANSPORTATION MODES AND CAPABILITIES

Figure 3.1-15. SOC Utilization Analysis Elements
Figure 3.1-16. Automated SOC Utilization Analysis System
The fourth element of the software system determines SOC crew activities and facility utilization, based on the transportation operations descriptions created by the manifesting analysis.

Table 3.1-3 presents a sample of the payloads data used by these programs. This sample includes some payloads delivered to SOC as indicated by the delta v's being zeroes.

Research and applications man-level information is also listed in this file, and is flagged so that the transportation manifesting code recognizes this as a man-level pass-through to the crew activities code. No manifesting is conducted for these mission elements.

In addition to the payloads physical data, a variety of time information is provided in order to ascertain crew activities required for such missions as satellite servicing and space construction.

The mission model also includes traffic information. Illustrated in Table 3.1-4 is a sample of such information for the flight support part of the mission model. This segment of flight support information is for the low traffic model. As can be seen by the numbers on the left, many of the payloads have been skipped for this low traffic model. Also the man-level missions are not counted as flight support missions.

Complete listings of mission model and payloads information are presented in Sections 8.1 through 8.4 of this report.

3.1.4.2 Manifesting Analysis

The manifesting code analyzes each traffic model year-by-year and mission-by-mission. The logic is diagrammed in Figure 3.1-17. At user option, either ground- or space-basing of the OTV can be selected. In either case the first step is to select an appropriate OTV mode if an OTV is required. For the ground-based logic, if a payload and OTV cannot be integrated on a single Shuttle flight the payloads and OTVs are loaded into a holding array. Payloads not requiring an OTV
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**Notes:**
- **ORBIT INCL:** Orbit inclination.
- **DELTA U’S:** Delta U’s values.
- **A/P:** Attitude and Position.
- **MASS:** Mass of the payload.
- **PAYLOAD RET:** Payload remaining.
- **LENGTH:** Length of the payload.
- **MANUFACTURER CODE:** Code for the manufacturer.
- **UP/DN ON MAINT:** Up/Dn on maintenance.
- **UP/DN EXP:** Up/Dn on expansion.
- **/code:** Code for the module.
### Table 3.1-4. Low Traffic Model (Sample)

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</table>
YEARS LOOP

MISSIONS LOOP

USER SELECTS GROUND OR SPACE BASING OF OTV

SELECT OTV MODE

PUT PAYLOADS AND OTV's THAT CAN'T BE INTEGRATED INTO HOLDING ARRAY

SELECT OTV MODE

PUT ALL PAYLOADS INTO HOLDING ARRAY

END MISSIONS LOOP

FLIGHTS LOOP

GROUPING LOGIC-MANIFEST SHUTTLE FLIGHTS

LOAD TANKERS (SPACE-BASED ONLY)

END FLIGHTS LOOP

END YEARS LOOP

Figure 3.1-17. Manifesting Logic General Flow
are loaded into the same array. For the space-based option the OTV modes are selected, following which all payloads are loaded into the holding array.

These steps complete the missions loop. At this point a transition is made from analyzing the model mission-by-mission to analyzing it Shuttle-flight-by-Shuttle-flight. A payload grouping logic manifests Shuttle flights using all the payloads in the holding arrays. In addition, for the ground-based case, payloads that can be manifested with their own OTV are also manifested on Shuttles. In the space-based case, it is then necessary to manifest tanker flights in order to bring up enough propellant to accomplish the year's missions. This completes the flights loop. When all of the years of the traffic model have been completed, then the manifesting code prints the manifesting analysis results and generates the files required for the crew activities analysis.

The manifesting logic selects from among nine ground-based OTV modes or five space-based modes. These modes are listed in Table 3.1-5. The mode for each mission is selected to provide the least cost, considering Shuttle and OTV costs. In the event a mission cannot be accomplished by the most capable OTV mode available, the software flags the mission as not achievable, but it charges the space transportation system with the most difficult applicable mode so that faulty comparisons do not arise from not manifesting missions in one case that are manifested in another.

Aerobraking operations are simulated by adjusting the delta v and the inert weight of the OTV to represent the delta v savings of the aerobraking pass and the increased inert weight of the aerobraking equipment.

On the left of Figure 3.1-18 is shown the ground-based OTV manifesting logic. Whenever possible, a payload is manifested with its own OTV in a Shuttle flight. In such an instance, SOC operations are not required unless the payload requires some sort of servicing from a SOC (such as construction). If necessary, the OTVs and payloads are manifested separately, in which case these OTVs and payloads go through the grouping logic to improve transportation manifesting whenever possible.
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<th>Space-Based Modes</th>
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- AEROBRAKING SIMULATED BY Adjusting DELTA v AND INERT WEIGHT
- SELECT LEAST-COST MODE THAT CAN DO MISSION, CONSIDERING SHUTTLE AND OTV COST

*Table 3.1-5. OTV Mode Selection*
If necessary, propellant scavenging from ET reduces number of shuttle flights by about 10%.

Figure 3.1-18. Space Shuttle Manifesting Options
The center diagram shows the space-based manifesting logic that was used earlier in the SOC study. This logic loaded all payloads into the holding array, manifested payloads together whenever possible, and then completed the year's flights by loading enough tankers to provide the propellant required for the year's missions. This manifesting mode turned out to be relatively inefficient inasmuch as the manifesting of payloads together ordinarily resulted in volume-limited rather than mass-limited flights.

On the right hand we show an improved space-based manifesting logic. Shuttle center of gravity constraints will allow approximately 20,000 pounds of payload to be loaded in the front of the Shuttle payload bay if a reduced-capacity tanker is placed in the back of the payload bay. Approximately the same payload is allowable whether the tanker is full or empty. Accordingly, a short tanker was designed with a propellant capacity of about 40,000 pounds. The manifesting logic manifests as many payloads with this short tanker as can be so manifested within the payload bay length and mass limits available. Those payloads that cannot be so manifested are then grouped together for additional Shuttle flights. Finally, any full-capacity tankers that may be necessary to bring up the balance of propellant required are manifested.

In either of the space-based cases, propellant scavenging from the ET reduces the number of Shuttle flights by about 10%. Propellant scavenging can be used to increase the mass loading of either the short tanker or the full tanker. In addition, when payloads manifested together have space available in the back of the payload bay for a small catch tank set, additional propellant can be brought up on payload flights.

Five OTV operating modes were analyzed in this study. These are compared in Figure 3.1-19. The results presented are for the median mission model, for ETR launches only.

A space transportation cost indicator was used, this being the number of Shuttle flights required plus the number of OTVs expended. Although neither the cost of an OTV nor the cost of a Shuttle flight are accurately known, it is presently thought that these costs are roughly comparable.
Figure 3.1-19. Comparison of OTV Operating Modes
Median Mission Model ETR Only
The comparison shows that the greatest leverage in reducing space transportation costs arises from the use of aerobraking in either the ground- or space-based case. The comparison also shows that space-basing offers an advantage of about 10% over ground-basing in the aerobraking case. Finally, the addition of ET scavenging adds about another 10%. The difference between the least effective OTV mode, ground-based or propulsive, and the most effective mode represents approximately a 40% reduction in the number of Shuttle flights required to accomplish the median traffic model.

The automated analysis did not process WTR-launched payloads and certain small payloads inasmuch as it is presently not expected that these would be involved in SOC operations. To complete the picture for the space transportation analysis, the WTR launches were included in a total space transportation demand forecast. The demand forecast for the three models is presented in Figure 3.1-20. This forecast assumes that space-based aerobraked OTVs are employed and that ET scavenging is implemented.

The total demand forecast for the low and median models is quite similar because the space transportation systems are used somewhat more effectively in the median models. There are more opportunities for payload grouping; on the average, the payloads are somewhat larger. The high model reflects a rapid growth in space transportation demand approaching 100 Shuttle flights per year by the year 2000.

The high model represents a scenario in which extensive commercial investments in space activities would occur along with a significant level of military operations. An assumption consistent with the high model scenario is one that would presume a development of a second generation space transportation system by the mid-1990s.

Table 3.1-6 lists the payloads that were deleted from the SOC mission model as they do not involve the SOC for one reason or another.
NOTE: THIS DEMAND FORECAST ASSUMES:
1) TRANSITION TO SPACE-BASED OTV IN 1992
2) ALL OTV'S ARE AEROBRAKED
3) ET SCAVENGING IS IMPLEMENTED FOR SPACE-BASING

Figure 3.1-20. Total Space Transportation Demand Forecast (Aerobraked OTV)
Table 3.1-6. Additional Payloads (Excluded from Automated Processing Model*)

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* Excluded because not considered missions involving potential involvement.

D = Direct
R = Related
Table 3.1-6. Additional Payloads (Excluded from Automated Processing Model*)

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<td>2</td>
<td>1450</td>
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<tr>
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<td>4</td>
<td>3</td>
<td>2000</td>
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<td>2.2</td>
<td>1700</td>
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<tr>
<td>NOAA – H &amp; I</td>
<td>8</td>
<td>3.7</td>
<td>4173</td>
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<td>Topex</td>
<td>4</td>
<td>3</td>
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<td>Operational Meteor Sat</td>
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<td>Global Atm. Monitor</td>
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<td>3.4</td>
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<td>6</td>
<td>4</td>
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<td>Chem Rel Module</td>
<td>2</td>
<td>3</td>
<td>2700</td>
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<td>1000</td>
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<tr>
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<td>4</td>
<td>4</td>
<td>4000</td>
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<tr>
<td>Solar Terr Observatory</td>
<td>15</td>
<td>4.5</td>
<td>20000</td>
<td></td>
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<td></td>
</tr>
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</table>
3.1.4.3 **SOC Crew Activities Analysis**

The crew activities analysis operated on the results of the manifesting analysis and employed additional input data as noted on an earlier chart. The crew activities analysis operates on a year-by-year basis and examines each Shuttle flight as manifested in sequence.

Figure 3.1-21 illustrates the Shuttle functions analysis in more detail than the other functions. Since a Shuttle may carry two payloads in addition to a tanker, the Shuttle functions for the first payload are identified. Those functions required are marked by setting flags. Then these functions are manloaded using a function-versus-skills matrix. Secondly, the Shuttle functions required for the second payload are then identified. A flag flip-flop routine is used to avoid double counting of Shuttle functions. In other words, if an Orbiter arrival operation is required for the first payload, the flag flip-flop prevents that arrival operation from being counted again for the second payload. The functions for the second payload are then manloaded using the functions skills matrix. In a similar manner, OTV functions, construction functions, satellite servicing functions and onboard science and applications functions are analyzed. These are then summed up and printed for each flight. Following the analysis of all the flights in each year, they are summed up and printed for the year.

Table 3.1-7 is an example of the crew skills matrix used to compute SOC crew skills requirements and manloading requirements. On the left-hand side are indicated five Orbiter functions that may occur for any particular payload delivery. The analysis logic selects those functions that are applicable to a particular flight. The time estimates in the second column represent the number of days required to accomplish a particular function. These represent days of continuous work. An Orbiter offloading activity is estimated to require 6/10ths of a day, representing 14.4 hours of continuous manned operations. As indicated in the body of the matrix, three skills would be required full time during this 14.4 hours of activity for Shuttle offloading.

Continuous hours of work are adjusted for actual shift operations and days off to determine calendar time required to accomplish a particular set of functions for a particular mission.
Figure 3.1-21. Crew Activities Analysis Overall Logic
Table 3.1-7. Shuttle SOC Crew Skills Matrix

<table>
<thead>
<tr>
<th>NO.</th>
<th>ITEM</th>
<th>TIME</th>
<th>T-VA OPERATOR</th>
<th>EVA OPERATOR</th>
<th>EVA WORKER</th>
<th>TEST &amp; C/O ENGR</th>
<th>ELECTRICAL/MECH ENGR</th>
<th>PROP/FLUIDS/SPL ST</th>
<th>FL-FL CONTRL/SPL ST</th>
<th>PILOT</th>
<th>MATLS ACCOUNT</th>
<th>VISITING RESEARCHER</th>
<th>LIFE SCI SPCLST/DIR</th>
<th>GENERAL</th>
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<tr>
<td>1</td>
<td>ORBITER ARRIVE</td>
<td>0.0416</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>ORBITER OFFLOAD</td>
<td>0.60</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>ORBITER RELOAD</td>
<td>0.60</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
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<td>4</td>
<td>ORBITER DEPART</td>
<td>0.021</td>
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<td>100</td>
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<td>5</td>
<td>ORBITER PROP, X-ER</td>
<td>0.5417</td>
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<td>25</td>
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</tbody>
</table>

ORBITER WAIT
RESERVED
RESERVED
Similar matrices were used for the OTV construction and satellite servicing functions. A slightly different mechanism was used to estimate the required science and applications functions inasmuch as the research manlevels were passed through from the traffic model.

3.1.5 CONCLUSIONS

Consideration of whether to base OTVs in space or on the ground requires evaluation of the SOC requirements as well as evaluation of the transportation requirements. Shown on the left of Figure 3.1-22 are the annual Shuttle flights plus OTVs expended for three cases all with aerobraking of the OTV. Space-basing saves on the average about four Shuttle flights per year. However, it requires an average about three-and-a-half extra SOC crew members.

Based on a cost estimate for SOC crew labor, to be described in Section 6.0, the costs of space-basing for the crew labor are approximately $1.67 billion over a 12-year mission model, and the savings are somewhat greater, approximately $2 billion over the same period based on a $40 million average Shuttle flight cost.

Several conclusions were drawn from this analysis. First, the mission model is dominated by the commercial and defense sectors as shown in Figure 3.1-23. This is an expected result inasmuch as these sectors represent important national priorities.

We found a definite need for a Space Operations Center. A manned space station pays off both for operations and for research and applications. In fact, the SOC utility divides roughly evenly between the operations functions and on-board science and applications.

The science and applications activities in this mission model were confined to those that have significance to either long-term manned space operations or potential commercial applications.

Because we project an increase in the SOC crew requirements with time, an evolutionary program is the best fit to mission needs. It would be logical to begin SOC operations with a ground-based OTV for the first two or three years. The
Space-basing saves 52 @ $40M = $2.081B

<table>
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<tr>
<th>CASE</th>
<th>TOTAL FLIGHTS (12 YR)</th>
<th>FLIGHTS SAVED (12 YR)</th>
<th>AVG SAVED PER YR</th>
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<td>-</td>
<td>-</td>
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<tr>
<td>SPACE</td>
<td>431</td>
<td>52</td>
<td>4.3</td>
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<tr>
<td>SPACE WITH SCAV</td>
<td>387</td>
<td>96</td>
<td>8</td>
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Figure 3.1-22. OTV Basing: Space vs Ground (Median Traffic Model)
Figure 3.1-23. Summary of the Mission Models: Delivery or Servicing Events
SOC crew will initially be largely occupied with smoothing out station operations. Further, it would be most practical to ground-base the OTV until some operating experience with the vehicle is obtained. It appears logical to begin with a four-man SOC and eventually grow to 8 to 12 people. Towards the end of the 1990s, it may be desirable to set up a separate station for research and application missions.

We found that OTV aerobraking is essential to reduce the demands on space transportation. It does not appear to make sense to develop an OTV without aerobraking. Finally, space-basing pays off as does ET external tank scavenging. It appears that the OTV should be designed for space-basing even though it will probably be initially operated in a ground-based mode.

The low and median mission models developed by this study represent moderate demands on space transportation. They do not appear to exceed the capabilities of a five-Orbiter fleet even by the year 2000, assuming that all five Orbiters are in the turnaround cycle. Only the high model exceeds this demand level. The high model represents an economic scenario in which commercial investment in space transportation fleet equipment could probably provide the additional capacity.
3.2 TELECOMMUNICATIONS MISSION MODEL

3.2.1 APPROACH AND RATIONALE
3.2.2 PARAMETRIC RESULTS
3.2.3 THE FINAL MODELS
3.2.4 EVALUATION OF MODELS
3.2 TELECOMMUNICATIONS MISSION MODEL

3.2.1 APPROACH AND RATIONALE

The commercial communications sector model was derived from an economic-technical rationale based on historical experience and technological projections.

New technologies introduced to the marketplace often generate a very high rate of economic growth over a substantial number of years. Rapid economic growth occurs, as lower costs made possible by the new technology cause rapid acquisition of a significant market sector for whatever service or product is offered. Examination of historical data suggests that the process begins with an infancy period in which the growth is erratic and often at very high rates. Then an adolescent period occurs, in which the growth rate is more predictable but still quite rapid. This is followed by a period in which the new industry has reached maturity and its growth generally parallels the gross national product. Many industries eventually reach an old age period when growth subsides and decline takes place, even in some instances, entirely phasing out an industry. The trending concept illustrated in Figure 3.2-1 represents this rationale and is based on an examination of historical development of market sectors.

A few years ago the Boeing Commercial Aircraft Company performed a study of historical growth and development in the transportation sector. Four principal industries were examined dating all the way back to clipper ships. The data presented in the figure are on a semi-logarithmic scale. In each instance, as in Figure 3.2-2, the transportation sector exhibited a period of rapid growth, followed by a leveling-off paralleling the gross national product. In all instances, these rapid growth periods represented the adolescent or shakeout period; very early history was not presented. The annual growth rates for the motor car and airline operations are on the order of 50% per year for 20 to 30 years. The items plotted represent delivered services or products. The growth rates presented are for growth in market quantity. Inasmuch as costs per unit were being reduced over this period the growth rates in actual market value would be less.

Illustrated in Figure 3.2-3 is the number of installed telephones versus time for the U.S. telephone industry. The infant and adolescent rapid growth periods are
Figure 3.2-1. The Economic Trending Concept
Figure 3.2-2. Growth and Maturing in the U.S. Economy

Sources: Historical Statistics of the U.S., Colonial Times to 1970
U.S. Dept. of Commerce
Figure 3.2-3. Telecommunications Growth
Since 1940 the growth has been nearly parallel to the gross national product. However, it is worthy of note that for 24 years the average growth rate was 39% per year. What began as a novelty in the late 19th century grew into one of the principal economic sectors in the U.S. economy today, with over 200 million telephones installed across the United States.

3.2.2 PARAMETRIC RESULTS

Figure 3.2-4 presents the space telecommunications model created as a part of this study. The economic trending concepts described earlier were used. This model presumes that space communications will acquire a larger and larger sector of the entire telecommunications marketplace until it reaches market saturation sometime in the future. In consonance with the idea of creating low, median and high models, three growth rate levels were presumed. The data on the chart represent the values actually used in the model.

The structure of the model projects economic developments in terms of investment in the industry, and technical trends in terms of technological improvements. These two sets of assumptions then allow derivation of the number and type of satellites launched. Information shown on the chart includes the following model elements: (1) Growth of total telecommunications, representing a ceiling for acquisition of market share by space telecommunications. (2) Growth rates for the space telecommunications sectors of the market. (3) The value of the space segment part of the space telecommunications system, this representing the actual value of assets placed in space. It is important to recognize that as the marketplace matures the fraction of the total investment in space telecommunications systems actually launched in space will decline. This is already taking place with the proliferation of ground receivers for television distribution. (4) The cost of spacecraft and space transportation, both expected to gradually decline on a unit mass basis over the next 20 years. The figures used for space transportation costs in the year 2000 are appropriate to a Shuttle with a reusable, aerobraked, high-energy orbit transfer vehicle. (Projections utilized in this study did not presume radical advances in space transportation such as fully-reusable heavy lift systems or advanced technology propulsion.) (5) Payload mass per representative transponder based on results of the General Dynamics study of space platforms. (6) The spacecraft bus to payload ratio, also as estimated by the
### Economic Trending

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<th>ASSETS (LOG SCALE)</th>
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</tr>
<tr>
<td>1990</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
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<tr>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>35%</td>
<td></td>
</tr>
<tr>
<td>30% / 25%</td>
<td></td>
</tr>
<tr>
<td>20% / 20%</td>
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### Model Elements

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<th>LOW</th>
<th>MED</th>
<th>HI</th>
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<td><strong>VALUE, 1980</strong></td>
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<td>20%</td>
<td>10%</td>
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<td>50%</td>
<td>20%</td>
<td>10%</td>
</tr>
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<td>14500</td>
<td>13500</td>
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<tr>
<td><strong>SPACE TRANSPORTATION COST, $/kg</strong></td>
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<td>11000</td>
<td>7200</td>
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<td>3</td>
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<td><strong>BUS/PAYLOAD RATIO</strong></td>
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<td>2</td>
</tr>
<tr>
<td><strong>REPRESENTATIVE S/C MASS</strong></td>
<td>1000 kg</td>
<td>3000 Kg</td>
<td>4000 Kg</td>
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<tr>
<td><strong>REPRESENTATIVE S/C LIFE</strong></td>
<td>7 YR</td>
<td>15 YR</td>
<td>15 YR</td>
</tr>
<tr>
<td><strong>U.S. MARKET SHARE OR TOTAL TELECOM,-launches</strong></td>
<td>100%</td>
<td>50%</td>
<td>50%</td>
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---

Figure 3.2-4. Space Telecommunications Model Concept
General Dynamics study, is expected to improve as size increases. (7) The representative spacecraft mass is expected to increase to the platform class by the year 2000. The size of the platform was varied as a function of the traffic models. (8) The representative spacecraft life is expected to gradually increase to 15 years. (9) Since this model is for U.S. space operations, a projection was made that the U.S. market share for total telecommunications launches would decrease from the present near 100% to about 50%.

One of the significant trends in this model is a decrease in the cost per transponder-year for spacecraft. This decrease results from a decrease in the payload mass per transponder, a decrease in the bus to payload ratio, a decrease in spacecraft plus space transportation cost, and finally a decrease in the annual capital charge as the spacecraft life increases. Sample calculations as illustrated in Figure 3.2-5 indicate that the cost per transponder-year may decline from a present figure of roughly $400,000 to something on the order of $30,000 by the year 2000. This result closely parallels the results presented in the General Dynamics platform studies.

The parametric graph presented in Figure 3.2-6 was taken from the General Dynamics platform study. It illustrates the decrease in space segment cost per transponder-year, both historical and projected, for a variety of platforms. The noted circles on the chart represent the results of our parametric trending models. The circles are about a factor of two above the General Dynamics curve because our cost per transponder-year included capital charges, whereas the General Dynamics data did not.

Tab runs from the final economics model are presented in Tables 3.2-1 through 3.2-4. Table 3.2-1 includes the inputs to the model and the remaining tables present model outputs for the high, median, and low cases. The model is implemented in a small software package on a timeshare minicomputer.

Figures 3.2-7 through 3.2-9 present a graphical summary of the results from the three telecommunications forecast models. The principal results are plotted on the chart. The result of primary significance to the modeling activity is the annual number of U.S. launches and the value of assets in space. The annual number of U.S. launches represents a potential demand for launch and SOC
COST PER XP-YR = \frac{(P/L \text{ MASS})}{\text{PER XP}} \times (1 + \text{BUS-P/L RATIO}) \times (S/C + S/T \text{ COST}) \times (\text{CCF FOR LIFE})

WITH A 15% RETURN, CCF = 0.24 FOR 7 YEARS
\hspace{1cm} = 0.17 FOR 15 YEARS

IN 1980, C = 10 \times 4 \times 45,000 \times 0.24 = $432,000 \hspace{1cm} 12\% \text{ PER YEAR}
IN 2000, C = 3 \times 3 \times 19,500 \times 0.171 = $30,000 \hspace{1cm} \text{DECLINE}

Figure 3.2-5. Sample Calculations:
Figure 3.2-6. Intelsat Series Demonstrates Economy of Scale in Communications Spacecraft
Initial Total Telecom Assets in Billions: 200
Telecom Assets Growth Rates: First and Second Ten Years: 10, 5
Initial Space Telecom Assets Value in Billions: 2
Space Telecom Growth Rates for Three Traffic Scenarios:
- High Model, First & Second Ten Years: 35, 30
- Median Model, First & Second Ten Years: 30, 25
- Low Model, First & Second Ten Years: 20, 20
Initial Value of Space Segment, % of Space Telecom Assets: 50
Decrease Rate (%/Yr) of Space Segment Percentage
  for High, Median and Low Models: 7.73, 7.73, 3.675
Initial Cost of Spacecraft Hardware, $/Kg: 25,000
Initial Cost of Space Transportation to GEO, $/Kg: 20,000
Decrease Rate (%/Yr) for S/T Cost for High, Median, and Low Models: 7, 5, 3
Initial U.S. Share of Launch Traffic, %: 100
Decrease Rate (%/Yr) of U.S. Share: 3.5
Initial Payload Mass Per Transponder, Kg: 10
Decrease Rate (%/Yr) of Mass/Transponder: 5.84
Initial Bus-to-Payload Ratio: 3
Decrease Rate (%/Yr) of Bus-to-Payload Ratio: 2
Initial Representative Spacecraft Mass, Tonnes: 1
Increase Rate (%/Yr) of Spacecraft Mass for
  High, Median, and Low Models: 12, 7, 6
Initial Spacecraft Life, Yr: 7
Increase Rate (%/Yr) in Spacecraft Life: 3.88
Spacecraft Cost Learning Curve: 95

Table 3.2-1 - Communications Mission Model Inputs
<table>
<thead>
<tr>
<th>Year</th>
<th>Total Telcom Assets</th>
<th>Space Telcom Assets</th>
<th>Space Seg Value</th>
<th>Space Cost/ Expend (S/K)</th>
<th>No. Expend Launch</th>
<th>S/C Mass, 1000KG</th>
<th>S/C+$5/T Cost $/KG</th>
<th>No. of S/C In Orbit</th>
<th>No. of U.S. Launches</th>
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<td>1981</td>
<td>220.0</td>
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<td>1.2</td>
<td>1647</td>
<td>650</td>
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# Table 3.2-3

RESULTS FOR MEDIAN MODEL

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Figure 3.2.7. Telecommunications Low Model
Figure 3.2-8. Telecommunications Medium Model
Figure 3.2-9. Telecommunications High Model
service. The accumulation of value and assets in space is a determining factor for the development of geosynchronous satellite servicing capability.

### 3.2.3 THE FINAL MODELS

In order to finalize the payloads launch forecast the parametric results from the model were made specific by projecting a range of satellite sizes that might be launched in the next 20 years. Figure 3.2-10 presents the assumed characteristics of the satellites including estimates of the type of service and the sizes and lengths needed as inputs for the analyses to be described on later pages.

The final telecommunications models were completed by making the parametric economic model results specific in terms of numbers of spacecraft of different sizes to be launched every year. The progression to larger and larger spacecraft was forecast to be gradual with a new, larger size of spacecraft introduced every two to five years, much as has been true in the past. The high model is forecast to grow to bigger spacecraft than the median or low models. Overlap was forecast to occur with as many as three different classes of spacecraft being launched simultaneously in some years. This also is typical of present systems. The models are presented in Figure 3.2-11.

The number of communications satellites actually launched in 1981 will be eight, and about five of those will be one-ton class with the other somewhat smaller. Launches of a two-ton class will begin with the initial launches of TDRSS.

A traffic model for space communications was developed in the earlier SOC study. The annual mass delivered in this earlier model is represented by the squares in Figure 3.2-12. The new models are also presented on the same chart.

### 3.2.4 EVALUATION OF MODELS

Table 3.2-5 presents a comparison of total cumulative equivalent transponders launched for the three mission models of the present study, and for a mission model created by Econ for the United States only, including video teleconferencing. In the Econ data, the term "equivalent transponders" includes only bandwidth considerations. In the present model, the term "equivalent transponders" includes
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*Figure 3.2-11. Telecommunications Models*
Figure 3.2-12. Communications Traffic Model
Table 3.2-5. "Equivalent Transponders" Comparison

"EQUIVALENT TRANSPONDERS" INCLUDES BANDWIDTH, POWER, AND COMPLEXITY FACTORS

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ECON (U.S. ONLY, INCLUDING VIDEO TELECONF.)

SERVICES NOT INCLUDED IN ECON FORECAST

- DIRECT BROADCAST TV
- STANDARD
- WIDEBAND
- USER-PREMISES ON-REQUEST SERVICES
- DATA & INFORMATION
- ENTERTAINMENT

NO FORECAST
bandwidth, power, and complexity factors, inasmuch as some future services may require additional mass per transponder for high gain multi-beam antennas, more complex switching systems, more power as for direct broadcast TV, or higher complexity associated with dividing a given transponder bandwidth into a large number of individual user-premises communication links.

The present traffic models trend higher than the Econ forecast. However, the Econ forecast included only one new demand segment, that of video teleconferencing. Historically, a new application of space communications has arisen every two to four years. Some services not included in the Econ forecast but now either on the horizon or technically feasible include direct broadcast TV. Direct broadcast TV with standard bandwidth is now in the planning stage with filings for over 20 satellite slots presently before the Federal Communications Commission. The Japanese are working on a wideband TV system using 3,000 or so scan lines instead of the 525-line U.S. standard. It is reported that this wideband TV provides a picture comparable in quality to technicolor movies. The bandwidth requirement would be something like 10 to 20 times that for standard TV broadcast. This very great bandwidth per channel would be probably feasible only with an advanced satellite direct broadcast system.

A wide variety of user-premises on-request services are technically feasible. Based on projected cost trends, direct satellite linking for home and small business computers could be less costly than installing a second telephone line to provide the same service. The communications cost for such services would be small compared to the charges normally accrued for the data services themselves. Even such applications as on-request stereo music broadcast or TV entertainment broadcast should be technically and economically feasible before the year 2000.

Satellite direct TV broadcasting is a representative new application not represented or under-represented in earlier forecasts. Table 3.2-6 summarizes the more significant proposals for direct broadcast satellites presently before the FCC. (This information comes from Barron's Magazine.) The total is 14, but some of the filings were regarded by this source as not likely to result in a satellite launch even if a slot were granted. The number of satellites in the proposals listed on the table totals 24.
Table 3.2-6. Orbital Slots Major U.S. Direct Satellite Broadcasting Proposals

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<th>COMPANY</th>
<th>SATELLITES</th>
<th>CHANNELS PER SATELLITE</th>
<th>DISH SIZE</th>
<th>SYSTEM COST</th>
<th>SERVICE</th>
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<td>CBS</td>
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<td>3</td>
<td>39&quot;</td>
<td>N.A.</td>
<td>ADVERTISING &amp; PAY</td>
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<td>DIRECT BROADCAST SATELLITE CORP.</td>
<td>3</td>
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<td>35&quot;</td>
<td>$725 MIL.</td>
<td>COMMON CARRIER</td>
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<td>FOCUS BROADCAST</td>
<td>1</td>
<td>1</td>
<td>29&quot; - 59&quot;</td>
<td>$53 MIL. YR. (LEASE)</td>
<td>PAY &amp; ADVERTISING</td>
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<tr>
<td>GRAPHIC SCANNING</td>
<td>2</td>
<td>4</td>
<td>23&quot; - 39&quot;</td>
<td>$136 MIL. (1 SAT)</td>
<td>PAY - $24.95/MO.</td>
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<tr>
<td>RCA</td>
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<td>6</td>
<td>23&quot; - 39&quot;</td>
<td>$775 MIL.</td>
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<td>SATELLITE TV CORP.</td>
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<td>3</td>
<td>23&quot; - 35&quot;</td>
<td>$683 MIL.</td>
<td>PAY</td>
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<td>HUBBARD BROADCASTING</td>
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<td>4</td>
<td>35&quot;</td>
<td>$234 MIL.</td>
<td>ADVERTISING</td>
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<td>WESTERN UNION</td>
<td>4</td>
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<td>15&quot; - 35&quot;</td>
<td>$516 MIL.</td>
<td>COMMON CARRIER</td>
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<td>Total Satellite Model from S/SUM Data Base</td>
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<td>Typical Satellite Program Costs vs Mass</td>
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<td>Comparison of Launch and Service Models</td>
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<td>3.3.2.8</td>
<td>Typical Waterfall Effects of Budget Limits Reference</td>
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3-77
3.3 SPACE SCIENCE, EARTH SENSING & SPACE TESTING MISSIONS

Grumman's mission needs and modeling analysis task on SOC are keyed to the Satellite/Service User Model (S/SUM) developed for its recent study of satellite services near the orbiter (Reference 3.3-1). The S/SUM contains 210 satellites and payloads, which were derived from the NASA 5-Year Plan (1981 - 85), (Reference 3.3-15), STS Flight Assignment, (Reference 3.3-5), OAST Space Systems Technology model (Reference 3.3-3) and other unclassified data sources. This model spans the years 1981 to 2000 and includes LEO service events for launch, on-orbit servicing revisits, and retrieval for earth return. In addition to Orbiter direct delivery satellites, it covers LEO selfpropelled satellites, GEO satellites, upper stages, planetary spacecraft, sortie payloads and DOD missions.

As shown in Figure 3.3-1 Grumman's SOC mission modeling effort was focused on Space Science, Earth Sensing and Space Testing missions. Information on current NASA programs was used to update the S/SUM database for these mission areas in the 1985 to 2000 year period. This mission forecast was then analyzed with respect to related budget projections and estimated satellite program costs. As a result of this analysis three mission models (High, Medium and Low) are defined for each area of interest.

3.3.1 MISSION MODEL DEVELOPMENT

In selecting a data base for carrying out the SOC Mission Modeling, Grumman initially revised the S/SUM model developed for the Satellite Service Systems study as reported in Reference 3.3-2. Inputs to this model were primarily from the 1980 NASA Space Systems Technology Model (Reference 3.3-3), The 1979 Low Energy Payload Model (Reference 3.3-4), The June 1980 NASA Flight Assignment Manifest (Reference 3.3-5) and the Mission Data Catalogue (Reference 3.3-6). Other data for completeness of the data file were drawn from References 3.3-7 through 3.3-11. This allowed compilation of a Shuttle use model containing the spectrum of missions covering Civil and DOD satellites and sorties as well as servicing and satellite recovery.
Fig. 3.3-1 Grumman SOC Mission Model Development

DATA SOURCES
- LOW ENERGY PAYLOAD MODEL
- MISSION DATA CATALOGUE
- NASA FLIGHT ASSIGNMENT MANIFEST
- NASA SPACE SYSTEM TECHNOLOGY MODEL - ETC

R81-2100-082W

SAT./SERVICES USER MODEL
- DOD MISSIONS
- SORTIES
- PLANETARY & OTHERS
- GEO SATELLITES
- SAT WITH LEO PROPULSION
- DIRECT DELIVERY & SERVICING

SOC MISSION SORT (NON-DOD)
- EARTH & SPACE SCIENCE
- EARTH OBSERVATION
- SPACE TESTING
- SATELLITES ONLY (NO PALLET SORTIES)

ECONOMIC ANALYSIS & MISSN. MODELS
- SATELLITE BUDGET PROJECTIONS
- [HI, MED & LOW]
- SATELLITE PROG COSTS
- HIGH, MEDIUM & LOW ACTIVITY LEVEL MISSION MODELS
operations. Comparison of this data base with the 1981 NASA Space Systems Technology Model (Reference 3.3-12), as shown in Figure 3.3-1, indicated limited program changes. Because of the preliminary nature of Reference 3.3-12, the choice was made to retain 1980 mission nomenclature as the primary baseline for mission modeling.

The contents of the S/SUM model and the development of SOC data base covering NASA's Space Science, Earth Sensing and Space Testing mission categories are discussed in the subparagraphs below.

3.3.1.1 Total Satellite Model from S/SUM Data Base

The histogram in Figure 3.3-2 provides the projected launch rate per year from 1981 through 2000 for the updated SAT/SUM data base of 11/2/81, including both military launches of Shuttle and the non-DOD payloads. During the post-1987 time period, this data base nominally covers 5 unclassified DOD launches per year: whereas, the non-DOD satellite launches per year range from 50 to 60 in the early 1990s and then approach 80 in the late 1990s. Since the data base covers a broad range of satellite orbital inclinations (i.e., 0 to 100 degrees), all of these satellites are not compatible with SOC. The non-DOD launches are divided into the overall mission areas being addressed by Boeing and Grumman. Grumman's assigned NASA mission areas covering Earth and Space Sciences, Earth Sensing, and Space Testing is depicted at the bottom of the chart. Boeing addressed the other mission areas, independently.

3.3.1.2 Earth and Space Science Satellite Model

A histogram of the satellite launch traffic from S/SUM for the Earth and Space Sciences mission category is presented in Figure 3.3-3. Earth and Space Sciences missions encompass Astrophysics, Solar Terrestrial Physics and Planetary satellites. Satellites launched in each of these three satellite categories are totaled each year for 1983 through the year 2000 inclusive, and range from a single launch in 1983 to 14 in 1989. Some 100 launches are included in the histogram with Astrophysics missions averaging about four launches per
Fig. 3.3-2 Total Satellite Model From S/SUM Data Base

Fig. 3.3-3 Earth and Space Sciences
year and Solar Terrestrial two per year. The Solar Terrestrial annual count is seen to be concentrated in the 1980s with only two launches after 1982. Although Planetary averaged slightly more than one launch per year, the traffic load is larger during the 1990s when SOC is operational, at nearly two launches per year. A significant number of solar terrestrial launches in the S/SUM are pallet missions, and are not included herein because they are short duration missions.

Satellite characteristics, their orbits and mission traffic schedule are provided for the three satellite categories in Tables 3.3-1 through 3.3-3. The satellite missions are listed chronologically within each category. These missions are identified in accordance with the nomenclature defined in the 1980 NASA Space Systems Technology Model (i.e., A-3, S-2, etc). The correlation between these designators and the revised listing in the 1981 NASA Space Systems Technology Model is shown parenthetically under the name of the satellite. Satellite service mission events for deployment (D), on orbit support service(S) and satellite return/retrieval (R), are scheduled on different lines. The Space Telescope (Table 3.3-1) for example, is planned to be launched in 1984. This satellite will be serviced on-orbit at least once (1986) during its 5 year mission. Potential service events for contingency situations are shown as dots. The Space Telescope is retrieved in 1989 for ground refurbishment and then re-launched in 1990 for another 5-year mission. This retrieval and re-launch cycle is repeated again in 1995 and 1996. Similar data are provided for other satellite missions included within the 1985 through 2000 time frame. Twenty six satellite programs are included in Table 3.3-1, seven are flagged for deployment and recovery directly by Orbiter because they are beyond SOC retrieval. Satellite count is much higher due to multiple satellites required in some programs as indicated by the numbers in the table.

Table 3.3-2 lists 15 Solar Terrestrial mission programs, 3 are flagged for deployment and recovery directly by Orbiter Programs, such as the International Solar Polar Mission (SS) and the X-Ray Observatory (S27) are included in the table.
TABLE 3.3-1 SATELLITE/SERVICE USER MODEL FOR ASTROPHYSICS MISSIONS

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**NUMERALS**

- NUMERALS DENOTED SCHEDULED EVENTS - DOTS DENOTE POTENTIAL SERVICE EVENTS - UNSCHEDULED

**DIRECT ORBITER LAUNCH AND RECOVERY**

- D - DEPLOY
- S - SERVICE
- R - RETRIEVE
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NUMERALS DENOTE SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

DIRECT ORBITER LAUNCH AND RECOVERY

*D – DEPLOY
*S – SERVICE
*R – RETRIEVE

SOC SERVICE OPTION TO BACK UP ORBITER AVAILABILITY

3-84
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NUMERALS DENOTE SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

1) DIRECT ORBITER LAUNCH AND RECOVERY
2) **D** – DEPLOY
3) **S** – SERVICE
4) **R** – RETRIEVE
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NUMERALS DENOTED SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

D – DEPLOY
S – SERVICE
R – RETRIEVE
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<td></td>
<td>(S:38)</td>
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<td>350 28.5</td>
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<td>(S:24)</td>
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|        | NUMERALS DENOTED SCHEDULED EVENTS - DOTS DENOTE POTENTIAL SERVICE EVENTS - UNSCHEDULED |
|        | DIRECT ORBITER LAUNCH AND RECOVERY  | D - DEPLOY  |
|        |                                      | S - SERVICE   |
|        |                                      | R - RETRIEVE  |

TABLE 3.3-2 SATELLITE/SERVICE USER MODEL FOR SOLAR TERRESTRIAL MISSIONS
SHEET 2 OF 2

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### TABLE 3.3-3 SATELLITE/SERVICE USER MODEL FOR PLANETARY MISSIONS

#### SHEET 1 OF 2

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**NUMERALS DENOTED SCHEDULED EVENTS - DOTS DENOTE POTENTIAL SERVICE EVENTS - UNSCHEDULED**

*D - DEPLOY

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### TABLE 3.3-3 SATELLITE/SERVICE USER MODEL FOR PLANETARY MISSIONS

**SHEET 2 OF 2**

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*D - DEPLOY

*Employee number is D - 2100-1408*
Fifteen Planetary programs are listed in Table 3.3-3 including Saturn Orbiter (P7) which involves deployment of two satellites in 1989. The Galileo Orbiter and Probe deployments are not shown on the Table since they occur prior to 1985. These satellites are listed because if they experience considerable delay in launch, possibly due to budget constraints, they could be deployed during the SOC era.

### 3.3.1.3 Earth Sensing Satellite Model

The data for Earth Sensing missions from S/SUM are presented in the Figure 3.3-4 histogram. Resource Observation and Global Environment mission categories are included in the Earth Sensing Model. The Resource Observation mission component for this category is seen to reach an average of nearly eight missions per year during the late 1980s but then slacks off to four or five launches per year during the 1990s.

The other component of the Earth Sensing mission category, Global Environment, is depicted in the upper portion of the histogram presented in Figure 3.3-4. During the potential SOC availability time period after 1987-88 the Global Environment mission launch rate holds at an average of over five per year until the 1997 where the increased totals reflect the build up of the postulated Department of Energy (DOE) nuclear waste disposal launches.

Tables 3.3-4 and -5 contain the satellite characteristics, orbits, and mission traffic scheduled for the Earth Sensing category. Resource Observation (Table 3.3-4) contains 16 satellite programs, which include 2 commercial programs. Landsat D (R1) and Magsat B (R2) are two of the better known NASA satellites in this category.

Global Environment (Table 3.3-5) contains 13 programs, which include a foreign satellite (Inmetsat), 3 commercial satellites, and the DOE Nuclear Waste Disposal. The high number of Waste Disposal Missions in the late 1990s drives the Earth Sensing Model.
Fig. 3.3-4 Earth Sensing Satellite Model
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**NUMERALS DENOTE SCHEDULED EVENTS - DOTS DENOTE POTENTIAL SERVICE EVENTS - UNSCHEDULED**

1. **DIRECT ORBITER LAUNCH & RECOVERY**
   - D - DEPLOY
   - S - SERVICE
   - R - RETRIEVE

*R81-2100-143B*

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<td>ADV THERMAL MAPPING</td>
<td>D S R</td>
<td>700</td>
<td>98</td>
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<tr>
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<td>(R7)</td>
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<td>1450</td>
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<td>D S R</td>
<td>700</td>
<td>57</td>
<td>1000</td>
<td>-</td>
</tr>
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<td></td>
<td></td>
<td></td>
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**Notes:**
- Numerals denote scheduled events.
- Dots denote potential service events - unscheduled.
- D - Deploy
- S - Service
- R - Retrieve

3-93
<table>
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<td>UPPER RES SAT ATMOS (E5)</td>
<td>D S R</td>
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<td>56</td>
<td>3700</td>
<td>3700</td>
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<td>E5</td>
<td>NOAA H &amp; I (E7)</td>
<td>D S R</td>
<td>830</td>
<td>99</td>
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<td>46</td>
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<td>1600</td>
<td>3600</td>
<td>3600</td>
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<td>E53</td>
<td>MAP GRAVITY FIELD/ COMM</td>
<td>D R</td>
<td>35786</td>
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<td>615</td>
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<tr>
<td>E9</td>
<td>TOPEX (E6)</td>
<td>D R</td>
<td>700</td>
<td>87</td>
<td>1000</td>
<td>1000</td>
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NUMERALS DENOTED SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

DIRECT ORBITER LAUNCH AND RECOVERY

* D – DEPLOY
S – SERVICE
R – RETRIEVE

SOC SERVICE OPTION TO BACK UP ORBITER AVAILABILITY

R81-2100-1418
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<td></td>
<td>H</td>
<td>I</td>
<td>UP</td>
<td>DN</td>
<td>M</td>
<td>5</td>
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<tr>
<td>E10</td>
<td>OPERATIONAL METEOROLOGY</td>
<td>D</td>
<td>S</td>
<td>R</td>
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<td>800</td>
<td>87</td>
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<td>(COMMERCIAL)</td>
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<td></td>
</tr>
<tr>
<td>E11</td>
<td>OCEAN RESEARCH (E9) (FIHex)</td>
<td>D</td>
<td>S</td>
<td>R</td>
<td></td>
<td>300</td>
<td>56</td>
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<td>E54</td>
<td>GLOBAL REG ATMOS MONIT (E9)</td>
<td>D</td>
<td>S</td>
<td>R</td>
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<td>(LARS)</td>
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<td>E57</td>
<td>NUCLEAR WASTE DISPOSAL (DOE)</td>
<td>D</td>
<td></td>
<td>.85AU</td>
<td>28.5</td>
<td>10430</td>
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NUMERALS DENOTED SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

DIRECT ORBITER LAUNCH AND RECOVERY
*D – DEPLOY
S – SERVICE
R – RETRIEVE

R81-2100-142B
3.3.1.4 Space Testing Modeling

A representative set of space test flight programs was developed for the 1981-2000 time period. These missions, which include approximately 22 launches, focus on experiments related to the SOC induced environment: long duration space exposure, micro gravity fluid mechanics, large space structure technology, and scientific instrument development.

The S/SUM launch activity for this mission category is presented in Figure 3.3-5. The activity profile shown indicates a maximum of two missions in a given year.

The following payloads/satellites are included in this mission category:

- **Long Duration Exposure Facility (LDEF)** - the LDEF is a reusable, gravity-gradient stabilized, free-flying structure. It has no propulsive capability and can accommodate many technology, science, and applications experiments, both passive and active, that require extended exposure to space. Experiments are mounted on 72 periphery trays and on 2 trays at each end. These trays could be removed and replaced with new experiments in SOC. The LDEF could even remain attached or tethered to SOC to facilitate periodic experiment examination.

- **Induced Environment Contamination Monitor (IECM)** - An IECM similar to the one used during the Orbiter flight tests, will also be used on SOC to measure gaseous and particulate contaminants during various orbital operations (i.e., Orbiter cargo removal, satellite servicing, etc). The IECM will be positioned at different locations around SOC, with the manipulator to measure contamination levels.

- **Space Deployable Antenna Experiment** - An antenna system of approximately 50-m diameter would be deployed on the SOC for a flight test. The antenna would contain a multibeam feed system that would be excited for RF transmission and beam pattern tests. The antenna would also be instrumented to measure
Fig. 3.3-5  Space Testing Modeling
dynamic response to environmental inputs, control system commands, and surface and structural distortions encountered. At the conclusion of testing, the antenna system would be restowed and returned to Earth where it would be studied and refurbished for a subsequent flight if required.

- **Structural Assembly Demonstration Experiment (SADE)** - the SADE will establish a quantitative correlation between earth-based assembly simulations and on-orbit operations. Space-based assembly will occur through a coordinated activity between the RMS and EVA crewman. Once assembly has been completed, a structural dynamics experiment will be performed to obtain correlation with ground testing and analytical predictions and to assess the effects of SOC Coupling. A large space structure mission will demonstrate on-orbit fabrication, assembly and integration of a large structure, and also provide a user-oriented satellite platform in the process.

- **Deployable Platform Experiment (DPE)** - The objective of the DPE is to validate the characteristics of large space system platform technology. Ground support programs will be initiated to study various aspects of platforms prior to flight experiments. Subsystem verification will also be done in flight testing.

- **Two Phase Fluid Mechanics and Heat Transfer Facility** - Specific objectives are to develop an understanding of, and mathematical models for, reduced-gravity physical phenomena such as two-phase flow, forced convection boiling, reorientation fluid dynamics, bubble dynamics, pool boiling, and sloshing dynamics.

Table 3.3-6 presents the descriptive data and traffic schedules on these Space Testing programs. The Long Duration Exposure Facility (LDEF) program at the top of Table 3.3-6 was launched prior to 1985 with its first retrieval scheduled for 1985. The 1986 launch for a longer mission offers the potential for servicing and change-out of experiments in 1987, with a retrieval schedule for 1988.
### TABLE 3.3-6 SATELLITE/SERVICE USER MODEL FOR SOC SPACE TESTING MISSIONS

<table>
<thead>
<tr>
<th>ID NO.</th>
<th>NAME</th>
<th>MISSION FUNCTION*</th>
<th>ORBIT</th>
<th>MASS</th>
<th>LENGTH</th>
<th>DIA</th>
<th>TRAFFIC</th>
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<tr>
<td></td>
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<td></td>
<td>H</td>
<td>I</td>
<td>UP</td>
<td>DN</td>
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</tr>
<tr>
<td>0110</td>
<td>LONG DURATION EXPOSURE FACILITY</td>
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<tr>
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<td>(01-23+)</td>
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</table>

* D – DEPLOY  
S – SERVICE  
R – RETRIEVE  

R81-2109-145B
3.3.2 ECONOMIC ANALYSIS

Alternate mission models (High, Medium and Low) were derived from the S/SUM-SOC data by assessing the cost of projected satellite programs with future NASA budgets. In the budget projection process, it was recognized that both national policy and national economic growth could influence the funding available to the various space mission categories. In the cost assessment, it was necessary to define simple cost estimating relationships to apply to the satellite within each mission area. Finally, it was necessary to test cumulative costs against budget funds available to define compatible programs schedules. The major ground rules and assumptions used in this analysis are shown in Figure 3.3-6.

This process, covered the 1983 through 2000 time frame for six NASA mission areas (Planetary, Astrophysics, Solar Terrestrial, Global Environment, Resource Observations and Space Testing). In projecting alternative budgets, baseline budgets were established based upon data from recent NASA 5-year plans and FY 82 budget estimates using satellite program costs only, excluding Research and Analysis, sub-orbital testing, Spacelab and other non-satellite programs.

Estimates of the cost per unit mass of a spectrum of types of satellites were developed using data derived from informal contacts with NASA centers and from in-house cost evaluation file data. Three rather distinct categories or types of satellites tended to emerge, suggesting three cost factors rather than a single one. Cumulative program costs for each mission area could then be developed assuming the S/SUM launch sequence with satellite costs assigned at launch date. By referencing the cumulative cost history from S/SUM against the three alternative budgets for each mission area, corresponding alternative budget-limited launch schedules were developed. Re-flights within a given satellite program and non-NASA satellite missions were then inserted on the budget limited schedules based upon
APPROACH
– DEVELOP HIGH, MEDIUM AND LOW BUDGETS
– COST S/SUM SOC SATELLITE LAUNCH PLAN
– MATCH LAUNCH SCHEDULES TO GUM BUDGETS AvAIL.

COVERAGE
– MAJOR NASA OFFICES (OSTA, OSS, ETC) ONLY

BUDGET PROJECTION
– BASELINE SAT PROG BUDGETS - 5 YR PLANS & BUDGET EST
– SAT. PROG ONLY; EXCLUDES R & A, SUB ORB, SPACELAB & OTHER

SATELLITE PROGRAM COST ASSESSMENT
– PROG COSTS & MASS FROM NASA & GAC DATA
– COST PER UNIT MASS - THREE SAT. CLASSES

CUM PROG COSTS & BUDGET LIMITED LAUNCH SCHED
– S/SUM LAUNCH SEQUENCE
– SAT. COSTS ASSIGNED AT LAUNCH DATE
– LAUNCH DATE KEYED TO AVAIL BUDGETS
– RE-FLIGHTS & NON-NASA SCHEDULED PER S/SUM

Fig. 3.3-6 Economic Analysis Ground Rules & Assumptions
the S/SUM intervals between follow-on missions, and upon S/SUM schedules for non-NASA programs.

3.3.2.1 Budget Trending Alternatives

From the baseline budget available on the six mission areas, covering a maximum of 6 years, it was necessary to project future alternative budgets covering a span of the next 18 years. Figure 3.3-7 illustrates three conceptual approaches for developing alternate budgets.

The first, Continued Trend, illustrates projecting the present trend of growth along with a High and Low budget based on a growth or shrinkage of this annual budget trend by an arbitrary percent each year. A second approach, Current Base, using FY-82 as an annual base budget level and projecting zero, and positive and negative annual percentage growth rates of 2.5% is illustrated second. This 2.5% real annual growth and its mirror shrinkage rate are keyed to the Autumn 1981 U.S. Long-Term Review assessment by Data Resources, Inc. of 2.5% real GNP growth rate through 2006. The third conceptual chart illustrates a choice of a constant (baseline) annual budget and then a constant delta above and below that level for the high and low projection.

The Continued Trend approach with varying growth rates above and below the trend offers the potential advantages of capturing the trend of budgeting for each mission area, and looks at growth potentials relative to trends in real Gross National Product. This approach has the weaknesses of a short trend base causing unrealistic swings of the annual budget on an 18-year projection. Study of NASA budgets over the last 15 years also indicates that the annual budgets in constant dollars fluctuate significantly, representing policy changes in contrast with national economic growth trends.

The Current Base approach establishes a recent budget as a base and looks at long term growth on an annual average basis comparable to real GNP changes. Although two weaknesses of this approach, potential
Fig. 3.3-7 Budget Trending Alternatives

- Continued Trend
- Current Base
- Alternate Levels

ASSESSMENTS
KEY DRAWBACKS – SHORT DATA BASE UNREALISTIC TRENDS
ADVANTAGE – CURRENT BASE & ALT GNP (REAL) TRENDS (ALL MISSIONS EXCEPT SPACE TESTING)
ADVANTAGE – REFLECTS POLICY ALTERNATIVES (SELECTED FOR SPACE TESTING PROGRAM)

NASA BUDGETS POLICY SENSITIVE

ALTERNATE APPROACHES

ANNUAL BUDGETS

+2.5%
0%
-2.5%

CURRENT BASE

ANNUAL BUDGET

+2.5%
0%
-2.5%

ALTERNATE LEVELS

YEAR

+33%
BASE
-33%
bias in the chosen base and the policy nature of NASA funding are recognized, the Current Base approach offered near term policy guidance and use of reasonable real GNP trends. Projections of future High, Medium and Low budgets for five of the six NASA mission areas were carried out using this approach.

The Alternate Levels approach primarily reflects government policy alternatives and was used for the Space Testing mission area, with plus and minus 33% shifts around the small constant baseline budget.

3.3.2.2 Recent Budgets for NASA Satellite Programs

Table 3.3-7 presents recent satellite program budget histories for five traditional NASA mission areas. Data are provided in 1981 dollars with the dollar base of the data sources and the required adjustment factor for conversion to 1981 dollars presented to the upper portion of the chart. Data covering satellite total program costs, without Research and Analysis were, obtained from NASA 5-Year Plans, References 3.3-13, 3.3-14 and 3.3-15 and the FY-82 Budget Request (Reference 3.3-16).

The Astrophysics and Solar Terrestrial mission budgets are combined in the last 3 fiscal years. These combined budgets were therefore used as the budget history, which represents a generally rising trend of about 6% per year from FY-78 through FY-82. Planetary, Global Environment and Resource observation presented less obvious trends.

Because of the sensitivity of NASA budgets to policy changes and the shortness of the budget data base for trending, the FY-82 column of data was chosen as the baseline for these NASA mission areas.

Since definitive budget histories for Space Testing were not readily defined, a budget base for this mission area was derived out of recent OSTS and OAST programs and average Space Testing annual program costs through the late 1990s.
TABLE 3.3-7  ASSESSMENT OF NASA SATELLITE BUDGET HISTORIES
BY TECHNICAL PROGRAM AREA

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<th>YEAR</th>
<th>FY-'77</th>
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<td>'79/'81</td>
<td>'80/'81</td>
<td>'80/'81</td>
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<td>30</td>
</tr>
<tr>
<td>RESOURCE OBS.</td>
<td>130</td>
</tr>
</tbody>
</table>
| COMBINED ASTROPHYSICS & SOLAR TERRESTRIAL DATA BASE: — NASA SYR PLANS FY'78, '79 & '80 & FY'82 NASA BUDGET REQUEST — SATELLITE PROGRAMS ONLY, EXCLUDES SUPPORT R&A — CONST '81$ USING JUNE '80 ESCALATION FACTORS

RB1-2100-100W
3.3.2.3 NASA Satellite Mission Alternative Budget Projections

Budget history data were used in combination with the Current Base concepts in Figure 3.3-7 for annual budget projection to establish alternative budgets for the six NASA mission areas. Data base and High, Medium and Low annual and cumulative budgets for the 1983 through 2000 time frame were used as discussed in the following sections.

3.3.2.3.1 Alternate Budgets for Planetary Satellite Programs - Three alternate budget projections in 1981 dollars for the Planetary satellite program through the year 2000 are shown in Figure 3.3-8 as projections from the Current Base (FY-82 Estimate) from Table 3.3-7. Annual Budget alternatives are seen as: (1) constant at $185 M; (2) $185 M at the start of 1983 growing at 2.5% per year, and (3) this $185 M baseline shrinking at 2.5% per year. Thus the High annual budget has grown to nearly $290 M by the end of the year 2000, while the Low annual budget is seen to drop from $185 M in 1983 to under $120 M at the end of the year 2000.

This chart also provides these three budgets in cumulative form in the curves which slope upward to the right from the start of 1983. The baseline constant budget projection cumulates to over $3.25 B over this 18 year period. The High Budget projection cumulates to nearly $4.4 B while the Low Budget accrues a total of about $2.6 B. Although the differences between the high and low budgets is small during the 1980s the cumulative effects are significant by the mid 1990s.

3.3.2.3.2 Alternate Budgets for Combined Solar Terrestrial and Astrophysics Satellite Programs - Annual and cumulative alternate budgets are presented for these combined mission areas in Figure 3.3-9. It is seen that the combined budget history showed an annual increase of approximately 6% per year, resulting in nearly a threefold annual growth by the end of this century.

Basic zero growth, and plus and minus 2.5% per year projections from the 1983 baseline of $295 M are shown as the assumed annual
Fig. 3.3-8 Satellite Program Alternative Budgets for Planetary Missions

Fig. 3.3-9 Satellite Program Alternative Budgets for Combined Solar Terrestrial & Astrophysics Missions
budgets. The cumulative High budget makes nearly $7 B available for these combined satellite programs compared to just over $4 B for the cumulative Low budget over the 18 year period.

3.3.2.3.3 Alternate Budgets for Resource Observation Satellite Program - Budget history, and annual and cumulative projections at three levels are presented in Figure 3.3-10 for the Resource Observation mission, in constant 1981 dollars.

The limited budget history data are relatively constant and close to the $120 M baseline from the FY-82 budget estimate. Annual growth rates of zero and plus and minus 2.5% per year were again assumed. The resulting cumulative budgets over the 18 year period show a spread of nearly $1.25 B between the high and low projections.

3.3.2.3.4 Alternative Budgets for Global Environment Satellite Program - The budget history along with annual and cumulative alternate projections are presented in Figure 3.3-11 for NASA's Global Environment satellite program. Rapid increases in the annual budget history from 1979 through 1982 are thought to reflect policy changes in this mission area funding which can not be considered as a trend. Thus the FY-82 budget estimate of approximately $120 M was chosen as the baseline, and zero and plus and minus 2.5% growth per year projections were assumed.

The projected budgets for this Global Environment satellite program are identical to those used for the Resource Observation program.

3.3.2.3.5 Alternative Budgets for Space Testing Program - Budget histories for this mission area were derived out of advanced programs at OSTS and space systems technology at OAST. Assessments of the cost of Space Testing articles in the S/SUM/SOC model indicated an annual expenditure comparable to the average Space Testing budgets of OAST and OSTS at about $9 M/year. This constant value was selected as the medium budget projection shown in Figure 3.3-12. Because of the small
Fig. 3.3-10 Satellite Program Alternative Budgets For Global Environment & Earth Resources

Fig. 3.3-11 Alternative Budgets for Global Environment Satellite Program
Fig. 3.3-12 Satellite Program Alternative Budgets For Space Testing Missions
overall budget level involved, it appeared appropriate to treat the high and low budgets as alternate policies parallel to the constant medium projection. A delta of 33% ($3 M) above and below the medium annual budget was chosen to reflect significant policy differences for the three budget projections.

Cumulative budgets corresponding to these three constant annual budget projections in Figure 3.3-12 show a significant spread by the end of the study time period.

3.3.2.4 Typical Satellite Program Costs vs Mass

As discussed previously in reviewing ground rules and assumptions for this economic analysis, simple cost estimating relationship (CERs) were needed to develop estimates of total mission area costs. The plot in Figure 3.3-13 of satellite total program cost versus total payload to operating orbit presents this simple CER development.

Program Costs in 1981 dollars and the on-orbit mass of a number of different classes of satellites were defined from informal NASA contacts and from Grumman internal studies. Data appeared to fall into three distinct bands of cost per unit mass.

Planetary programs and high technology programs involving advanced state-of-the-art sensors and/or guidance and control formed one band at the upper left of the chart. A CER of $250,000 per kilogram as indicated by the heavy line labeled Planetary/Landsat appeared to adequately represent this group.

A second band, shown through the center of the chart is based on several rather "conventional" high technology satellites not requiring major breakthroughs in technology. NOAA, HEAO and Solar Max define a slope of approximately $50,000 per kilogram shown for the Conventional LEO and GEO line.

A third type of satellite involving primarily structural elements was found to be again significantly less expensive per unit mass. A
Fig. 3.3-13  Typical Satellite Program Costs vs Mass, 1981 $
total of four of these type articles was used to define the $10,000 per kilogram CER line at the lower right of the chart.

3.3.2.5 Cumulative Costs and Budget Limited Schedules

In this section the costs based on the preceding CER development are consolidated for each mission area and launch schedules are keyed to available budget to establish budget limited launch schedules.

3.3.2.5.1 Alternative Cumulative Budgets and Cumulative Program Costs - Planetary Satellites - The relationship between cumulative budgets and cumulative Planetary satellite program costs is shown in Figure 3.3-14. Cumulative costs were generated by summing costs based on the planetary CER applied to the satellite weights on the traffic schedule from the S/SUM/SOC planetary mission model in Table 3.3-3.

The cumulative cost progression, with each satellite identification number called out in Figure 3.3-14, indicates that out through 1991 the S/SUM/SOC schedule is generally close to the high cumulative budget (+2.5%/Yr) line. From 1993 on, the cumulative costs line rapidly diverges from the high budget line alternate. Cumulative budget lines of 5 to 10% per year are shown to illustrate general level of growth involved. The data point at the upper right labeled P-5 with an arrow denoting $14.2 B indicates that even a 10% annual real growth accrues only about two-thirds of the budget required to fund the complete S/SUM in the same time frame.

Figure 3.3-14 is also useful for defining satellite launch schedules for the three chosen projected budget levels of zero and plus and minus 2.5% annual growth. The horizontal, constant cost line drawn through the P-7 data point intercepts the High, Medium and Low cumulative budget curves. These points of intersection correspond to the schedule on which the budgets would be available to launch Planetary satellite P-7, Asteroid Multiple Rendezvous. Thus where S/SUM/SOC calls for a mid 1993 launch of P-7, the High budget allows Fall of 1994 launch, the Medium budget in late 1996 and the Low projection not until the first half of 2000.
CONSTANT 1981 DOLLARS
$185 M ANNUAL BUDGET BASE IN 1982

- APPROVED & PLANNED
PROGRAMS

Fig. 3.3-14 Alternate Cumulative Budgets and Cumulative Program Costs
—Planetary Satellites
Dashed horizontal lines drawn through P-11, Near Earth Asteroid Sample and the first and second launches of P-5, Mars Sampler Return, indicates the potential extension of the Planetary satellite program through real annual budget growth rates for 5 and 10% per year.

3.3.2.5.2 Alternative Cumulative Budgets and Cumulative Costs for Combined Solar Terrestrial and Astrophysics Satellites - Cumulative projected budgets and cumulative program costs are shown in constant 1981 dollars in Figure 3.3-15 for the combined Solar Terrestrial and Astrophysics programs. The basic zero, plus and minus 2.5% annual growth rate curves are augmented by a 5% growth line for added growth rate insight. Projection of a constant $295 M annual budget through the year 2000 would make a total of over $5 B available, whereas the high (+2.5% per year) budget would provide nearly $6.5 B.

The cumulative costs of these two mission areas, versus years within the S/SUM/SOC model, are seen as the series of data points coded with satellite identification numbers (ID numbers) across the center of the chart. Note that the sequence of cost cumulation arbitrarily "launches" the Astrophysics satellites first in each year. Again the cost curve moves out above the projected budgets including the added curve for 5% annual growth.

The costs of the S/SUM/SOC mission model clearly outstrip normal growth or even priority redistributions within the Earth Sensing, Earth and Space Science and Space Testing mission categories. The end data point of $26.1 B in the upper right corner is a factor of five larger than the cumulative constant budget (Medium) projection. Changes in priorities within the combined Solar Terrestrial and Astrophysics programs as relative to other mission areas within the three mission categories will serve to prevent the excessive delays of most programs as implied by maintaining the S/SUM/SOC launch sequence and the individual budget ceilings.
Fig. 3.3-15 Alternative Cumulative Budgets and Cumulative Program Costs — Combined Solar Terrestrial and Astrophysics Satellites
3.3.2.5.3 Alternative Cumulative Budgets and Cumulative Program Costs - Global Environment Satellites - The budget projections and satellite program cost cumulations for Global Environment satellites are presented in constant 1981 dollars in Figure 3.3-16 showing a similar trend of costs exceeding budget projections. This trend is again particularly strong in the 5-year period from 1988 through 1992. After the mid-1990s the S/SUM/SOC model shows limited numbers of satellites programmed, providing a closer match between budgets and program costs in the late 1990s.

Satellite E-9 (TOPEX), seen in this chart to be scheduled for late 1987 within S/SUM/SOC, would be delayed until early 1993, mid 1994 or late 1996 within the High, Medium and Low budgets, respectively. The Approved and Planned status programs, except for the last two E-2 (GOES) launches, are compatible with launch prior to 2000 within the High budget.

3.3.2.5.4 Alternative Cumulative Budgets and Cumulative Program Costs - Resource Observation Satellites - The Resource Observation cumulative program costs are seen in Figure 3.3-17 to start above budget in the early 1980s and never approach the trends of projected budget.

In the beginning of 1991 the cost of satellites launches on the S/SUM/SOC schedule exceeds $3.2 B while at the time that the High cumulative budget is less than $1.2 B. Due to the apparent high cost of the early satellite program within this mission area only five launches in the sequence of S/SUM could occur before the year 1999 within the Low budget projection. Even on the High budget projection this fifth launch (R-4 second launch) would be delayed until mid 1994.

3.3.2.5.5 Alternative Cumulative Budgets and Cumulative Program Costs - Space Testing Articles - Cumulative S/SUM/SOC program costs are presented in comparison with the three projected cumulative budgets in Figure 3.3-18. Costs in the early '90s exceed the high budget cumulative line by about 25% but fall back within this projection before the year 2000.
Fig. 3.3-16 Alternative Cumulative Budgets and Cumulative Program Costs —
Global Environment Satellites

Fig. 3.3-17 Alternative Cumulative Budgets and Cumulative Program Costs —
Resource Observation Satellites
ANNUAL BUDGETS
HIGH $12M/YR
MEDIUM $9M/YR
LOW $6M/YR

CUMULATIVE BUDGET & PROGRAM COST, 100M$ ('81 $)

CONSTANT 1981 DOLLARS

Fig. 3.3-18 Alternative Cumulative Budgets and Cumulative Program Costs — Space Testing Articles
The relationship between cumulative mission program costs and the projected cumulative budgets should show close correspondence. As discussed in conjunction with the Space Testing budget projection chart, the budget levels selected were guided partially by average annual estimated costs within the S/SUM/SOC mission module.

3.3.2.6 Economic Based Mission Activity Summaries

The budget impact upon satellite launch frequency in the 1988 through 2000 time frame is summarized in Table 3.3-8 for Earth and Space Science satellite programs. High, Medium and Low budget-constrained annual launch frequency is shown for the combined Solar Terrestrial and Astrophysics mission area and for the Planetary mission.

Annual totals launched for the three budget levels show the effects of low budgets, particularly in the 1990s. The total impact of the decreasing budget level is most apparent in cumulating the total annual launches over the 18-year model period. A total of 44 launches were available within the High budget, 39 under the Medium model and 31 launches when constrained by the Low budget model.

The annual mission rate for the Earth Sensing mission category satellite flights is presented in Table 3.3-9. In this mission category, significant numbers of satellite flights are financed by foreign organizations, commercial interests and other U.S. Government agencies, and are therefore independent of NASA budget projection levels. These annual flight rates are summarized separately at the bottom of the chart.

Launch rates for the three budget level models for Global Environment and Resource Observation are shown in the three data groups above. Total annual NASA funded launches may be seen to drop significantly as the constraints are increased from the High to Medium to Low model. These decreases in annual flight rates reflect in the 18-year flight totals which drop from 32 launches under the High budget to only 14 under the Low budget constraints.
### TABLE 3.3-8 Earth & Space Science Satellite Flights — Economic Missions Models

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### TABLE 3.3-9 EARTH SENSING SATELLITE FLIGHTS — ECONOMIC MISSION MODELS

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R81-2100-083W
The non-NASA Earth Sensing missions (foreign, commercial and DOE) are seen to increase significantly in the late 1990s. These added missions are the projected DOE Nuclear Waste Disposal missions at 10 per year after 1987.

The flight activity levels for the three budget levels projected for the Space Testing mission category are summarized in Table 3.3-10. The drop in numbers of missions per year is obvious as the High budget of $12 M/yr drops to $9 M/yr in the Medium model and to $6 M/yr at the projected Low level.

Total missions for the 18 year period drop successively from 15 to 8 to 7 for the High, Medium and Low budget models, respectively.

3.3.2.7 Comparison of Launch and Service Models

The economic based satellite launch schedules developed from the Cumulative Cost and Budget projections data in Figures 3.3-14 through 3.3-18 and summarized in Tables 3.3-8 through 3.3-10 are related back to the contents in the S/SUM model in the following traffic comparison tables. The comparison format places the traffic tables from the Satellite/Services User Model for SOC alongside the traffic tables generated for the High, Medium and Low economic projections. Sheet 1 of 3 of the Astrophysics mission listings Table 3.3-11, can be used to illustrate the re-incorporation of on-orbit servicing in the economic based models, and the waterfall effect of decreasing funding on mission schedules.

A simple case of re-incorporation of servicing and retrieval into the launch model is illustrated in the second Table 3.3-11 listing, A-7, Gamma Ray Observatory (GRO). In the S/SUM/SOC model, the traffic listing in Table 3.3-11 showed a launch in 1985, an unscheduled potential servicing in space in 1986, and a retrieval from space in 1987. For the High and the Medium Traffic Models on the right in Table 3.3-11, the launch schedule shifts to 1987 and the servicing and retrievals are then scheduled in the following two years as in the S/SUM/SOC model. For the Low Astrophysics budget model, cumulative
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### TABLE 3.3-11  ASTROPHYSICS MISSIONS,
SHEET 1 OF 3

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- **Numerals denoted scheduled events - Dots denote potential service events - Unscheduled**
- **Direct orbiter launch and recovery**

R81-2100-045R
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NUMERALS DENOTE SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

DIRECT ORBITER LAUNCH AND RECOVERY

SOC SERVICE OPTION TO BACK UP ORBITER AVAILABILITY

R&A 2100-0448
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NUMERALS DENOTE SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

DIRECT ORBITER LAUNCH AND RECOVERY
funding does not allow launch of GRO until 1988. The follow-on potential servicing and retrieval remain on the same one-year intervals after launch on the assumption that total satellite costs are assigned at launch, and other events for that satellite do not effect budget scheduling.

The Space Telescope, listed at the top of Table 3.3-11 illustrates one of the three cases where it was assumed that the satellite would be refurbished after retrieval. Here it was assumed that the total Space Telescope (ST) costs were expended at initial launch, and retrievals, re-furbishing and re-launch costs were included in the original costs. This then established the total sequence of the ST program to be identical to that presented in the S/SUM/SOC Traffic Schedule. The budget restrictions would only shift the year of initial launch. The other two satellites assumed re-furbished are A-9, the Advanced X-Ray Astrophysics Facility listed at the bottom of Sheet 1 of Table 3.3-11 and S-9, Subsatellite Facility, the fourth entry in Table 3.3-12, Sheet 1.

The comparisons of traffic schedules for S/SUM, and High, Medium and Low budgets for the six mission areas are provided in this visual data base in Tables 3.3-11 through 3.3-16. The updating of the data base during the study to reflect input from the most recent NASA Systems Technology Model Reference 3.3-12 is illustrated in Table 3.3-12, Sheet 1, for entry S-51, Astronomy. Since this mission did not appear specifically in Reference 3.3-12, it was not considered in the costing and was dropped from the economic models as indicated by the blank traffic modeling under High, Medium and Low traffic scheduling.

It may also be noted in Table 3.3-12 that the new 1981 identity numbers from Reference 3.3-12 are included in parentheses under the satellite name in Tables 3.3-1 through 3.3-6 and Tables 3.3-11 through 3.3-16.
### TABLE 3.3-12 SOLAR TERRESTRIAL MISSIONS, SHEET 1 OF 2

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**NUMERALS DENOTED SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED**

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NUMERALS DENOTE SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

DIRECT ORBITER LAUNCH AND RECOVERY

R81-2103-049B
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NUMERALS DENOTE SCHEDULED EVENTS — DOTS DENOTE POTENTIAL SERVICE EVENTS — UNSCHEDULED

DIRECT ORBITER LAUNCH AND RECOVERY

SOC SERVICE OPTION TO BACK UP ORBITER AVAILABILITY
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NUMERALS DENOTE SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

DIRECT ORBITER LAUNCH AND RECOVERY
### Table 3.3-15 Resource Observation Missions, Sheet 1 of 2

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**Table Notes:**
- Numerals denote scheduled events.
- Dots denote potential service events.
- Unscheduled events.
- Direct orbiter launch & recovery.
### TABLE 3.3-15  RESOURCE OBSERVATION MISSIONS,
**SHEET 2 OF 2**

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NUMERALS DENOTE SCHEDULE EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED
DIRECT ORBITER LAUNCH & RECOVERY

R31-3100-5868
3.3.2.8 Typical Waterfall Effects of Budget Limits

The effects of budget constraints on program schedules is cumulative both from the standpoint of depth of budget constraint and length of time the constraint is in effect. These effects on the NASA missions schedules are illustrated in Figure 3.3-19. Schedules on two Astrophysics satellite programs, Gamma Ray Observatory (GRO) and Very Long Base Line Radio Interferometer (VLBI) are presented for the S/SUM/SOC (full funding), and the High economic and Low economic models are shown.

Astrophysics program A-7 (GRO) is planned for early launch in S/SUM/SOC (1985) and therefore should be least affected by cumulative budget constraints. It is seen at the middle of the chart the High budget model (with growth at 2.5% per year above the FY-82 baseline) still allows launch of A-7 in 1985. At the Low budget level, corresponding to shrinkage at 2.5% per year below the FY-82 baseline, A-7 launch is delayed until 1988.

The VLBI satellite program, A-15, comes later in the S/SUM/SOC schedule with the initial launch shown for 1988 in the upper portion of the chart. At the High economic model budget level, cumulative funds to support launch of A-15 (and all of those prior to it in the S/SUM/SOC model sequence) are not accrued until 1994. The combined effects of lower annual budget and this budget constraint over a longer time is seen for A-15 in the Low economic model section of the chart, indicating delay of first launch until 1999.

Thus a moderate budget constraint has small impact on launch schedules in the mid 1980s, a moderate effect in the late 1980s and significant stretch-out impact on programs scheduled in the early 1990s in S/SUM/SOC.
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**HIGH ECONOMIC MODEL**

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**LOW ECONOMIC MODEL**

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D – DEPLOY,  S – SERVICE,  R – RETRIEVE

Fig. 3.3-19  Typical Waterfall Effects of Budget Limits
SUBSECTION 3.3 REFERENCES

3.3-2 Satellite/Services User Model (S/SUM) ENCL (1), Satellite Service System Analysis Study, Seventh Progress Report, Mar 1981
3.3-3 NASA Space Systems Technology Model, Volume I and II, June 1980
3.3-5 STS Flight Assignment Manifest, 13000-3 November 1980
3.3-6 Mission Data Catalogue Advanced Spacecraft Deployment Systems Martin Marietta Aerospace, L.A-5-80-1 Oct 1979
3.3-7 NASA Program Plan Fiscal Years 1981 through 1985
3.3-8 Goddard Space Flight Center Reports Series, July 1980
3.3-9 Department of Defense STS Utilization Plan, July 1980
3.3-10 Goddard Space Flight Center Multi-Mission Spacecraft Listing
3.3-11 International Astronautics Federation 81-125, September 12, 1981
3.3-12 1981 NASA Space Systems Technology Model, (Second Draft)
3.3-13 NASA Fiscal Year 1978 Five year Plan
3.3-14 NASA Fiscal Year 1979 Five year Plan
3.3-15 NASA Fiscal Year 1980 Five year Plan
3.3-16 NASA Fiscal Year 1982 Budget Estimate

3-139
3.4 RESEARCH AND APPLICATIONS MISSIONS

The research and applications missions include life sciences research, materials processing research and development, and advanced military technology testing. The definition of these missions was one of the primary tasks for the study extension. The complete reports on these three research and applications missions are found in Sections 5.2.2, 5.2.3, and 5.2.4 of this document.

The integrated SOC Research Mission Models (the Low, Medium, and High) are given in Tables 3.4-1 through -3. Table 3.4-4 summarizes the involvement of SOC in these missions.
## Table 3.4-1. SOC Low-Research Mission Model

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|               | TOTAL NO. OF RETURNS    | 2 | 2 | 3 | 4 | 5 | 8 | 8 | 7 | 8 | 7 | 7 |
|               | TOTAL MAN-LEVEL         | .8| .8| 1.05|1.15|3.05|3.15|3.85|3.85|4.85|4.85|4.85|4.85|
Table 3.4-2. SOC Medium-Research Mission Model

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Table 3.4-3. SOC High-Research Mission Model
## Table 3.4-4. Summary of SOC Involvement in Research/Applications Missions

<table>
<thead>
<tr>
<th>RESEARCH/APPLICATIONS SYSTEM</th>
<th>SOC INVOLVEMENT</th>
<th>BENEFITS OF SOC INVOLVEMENT</th>
</tr>
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</table>
| **“SUITCASE” EXPERIMENTS**   | • PROVIDE INTERNAL STOWAGE LOCATION  
• PROVIDE POWER  
• PROVIDE CREW TIME TO INSTALL PACKAGE, INFREQUENTLY ATTEND  | • CONTINUOUS LONG DURATION EXPERIMENTAL TIME  |  
| **“SPACE AVAILABLE” EXPERIMENTS** | • PROVIDE INTERNAL LOCATION  
• PROVIDE POWER, THERMAL CONTROL, DATA MANAGEMENT, ECLS, ETC.  
• PROVIDE CREW TIME (FRACTIONAL MAN-YEAR PER YEAR) TO INSTALL EQUIPMENT, CONDUCT EXPERIMENTS, MODIFY EXPERIMENTAL SETUPS, INTERPRET DATA  | • CONTINUOUS LONG-DURATION EXPERIMENTAL TIME  
• EXPERIMENTERS DO NOT HAVE TO INCUR THE EXPENSE OF DESIGNING, MANUFACTURING, TESTING, AND DELIVERY OF A HABITABLE MODULE FOR INSTALLATION OF THEIR EXPERIMENTAL EQUIPMENT  |  
| **RESEARCH MODULES**         | • PROVIDE BERTHING PORTS  
• PROVIDE POWER, DATA BUS, COMMUNICATIONS, AND PARTIAL ECLS SUPPORT  
• PROVIDE CREW TIME (UP TO SEVERAL MAN-YEARS PER YEAR) TO CONDUCT FULL TIME RESEARCH/PROCESS DEVELOPMENT OPERATIONS, SOME OF THE CREW MAY BE COMMERCIAL CUSTOMER EMPLOYEES.  | • CONTINUOUS, LONG-DURATION EXPERIMENTAL TIME  
• SOC WILL PROVIDE SOME OF THE SUBSYSTEMS, THEREFORE, THE RESEARCH MODULE BUYER DOES NOT HAVE TO PAY FOR THE DEVELOPMENT OF THESE.  
• SOC WILL PROVIDE THE CREW SUPPORT PROVISIONS (SLEEPING QUARTERS, DINING, ETC.)  |  
| **COMMERCIAL MANUFACTURING STATION (FREE-FLYER)** | • PROVIDE PERIODIC IN-SITU SERVICING OF STATION TO PROVIDE RESUPPLY, MAINTENANCE, REFURBISHMENT  | • THIS WILL BE A ROUTINE SERVICE PROVIDED BY SOC SO THE COMMERCIAL CUSTOMER WILL NOT HAVE TO PAY FOR THE DEVELOPMENT OF DEDICATED EQUIPMENT OR OPERATIONS  |
3.5 DoD MISSION MODEL

3.5.1 Introduction .............................................. 3-146
3.5.2 Economic Basis of DoD Mission Models .................. 3-146
3.5.3 DoD Mission Models ........................................... 3-149
3.5 DoD MISSION MODEL

3.5.1 Introduction

Military mission models were discussed with Dr. Robert Davis of Aerospace Corporation. There are a number of classified sources for military mission models such as the STS Utilization Plan, but these cannot be used as source material for unclassified models because of their classification. The discussion with Dr. Davis concluded that it is not possible to "sanitize" these sources and retain sufficient information to permit a mission analysis.

Further problems with the available sources are that they do not project far enough into the future, and when subjected to a rough budget analysis, the resulting funding profile does not follow the expected trends.

Because of these problems it was decided to create an unclassified mission model for the SOC mission analysis. This model, based entirely on unclassified sources, on speculation, and on budget projects, suffers from a lack of "authenticity" in not being derived from official sources, but is probably at least as realistic as one which might be derived from those sources. Figure 3.5-1 presents the main considerations used in deriving the models.

3.5.2 Economic Basis of DoD Mission Models

In order to develop budget-driven models, one must employ some sort of cost model to derive spacecraft cost as a first step in estimating the number of launches. Figure 3.5-2 presents the high-level model used. On the left of the figure, we present historical experience for simple and complex spacecraft, in terms of 1980 dollars versus weight. On the right, we have converted this to 1982 dollars per pound. Development of a spacecraft is estimated as five times the unit cost. The representative military program is estimated to include ten product units. This assumption yields the typical program aggregate shown on the curve.
Military Mission Model
Considerations and Assumptions

- Can't Use STS Utilization Plan
  - Classified Data
  - Does Not Project Far Enough Into Future

- Budget - Driven Mission Model Most Realistic
  - Three levels: low, medium, high

- Unclassified Sources Permit Projection of General Classes of Missions

- Simplifications:
  - WTR launches not included but presumed to consume 40% of available launches; 70% of launched spacecraft mass
  - All ETR launches to high-energy orbits go to GEO
Figure 3.5-2. High-Level Cost Model
Budgetary assumptions are presented in Figure 3.5-3. Three models are considered, with themes, budgets, and annual launches as presented in the figure. The launched mass is based on that proportion of the military budget allocated to ETR activities. WTR activities were not considered as they would not involve the use of a Space Operations Center.

3.5.3 DoD Mission Models

In order to predict the number of launches, it is also necessary to know something about spacecraft characteristics. The assumptions used are presented in Table 3.5-1. These were used with the launch mass estimates from the previous figure to derive the specific mission models presented in Table 3.5-2. Additional estimates of system characteristics, needed to conduct the specific SOC utilization analyses, are being developed.
CALCULATION
YEARS
BUDGET
LAUNCHED
MEDIAN
LOW
HIGH
- NO SIGNIFICANT CHANGE IN USES OF SPACE
- GRADUAL GROWTH OF AVERAGE SPACECRAFT
  MASS TO 500 kg BY END OF CENTURY
- ASAT THREAT LEADS TO BUDGET GROWTH FOR
  SPACE DEFENSE
- SPACECRAFT MASS GROWTH SAME AS LOW MODEL
- MANNED ACTIVITY ONLY FOR SPACE TESTING AT A
  NATIONAL SPACE STATION
- SPACE EVOLVES TO THEATER OF CONFLICT
- SPACECRAFT AVERAGE MASS GROWTH TO
  10,000 kg
- SMALL MILITARY MANNED STATION IN
  HIGH ORBIT

Figure 3.5-3. Military Mission Model Budgetary Assumptions
Table 3.5-1  
Assumed Spacecraft Characteristics

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<tr>
<th>ASSUMED MILITARY SPACECRAFT</th>
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<td>1000</td>
<td>2.8 3</td>
<td>Compatible With T-IV</td>
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<td>2-Tonne Class</td>
<td>2000</td>
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<td>6.58 4.4</td>
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<td>10-Tonne/Class</td>
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<td>13.16 4.4</td>
<td></td>
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<td>15 4.4</td>
<td>Single Shuttle Launch for Delivery to LEO</td>
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<tr>
<td>Manned Station Resupply</td>
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<td>6 4.4</td>
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<tr>
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<td>4000 down</td>
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Table 3.5-2
Military Mission Models

Calendar Year

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| MEDIAN    | 3  | 2  | 2  | 1  | 1  |    |    |    |    |    |    |     |
| 1-tonne class | 6  | 5  | 5  | 5  | 4  | 4  | 3  | 2  | 2  | 1  |    |     |
| 2-tonne class | 6  | 5  | 5  | 4  | 4  | 3  | 3  | 2  | 2  | 2  | 3  |     |
| 3-tonne class | 2  | 2  | 3  | 4  | 4  | 5  | 5  | 5  | 6  | 5  | 5  |     |
| 5-tonne class | 1  | 1  | 2  | 2  |    |    |    |    |    |    |    |     |

| HIGH      | 3  | 2  | 2  | 1  | 1  |    |    |    |    |    |    |     |
| 1-tonne class | 6  | 5  | 5  | 5  | 4  | 4  | 3  | 2  | 1  |    |    |     |
| 2-tonne class | 6  | 5  | 5  | 4  | 4  | 5  | 3  | 2  | 2  | 2  | 3  |     |
| 3-tonne class | 4  | 4  | 6  | 8  | 8  | 6  | 8  | 10 | 10 | 10 |     |
| 10-tonne class | 1  | 1  | 1  | 2  | 2  | 3  | 4  | 4  |     |    |    |     |
| Manned Station | 1  | 1  |    |    |    |    |    |    |    |    |    |     |
| Manned Station | 2  | 4  | 4  | 4  | 4  | 4  | 4  |     |    |    |    |     |

Note: Space Testing at SOC Not Included in These Payloads
3.6 SATELLITE SERVICING MISSIONS

Satellite servicing missions are an extension of the Space Transportation System which provides on-orbit services and operational capabilities that exploit the unique capabilities of the Shuttle (vis-a-vis expendable launch vehicles) with the advantages of manned presence in orbit. The Space Operations Center (SOC) will add a new dimension to these services which are decoupled from Shuttle launch delays (i.e., weather, strikes, accidents, etc), Orbiter mission duration constraints, and Orbiter availability. Because of its continuous manned operation in low earth orbit, the SOC offers greater flexibility for dealing with extended contingency situations than the Orbiter (such as satellite deployment hang-ups or difficult repairs). As discussed in Section 4, the SOC provides more economical services than the Orbiter and facilitates the assembly of very large systems in orbit.

Section 4 provides further discussion on the requirements and approaches for servicing attached and co-orbiting satellites on SOC. It also identifies commonality of requirements and equipment for space construction and satellite servicing operations; defines servicing mission needs and benefits; determines differential decay characteristics of co-orbiting satellites, and provides information on satellite servicing transportation considerations.
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4.0 SATELLITE SERVICING TEST AND CHECKOUT

4.1 INTRODUCTION

Satellite services is an extension of the Space Transportation System which provides on-orbit services and operational capabilities that exploit the unique capabilities of the shuttle (vis-a-vis expendable launch vehicles) with the advantages of manned presence in orbit. The Space Operations Center (SOC) will add a new dimension to these services which are decoupled from Shuttle launch delays (i.e., weather, strikes, accidents, etc), Orbiter mission duration constraints, and Orbiter availability. Because of its continuous manned operation in low earth orbit, the SOC offers greater flexibility than the Orbiter for dealing with extended contingency situations (such as satellite deployment hangups or difficult repairs). As discussed below, the SOC provides more economical services than the Orbiter and facilitates the assembly of very large systems in orbit.

Satellite servicing covers the full mission cycle from initial checkout and orbital deployment to subsequent in-orbit support, and finally, removal of the spacecraft from orbit. In-orbit support includes examination, maintenance/repair of basic subsystems and mission peculiar equipment, resupply of consumables, and reconfiguration of experiments. End of mission retrieval and temporary on-orbit storage of satellites awaiting repair, earth return or controlled re-entry disposal are also part of satellite servicing.

The objectives of this task were to define requirements and approaches for servicing attached and coorbiting satellites on SOC, identify commonality of requirements and equipment for space construction and satellite servicing operations, define servicing mission needs and benefits, determine differential decay characteristics of co-orbiting satellites, and analyze satellite servicing transportation considerations. The first three tasks were performed by Grumman and the two remaining tasks were performed by Boeing.
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4-2
4.2 SERVICING REQUIREMENTS AND APPROACHES

Satellite servicing covers the full mission cycle from initial checkout and orbital deployment to subsequent in-orbit support and finally, removal of the spacecraft from orbit. In-orbit support includes examination, maintenance/repair of basic subsystems and mission peculiar equipment, resupply of consumables, and reconfiguration of experiments. End of mission retrieval and temporary on-orbit storage of satellites awaiting repair, earth return, or controlled re-entry disposal are also part of satellite servicing.

Servicing requirements were analyzed for the Advanced X-ray Astrophysics Facility (AXAF) and the GEO Communications Platform missions. Functional analysis, procedures, crew tasks, operational timelines and equipment for accomplishing these functions were determined when operating from SOC and from Orbiter.

Specifically the following orbital servicing operations were analyzed in detail:

- AXAF and communications platform maintenance
- AXAF checkout before and after mating to a versatile service stage
- Communication platform checkout after unfolding/assembly and after mating to an orbital transfer vehicle.

Comparison was made of SOC and Orbiter operations, servicing the AXAF and the Communication Platform with respect to Orbiter flights, crew requirements, and costs of operations.

4.2.1 FUNCTIONAL ANALYSIS OF SERVICING OPERATIONS

Satellite servicing operations are subdivided into two main categories, those that are accomplished on SOC and those that are conducted remotely from SOC (see Figure 4.2-1). Satellite servicing operations are designated Block 5, as established by the Boeing top level functions.
5.1.1 ATTACHED PAYLOADS
5.1.2 SAT WITHOUT PHPLN
5.1.3 SAT WITH PHPLN
5.1.4 ASSEMBLE & LAUNCH

Fig. 4.2-1 Satellite Servicing Operations
Remote in situ operations would be performed on LEO satellites that are too large to be brought to SOC or would impose prohibitive propulsion requirements to transport them to SOC. Remote satellites are serviced in the same way as those serviced on SOC.

In later years, the availability of a manned OTV will greatly extend the range of access for LEO SOC satellite servicing. Satellites in orbits of significantly different inclination and altitude than SOC will be accessible for service, even to GEO orbit. Staging OTV service operations from the SOC with a manned OTV will reduce the number and complexity of Shuttle flights required. This is especially true where multiple-flight missions would otherwise be needed; space-basing decouples OTV operations from Shuttle operations.

Figure 4.2-1 shows the following functional modes of satellite servicing at SOC:

• Payloads that are attached and operated on SOC
• On-orbit satellites without propulsion
• On-orbit satellites with propulsion
• Satellites that are prepared/assembled at SOC and launched for co-orbiting flight or transfer to another operating orbit.

4.2.1.1 SOC Attached Payloads

The item to be serviced is attached to the SOC. This would be the case for Spacelab-derived missions or instruments. The SOC would provide services such as power and communications in addition to crew attention for maintenance or instrument changes. This mode of operations would "extend" certain Spacelab missions to arbitrarily long duration and could be quite beneficial in improving Shuttle fleet utilization by performing long-duration missions to avoid long on-orbit stay times by Shuttle.
SOC-based science missions will include life sciences and materials processing research. Materials processing research, as opposed to process development and prototyping, should be carried out onboard SOC because of the relatively short duration of most experiments, the need for crew involvement to avoid high automation costs for one-of-a-kind tests, and the benefits of crew participation in a research-oriented activity where dealing with the unexpected is much more likely than in development and prototyping.

These experiment programs will initially be carried out on a time and equipment available basis, but to reach full potential will probably require a dedicated mission module.

4.2.1.2 Satellites Without Propulsion

**SOC Proximity Operated Satellites** - Proximity operated spacecraft could be intentionally station-kept with the SOC. This would allow convenient access at frequent intervals. It could be the preferred operational mode for missions that require frequent service but are separated from the SOC to avoid contamination of the mission environment. A good example is a space processing facility that needs a high-purity zero-g environment. Certain optical instrument missions will also be best flown in this mode because of outgassing and similar contamination problems.

**Remotely Operated Satellites** - Satellites that are operated remotely from SOC and do not have orbit transfer capability, either due to propulsion fuel depletion or have no propulsion system, must be transported to SOC for service. In this case, the SOC will dispatch a vehicle such as the Proximity Operations Module, Versatile Service Stage, or Orbit Transfer Vehicle, depending on propulsion needs, to fetch the satellite. Figure 4.2-2 contains the primary servicing functions. After the satellite is berthed to SOC, the propulsion stage requires servicing in addition to SOC meeting the needs of the satellite. The satellite could be repaired, resupplied, and reconfigured then checked out and returned to operational orbit.
5.1.2

**SATELLITE WITHOUT PROPULSION**

- UNLOAD REPLACEMENT EQUIPMENT FROM ORBITER
- C/O & DEPLOY PRPLN STAGE
- PRPLN STAGE RENDEZVOUS WITH SAT.

**POCC SAFE SAT. FOR DOCKING**

- PRPLN STAGE CAPTURE SATELLITE
- PRPLN/ SAT. RENDEZVOUS WITH SOC
- SOC CAPTURE & HANDLE SATELLITE

**DEMATE PRPLN/SAT.**

- RESUPPLY PRPLN STAGE

*Fig. 4.2-2 Satellites Without Propulsion*  
*(Sheet 1 of 2)*
Fig. 4.2-2  Satellites Without Propulsion
(Sheet 2 of 2)
Scientific satellites such as the Space Telescope, Long Duration Exposure Facility, Advanced X-Ray Astrophysics Facility, and materials processing free flyers are likely candidates.

4.2.1.3 Satellites with Propulsion

Satellites with propulsion are maneuvered to the vicinity of SOC when servicing is required, being controlled by their respective Payload Operations Control Center, so that SOC operations can implement retrieval using a Proximity Operation Module (POM). The same types of services would be provided as those satellites fetched by SOC based vehicles. An additional item is servicing of the onboard propulsion system. Scientific satellites, such as the X-Ray Observatory, are expected to require about one visit every 2 years. The most practical mode of operation will be for these satellites to rendezvous with the SOC and be berthed for the service interval.

4.2.1.4 SOC Assembled & Launched Satellites

The assembly and launch mode (Figure 4.2-3) consists of satellites such as the GEO Communications Platform that are delivered to SOC by Orbiter for subsequent launch. Satellites could be launched at the appropriate time into a near SOC co-orbiting operational location or launched with a propulsion stage to transport them to operational location. Therefore, an appropriate propulsion stage would be checked out and attached to the satellite prior to launching operations.

4.2.2 SOC SATELLITE SERVICE REQUIREMENTS

SOC satellite servicing requirements are keyed to the major ground rules in Table 4.2-1. The analysis of satellite services for the Space Operations Center is focused on the operational configuration defined for SOC during the previous Boeing study. Satellite service concepts for SOC shall be common with the Orbiter, wherever possible. Maximum use of existing equipment (or those under development, such as the Open Cherry Picker) shall also be a goal in order to achieve low development costs. Candidate satellite service equipment concepts have been recently defined by Grumman and Lockheed (Reference 4.2-6 and 4.2-7).
5.1.4

ASSEMBLE & LAUNCH

-->

UNLOAD SAT FROM ORBITER

-->

&

ASSEMBLE/DEPLOY SAT

-->

C/O SAT (POCC I/FACE)

-->

C/O PROPN STAGE (OTV)

-->

MATE SAT & PROPN

-->

C/O SAT & PROPN I/FACES

-->

LAUNCH SAT & PROPN (OTV)

-->

POCC CONTROL SAT & PROPN

--- Fig. 4.2-3  Satellite Assembly & Launch Services ---
### TABLE 4.2-1 SOC SATELLITE SERVICES GROUND RULES

- SOC CONFIG DEFINED IN BOEING FINAL REPORT D180 – 26495-4, 7/81, NAS 9 – 16151
- STANDARDIZE ON-ORBIT SERVICE OPS WITH ORBITER
- MAXIMIZE USE OF EXISTING EQUIP OR THOSE UNDER NEW
-STS SAT SERVICES CONCEPTS
  - GAC FINAL REPORT LSS-SSS-RP009, 7/81, NAS 9 – 16120
  - LMSC FINAL REPORT LMSC D764514, 7/81, NAS 9 – 16121

### TABLE 4.2-2 SOC SATELLITE SERVICE MISSIONS

<table>
<thead>
<tr>
<th>SERVICE OPERATIONS</th>
<th>TEND</th>
<th>SAT. LAUNCH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ATTACHED PAYLOADS</td>
<td>CO-ORBITING SATELLITES</td>
</tr>
<tr>
<td>EXAMINATION</td>
<td>∙</td>
<td>∙</td>
</tr>
<tr>
<td>RETRIEVAL</td>
<td>∙</td>
<td>∙</td>
</tr>
<tr>
<td>MAINTENANCE/REPAIR</td>
<td>∙</td>
<td>∙</td>
</tr>
<tr>
<td>RESUPPLY</td>
<td>∙</td>
<td>∙</td>
</tr>
<tr>
<td>RE CONFIGURATION ON-ORBIT ASSEMBLY</td>
<td>∙</td>
<td>∙</td>
</tr>
<tr>
<td>MATE UPPER STAGES</td>
<td></td>
<td>∙</td>
</tr>
<tr>
<td>TEST &amp; CHECKOUT</td>
<td></td>
<td>∙</td>
</tr>
<tr>
<td>ON-ORBIT STORAGE DEPLOY</td>
<td></td>
<td>∙</td>
</tr>
</tbody>
</table>

### TABLE 4.2-3 SATELLITE ORBITAL PARAMETERS

<table>
<thead>
<tr>
<th>SATELLITE</th>
<th>OPS ALT (km)</th>
<th>OPS INC (DEGREES)</th>
<th>LENGTH (m)</th>
<th>DEPLOYED DIA (m)</th>
<th>MASS. (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AXAF</td>
<td>500</td>
<td>28.5</td>
<td>13.1</td>
<td>12</td>
<td>10 - 12,000</td>
</tr>
<tr>
<td>LAMAR</td>
<td>400</td>
<td>28.5</td>
<td>6.5</td>
<td>14</td>
<td>5,200</td>
</tr>
<tr>
<td>X-RAY OBSERVATORY</td>
<td>400</td>
<td>28.5</td>
<td>6</td>
<td>16</td>
<td>3,650</td>
</tr>
<tr>
<td>LDEF</td>
<td>556</td>
<td>28.5 &amp; 57</td>
<td>19.1</td>
<td>4.3</td>
<td>4,500</td>
</tr>
<tr>
<td>GEO COMM PLAT</td>
<td>35786</td>
<td>0</td>
<td>20.7</td>
<td>66</td>
<td>6,100</td>
</tr>
</tbody>
</table>
The satellite service missions for the Space Operations Center includes those satellites which are in orbit and require periodic tending for continued operations as well as those satellites which are ready for initial launch into orbit (see Table 4.2-2). Tended satellites encompass attached payloads, co-orbiting, and remote accessible satellites. Co-orbiting satellites station keep with SOC, those that are initially in the same orbital plane and similar altitude (within \(\approx 100\) km) and those that are transferred to SOC by a propulsion stage. Remote accessible satellites are remote to SOC but accessible by in-situ remote servicing from a manned/remote teleoperated service stage.

The launched satellites are subdivided into two energy orbit categories (i.e., low energy orbits up to 2000 km and high energy orbits above 2000 km).

The types of service operations that can be performed on SOC are listed in Table 4.2-2 and keyed to the respective missions. Many of the co-orbiting satellite services are the same as those required for attached payloads. Much of the equipment required to perform these service operations have been previously identified in Satellite Service Studies and some are already under development. While most of these service operations can be performed with the Shuttle Orbiter the SOC can also offer other services. These services include on-orbit assembly of large systems, mating of large upper stages and the option for on-orbit storage of satellite hardware if predeployment test and checkout fails.

Several of the satellites that are in compatible orbits for servicing by SOC (370 km, 28.5 degrees inclination) are shown in Figure 4.2-4 and pertinent operational data is listed in Table 4.2-3 (Reference 4.2-1).

The Advanced X-ray Astrophysics Facility (AXAF) configuration (Reference 4.2-2, 3, 4 and 5) is similar in many respects to the Space Telescope. It will be designed for space maintenance and the instruments are located at the opposite end to the aperture and accessible through an external door. The instruments are mounted in quadrants of
Fig. 4.2-4 Typical Satellites Launched or Tended From SOC
a carousel that rotates the instrument to the focal plane and also makes the instruments accessible at the door opening. The subsystems are contained in a donut-configured structure that has many access doors. Approximately 80 to 100 components are replaceable on the AXAF. The AXAF has no on-board capability to change its orbital location.

The Large Area Module Array of Reflectors (LAMAR) is mounted on a Multimission Modular Spacecraft (MMS) bus including a propulsion module. The MMS is designed for maintenance but the instrument's capability for space maintenance is yet to be determined.

The X-ray Observatory is similar in configuration to the LAMAR as can be seen in the figure.

The Long Duration Exposure Facility (LDEF) is a reusable, gravity-gradient-stabilized, free flying structure. It has no propulsive capability and can accommodate many technology, science, and applications experiments, both passive and active, that require exposure to space. Experiments are mounted on 72 periphery trays and on 2 trays at each end. At present, the trays are not designed for replacement in space.

The GEO Communications Platform is a large structure that unfolds like an umbrella in low earth orbit and is attached to an orbital transfer vehicle, then boosted to geosynchronous orbit.

4.2.2.1 Maneuverable Television - (MTV)

The MTV, an equipment expected to have a high utilization rate in satellite service operations, is shown in Figure 4.2-5. Currently under development, the MTV is used to remotely examine satellites prior to retrieval, observe attached satellite operation, view or record satellite upper stage firing, and support numerous experiments in a free-flying mode.

The system is flown remotely from the Orbiter and SOC via translational and rotational hand controllers. Video and telemetry data recorded by the MTV are transmitted back to the SOC.
4.2.2.2 Strategies for Retrieving Co-orbiting Satellites

Three strategies for retrieving co-orbiting satellites, for maintenance/resupply/reconfiguration at SOC, are shown in Figure 4.2-6. The requirements imposed on SOC will vary in accordance with the proximity or relative position of each co-orbiting satellite to SOC and the satellite's orbit adjust capabilities. In the first retrieval scenario, the satellite is shown to be in the same orbit (altitude and inclination) and station keep with respect to SOC; in this situation, the satellite could be either a free flyer which can be controlled by SOC or any satellite which operates under ground control. When free flying vehicles return to SOC, operating in close proximity and berthing, they will be controlled by the SOC. For on-orbit safety, ground controlled satellites would not be flown all the way to dock at SOC. Nor is it practical to maneuver the SOC toward the satellite for terminal acquisition. Final satellite retrieval, instead, is accomplished by a Proximity Operation Module (POM) which can be readily deployed and controlled from the SOC.

Many satellites will not actively station keep with SOC but will be allowed to decay in altitude and drift out of plane. If the satellite has an orbital maneuvering system, as shown in the second scenario, it could be used to adjust its altitude so that it will drift back toward SOC when it is time for maintenance. A SOC controlled POM can then retrieve these satellites as before; on the other hand, if the satellite does not have an orbital adjust capability it will continue to drift out of plane from SOC as shown in the third scenario. The latter satellite must be retrieved by a more capable SOC based vehicle, such as the Versatile Service Stage, which must rendezvous with the satellite, dock and transport it back to SOC.

4.2.2.3 Alternate Proximity Operations Equipment

The Orbiter can readily rendezvous with a satellite to within a 1000-ft distance. However, concerns by some satellite users regarding Orbiter thruster plume impingements or contamination during terminal closure maneuvers could preclude direct Orbiter rendezvous/retrieval.
Fig. 4.2-6 Strategies for Retrieving Co-Orbiting Satellites

- Satellite continually station-keeps with SOC
- POM retrieves satellite

- Satellite ops allows drift from SOC
- Satellite applies corrective maneuvers
- POM retrieves satellite

- Satellite allowed to drift from SOC
- VSS retrieves satellite
of a spacecraft. Retrieval of satellites within a 1000-ft range can be accomplished by a manned or unmanned Proximity Operations Module (POM).

The manned POM concept (Figures 4.2-7 and 8) is an adaptation of the Work Restraint Unit (WRU) and can be used in conjunction with an Manned Maneuvering Unit (MMU) to retrieve moderate size satellites of the Multimission Modular Spacecraft class. The WRU is equipped with an extendible mast and an RMS end-effector mounted to a support structure to allow the astronaut to fly with the snare end-effector in a forward position during satellite engagement and in an aft position during satellite towing operations. An astronaut would fly the manned POM to the satellite, capture it via the satellite's RMS-compatible grapple fixture, and tow the satellite to within reach distance of the RMS. The WRU was developed by Grumman to support a potential on-orbit Orbiter tile repair mission. During the development program, neutral buoyancy testing was performed in the NASA Johnson Space Center's Water Immersion Facility to validate the WRU design. The mission requirement has since been cancelled, but the WRU hardware is presently in storage at NASA Johnson Space Center.

Unmanned retrieval of satellites within ≈1 km of the Orbiter or SOC can be accomplished by a POM (Figure 4.2-9 and 10) that is an adaptation (or outgrowth) of the MTV. Controlled by the crew in the SOC, the POM would be dispatched to capture the satellite and return it to within the reach distance of the RMS. The POM would be flown via TV (using essentially MTV equipment) to effect satellite capture by an RMS end-effector on an extendible boom mating to a compatible grapple fitting. TV visibility is needed only during the satellite capture phase; return to the SOC is via remote command/control from the SOC crew station. The POM could be designed to retrieve satellites of varying size/mass. It used a non-contaminating cold gas propulsion system that provides three axes of translation and rotation during free-flight and towing operations.
Manned Proximity Operations Module — Satellite Capture
Manned Proximity Operations Module — Satellite Retrieval
4.2.2.4 Versatile Service Stage (VSS)

A versatile service stage which is needed primarily for the transfer and return of satellites to/from higher-energy LEO orbits is illustrated in Figure 4.2-11.

The VSS is designed to operate with several front-end attachments to satisfy a wide assortment of mission needs. Included are a snare end effector on an extendible mast for grappling satellites rotating at higher rates than that accomplishable for docking, a docking/berthing system for attaching to compatible spacecraft, and manipulators that provide berthing to uncooperative or tumbling satellites and debris.

It is equipped with a high performance propulsion system for performing large delta-V maneuvers and a clean-firing cold gas propulsion system for satellite and SOC close proximity operations. An on-orbit refueling capability is also provided. The VSS is also equipped with TV systems for satellite examination.

4.2.2.5 VSS & MOTV Plane Change Capability

Figure 4.2-12 is a nomograph which shows the payload capability of the MOTV core stage, and the Versatile Service Stage (VSS) in terms of its ΔV capability to perform a given plane change from SOC and then return to SOC. Two cases are illustrated; one where the payload out and back are equal (i.e., round trip), and the other where the stage goes out alone to retrieve a satellite and then return with it to SOC. If an MOTV crew capsule, plus general purpose mission equipment and one MMS module weighing around 8000 kg were brought round trip to a service site away from SOC, then that site may not be more than 18 degrees from SOC. If SOC is nominally at 28.5 degrees, then the MOTV core stage can perform plane change transfer to inclinations up to 46.5 degrees and still return to SOC with its payload.
Fig. 4.2-11 Versatile Service Stage (VSS)

Fig. 4.2-12 VSS & MOTV Plane Change Capability from SOC with Return
4.2.3 REPRESENTATIVE SATELLITE SERVICE OPERATIONS

Candidate service missions in Figure 4.2-13 imposed the requirements on SOC to provide the service operations listed previously (Reference Table 4.2-1). From the candidate list, two representative satellites, the Advanced X-ray Astrophysics Facility (AXAF) and a GEO Communication Platform, were selected for further analysis.

The AXAF has a planned lifetime of 10 to 15 years. It will be maintained in orbit and returned to earth for major improvements. The following SOC provided service operations are needed: examination of external configuration, retrieval, maintenance, resupply, reconfiguration, mating of propulsion stage, test and checkout, potential on orbit storage, and deployment.

The GEO Communications Platform requires unfolding/assembly and checkout in low earth orbit on SOC. It will be mated to an orbital transfer vehicle propulsion stage (which will normally be based at SOC), then released for subsequent transportation to geosynchronous orbit.

4.2.3.1 Servicing Scenario Assumptions

The servicing scenario assumptions (Figure 4.2-14) were based on those formulated for the Satellite Services Systems Analysis Study. Satellites with propulsion systems will be controlled via their normal operational ground station and rendezvous with SOC. When they are in the vicinity of SOC, control will be turned over to SOC for terminal guidance or for docking and retrieval by POM or manipulator grappling and berthing. Deployment will be done by SOC and when a safe separation distance is achieved, the ground Payload Operations Control Center (POCC) will control subsequent operations.

4.2.3.2 Description of SOC Satellite Service Facility

Operational SOC configuration was used as the baseline configuration for satellite servicing operations (Figure 4.2-15). The tracks
**Fig. 4.2-13 Candidate Service Missions**

- **TEND ATTACHED PAYLOAD**
  - National Material Laboratory Payloads

- **TEND CO-ORBITING SATELLITES**
  - Advanced X-ray Astrophysics Facility (AXAF)

- **LAUNCH CO-ORBITING SATELLITES**
  - Science & Applications Space Platform Payloads (SASP)

- **LAUNCH LOW ENERGY ORBIT SATELLITES**
  - Gamma Ray Observatory (GRO)

- **LAUNCH HIGH ENERGY ORBIT SATELLITES**
  - Communications Platform
  - Planetary Probe

---

**Fig. 4.2-14 Assumptions – Servicing Scenarios**

- **GO-NO-GO FOR DEPLOYMENT, SERVICING VERIFICATION/EFFECTIVENESS IS SAT USER DECISION**

- **SAT DEPLOYMENT VIA SOC COMMAND**

- **SAT SEPARATION ΔV DURING DEPLOYMENT IMPARTED BY SOC EQUIPMENT WHERE PRACTICAL**

- **SOC SAFETY CONSIDERATIONS**
  - Sat Hot RCS Firings
  - Liquid Rocket Engine Firings
  - Solid Rocket Engine Firings

- **CLOSE PROXIMITY OPERATIONS**
  - Terminal Acquisition of S/C Will Be Controlled by SOC
  - "Clean" Vehicle Provides Closure ΔV

- **STATUS MONITORING, CHECKOUT, ACTIVATION/DEACTIVATION OF SATS IS USER-CONTROLLED (SAT COMM VIA SOC S-BAND OR SAT'S SYSTEM VIA TDRS)**

- **MINIMIZE SOC STATUS/CHECKOUT INVOLVEMENT**
  - Power (as required)
  - Overall Health (Extent TBD, Standardized for All Satellites)

- **EVA IS ACCEPTABLE SERVICE MODE**
Fig. 4.2.15 Operational SOC with Satellite Servicing Facilities
running around three sides of the two habitat modules are part of the basic configuration, as is the service modules with docking ports.

For satellite servicing operations, a 7.5-m extension pier is added to one arm of the SOC track system in the direction outboard of the docking module (Figure 4.2-16). A Handling and Positioning Aid (HPA) is mounted on a truss structure at the tip of the pier. An end effector, suitable for the particular mission, attaches to the HPA tip. An OCP to hold an EVA crewman can be mounted on a track running along the HPA arm for a two-man satellite service operation. A mobile platform runs around the existing track system, as well as along the extension pier, to locate a twin manipulator system where required for the particular service mission. These manipulators are based on the RMS and one of them mounts on Open Cherry Picker (OCP) at its tip, while the other mounts a standard mount snare end effector. The EVA crewman on the OCP controls both manipulator arms and the HPA, each in selective sequence. These facilities can also be controlled from a station in the SOC habitation module.

Unless self-propelled, free-flying satellites must be brought to SOC by a propulsion stage. It is necessary to service and refuel these propulsion stages. OTV/MOTV have their own service hangar but smaller propulsion stages, such as Versatile Service Stage (VSS) and Proximity Operations Module (POM), require another facility which is located on the "underside" of the extension pier, as illustrated. A second HPA is mounted on a truss structure to handle VSS and POM. An OCP mounts to a track on the HPA arm and holds an EVA crewman who controls the HPA and thus, the servicing and refueling operations.

4.2.3.3 AXAF Servicing by SOC

The AXAF normally operates at 450 km altitude at 28.5 degrees inclination. The scenario illustrated in Figure 4.2-17 shows its retrieval by a Versatile Service Stage (VSS), which originates from SOC, rendezvous with AXAF and brings it to SOC for scheduled on-orbit
Fig. 4.2-16 SOC Modified for Satellite Servicing

Fig. 4.2-17 AXAF Service Mission Scenario
service. After service and check out, the VSS returns the AXAF satellite to its operational orbit.

The operational SOC configuration is shown in Figure 4.2-18. The AXAF is berthed to an HPA and is being maintained by astronauts on OCPs. The HPA can position the AXAF as shown, or alternatively swing it 90 degrees so that it is parallel with the SOC service modules, depending on accessibility requirements. AXAF subsystems are being serviced by a manipulator-mounted OCP while the instruments are serviced at the same time from an OCP mounted on an HPA extension boom. An MTV is shown inspecting the far side of the AXAF, by transmitting TV to SOC. The VSS is also berthed to an HPA and components are being replaced by EVA OCP operations. In the background a POM has grappled a satellite and its transporting it to SOC for subsequent service operations. Note that the HPAs are mounted on a servicing pier and two logistic pallets with satellite replacement equipment conveniently positioned to support the servicing operations.

4.2.3.3.1 AXAF Service Mission Timeline - SOC operations associated with servicing the AXAF are shown in Figure 4.2-19. Replacement parts and consumables are delivered to SOC by Orbiter logistic flights. These flights would occur on a regularly scheduled basis, meeting anticipated demands for satellite servicing operations and, therefore, would not impact plans for maintenance on any particular satellite.

The VSS is checked out, then sent to fetch the AXAF under control of the VSS POCC and bring it to SOC for maintenance. Twenty-four hour rendezvous time has been allowed each way since phasing could take considerable time. Three EVAs were judged sufficient to replace malfunctioning equipment. After the AXAF has been buttoned up, three and one-half hours are allocated for remote check out from the SOC operations room in conjunction with the AXAF POCC. Then the AXAF is mated to a VSS for subsequent redeployment. Time for redeployment is approximately one-quarter of that for retrieval because phasing is not a factor. The time for nominal AXAF maintenance support operations is six and one-half days. This could easily be extended if problems
- LAUNCH ORBITER
- RENDEZVOUS, DOCK & UNLOAD
- ORBITER READY FOR OTHER OPS
- CHECKOUT & DEPLOY VSS
- VSS RENDEZVOUS, INSPECT & DOCK
- VSS/AXAF TRANSFER & BERTH TO SOC
- SEPARATE VSS, REFUEL & C/O
- MAINTAIN AXAF
- C/O AXAF
- MAINTAIN AXAF
- REPAIRS
- CLEAN OPTICAL SURFACES

MAINTENANCE TASKS:
- REPLACE 10 ORU
- REPLACE 3 INST
- REPLACE 2 SOLAR ARRAY
- REPLACE 2 SA MOTORS
- REPAIRS 3
- CLEAN 2 OPTICAL SURFACES

R81-2100-226W

Fig. 4.2-19 Timeline – AXAF Servicing from SOC

Fig. 4.2-20 Time to Replace Component vs Task Difficulty
developed during servicing. A contingency time of one day has been allocated.

Contingency time allowance adequate for satellites designed for space repair may be inadequate for satellites not designed for in-flight maintenance. Figure 4.2-20 shows the likely increase in time required to change-out a component in an spacecraft not designed for maintenance. Ground simulation tests with a suited astronaut established the time to change one MMS module (Reference 4.2-8). Time to remove an LDEF tray was similarly estimated from ground tests. Although the LDEF trays were not designed for in-flight maintenance, the bolts are accessible for removal. The next task time that was evaluated consists of replacing a component which is behind a ground service access panel. The task here is to cut away a thermal shield, then remove the panel bolts to provide access to the malfunctioning component. This component is attached with four accessible bolts and has one electrical connector to be removed. The time to replace this component, including taping the thermal shield in place, is five times that required to replace an MMS module. The most difficult task shown in the figure repeats the work just described but two of the four bolts are in a blind location to the suited astronaut. While this task would be easy for ground operations (the EMU helmet limits access and visibility) it would be very difficult for space suit operations even with ground simulation training. The astronaut would have to rely on feel to remove and re-install two bolts. Consequently, this task is estimated to take 10 times as long as the MMS module replacement.

4.2.3.3.2 AXAF Service Operations - The operations for servicing an AXAF at SOC starts with delivery of supplies by an Orbiter. These supplies are mounted on pallets which are transferred from a docked Orbiter, as shown in Figure 4.2-21. These operations are performed by a mobile platform manipulator which berths the supplies pallet to a berthing port on the SOC docking module. The pallets for servicing and refueling the VSS and the POM are transferred to mountings on the extension pier. Both operations are controlled by an EVA crewman on the OCP.
Fig. 4.2-21 AXAF Service Mission — Transfer of Supplies

Fig. 4.2-22 AXAF Satellite Service — Satellite Capture & Preparation for Service
The AXAF is a free flyer with no transfer propulsion of its own. A small SOC based propulsion stage, in this case a VSS, is sent to dock to the AXAF and bring it to SOC. The mobile platform is moved along the tracks to the tip of the extension pier. Then, controlled by the OCP/EVA crewman, the platform manipulator is maneuvered to capture the VSS/AXAF (Figure 4.2-22 and 23). The manipulator then transfers the VSS/AXAF to berth it to the end effector on the satellite service HPA. For this mission, the end effector has a yoke which holds the base of the AXAF. The propulsion service HPA is then moved to grasp the VSS with its end effector (Figure 4.2-24). This operation is controlled by an EVA crewman operating the OCP mounted to that HPA. The AXAF and VSS are now separated at their docking interface. The VSS is transferred, on its HPA mount, to the propulsion service area. There it is serviced by the EVA crewman operating the OCP which has module handling arms. After servicing, the HPA transfers VSS to the refueling pallet where it mates to the fuel transfer umbilical (Figure 4.2-25).

While VSS servicing and refueling is proceeding the AXAF can be serviced in its capture attitude, or rotated by the satellite service HPA to the "horizontal" position for servicing. Figures 4.2-26 and 27 show the operations. The mobile platform has been moved along the SOC track from its satellite capture location at the tip of the extension pier to the location shown here. Considering a one man AXAF service operation, the EVA crewman locates his OCP so that he can service the subsystems area of the satellite. He also controls the second manipulator to fetch and carry change-out modules from the services pallet. Having serviced the subsystems, the mobile platform is relocated so that the crewman can service the scientific instrument area in a similar manner. This last operation is not shown in either figure. Instead, a second crewman is shown as an alternate for servicing the instrument area from an OCP mounted to the HPA arm, much as the propulsion stage servicing is performed.

After servicing, the AXAF and VSS, are remated and prepared for final checkout. In this operation, the VSS is located as shown in
Fig. 4.2-23 AXAF Service Mission — Satellite Capture

Fig. 4.2-24 AXAF Service Mission — Satellite Handling & VSS Service
Fig. 4.2-25 AXAF Service Mission – VSS Refueling

Fig. 4.2-26 AXAF Satellite Service, Checkout & Separation
Fig. 4.2.27 AXAF Service Mission — AXAF Service

Fig. 4.2.28 AXAF Service Mission — Satellite Preparation & Deployment
step 1 of Figure 4.2-28. The AXAF is then berthed to VSS by its HPA, controlled from the Mobile Platform OCP. This HPA is now withdrawn, leaving the mated VSS/AXAF mounted on the other HPA which now locates the satellite for separation. Final checkout is performed, then separated from SOC as illustrated in Figure 4.2-28.

4.2.3.3.3 AXAF Maintenance Operations Assumptions - Maintenance of the AXAF (see Table 4.2-1 for maintenance assumptions) is planned to be accomplished by crew EVAs to replace subsystem and instrument components. With adequate crew restraint, good suit mobility, and simple EVA compatible equipment interfaces, time to complete space operations are comparable with simulated ground operations. Our simulation experience utilizing the Open Cherry Picker (OCP) found that pressure suit operations took 60% longer than unsuited work.

The single shift crew work days in 11 hours. This is the time remaining after allowance has been made for 10 hours rest and 3 hours for meals.

EVA assumptions are:

* No prebreathing required
* Two EVA/day of 4 hours each
* RMS operator serves as EVA monitor
* Single person EVA permissible.

The OCP is currently under development at Grumman. Its initial configuration, the manned foot restraint, is being considered for the Solar Maximum Mission retrieval and repair in 1983.

Equipment to be replaced will be determined prior to maintenance operations by down link data to the POCC.

It is postulated that orbital replacement and units (subsystem electronic boxes and components) will be mounted in racks that are attached to a logistic pallet (standard Spacelab pallet). An effective way of transferring this equipment is to move the entire rack to
### TABLE 4.2-4 AXAF MAINTENANCE ASSUMPTIONS

- Maintenance accomplished by EVA utilizing OCP
- Replacement ORUs & instruments mounted on racks/modules for handling at SOC
- Second RMS available to transport equipment
- Instrument fluid replenishment accomplished by replacement of tank or instrument
- ORUs designed with one or two latches for mechanical attachment, electrical connection mates/demates automatically with mechanical operation
- Solar arrays & antennas designed for on-orbit replacement
- Access provided for replacement of drive motors
- No EVA prebreathing required

R81-2100-234W
the AXAF within reach of the astronaut to exchange failed units. Transportation of the rack could be accomplished by the OCP payload handling device or the second RMS. Instruments could be handled in a similar manner to the ORUs. Either individual instruments could be changed-out in each segment of the instrument carousel, or each segment module containing its complement of instruments could be exchanged as a unit. When fluids (xenon, propane, carbon dioxide, and argon) require replenishment, the impact on support equipment is reduced by exchanging instrument tanks or the instrument. The alternate is to provide dewars and fluid transfer equipment. Fluid replenishment would be required if there were a leak in the system, and in that event the instrument and/or tank plumbing would probably be replaced anyway.

4.2.3.3.4 Maintenance Operations Functions - Functional analysis of on orbit maintenance operations associated with the following tasks was performed:

- Replace subsystem orbital replacement units (ORU) (Figure 4.2-29)
- Replace instruments (Figure 4.2-30)
- Replace solar array or antenna (Figure 4.2-31)
- Repair damage/replace equipment (Figure 4.2-32)
- Clean optical surface (Figure 4.2-33).

Subfunctions of the operational functions shown in the figure were determined and task times were assigned to each of the subfunctions, then summed, to establish the time listed to perform each maintenance function.

4.2.3.3.5 AXAF Checkout - After the AXAF has been maintained, its operability will be verified. The checkout functions are shown in Figure 4.2-34 with estimated time to perform each function. Time for
CHECKOUT PRIOR & AFTER MATING PROPULSION

CLEAN OPTICAL SURFACES

REPAIR DAMAGE/REPLACE EQUIPMENT

REPLACE SOLAR ARRAY OR ANTENNA

REPLACE INSTRUMENTS

REPLACE ORU

- ORIENT FOR ACCESS TO ORU (PARALLEL OPS. DURING EVA PREP.)
- C/O OCP & TRANSFER CREW TO AXAF 7 MIN
- TRANSFER ORU RACK TO AXAF 5 MIN
- REMOVE NEW ORU FROM RACK 3% MIN

- REMOVE OLD ORU FROM AXAF 4½ MIN
- INSTALL NEW ORU 3½ MIN
- REPLACE ADDITIONAL ORUs 12 MIN x NO. ORUs
- RETURN ORU RACK TO PALLET 6 MIN

- CREW RETURN TO AIRLOCK 3 MIN

TIME TO REPLACE 1 ORU = 32 MIN
TIME TO REPLACE 1 + N ORU = 32 + 12 N

Fig. 4.2-29 AXAF Maintenance - Replace ORU
Fig. 4.2-30 AXAF Maintenance – Replace Instruments

TIME TO REPLACE 1 INST = 31 MIN
TIME TO REPLACE 1 + N INST = 31 + 12 N
Fig. 4.2-31 AXAF Maintenance — Replace Solar Array or Antenna
**Fig. 4.2-32 AXAF Maintenance — Repair Damage/Replace Equipment**

**Fig. 4.2-33 AXAF Maintenance — Clean Optical Surfaces**
Fig. 4.2-34 AXAF Checkout Prior Mating Propulsion

Fig. 4.2-35 AXAF Checkout After Mating Propulsion
Subsystem checkout and instruments is estimated at 90 minutes each. At the end of the checkout, the equipment is turned off or put in a standby mode. The solar arrays and TDRS antennas remain deployed.

Next, a propulsion stage, the versatile service stage (VSS), is attached to the AXAF to boost it to operating altitude. Only the interface between the AXAF and VSS requires verification as shown in Figure 4.2-35, and this consists of power/control of communication equipment and monitoring temperature of critical equipment.

4.2.3.4 GEO Communication Platform Launched by SOC

The folded GEO Communication Platform completely fills the Orbiter payload bay and may require a dedicated flight to deliver it to SOC (Reference 4.2-10). It is unloaded from the Orbiter cargo bay and supported by an HPA during unfolding operations, (see Figure 4.2-36). After checkout, an orbital transportation vehicle (OTV) that is based on SOC is mated to the GEO Platform, interfaces verified, and then released for transfer to geostationary orbit.

4.2.3.4.1 GEO Communications Platform Launch Mission Time Line - Figure 4.2-37 shows 27 hours for Orbiter rendezvous with SOC and unloading of the GEO platform. After emptying the cargo bay, the Orbiter is ready for other operations. The Orbiter could be loaded with debris or a satellite that requires earth refurbishment. Next, the platform is unfolded and a calibration MTV launched for determining antenna patterns. The major portion of the 44.5 hours shown in the figure is required to obtain the antenna patterns. The antenna pattern data is obtained during around the clock operations for 40 hours. Two crew members alternate 12 hours on and 12 hours off to control test operations. Only 3 additional hours are required to mate the Platform to the OTV, check interfaces, and deploy it. If the OTV was based on earth, then another orbiter logistics flight would be required.
Fig. 4.2-36  GEO Communications Platform Launch Mission Scenario

LAUNCH ORBITER

RENNZVOUS, DOCK & UNLOAD PLATFORM

ORBITER READY FOR OTHER OPS

UNFOLD PLATFORM APPENDAGES, DEPLOY CALIBRATION MTV & C/O PLATFORM

TRANSLATE OTV TO PLATFORM

ATTACH PLATFORM TO OTV

C/O OTV/PLAT INTERFACES & DEPLOY

RETRIEVE & STOW CALIBRATION MTV

SOC CREW READY FOR OTHER OPS

NOTES:
1. REPEAT THIS MISSION FOR EARTH BASED OTV
2. SPACE BASED OTV REFUELED & C/O PREVIOUSLY

Fig. 4.2-37  Timeline – GEO Communication Platform Deployed from SOC
4.2.3.4.2 GEO Communication Platform Launch Operations - Two assumptions were used during the compilation of launch operations:

(1) The nominal plan for unfolding the platform is to control the operations remotely from the SOC control room. If appendages get hang-up, EVA operations, if warranted, will be used to solve the problem.

(2) The fuel for the SOC based OTV is assumed to be scavenged from Orbiter external tanks during previous delivery flights.

Launch of a communication platform to geosynchronous orbit from SOC starts with delivery of the platform by an Orbiter which docks to SOC (Figure 4.2-38 and 39). The platform, folded for stowage in the Orbiter cargo bay, is transferred by the mobile platform manipulator to be berthed to the satellite servicing HPA on SOC. The HPA then articulates to move the platform to its preferred location for deployment of appendages.

Figure 4.2-40 shows deployment of the appendages which mount antennas, reflectors, experiments, solar arrays and radiators. Most are deployed automatically, others may need assistance by the OCP mounted EVA crewman as shown in Figure 4.2-41. The platform can be rotated on the HPA, as indicated, to bring a radial appendage arm within reach of the OCP.

There maybe a hangup in an automatic deployment sequence. To illustrate the proposed handling of this problem, Figure 4.2-42 assumes that the forward point 10-m antenna receive feed mast is deployed automatically. Should there be a problem with this feed mast requiring direct attention by the EVA crew, the crewman can go out on an MMU, or a tether, to deal with it. A preferred way of reaching the mast is shown in this figure, which is with the HPA extended and tilted to bring the problem area within reach of the OCP and its supportive capabilities. Between the degrees of freedom and reach of the HPA and the capabilities of the mobile platform with its manipulators, any part of this large platform can be reached. This is shown in
Fig. 4.2-38  GEO Comm Platform Launch — Unload & Unfold Payload

Fig. 4.2-39  GEO Comm Platform Initial Launch — Transfer to SOC From Orbiter
Fig. 4.2-40 GEO Comm Platform Launch Checkout, Mate to OTV

Fig. 4.2-41 GEO Comm Platform Initial Launch – Appendage Deployment
Fig. 4.2-42 GEO Comm Platform Initial Launch – Typical Access to Remote Area

Fig. 4.2-43 Sketch Illustrating Reach Capabilities of Satellite Service Equipment
Figure 4.2-43 which uses the communications platform to illustrate the reach capabilities of satellite servicing equipments. One attitude of the platform (Figure 4.2-43) shows access to the feed mast; the other attitude illustrates a possible location for the platform when calibrating antennas from a free flying signal source.

After deployment of the platform appendages, the checkout of the systems and subsystems and the calibration of antenna patterns, the platform is mated, (Figure 4.2-40 and 44) to an OTV which will transfer it to geosynchronous orbit. The carriage-mounted OTV has been serviced in its hangar and refueled. It is then translated out of the hangar, put on the track system and run along to the tip of the SOC extension pier. The satellite servicing HPA, controlled by the OCP/EVA crew, then berths the platform to the OTV. After final check out, the platform/OTV is separated from SOC. The method of separation will be determined when groundrules governing the burning of "dirty" RCS, separation and approach corridors, etc have been established.

4.2.3.4.3 GEO Communication Platform Checkout Functions - The functions required to assemble the communications platform to the OTV are shown in Figure 4.2-45. A major portion of the time required for checkout is measuring the antenna patterns to calculate gain. The MTV will separate incrementally from SOC, e.g. at 25 and 50 km, and a signal generator on the MTV will radiate energy to the communication platform. The antenna will be rotated incrementally about its boresight 360 degrees. At each position, the antenna will be pitched one or two degrees each side of its boresight while received signal level is recorded. Several other items of equipment such as the DMSP data relay, tactical satcom, lightning mapper and magnetic substorm monitor also require verification of operability. After checkout, the platform will be assembled to the OTV and interfaces verified prior release from SOC. Should a malfunction be uncovered during checkout then additional time and EVA operations are available to resolve the problem.
Fig. 4.2-44 GEO Comm Platform Initial Launch — Mating To OTV

Fig. 4.2-45 Communications Platform SOC Assembly and Checkout
4.2.3.5 Comparison of SOC & Orbiter Servicing

Representative satellite service operations that were analyzed for SOC were also analyzed for operations from Orbiter. This data is compared for number of Orbiter flights, orbital time to perform servicing operations, crew operations time and costs.

4.2.2.5.1 AXAF Servicing by Orbiter - After the Orbiter is inserted into orbit, it immediately commences rendezvous with the AXAF which will have decayed from its initial operational orbit of 500 km. When the Orbiter is in close proximity to the AXAF, the POM will be launched from Orbiter, maneuvered to the AXAF, grapple it, and then transfer the AXAF to the Orbiter for berthing on the HPA. The POM will maneuver the AXAF to the HPA berthing mechanism where the HPA completes the operation by latching onto the AXAF. Figure 4.2-46 shows a time allowance of 30 hours for these operations and Figure 4.2-47 illustrates this sequence of events. One and one-half days have been allowed for maintaining the AXAF which includes 3 EVAs. The nominal approach is to work serially at two levels. To shorten the operations time, Figure 4.2-48 depicts parallel maintenance operations being performed on the instruments by an OCP mounted on an HPA extension and at the subsystem donut at the same time. After completing AXAF maintenance, the Orbiter transfers to 500 km, checks out the AXAF and deploys it as illustrated in Figure 4.2-49. This AXAF servicing operation from Orbiter is completed in 4 days. Contingency time of one or two days could be accommodated if needed, within the Orbiter flight time of 7 days.

4.2.3.5.2 GEO Communications Platform Launched by Orbiter - The GEO communications platform is placed in low earth orbit, and attitude stabilized for later retrieval. The attitude could be gravity gradient stabilized by a simple mechanical boom or cable and mass. See Figure 4.2-50 for the operations timeline.

The second Orbiter transports the OTV to orbit and rendezvous with the communications platform; see Figure 4.2-51 for the sequence of events. Next the RMS grapples the platform and berths it to the HPA.
MAINTENANCE TASKS:

- REPLACE 10 ORUs: 152
- REPLACE 3 INST: 67
- REPLACE 2 SOLAR ARRAYS: 68.5
- REPLACE 2 SA MOTORS: 140.5
- REPAIRS: 86.5
- CLEAN 3 OPTICAL SURFACES: 20.5

AT 75% EFF = 11 HR

483 MIN = 8 HR

Fig. 4.2-46 Timeline - AXAF Servicing from Orbiter

Fig. 4.2-47 AXAF Servicing Sequence
Dual Servicing Capabilities

Fig. 4.2-48  AXAF Servicing By Orbiter
Fig. 4.2-49 AXAF Servicing Sequence (continued)

- Launch Orbiter No. 1
- Attach attitude control device & deploy comm platform
- Orbiter ready for other ops
- Orbi ther no. 2 launch, rendezvous, & berth with comm platform
- Unfold platform appendages, deploy calibration MTV & C/O platform
- Erect OTV, remove att control module from plat & attach plat to OTV
- C/O OTV/PLAT, interfaces & deploy
- Retrieve & stow calibration MTV
- Orbiter separate for OTV burn & stow attitude control module
- Orbiter ready for other ops

---

Fig. 4.2-50 Timeline – GEO Communication Platform Deployed From Orbiter

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Fig. 4.2-51 GEO Comm Platform — Initial Launch From Orbiter

Fig. 4.2-52 GEO Comm Platform—Initial Launch from Orbiter (continued)
Now the communication platform unfolding is controlled from the Orbiter aft flight deck. In the event that appendages do not deploy completely, EVA operation will rectify the situation. Platform checkout operations are similar to those described for SOC, i.e., the calibration MTV is released and antennae patterns determined. Figure 4.2-52 shows the OTV erected out of the cargo bay so that the platform can be assembled to it. After interfaces are verified and the OTV checkout out, the OTV is released for subsequent transfer to geosynchronous orbit. The last event to be accomplished prior to Orbiter departure is the retrieval and stowage of the calibration MTV.

Figure 4.2-53 contains the functions required for orbiter assembly and checkout of the platform/OTV and includes the block time allocated for each operation.

4.2.3.5.3 Comparative Data - Comparative data of AXAF servicing from the SOC and Orbiter is shown in Figure 4.2-54. All parameters compared are quite similar, except costs (Reference 4.2-11) for the planned operations and cost allowance for contingencies. Increased costs when servicing the AXAF from Orbiter and launching the Communication platform, without utilizing SOC, are illustrated in Figure 4.2-56. The reason the Orbiter transportation costs associated with the AXAF ($13.5 + 5.6 = $19.1 million 1981 constant dollars) are high is that the HPA, AXAF replaceable equipment, POM, and OMS kit require a payload bay length factor of 0.67.

A similar comparison of the Communications Platform costs are shown in Figures 4.2-55 and 4.2-56. The Orbiter transportation costs of $57.7 million (1981 constant dollars) includes two flights, with full cargo bays on each flight. The SOC transportation cost of $29.8 million (1981 constant dollars) (Reference 4.2-11 and 12) is the Orbiter flight that transports the communications platform to SOC.

4.2.4 MISSION MODEL IMPACT ON SATELLITE SERVICE FACILITY

This task assessed the impact of mission and traffic models on equipment requirements and on the initial, operational, and growth SOC configurations.
Fig. 4.2-53 Communications Platform Orbiter Assembly and Checkout

Fig. 4.2-54 Comparison of AXAF Servicing From SOC and Orbiter

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<tr>
<th>MISSION PARAMETER</th>
<th>SOC</th>
<th>ORBITER</th>
<th>COMMENTS</th>
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<tr>
<td>NUMBER OF ORBITER FLIGHTS</td>
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<td>AXAF REPLACEMENT EQUIP. &amp; VSS PROP. DELIVERED TO SOC BY SHARED LOGISTIC FLIGHT</td>
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<td>MISSION TIME IN DAYS</td>
<td>5%</td>
<td>4</td>
<td>AXAF/SOC OPERATIONS (ORBITER SHARED LOGISTICS FLIGHT NOT INCLUDED)</td>
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<td>NO. CREW (AXAF WORKERS)</td>
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<td>SINGLE SHIFT</td>
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<td>CREW WORK TIME (HR) (AXAF RELATED)</td>
<td>18</td>
<td>21</td>
<td>INCLUDES ORBITER BOOST OF AXAF TO OPERATING ALTITUDE</td>
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<td>EVA TIME (HR)</td>
<td>11</td>
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<td>COSTS MILLION (1981 DOLLARS)</td>
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<td>ORBITER RESUPPLY FLT TO SOC COSTS INCLUDED</td>
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<td>CONTINGENCY $ MILLION (1981 DOLLARS)</td>
<td>$0.03</td>
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<td>ONE DAY WITH 2 EVAs</td>
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### Table: Mission Parameter Comparison

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<td>Contingency Million (1981 Dollars)</td>
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<td>$ 0.4</td>
<td>One Day Operations</td>
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**Fig. 4.2-55** Comparison of Communication Platform Assembly and Checkout from SOC and Orbiter

### Bar Chart: Representative Mission Service Costs (1981 Constant $)

- **Transportation**
- **Misc Charges**
- **Service Equip.**

**Fig. 4.2-56** Representative Mission Service Costs (1981 Constant $)
Figure 4.2-57 illustrates satellite servicing at the initial SOC. The main equipment added to the baseline configuration is a handling and positioning aid (HPA) to handle the satellite and an OCP to mount to the tip of the standard manipulator. A service supplies pallet, delivered by the Orbiter, is berthed to a standard port on the Service Module (SM). This pallet provides supplies for maintenance/ resupply operations of co-orbiting satellites and the Proximity Operations Module (POM) which retrieves these satellites. A grappling point is also provided on the pallet to hold a POM for service. When a satellite has been captured and returned to SOC, the POM propulsion unit berth the satellite to the HPA. The POM is demated from the satellite and transferred to the grapple point on the service supplies pallet where it is serviced and refueled by the EVA crewman on the OCP. The satellite is also serviced, in turn, by the EVA crew who obtains change-out modules, etc from the supplies pallet.

Satellite servicing from the operational SOC was discussed previously in detail. Considering the impact of traffic model variation, it has been established that with the current models, no increase in equipments will be required before 1995, after the proposed IOC for growth SOC.

Figure 4.2-58 shows a concept for satellite servicing on growth SOC. It utilizes the same equipments as proposed for operational SOC. However, introduction of the construction facility forces the pier, which supports the HPAs, to another location. It is shown here as extending out from the underside, i.e., the side opposite to that mounting the standard track system. A cross track is also added to this side to provide mobility for the carriage platform which mounts the two manipulators. Servicing operations follow those described for the operational SOC.

The reason for the operational SOC not having its satellite service facility located where shown for growth SOC, thus avoiding rework, is that it is believed that the operational SOC concept will
Fig. 4.2-57  Satellite Service at "Initial" SOC

Fig. 4.2-58  Satellite Service at "Growth" SOC
be utilized for a long period of time. Facility location on operational SOC is more convenient since it gives more flexibility in reach for the manipulators and HPAs. The locations shown here for growth SOC satellite servicing is just one of many alternates which require further study. Additional servicing equipment will be required after 1995 if parallel servicing is necessary to meet scheduled events.
SUBSECTION 4.2 REFERENCES

4.2-1 Space Systems Technology Model, Second Draft, July 1981, NASA


4.2-12 Man-Hour Cost Estimate for SOC-Based OTV Servicing LR-15-1622, Oct. 15 1980, NASA JSC Memorandum
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<td>Identification of Similar Equipments</td>
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4.3 ANALYSIS OF CONSTRUCTION AND SERVICE EQUIPMENT REQUIREMENTS

There were four main objectives to this task:

- To identify common requirements and equipments for implementing satellite service missions and construction missions on SOC. Candidate equipment concepts are based on the findings of three earlier studies and on the servicing requirements established in the preceding task. The earlier studies include the orbiter based Satellite Servicing Systems Analysis Studies by Lockheed and Grumman (Ref 4.3-1 and 4.3-2), and Boeing's previous SOC Systems Analysis Study (Ref. 4.3-3).
- To analyze these requirements and equipments for maximum commonality and utility.
- To provide updated equipment lists, and
- To define the evolutionary growth of servicing and construction capabilities through the first 10 years of SOC operations.

4.3.1 IDENTIFICATION OF SIMILAR EQUIPMENTS

The initial list of satellite servicing equipments for SOC was derived from the reference mission scenarios defined in the preceding task. Additional equipments defined in the three earlier studies for servicing satellites and constructing large space systems were also incorporated into the listing. The entire list was then categorized into five areas:

- Required satellite service equipment for SOC
- Required flight support equipment for SOC based servicing
- Potential use satellite service equipment group
- Potential use flight support equipment group
- Other equipments.
Satellite service equipment required for SOC is listed in Table 4.3-1. This list includes the major equipment needed to perform the two reference missions (e.g., open cherry pickers, manipulators and handling/positioning aids). Some of these equipments were also identified in the earlier studies and are so indicated. The technology status of each equipment item is also listed. Required flight support equipment for SOC based satellite servicing is provided in Table 4.3-2, which covers the propulsion equipments and their service requirements neccessary to perform the reference missions. Limited resources for this short study extension did not permit an in-depth analysis of all equipment concepts identified to date. Thus, it is possible that further analysis will identify additional equipment which will also be required for use on SOC. Tables 4.3-3 through 4.3-5 list those remaining equipments defined in the earlier studies for satellite servicing which were not derived from the reference missions. The satellite service equipment group shown in Table 4.3-3, and the flight support equipment group, Table 4.3-4, are not considered necessary for the reference missions but are considered to have potential use as general purpose equipments for servicing satellites.

The remainder of the earlier equipments were considered to have no obvious use for SOC based servicing since they are unique to orbiter based servicing. These items are listed under "other equipments", as shown in Table 4.3-5.

Turning to construction equipment, 21 pieces were identified in the SOC main study, (Ref. 4.3-3) and are listed in Table 4.3-6. They were compared to the "required equipments" and the "potential use equipments" listed for satellite servicing. Some construction equipments had no equivalent requirement in satellite servicing and were identified as such. Others were identical or similar to equipments required for satellite servicing. For each of the "similar equipments" in this category, the comparable piece of satellite service equipment was identified. Also identified in this table is construction equipment which also appears as "potential use" equipment on the satellite servicing listing.
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</tr>
<tr>
<td>- END EFFECTORS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>NEW</td>
</tr>
<tr>
<td>- OCP SUPPORT BOOM</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>NEW</td>
</tr>
<tr>
<td>- UMBILICALS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>NEW</td>
</tr>
<tr>
<td>• HAND TOOLS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>EXISTING/DEVLT/NEW</td>
</tr>
<tr>
<td>• SATELLITE/PAYLOAD CHECK OUT</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>DEVLT/NEW</td>
</tr>
<tr>
<td>• SERVICE SUPPLIES PALLETS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>EXISTING (SPACELAB)</td>
</tr>
<tr>
<td>• FAULT DIAGNOSIS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>NEW</td>
</tr>
<tr>
<td>• TOOL/AID STORAGE ON SOC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>SOC STD EQMT</td>
</tr>
<tr>
<td>• HANDHOLDS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>SOC STD EQMT</td>
</tr>
<tr>
<td>• HANDRAILS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>SOC STD EQMT</td>
</tr>
<tr>
<td>• GROUNDING STRAP</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>NEW</td>
</tr>
<tr>
<td>• OPTICAL SURFACE CLEANING KIT</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>NEW</td>
</tr>
<tr>
<td>• TELEMETRY &amp; COMMAND SYS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>SOC STD EQMT</td>
</tr>
</tbody>
</table>

TABLE 4.3-1 REQUIRED SATELLITE SERVICE EQUIPMENT – REFERENCE SATELLITE SERVICE MISSIONS
TABLE 4.3-2 REQUIRED FLIGHT SUPPORT EQUIPMENT – REFERENCE SATELLITE SERVICE MISSIONS

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>WHERE IDENTIFIED</th>
<th>TECH STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOC EXTN STUDY</td>
<td>SOC MAIN STUDY</td>
</tr>
<tr>
<td>OTV</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>HANGAR</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>OTV ELEVATOR</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>OTV UMBILICAL</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>OTV DOLLY</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>OTV SERVICE EOMT</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>OTV REFUEL EOMT</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>OTV CHECKOUT EOMT</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VERSATILE SERVICE STAGE (VSS)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VSS SERVICE EOMT</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VSS REFUEL EOMT</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VSS CHECKOUT EOMT</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MANEUVERABLE TELEVISION (MTV)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PROPN ARMING/SAFING</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>FLUID LINE REPAIR KIT</td>
<td>✓</td>
<td>✓</td>
</tr>
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</table>
### TABLE 4.3-3 ‘POTENTIAL USE’ SATELLITE SERVICE EQUIPMENT — IDENTIFIED IN PREVIOUS STUDIES

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>WHERE IDENTIFIED</th>
<th>TECH STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOC MAIN STUDY</td>
<td>LOCKHD SAT. SERV</td>
</tr>
<tr>
<td></td>
<td>New (Local illumination)</td>
<td>New (Beyond OCP reach)</td>
</tr>
<tr>
<td></td>
<td>New</td>
<td>New</td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New</td>
<td>New</td>
</tr>
<tr>
<td></td>
<td>New</td>
<td></td>
</tr>
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<td></td>
<td>New</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Devlt (Future IVA Opn)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Existing/Devlt/New</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Devlt (Spin Stabilized Propn)</td>
<td></td>
</tr>
</tbody>
</table>

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## Table 4.3-4 Potential Use' Flight Support Sys Equipment – Identified in Previous Studies

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Soc Ext Study</th>
<th>Soc Main Study</th>
<th>Lockh'd Sat. Serv</th>
<th>Grumman Sat. Serv</th>
<th>Tech Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmanned Proximity Ops Module (POM) Propn</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Devlt</td>
</tr>
<tr>
<td>- MTV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New</td>
</tr>
<tr>
<td>- Propn Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manned POM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Existing</td>
</tr>
<tr>
<td>- MMU</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>- Work Restraint Unit (WRU)</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>Partially Developed</td>
</tr>
</tbody>
</table>

V81.2101-012W
<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>WHERE IDENTIFIED</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOOT RESTRAINT &amp; RECEPTACLE</td>
<td>✓</td>
<td>FUNCTIONS REQUIRING THESE EQMTS ARE PROVIDED BY EVA/OCP/MANIPULATOR SYSTEM</td>
</tr>
<tr>
<td>MINI WORK STN</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>TOOL CADDY</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>PORTABLE LIGHTS</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>MODULE EXCHANGE MECHM.</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>SLIDE WIRES</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>CLOTHES LINE</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>UMBILICAL</td>
<td>✓</td>
<td>FUNCTIONS REQUIRING THESE EQMTS ARE PROVIDED BY HPA SYSTEM</td>
</tr>
<tr>
<td>EXTRACT/INSERT TABLE</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>PIVOT/ROTATE TABLE</td>
<td>✓</td>
<td>THESE ARE CONSIDERED 'HANDTOOLS' – LISTED AS 'REQD EQMT'</td>
</tr>
<tr>
<td>NASA TOOLS</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>POWER WRENCH</td>
<td>✓</td>
<td>THESE ARE CONSIDERED 'END EFFECTORS' – LISTED AS 'REQD EQMT'</td>
</tr>
<tr>
<td>ENERGIZED DRILL WRENCH</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>MANUAL OVERRIDE TOOL</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>ATTACH/REMOVE GRAPPLE FXTRS</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>GRAPPLE ASSY STANDOFF</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>SPARES RACK/ENCLOSURE</td>
<td>✓</td>
<td>SEE 'SERVICE SUPPLIES PALLETS'</td>
</tr>
<tr>
<td>DESPIN PACKAGE</td>
<td>✓</td>
<td>PERFORMED BY VSS OR POM</td>
</tr>
<tr>
<td>FLUID CONNECTOR</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>FLUID MANIFOLD</td>
<td>✓</td>
<td>PART OF OTV/VSS/ POM REFUEL EQMT</td>
</tr>
<tr>
<td>FLUID TRANSFER KIT</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

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### TABLE 4.3-5  OTHER EQUIPMENTS PREVIOUSLY IDENTIFIED (CONT'D)

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>WHERE IDENTIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOC EXTN STUDY</td>
</tr>
<tr>
<td>MESA KIT</td>
<td></td>
</tr>
<tr>
<td>ORBITER LIGHTS</td>
<td></td>
</tr>
<tr>
<td>FSS</td>
<td></td>
</tr>
<tr>
<td>DOCKING MODULE</td>
<td></td>
</tr>
<tr>
<td>OMS KIT MOD</td>
<td></td>
</tr>
<tr>
<td>RMS NET</td>
<td></td>
</tr>
<tr>
<td>RETENTION STRUCTURES</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>PIDA</td>
<td></td>
</tr>
<tr>
<td>NON CONTAMINATING ACS</td>
<td></td>
</tr>
<tr>
<td>ATTITUDE TRANSFER</td>
<td></td>
</tr>
<tr>
<td>LATCH MECHANISM</td>
<td>√</td>
</tr>
<tr>
<td>DE ORBIT KIT</td>
<td>√</td>
</tr>
</tbody>
</table>

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**TABLE 4.3.6 Constr Equipment - Commonality with Sat. Service Equipment**

<table>
<thead>
<tr>
<th>Constr Equipment - Defined in Main Study</th>
<th>No. Sat Service Equiv Identified</th>
<th>Required for Sat. Service</th>
<th>Identified As 'Potential Use' For Sat. Service</th>
<th>Comparable Sat. Service Eqmt – Where Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Mobile Cherry Picker</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>Mobile Platform</td>
</tr>
<tr>
<td>• Handling Tools</td>
<td></td>
<td>✓</td>
<td></td>
<td>End Effectors</td>
</tr>
<tr>
<td>• Portable EVA Work STN</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• EMU</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Std Hand Tools</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Manipulator Sys</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Articulated Constr Fixture</td>
<td></td>
<td>✓</td>
<td></td>
<td>Mobile Platform Function</td>
</tr>
<tr>
<td>• Modular Constr Fixture</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Turntable/Tilttable</td>
<td></td>
<td>✓</td>
<td></td>
<td>HPA Function</td>
</tr>
<tr>
<td>• Constr Umbilical Sys</td>
<td></td>
<td>✓</td>
<td></td>
<td>HPA Function</td>
</tr>
<tr>
<td>• Beam Builder Sys</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Strut Assy Aide</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Tape Dispenser</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Light Leak Sensor Instr</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>• Contour Measuring Instr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Data Recorder</td>
<td></td>
<td>✓</td>
<td></td>
<td>c/o Eqmt</td>
</tr>
<tr>
<td>• Tethers</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Data Bus Test Module</td>
<td></td>
<td>✓</td>
<td></td>
<td>c/o Eqmt</td>
</tr>
<tr>
<td>• Electrical Continuity Tester</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Measuring Tapes</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• OTV + Necessary Service &amp; Refuel Eqmt</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In summary, 21 pieces of construction equipment were identified in the SOC main study, 15 of which had comparable satellite servicing functions. Considering these 15 pieces of comparable equipment, 9 of them were identical to satellite servicing equipments, either as "required" or as "potential use", and could be used directly. The remaining 6 comparable equipments had functions similar to satellite servicing and were, therefore, investigated further to assess the impacts of using common equipments.

4.3.2 COMPARISON OF SIMILAR EQUIPMENTS

The six construction equipments, with their similar function satellite servicing equipments, are shown in Figures 4.3-1 thru 4.3-5.

Figure 4.3-1 shows the Mobile Cherry Picker, a new piece of construction equipment with 18 m total reach. At its tip it can mount on open cherry picker (OCP) which, in turn, can mount a payload handling tool. The whole is mounted on a carriage to run along the SOC track.

For satellite servicing, two STS manipulators are mounted on a carriage to provide a mobile platform. One manipulator mounts an OCP at its tip while the other manipulator mounts an appropriate end effector. Two manipulator arms are provided which allows the crewman on the OCP to control both arms, yet position himself to watch and control the handling of the payload by the other arm from a suitable, safe location. This is of particular significance when, for example, capturing a free flying satellite prior to berthing. There is also operational flexibility in the two-arm system when, for example, the second manipulator arm can fetch and carry change out modules for the crewman working from the OCP. Questions of reach, degrees of freedom and load handling capabilities are considered elsewhere in this report.

Payload handling tools require a "small object" and "large object" tool for construction work. If proven to be suitable, these tools can be adapted to attach to the STS manipulator snare end effector for satellite servicing.
Fig. 4.3-1 Similar Equipments — Mobile Cherry Picker and Mobile Platform

Fig. 4.3-2 Similar Equipments — Manipulator Systems
The Manipulator System for construction missions, shown in Figure 4.3-2, is used for build up and operations of the Initial SOC. It comprises a manipulator mounted to a turntable, which is mounted in turn to a berthing ring. The manipulator is defined as being based on the Orbiter RMS configuration.

Since the manipulators for the satellite servicing mobile platform are also based on the Orbiter RMS, this piece of equipment can be used directly. The handling and positioning aid (HPA) has the capability of turning and, although elaborate for the function, it could be used as a turntable. The berthing ring is standard. Therefore, a manipulator system, which is assembled from satellite servicing equipment, can be provided for construction activities.

The primary objective of the Turntable/Tilt Table (Figure 4.3-3) is to reorient a workpiece of accessibility by a cherrypicker or an EVA crewman. The HPA, presently being developed for orbiter operations and used for satellite servicing, has the same objectives and provides similar degrees of freedom.

Figure 4.3-4 shows the articulated construction fixture necessary to provide the support and positioning interface between the workpiece and the SOC. It has an articulating arm mounted to the turntable/tilt table and has a payload attachment grapple fixture at its tip. The HPA offers similar articulations and can, with suitable interface, mount the same grapple fitting at its tip. Questions of reach, degrees of freedom, and load handling capabilities are considered elsewhere in this report.

An umbilical system is necessary to carry power, data, and (in the growth SOC) fluids to the work piece. The system, shown in Figure 4.3-5 for construction missions, has an articulated arm which mounts the utilities at its tip. These umbilicals will be located at fixed locations on the SOC. Although not presently incorporated in the HPA, since it is still in the early development stage, it is envisaged that an umbilical system will be incorporated into the flight version. A
Fig. 4.3-3 Similar Equipments — Turntable/Tilttable and HPA

Fig. 4.3-4 Similar Equipments — Construction Umbilical System and HPA Umbilical System
Fig. 4.3-5 Similar Equipments — Articulated Construction Fixture and HPA
A panel carrying the utilities will probably be located near the tip and the lines run up the arm. Direct mating for the workpiece to the umbilical panel will probably prove to be too restricting on design and may, therefore, be flying leads to be connected to a workpiece panel by the EVA crewman. Thus, the utilities would be readily available on the piece of equipment which supports the workpiece. However, in locations where the HPA is not required, the provision of utilities at an interface may require development of the construction umbilical system. To compare these equipments, requirements for the six construction equipments were taken from the main study and listed, as shown in Table 4.3-7. Capabilities of the comparable pieces of satellite service equipment were then listed and compared, item for item, with the requirements.

Table 4.3-8 summarizes the results of this comparison and shows that most of the requirements could be satisfied directly. Some requirements were TBD and will require further study when they are known. This table considered those requirements which cannot be satisfied directly by the capabilities and offers candidate solutions.

Considering the Mobile Cherry Picker, its reach is required to be 18 m to place an OTV in its service hangar. There is, however, an elevator proposed to lift the OTV and its carriage out of the hangar and put it in line with the track system. Alternately, the latest SOC configuration shows a hangar which is located so that an OTV can be moved directly onto the track system. Either of these proposals would, presumably, reduce the required 18-m reach. The satellite service mobile platform arms offer a tip reach of 15.24 m, excluding added handling tools. Regarding maintenance, the satellite service mobile platform arm is an STS manipulator, which is designed to be maintained on the ground, whereas the requirement is for EVA space maintenance. It is proposed that spare arms be kept at the SOC to replace an operating arm for regular maintenance or for repair. This arm would then be transported to ground by the Orbiter in its unused starboard RMS location, serviced, then returned to SOC. Alternately, the arm could be modified for EVA maintenance. The last
### TABLE 4.3-7 EQUIPMENTS COMPARISON — CONSTRUCTION REQUIREMENTS vs SAT. SERVICE CAPABILITIES

<table>
<thead>
<tr>
<th>CONSTRUCTION EQMT REQMT</th>
<th>SAT. SERVICE EQMT CAPABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MOBILE CHERRY PICKER</strong></td>
<td></td>
</tr>
<tr>
<td><strong>MAXIMUM LOAD</strong> — THE LARGEST AND THE HEAVIEST LOAD TO BE MOVED IS A FULLY FUELED OTV (APPROX 40,000 kg) PLUS ITS HEAVIEST PAYLOAD (APPROX 15,000 kg), FOR A TOTAL OF 55,000 kg. THIS REQUIREMENT COMES FROM THE CONTINGENCY CONDITION WHERE A JUST-LAUNCHED OTV MALFUNCTIONS AND MUST BE RECAPTURED.</td>
<td>SPAR SIMULATION RUNS SHOW THAT IT IS FEASIBLE TO BERTH ORBITER (90,000 kg) TO SOC USING ORBITER MANIPULATORS, IF SOFTWARE IS MODIFIED [RMS 2ND USERS CONFERENCE]</td>
</tr>
<tr>
<td><strong>MAXIMUM SPEED</strong> — TBD.</td>
<td>MANIPULATOR TIP SPEED IS 0.2 FT/SEC WITH 14,500 kg.</td>
</tr>
<tr>
<td><strong>REACH ENVELOPE</strong> — 18-m TIP RADIUS TO PLACE OTV IN HANGAR.</td>
<td>MANIPULATOR TIP RADIUS IS 15.24 m</td>
</tr>
<tr>
<td><strong>MAXIMUM SIZE PAYLOAD</strong> — 4.2 m DIAMETER X TBD m LONG (DEPENDS ON SPACECRAFT GEOMETRY WHEN ATTACHED TO AN OTV).</td>
<td>MANIPULATOR HANDLES AT LEAST 4.2 m DIAM X 17.5 m PAYLOAD. CONTRIBUTION TO INERTIA IS THE RESTRICTION.</td>
</tr>
<tr>
<td><strong>TRANSLATION CAPABILITY</strong> — PROVIDE CAPABILITY TO MOVE ALONG THE FACILITY TRACK NETWORK. THIS REQUIREMENT IS BASED ON THE FACT THAT THE SOC OPERATIONAL AREAS (CONSTRUCTION AND FLIGHT SUPPORT) WERE SEPARATED TO ALLOW PLENTY OF WORKING ROOM. IN ADDITION, PROVIDING TRANSLATION CAPABILITY PROVIDES AN ADDITIONAL DEGREE OF FREEDOM IN MOVING PAYLOADS.</td>
<td>CAN UTILIZE SAME CARRIAGE AS DEFINED FOR MOBILE CHERRY PICKER.</td>
</tr>
<tr>
<td><strong>MANNED REMOTE WORK STATION</strong> — A MANNED WORK STATION TO BE LOCATED AT THE END OF THE CHERRY PICKER BOOM ASSEMBLY. THIS WORK STATION PROVIDE FOOT RESTRAINTS, LIGHTING, AND A CONTROL CONSOLE.</td>
<td>OPEN CHERRY PICKER (OCP) HAS CAPABILITY.</td>
</tr>
<tr>
<td><strong>END EFFECTOR GRAPPLE SYSTEM</strong> — PROVIDE A GRAPPLING GLASS FOR EASILY CHANGING THE END EFFECTORS TO BE ATTACHED TO THE WORK STATION. TWO TYPES OF END EFFECTORS HAVE BEEN DEFINED — A SMALL OBJECT HANDLING TOOL AND A LARGE OBJECT HANDLING TOOL.</td>
<td>MANIPULATOR CAN GRAPPLE SPECIAL PURPOSE END EFFECTORS.</td>
</tr>
<tr>
<td><strong>CONTROL MODES</strong> — THE CHERRYPICKER MUST BE CONTROLLABLE FROM THE MANNED REMOTE WORK STATION AND REMOTELY FROM THE HABITAT MODULE COMMAND CENTER. THE NUMBER AND TYPES OF CONTROL MODES HAVE NOT BEEN DEFINED.</td>
<td>MOBILE PLATFORM SYSTEM WILL PROVIDE THESE CAPABILITIES.</td>
</tr>
<tr>
<td><strong>MAN-RATED</strong> — THE MOBILE CHERRYPICKER MUST INCORPORATE FEATURES WHICH MAKE IT A MAN-RATED SYSTEM.</td>
<td>ORBITER MANIPULATOR IS MAN RATED.</td>
</tr>
<tr>
<td><strong>MAINTAINABILITY</strong> — DESIGN THE CHERRYPICKER TO BE MAINTAINABLE VIA EVA.</td>
<td>ORBITER MANIPULATOR IS GROUND MAINTAINED.</td>
</tr>
<tr>
<td><strong>RELIABILITY</strong> — THE MOBILE CHERRYPICKER IS USED IN ALMOST ALL OF THE SOC OPERATIONS. IT MUST, THEREFORE, BE A HIGHLY RELIABLE SYSTEM SO THAT DOWN TIME IS MINIMIZED. THE EXACT RELIABILITY REQUIREMENTS ARE TBD.</td>
<td>MANIPULATOR CAPABILITIES WILL BE EVALUATED WHEN REQUIREMENTS ARE KNOWN.</td>
</tr>
<tr>
<td><strong>FAIL OPERATIONAL/FAIL SAFE</strong> — THE MANIPULATOR SHALL BE DESIGNED FOR FAIL OPERATIONAL/FAIL SAFE PERFORMANCE.</td>
<td>MANIPULATOR IS FAIL SAFE.</td>
</tr>
<tr>
<td><strong>STOPPING DISTANCE</strong> — THE MAXIMUM STOPPING DISTANCE OF THE MANIPULATOR, AS MEASURED AT THE WRIST TO MRWS INTERFACE, SHALL BE LIMITED TO 2 FT IRRESPECTIVE OF ITS LOADING CONDITIONS (UP TO 55,000 kg PAYLOAD).</td>
<td>MANIPULATOR STOPS IN 2 FT AT 0.2 FT/S WITH 14,500 kg PAYLOAD. CAPABILITY WITH 55,000 kg STOPPED IN 2 FT IS A FUNCTION OF RATE.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>CONSTRUCTION EQUIPMENT REQUIREMENTS</th>
<th>SAT. SERVICE EQUIPMENT CAPABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MOBILE CHERRY PICKER</strong></td>
<td></td>
</tr>
<tr>
<td>TRACK AND CAPTURE - THE MANIPULATOR SHALL HAVE THE CAPABILITY TO TRACK AND CAPTURE INCOMING SPACECRAFT UP TO 55,000 kg MASS WITH SPACECRAFT VELOCITIES RELATIVE TO SOC OF UP TO TBD FT/S AND RATES OF TBD DEGREES/S.</td>
<td>MANIPULATOR CAPTURES 14,500 kg MOVING AT 0.1 FT/S. CAPABILITY WITH 55,000 kg TO BE EVALUATED WHEN REQUIREMENTS ARE KNOWN.</td>
</tr>
<tr>
<td><strong>POWER</strong> - POWER SHALL BE SUPPLIED TO THE MANIPULATOR BY RECHARGEABLE BATTERIES MOUNTED ON THE CARRIAGE. VOLTAGE AND POWER LEVELS TBD.</td>
<td>THIS SYSTEM WILL PROVIDE</td>
</tr>
<tr>
<td><strong>DUTY CYCLE</strong> - THE CHERRY PICKER SHALL BE CAPABLE OF OPERATING FOR 16 HOURS IN ANY 24-HOUR PERIOD.</td>
<td>REQUIRES FURTHER STUDY</td>
</tr>
<tr>
<td><strong>CCTV'S AND LIGHTING</strong> - SHALL BE PROVIDED AT TBD LOCATIONS ON THE MANIPULATOR. VIDEO DATA SHALL BE TRANSMITTED TO THE D&amp;C PANELS IN THE HABITAT MODULE. PROVISION SHALL BE MADE FOR TWO PARALLEL VIDEO CHANNELS TO THE MRWS SUCH THAT THE MRWS OPERATOR MAY SELECT ANY TWO CAMERA COMBINATIONS FROM THOSE MOUNTED ON THE MANIPULATOR AND ANYWHERE ELSE ON SOC (SUCH AS THE OTV HANGAR).</td>
<td>MANIPULATOR PROVIDES CCTV &amp; LIGHTING. THE REQUIREMENTS CAN BE INCORPORATED INTO THE SYSTEM</td>
</tr>
<tr>
<td><strong>PAYLOAD HANDLING TOOLS</strong></td>
<td></td>
</tr>
<tr>
<td>A SMALL OBJECT HANDLING TOOL IS AFFIXED TO THE MOBILE CHERRY PICKER'S MANNED WORKSTATION END-EFFCTOR VIA A QUICK-DISCONNECT GRAPPLE FITTING. THIS TOOL IS OPERATED FROM THE WORKSTATION CONTROL PANEL. THE TOOL HAS ADJUSTABLE ARMS AND INTERCHANGEABLE TIPS SO THAT IT CAN BE CONFIGURED TO HANDLE A VARIETY OF OBJECTS.</td>
<td>MANIPULATOR PROVIDES A STANDARD END EFFECTOR WHICH CAN QUICK-DISCONNECT OTHER END EFFECTORS SUCH AS HANDLING TOOLS</td>
</tr>
<tr>
<td>A LARGE-OBJECT HANDLING TOOL IS AFFIXED TO THE MOBILE CHERRY PICKER'S MANNED WORKSTATION END-EFFECTOR VIA A QUICK-DISCONNECT GRAPPLE FITTING. THIS TOOL IS OPERATED FROM A CONTROL STAND THAT IS WITHIN REACH OF THE OPERATOR AFTER THE TOOL IS ATTACHED TO THE MOBILE CHERRY PICKER. THE TOOL HAS ADJUSTABLE ARMS AND TIPS THAT CAN BE CONFIGURED TO HANDLE A VARIETY OF LARGE OBJECTS.</td>
<td>CONSTRUCTION HANDLING TOOLS MAY BE OF USE IN SATELLITE SERVICING</td>
</tr>
<tr>
<td><strong>MANIPULATOR SYSTEM</strong></td>
<td></td>
</tr>
<tr>
<td>MAXIMUM LOAD - THE LARGEST AND HEAVIEST LOAD TO BE HANDLED BY THE MANIPULATOR IS THE HABITAT MODULE NO. 2 (21,740 kg) WHICH IS PUT INTO PLACE DURING THE SOC BUILD-UP OPERATIONS.</td>
<td>MANIPULATOR CAN HANDLE &amp; BERTH 90,000 kg IF CONTROL SOFTWARE IS MODIFIED.</td>
</tr>
<tr>
<td><strong>MOBILE PLATFORM MANIPULATOR + HPA</strong></td>
<td></td>
</tr>
<tr>
<td>MAXIMUM SPEED - TBD.</td>
<td>TIP SPEED 0.2 FT/S FOR 14,500 kg. EVALUATE WHEN REQUIREMENTS KNOWN.</td>
</tr>
<tr>
<td>MAXIMUM REACH - APPROXIMATELY 50 FT. THIS REACH DISTANCE IS ESTABLISHED BY THE REQUIREMENTS FOR INSTALLING HM2 ONTO SM2.</td>
<td>15.24 m (50 FT)</td>
</tr>
<tr>
<td>END EFFECTOR - USE THE STANDARD ORBITER RMS END EFFECTOR.</td>
<td>USECS STANDARD END EFFECTOR</td>
</tr>
<tr>
<td>CONTROL - THIS MANIPULATOR IS REMOTELY CONTROLLED FROM THE HM1 COMMAND CENTER VIA THE OPERATIONS CONTROL PANEL.</td>
<td>MOBILE PLATFORM SYSTEM CONTROLLABLE FROM HM1</td>
</tr>
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<th>SAT. SERVICE EQMT CAPABILITY</th>
<th>MOBILE PLATFORM MANIPULATOR + HPA (CONT'D)</th>
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</thead>
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<td>ARTICULATIONS – THE FOLLOWING DEGREES OF FREEDOM ARE REQUIRED:</td>
<td></td>
<td></td>
<td>– MEETS ALL REQUIREMENTS EXCEPT SHOULDER YAW WHICH IS ± 180°</td>
</tr>
<tr>
<td>- SHOULDER YAW (±360°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- SHOULDER PITCH (-2° TO +145°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- ELBOW PITCH (+2° TO -160°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- WRIST PITCH (+120° TO -120°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- WRIST YAW (+120° TO -120°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- WRIST ROLL (+447°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TURNTABLE ROTATION – ±360°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DATA AND POWER – PROVIDED VIA THE STANDARD UTILITY INTERFACES CONTAINED IN THE STANDARD SOC BERTHING PORT.</td>
<td></td>
<td></td>
<td>– HPA PROVIDES</td>
</tr>
<tr>
<td>INTERFACES – TURNTABLE MATES TO SM1 BERTHING PORT NO. 2 VIA A STANDARD BERTHING FIXTURE AND TO THE BOOM'S SHOULDER JOINT.</td>
<td></td>
<td></td>
<td>– HPA REQUIRES MOUNTING STRUCTURE TO MATE WITH BERTHING RING</td>
</tr>
<tr>
<td>TURNABLE/TILT/TABLE</td>
<td></td>
<td></td>
<td>HANDLING &amp; POSITIONING AID</td>
</tr>
<tr>
<td>DEGREES OF FREEDOM – THE FIGURE SHOWS THE VARIOUS DEGREES OF FREEDOM THAT ARE REQUIRED (4 DOF SHOWN)</td>
<td></td>
<td></td>
<td>– DTA HAS 5 DOF</td>
</tr>
<tr>
<td>DIMENSIONS – THE DIMENSIONS OF THE TURNABLE/TILT/TABLE ARE TBD.</td>
<td></td>
<td></td>
<td>– 6 m REACH. EVALUATE WHEN REQUIREMENTS KNOWN</td>
</tr>
<tr>
<td>INTERFACES –</td>
<td></td>
<td></td>
<td>– MOUNT TO BERTHING RING USING A DEDICATED MOUNTING STRUCTURE</td>
</tr>
<tr>
<td>INITIAL AND OPERATIONAL SOC – BERTHED TO ONE OF THE BERTHING PORTS. MECHANICAL ELECTRICAL POWER, AND CONTROL SIGNAL INTERFACES ARE MADE THROUGH THE BERTHING RING.</td>
<td></td>
<td></td>
<td>– MOUNT TO CARRIAGE, USE SAME STRUCTURE AS FOR BERTH RING MOUNT</td>
</tr>
<tr>
<td>GROWTH SOC – MOUNTED ON A CARRIAGE THAT IS, IN TURN, MOUNTED ON THE CONSTRUCTION FACILITY PIER. MECHANICAL INTERFACE IS THE WHEELS AND TRACKS. ELECTRICAL POWER AND CONTROL SIGNALS INTERFACES ARE TBD. NOTE – THIS CARRIAGE SHOULD BE IDENTICAL TO THE CARRIAGE USED BY THE MOBILE CHERRY PICKER.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TURNABLE INTERFACE – THE PLATEN OF THE TURNABLE SHOULD BE CONFIGURED SO THAT A WIDE VARIETY OF MECHANICAL ATTACHMENTS COULD BE MADE. A PATTERN OF TIGHTENED HOLES SHOULD SUFFICE.</td>
<td></td>
<td></td>
<td>– HPA TIP WILL PROVIDE STANDARD INTERFACE TO MOUNT END EFFECTORS &amp; ATTACHMENTS</td>
</tr>
<tr>
<td>CONTROL – THE VARIOUS MECHANISMS SHOULD BE CONTROLLABLE VIA THE SOC DATA BUS INTERFACE.</td>
<td></td>
<td></td>
<td>– CAN BE INCORPORATED</td>
</tr>
<tr>
<td>EXTENSION STRUCTURE – A SEPARATE TBD LONG EXTENSION STRUCTURE SHOULD BE PROVIDED SO THAT THE TURNABLE CAN BE OFFSET FROM THE SOC STRUCTURES.</td>
<td></td>
<td></td>
<td>– HPA CAN OFFSET TIP 6 m. EVALUATE WHEN REQUIREMENTS KNOWN</td>
</tr>
<tr>
<td>MASS AND SIZE OF ARTICLE TO BE REORIENTED – ARTICLES RANGE IN SIZE FROM 1 m DIAMETER TO 100 m DIAMETER; MASS RANGE IS 1000 kg TO 100,000 kg.</td>
<td></td>
<td></td>
<td>– SIZE CAN BE ACCOMMODATED</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>– MASS &amp; INERTIA DEPENDS ON CONTROL SYSTEM. REQUIRES FURTHER STUDY WHEN FLIGHT HPA CAPABILITIES ARE KNOWN.</td>
</tr>
</tbody>
</table>

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### TABLE 4.3-7 EQUIPMENTS COMPARISON – CONSTRUCTION REQUIREMENTS

<table>
<thead>
<tr>
<th>ARTICULATED CONSTRUCTION FIXTURE</th>
<th>SAT. SERVICE EQMT CAPABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>THE FIXTURE PROVIDES THE SUPPORT AND POSITIONING INTERFACE BETWEEN THE SPACECRAFT AND THE SOC.</td>
<td>- HPA PROVIDES</td>
</tr>
<tr>
<td>THE FIXTURE SHOULD ATTACH TO THE TURNTABLE/TILTTABLE.</td>
<td>- PROVIDES TURNTABLE/TILTTABLE FUNCTION</td>
</tr>
<tr>
<td>THE FIXTURE DESIGN SHOULD IMPOSE A MINIMAL DESIGN IMPACT ON THE SPACECRAFT.</td>
<td>- ONLY REQUIRES MATING FITTING FOR END EFFECTOR</td>
</tr>
<tr>
<td>WHEREVER FEASIBLE, FIXTURE ATTACHMENT DEVICES ON THE SPACECRAFT SHOULD SERVE MULTIPLE PURPOSES (E.G., THE HARDPOINTS USED TO ATTACH THE SPACECRAFT TO THE TRANSPORTATION PALLET SHOULD ALSO BE USED AS THE HARDPOINTS FOR ATTACHING THE FIXTURE, IF FEASIBLE).</td>
<td>- FUNCTION OF THE END EFFECTOR</td>
</tr>
<tr>
<td>THE DIMENSIONS OF THE FIXTURE ARE TBD.</td>
<td>- HPA HAS 6 m REACH. EVALUATE WHEN REQUIREMENTS KNOWN</td>
</tr>
<tr>
<td>THE DEGREES OF FREEDOM PROVIDED BY THE FIXTURE ARE TBD.</td>
<td>- HPA DTA PROVIDES 5 DOF. EVALUATE WHEN REQUIREMENTS ARE KNOWN</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONSTRUCTION UMBILICAL SYS</th>
<th>UMBILICAL I/F ON HPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>THE UMBILICAL SYSTEM CONNECTS THE SOC UTILITIES TO THE SPACECRAFT. THESE UTILITIES INCLUDE POWER, DATA BUS, AND (IN THE GROWTH CONFIGURATION ONLY) FLUIDS.</td>
<td>- HPA UMBILICAL WILL PROVIDE THESE UTILITIES</td>
</tr>
<tr>
<td>THE UMBILICAL SERVICES SHOULD BE REMOTELY CONTROLLED FROM THE SOC COMMAND CENTERS VIA DATA BUS SIGNALS TO A MICROPROCESSOR VALVE/SWITCH CONTROLLER LOCATED ON THE UMBILICAL STATION.</td>
<td>- SYSTEM CAN INCORPORATE</td>
</tr>
<tr>
<td>TABLE 4.3-8 SIMILAR EQUIPMENTS COMPARISON SUMMARY</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>CONSTR. EQMT REQMTS</strong></td>
<td><strong>SAT. SERVICE EQMT CAPABILITY</strong></td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>MOBILE CHERRY PICKER</td>
<td></td>
</tr>
<tr>
<td>• 17 REQMTS DEFINED</td>
<td></td>
</tr>
<tr>
<td>• UNSATISFIED REQMTS</td>
<td></td>
</tr>
<tr>
<td>- REACH 18 m AT TIP (TO PUT OTV IN HANGER)</td>
<td></td>
</tr>
<tr>
<td>- EVA MAINTENANCE</td>
<td></td>
</tr>
<tr>
<td>- FAIL OP/FAIL SAFE</td>
<td></td>
</tr>
<tr>
<td>HANDLING TOOLS</td>
<td></td>
</tr>
<tr>
<td>- SMALL OBJECT HANDLING</td>
<td></td>
</tr>
<tr>
<td>- LARGE OBJECT HANDLING</td>
<td></td>
</tr>
<tr>
<td>- QUICK DISCONNECT MOUNT</td>
<td></td>
</tr>
<tr>
<td>MANIPULATOR SYSTEM</td>
<td></td>
</tr>
<tr>
<td>• 9 REQMTS DEFINED</td>
<td></td>
</tr>
<tr>
<td>• UNSATISFIED REQMTS</td>
<td></td>
</tr>
<tr>
<td>- ARM ARTICULATION FOR SHOULDER YAW IS ± 360°</td>
<td></td>
</tr>
<tr>
<td>- MOUNT MANIP TURNTABLE ON STD BERTHING FIXTURE</td>
<td></td>
</tr>
<tr>
<td>TURNTABLE/TILT TABLE</td>
<td></td>
</tr>
<tr>
<td>• 8 REQMTS DEFINED</td>
<td></td>
</tr>
<tr>
<td>• UNSATISFIED REQMTS</td>
<td></td>
</tr>
<tr>
<td>- MOUNT ON STD BERTHING FIXTURE FOR INITIAL &amp; OPNL SOC</td>
<td></td>
</tr>
<tr>
<td>- MOUNT ON CARRIAGE FOR GROWTH SOC</td>
<td></td>
</tr>
<tr>
<td>ARTICULATED CONSTR FIXTURE</td>
<td></td>
</tr>
<tr>
<td>• 9 REQMTS DEFINED</td>
<td></td>
</tr>
<tr>
<td>UMBILICAL SYS</td>
<td></td>
</tr>
<tr>
<td>• 5 REQMTS DEFINED</td>
<td></td>
</tr>
<tr>
<td>MOBILE PLATFORM</td>
<td></td>
</tr>
<tr>
<td>• 10 REQMTS SATISFIED</td>
<td></td>
</tr>
<tr>
<td>• 3 REQMTS ARE TBD</td>
<td></td>
</tr>
<tr>
<td>• 1 REQMT FOR DUTY CYCLE REQUIRES FURTHER STUDY</td>
<td></td>
</tr>
<tr>
<td>- 15.24 m TIP RADIUS</td>
<td></td>
</tr>
<tr>
<td>- STS MANIP GROUND MAINTAINED</td>
<td></td>
</tr>
<tr>
<td>- STS MANIP IS FAIL SAFE</td>
<td></td>
</tr>
<tr>
<td>END EFFECTORS</td>
<td></td>
</tr>
<tr>
<td>- SIMILAR TOOLS REQD</td>
<td></td>
</tr>
<tr>
<td>- STS MANIP STANDARD END EFFECTOR PROVIDES THIS</td>
<td></td>
</tr>
<tr>
<td>MOBILE PLTFM ARM + HPA + BERTH RING</td>
<td></td>
</tr>
<tr>
<td>• 6 REQMTS SATISFIED</td>
<td></td>
</tr>
<tr>
<td>• 1 REQMT IS TBD</td>
<td></td>
</tr>
<tr>
<td>- STS MANIP PROVIDES ± 180° FOR SHOULDER YAW</td>
<td></td>
</tr>
<tr>
<td>- HPA DOES NOT MOUNT DIRECTLY TO BERTHING FIXTURE</td>
<td></td>
</tr>
<tr>
<td>HANDLING &amp; POSITIONING AID</td>
<td></td>
</tr>
<tr>
<td>• 4 REQMTS SATISFIED</td>
<td></td>
</tr>
<tr>
<td>• 2 REQMTS TBD</td>
<td></td>
</tr>
<tr>
<td>- DOES NOT MOUNT DIRECTLY TO BERTHING FIXTURE</td>
<td></td>
</tr>
<tr>
<td>- DOES NOT MOUNT DIRECTLY TO CARRIAGE</td>
<td></td>
</tr>
<tr>
<td>UMBILICAL SYS</td>
<td></td>
</tr>
<tr>
<td>• 7 REQMTS SATISFIED</td>
<td></td>
</tr>
<tr>
<td>• 2 REQMTS ARE TBD</td>
<td></td>
</tr>
<tr>
<td>HPA UMBILICAL</td>
<td></td>
</tr>
<tr>
<td>• REQMTS SATISFIED</td>
<td></td>
</tr>
</tbody>
</table>
concern with the Cherry Picker is that it is required to be fail operation/fail safe, but the STS manipulator is fail safe. It is considered that the two manipulator system of the mobile platform allows the second manipulator to continue a task or, at the least, to hold the workpiece while the failed manipulator is replaced.

Handling tools present no problem since they are general purpose equipment and of use for construction and servicing. They can be mounted to the tip of the mobile platform manipulator if the interface is designed to be compatible with the manipulator standard snare end effector.

The Manipulator System, required for operations and build-up of the Initial SOC, bases its manipulator requirements on those of the STS manipulator, which provides ±180 degrees of shoulder yaw movement. However, the requirement is at variance with this since it calls for ±360 degrees of shoulder yaw. It is suggested that ±180 degrees be accepted, since it covers 360 degrees in total. If an HPA it used as the system turntable, then an interface structure is necessary to mount the system on a berthing ring.

Use of an HPA as a turn/tilt table requires that it be mounted on a standard berthing ring for use on initial and operational SOC and that it be mounted on a carriage for the growth SOC. Here again, interface structures are necessary to mount the HPA.

The articulated construction fixture and the umbilical system have their requirements satisfied by an HPA.

It is considered that the only significant issues are those concerning the mobile cherry picker/mobile platform and that they are capable of resolution, as suggested.
4.3.3 EVOLUTIONARY GROWTH OF COMMON EQUIPMENTS

Much of these common usage equipments are used directly, or developed, from Orbiter hardware. Figure 4.3-6 shows how the RMS, OCP, and HPA lead into initial, operational, and growth SOC equipments and the inter-relationships of those equipments over the early SOC years of operation.

4.3.4 IMPACT OF VARIATIONS IN SATELLITE SERVICE TRAFFIC MODEL

Results of the preceding tasks answer, in general, the requirements for this task. Analysis of the current mission model shows that the facilities and equipments defined for satellite servicing at operational growth SOC's will support the missions until 1995, after the planned introduction of growth SOC. Subsequent to that date, projected traffic may require parallel satellite service operations which may demand additional equipments. These will be duplications of the equipments then existing.

Variations in the traffic model may introduce satellite servicing at the initial SOC. A configuration to provide this capability was shown in Figure 4.2-57 which shows the addition of an HPA to the equipment requirements.

Figure 4.3-7 shows the impact that these increases in traffic may have on the introduction of satellite service equipments.

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Fig. 4.3-6 Evolutionary Growth of Common Sat. Service & Construction Equipments

Fig. 4.3-7 Impact on Equipments IOC of Increased Satellite Service Traffic

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SUBSECTION 4.3 REFERENCES

4.3-1  Satellite Services System Analysis Study, Feb 1981
       LMSC-D792242, Lockheed Missiles & Space Co.

4.3-2  Satellite Services System Analysis Study, Aug 1981
       CSS-SSS-RP009, Grumman Aerospace Corp.

4.3-3  Space Operations Center System Analysis, Final
       Report, D180-26495-4, July 1981, The Boeing Company
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<tr>
<td>4.4.2.1</td>
<td>Potential Savings for LEO Satellite Users</td>
<td>4-133</td>
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<td>4.4.2.2</td>
<td>Potential Savings for GEO Communication Satellites</td>
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<tr>
<td>4.4.2.3</td>
<td>Summary of Benefits</td>
<td>4-136</td>
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4.4 SERVICING MISSION NEEDS AND BENEFITS

The objective of this task was to survey and analyze the user mission needs for servicing satellites in low earth orbit and geosynchronous orbit. Particular attention was given to the user mission requirements as they relate to SOC. Alternate satellite services have been identified together with the benefits that SOC could provide to the user. In addition, satellite servicing needs have been forecast for the period between 1985 and 2000. Co-orbiting satellite missions, which can be serviced at SOC, and remote satellites, which can be reached from SOC for servicing in situ, have also been identified. Potential savings have been defined for using SOC to service satellites in LEO and GEO. Finally the benefits of using the SOC to service satellites, in lieu of the Orbiter, are identified.

4.4.1 SATELLITE SERVICING NEEDS FORECAST

4.4.1.1 User Mission Requirements

The overall mission model includes a broad array of satellites and payloads which are deployed into various orbits. The satellites in low altitude orbits and higher energy orbits can be classified with respect to the Space Operations Center in the manner shown in Figure 4.4-1. Some payloads will be attached directly to the SOC, while others will co-orbit as free flying satellites that can be reached from SOC. At higher altitudes, the satellites will be deployed with either a low energy or high energy upper stage that will deliver it to its proper orbit as depicted by the LEO propulsion, geosynchronous and planetary satellite classes. Each of these satellites can be supported by the Space Operations Center for in-orbit verification testing, checkout and launch into final orbit. Satellites at very high inclination orbits are beyond normal reach from the SOC and must rely upon services provided by the Orbiter.

The mission model encompasses both satellites and payloads for scientific mission, space applications missions, and DOD missions.
Figure 4.4-1 SOC Satellite Classes
Potential commercial and foreign missions for the shuttle orbiter are also included.

As shown in Figures 4.4-2 through 4.4-4 most space science satellites for astrophysics and solar terrestrial physics are assemble from the low orbital altitude and low inclination of the SOC. Hence the SOC could be quite useful in supporting their initial deployment and providing in-orbit maintenance. At the end of the satellite mission, the SOC could also aid in the final operations to remove the satellite from orbit.

Planetary spacecraft, of course, can only be supported for their initial launch. The Space Operation Center could support on-orbit assembly of the unmanned planetary spacecraft with a reusable upper stage or facilitate on-orbit buildup of a large planetary exploration vehicle. All planetary spacecraft launches from SOC must be timed to occur when the line of nodes coincide with the plane of the ecliptic. While this situation occurs at least seven times each year with a 400-km altitude, 28.5 degree orbit, it may not be at the optimal time to perform certain minimum energy planetary missions. However multiple impulse departure maneuvers can broaden the on-orbit launch window while using less propellant than a single departure burn.

In contrast to the space science missions, very few of the earth sensing missions on resource observations or global environment are accessible in 28.5 degree Orbit to LEO SOC. These missions generally operate in highly inclined polar and sun synchronous orbits or are deployed into geostationary orbits as shown in Figures 4.4-5 through 4.4-7. The high orbital inclination missions must rely upon the Shuttle or expendable launch vehicles for initial deployment. Retrieval for in-orbit maintenance/repair or final removal from orbit can only be provided by the Shuttle. The SOC, however, can support in-orbit checkout and launch of the geosynchronous satellites. In-situ maintenance/repair of these geosynchronous satellites could be performed with the use of Manned Orbital Transfer Vehicles (MOTV) operating from SOC.
Figure 4.4-2 Astophysics Satellite Altitudes

Figure 4.4-3 Astrophysics Satellite - Orbital Inclinations
Figure 4.4-4  Solar Terrestrial Satellites - Orbital Inclination

Figure 4.4-5  Resource Observation Satellites - Orbital Altitude
Figure 4.4-6 Resource Observation Satellites - Orbital Inclination

Figure 4.4-7 Global Environment Satellites - Orbital Inclination
Other space application missions include telecommunications satellites and material processing payloads. All telecommunication satellites operate in geosynchronous and can be supported for initial deployment and subsequent on-orbit maintenance and resupply as described above. The materials processing payloads require periodic tending and may either be attached to the SOC or deployed as a free flyer, which can be retrieved, as needed, to remove and reload throughput materials.

Space testing missions are also viewed as attached or free-flying payloads such as the Long Duration Experiment Facility (LDEF), which can be supported directly from the SOC.

Finally the DOD missions are generally operated in either high energy orbits or low energy orbits. Depending upon the specific orbital parameters, these missions can also be supported for initial deployment, on-orbit resupply/maintenance, and finally, retrieval by one or more of the systems discussed above.

Figure 4.4-8 summarizes the orbital distribution of each program category within the total mission model. SOC can support those missions which operate in low inclination orbit, nominally for 0 to 5 degrees, and can initiate planetary and escape missions. In all but two categories, the majority of programs can utilize SOC. With resource observation programs, most missions require polar orbits and are therefore not accessible from SOC. Similarly, about half of the global environment missions require polar orbits.

4.4.1.2 Satellite Services Available

Recent studies on satellite servicing from the Shuttle Orbiter (References 4.4-2 and 4.4-14) have identified a broad range of services which could be made available to the satellite user community. The Space Operations Center (SOC) will be able to provide many of the same services as the Space Transportation System (STS), and thereby release the orbiter for other mission assignments. Figure 4.4-9 denotes which services can be provided by either the STS or SOC and identifies the potential benefits which may be derived by the satellite user community.

4-99
**Figure 4.4-8**  SOC Support of Satellite/Payload Mission Needs

<table>
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<th>LOW INCL</th>
</tr>
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<td>LEO</td>
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<td>63%</td>
</tr>
<tr>
<td>SOLAR TERRESTRIAL</td>
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<td>25%</td>
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<tr>
<td>PLANETARY</td>
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<td>-</td>
</tr>
<tr>
<td>LIFE SCIENCES</td>
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<td>RESOURCE OBS</td>
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<td>GLOBAL ENVIRON.</td>
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<td>8%</td>
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<tr>
<td>MATL PROCESS</td>
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<td>100%</td>
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<td>COMMUNICATIONS</td>
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<td>SPACE TESTING</td>
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<tr>
<td>DOD</td>
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**Figure 4.4-9**  Satellite Services and Potential Benefits to Satellite User Community

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<th>SOC</th>
<th>BENEFITS</th>
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<td>✓</td>
<td>ENHANCED MISSION SUCCESS</td>
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<td>✓</td>
<td>✓</td>
<td>NEEDED FOR ON-ORBIT SUPPORT AND EARTH RETURN SERVICES</td>
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<td>✓</td>
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<td>ON-ORBIT SUPPORT</td>
<td>✓</td>
<td>✓</td>
<td>COST EFFECTIVE FOR UNPLANNED REPAIR</td>
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<td>ON-ORBIT STORAGE</td>
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<td>COST EFFECTIVE FOR HIGH DEVELOPMENT COST SATELLITES; SCIENTIFIC OBSERVATION</td>
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<tr>
<td>EARTH RETURN</td>
<td>✓</td>
<td></td>
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</tr>
</tbody>
</table>

SOC SERVICING INDEPENDENT OF STS SCHED, MISSION TIME & AVAILABILITY
Both systems, of course, can provide on orbit checkout and back-up support during initial satellite deployment. Subsequent revisits for in-orbit examination and/or retrieval can also be performed with similar proximity equipment operating from either system. In addition, both systems can provide on-orbit support to maintain, resupply, and reconfigure appropriate satellites, as needed. However, since the SOC is continuously manned in low earth orbit, it can provide more flexibility to deal with contingency situations than the Orbiter. Once the satellite supplies and servicing equipment is delivered to orbit, the SOC can perform satellite servicing operations completely independent of STS schedule, mission time constraints and availability. Of course, only the Orbiter is able to return high value satellites to earth. The SOC, in turn, can more readily provide on-orbit storage for satellites awaiting emergency repair instructions/equipment, return to earth or reentry disposal as unwanted debris.

Manned presence on SOC during satellite deployment can provide users with a higher prospect of mission success than can be expected from expendable launch vehicles. Unstowing satellite appendages, providing on-the-spot examination to deal with hangups and other contingencies during predeployment checkout will significantly reduce infant mortality. Previous studies (References 4.4-14 and 4.4-15) have indicated that payload failures can be reduced by approximately one half by Orbiter support through the infant mortality phase (see Figure 4.4-10). Similar benefits are expected from the SOC which can "nurse" a newly launch spacecraft free of STS mission duration constraints.

On-orbit maintenance, resupply, and reconfiguration of satellites is another avenue for user program cost reduction which can be used either to achieve long mission life times, to reduce requirements for on-orbit stand by spacecraft, or to fix random failures that threaten mission continuation. Studies have been conducted (Reference 4.4-16 and 4.4-17) which show that once the satellite mission exceeds one year, it is cheaper to double satellite design life through maintenance and resupply than through overly redundant design techniques.
ANOMALY RATE DECREASES WITH TIME & HALVES AFTER FIRST 100 HR

DATA REPRESENT 72 S/C & 700,000 OPER HR

REF: "RELIABILITY PREDICTION AND DEMONSTRATION FOR MISSILE AND SATELLITE ELECTRONICS" RADC-TR-68-281, BELLINGER, BOOTHMAN, ET. AL., NOV 1968

Figure 4.4-10 Payload Failure Rate After Launch Conventional Launch Vehicles

COST TO DOUBLE SATELLITE LIFE THROUGH DESIGN
CHEAPER TO DESIGN-IN RELIABILITY
CHEAPER TO RESUPPLY

COST TO DOUBLE SATELLITE LIFE THROUGH RESUPPLY


Figure 4.4-11 Resupply/Design Tradeoff

SURVEY OF 80 GEO SATS
ESA CONTRACT REPORT
GTS 790174 – OCT ’79

Figure 4.4-12 Demonstrated Communications Spacecraft Lifetimes Achieved
Figure 4.4-11 shows a tradeoff performed for GSFC which ultimately led to the present Multimission Spacecraft design for on-orbit servicing. The cost data provided in the figure are based on 1972 dollars. The tradeoff is just as valid today except that the 12-month MTTF crossover will occur at $50 M in 1981 dollars.

Early GEO communication satellites, for example, have demonstrated very poor lifetime performance. A recent survey of 80 satellites in geosynchronous orbit showed that at least half of the satellites failed before they reached their design life. The satellites included in Figure 4.4-12 are visualized as test articles in a 100% sample. Each is activated at time zero and deactivated when it fails or reaches the end of its test period. Satellite deactivation times were plotted as a fraction of design life to provide the normalized reliability curve shown for communication satellites. The convex appearance of the upper portion of the curve is characteristic of a design employing extensive redundancy - usually the case in a modern communications satellite. The use of high-reliability parts, together with extensive redundancy, have been the only options available to date. During the SOC era, the introduction of space based Manned Orbital Transfer Vehicles will allow GEO satellites and LEO satellites remote from SOC to be serviced in situ.

SOC satellite service modes are illustrated in Figure 4.4-13. The SOC is used as a transportation node for: assembly and deployment of satellites; on orbit support of attached and retrieval payloads; and as a base of in-situ servicing of remote satellites in LEO and GEO. Since the SOC is decoupled from ground launch constraints, it can provide on-demand service to examine and repair satellite random failure situations. The probability of random failure prior to end of mission or scheduled maintenance for observatory class satellites could be as high as 20%. The SOC can also support the buildup of large systems in orbit such as an IR Interferometer in LEO, a Cosmic Coherent Optical System for GEO or perhaps a new large interplanetary spacecraft.

Whenever practical, all co-orbiting satellites in need of maintenance/resupply should be returned to the SOC for that purpose. Out-
Figure 4.4-13 Satellite Service Modes

Figure 4.4-14 LEO Satellite Servicing Regions for SOC Based Vehicles
sized platforms of comparable size to SOC should, of course, be serviced in situ. Cost effective satellite servicing regions in LEO are shown in Figure 4.4-14 for SOC based vehicles. The region identified for service at SOC versus service in situ are bounded by MOTV core stage capabilities for half range and maximum range payload retrieval performance, when limited to one STS propellant delivery flight. For example, the MOTV half-range retrieval capability defines the maximum plane change maneuver for bringing a satellite back to SOC for servicing and to then return the satellite to its original orbit. Satellites beyond the MOTV half range capability can also be returned to SOC for servicing if needed. However, it would be more economical if they were serviced in situ. As shown in the figure, an MOTV can provide in-situ service to an MMS class satellite in a 185 km higher orbit which is almost 20 degrees out of plane with respect to the SOC. The maximum payload retrieval range of the Versatile Service Stage (VSS) is also shown for comparison.

4.4.1.3 Satellite Servicing Missions

Grumman's Satellite Services User Model (S/SUM) was used to identify potential service missions for the period between 1985 and 2000. Emphasis was placed on those satellite missions which could be supported by SOC in the areas of space science, space applications and space testing. The following ground rules were used to define on-orbit support and retrieval requirements for satellites deployed in LEO and GEO:

- All satellites built after 1988 shall be capable of being serviced on orbit
- Satellites greater than 500 kg are candidates for on-orbit servicing and retrieval.
- Scheduled servicing revisits for LEO Observatory class satellites shall occur at 2 to 3 year intervals after deployment or as needed
GEO satellites shall be serviced on 3- to 5-year intervals
- Foreign satellites shall be excluded from post deployment servicing and retrieval analysis
- All satellites shall be removed from orbit at the end of their mission
- Small scientific satellites and larger space application satellites in GEO shall be removed from their orbital slots after 5 years and 10 years, respectively.

Tables 4.4-1 through 4.4-12 provide mission information for servicing satellites with the SOC or the STS as appropriate. These data cover projected missions for astrophysics, solar terrestrial, planetary, resource observation, global environment, and the space testing categories. The satellite missions are listed chronologically within each category. These missions are identified in accordance with the nomenclature defined in the 1980 NASA Space Systems Technology Model (i.e., A-3, S-2, etc). The correlation between these designators and the revised listing in the 1981 NASA Space Systems Technology Model is shown parenthetically on the first part of these data sheets. Satellite service mission events for deployment, on-orbit support, and satellite return are identified with the following codes for operations and transportations.

FL - Self-propelled satellite
FTU - Versatile Service Stage Operations
POU - Unmanned Proximity Operations Module Support
FSSML - SOC Based Manned Orbit Transfer Vehicle Core Stage/LEO support capability
FSSMG - SOC Based Manned Orbit Transfer Vehicle/GEO support capability
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<th>DELTA VKM/S</th>
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<p>|        | NUMERALS DENOTED SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED |
|        | D = DEPLOY            S = SERVICE  R = RETRIEVE                                     |
|        | DIRECT ORBITER LAUNCH AND RECOVERY                                          |
|        | ( ) NASA 1981 SYSTEMS TECHNOLOGY MODEL ID No.                           |</p>
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**NUMERALS** DENOTE SCHEDULED EVENTS - DOTS DENOTE POTENTIAL SERVICE EVENTS - UNSCHEDULED

**DIRECT ORBITER LAUNCH AND RECOVERY**

**SOC SERVICE OPTION TO BACK UP ORBITER AVAILABILITY**

( ) NASA 1981 SYSTEMS TECHNOLOGY MODEL ID NO.
TABLE 4.4-1 ASTROPHYSICS MISSIONS PART 1 SHT 3 OF 3

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NUMERALS DENOTE SCHEDULED EVENTS - DOTS DENOTE POTENTIAL SERVICE EVENTS - UNSCHEDULED DIRECT ORBITER LAUNCH AND RECOVERY.

* D - DEPLOY
  S - SERVICE
  R - RETRIEVE

( ) NASA 1981 SYSTEMS TECHNOLOGY MODEL ID NO.

R81-2300-059

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* LAPPED TIME FOR POST DELIVERY, SEPARATION, AND CHECKOUT — ASSUME 0.12 DAY
** LAPPED TIME FOR ON ORBIT SERVICE AND CHECKOUT OF SATELLITES < 3000 kg ASSUME 0.3 DAY TOTAL OR 1 WORK SHIFT
*** LAPPED TIME FOR ON ORBIT SERVICE AND CHECKOUT OF SATELLITES > 3000 kg ASSUME 0.9 DAY TOTAL OR 2 WORK SHIFTS
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**Notes:**
- Numerals denote scheduled events - Dots denote potential service events - Unscheduled
- D = Deploy
- S = Service
- R = Retrieve
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* LAPSED TIME FOR POST DELIVERY, SEPARATION, AND CHECKOUT – ASSUME 0.12 DAY
** LAPSED TIME FOR ON ORBIT SERVICE AND CHECKOUT OF SATELLITES
< 3000 kg ASSUME 0.3 DAY TOTAL OR 1 WORK SHIFT
*** LAPSED TIME FOR ON ORBIT SERVICE AND CHECKOUT OF SATELLITES > 3000 kg ASSUME 0.9 DAYS TOTAL OR 2 WORK SHIFTS
## Table 4.4-5 Planetary Missions Part 1

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* D = Deploy

Numerals denoted scheduled events - Dots denote potential service events - Unscheduled: NASA 1981 System Technology Model ID Nos.
### TABLE 4.4-6 PLANETARY MISSIONS PART 2

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**Table 4.4-7 Global Environment Missions Part I SHT 1 of 2**

- Numerals denote scheduled events - Dots denote potential service events - Unscheduled
- D - Deploy
- S - Service
- R - Retrieve
- SC Service option to back up orbiter availability

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NUMERALS DENOTED SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

* D – DEPLOY
S – SERVICE
R – RETRIEVE

( ) NASA 1981 SYSTEMS TECHNOLOGY MODEL ID NO.

R81-2100-065W
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* Lapsed time for post delivery, separation, and checkout – Assume 0.12 day
** Lapsed time for on-orbit service and checkout of satellites < 3000 kg – Assume 0.3 day total or 1 work shift
*** Lapsed time for on-orbit service and checkout of satellites > 3000 kg – Assume 0.9 day total or 2 work shifts

R81-2100-070W
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<td>D S</td>
<td>772</td>
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<tr>
<td>R56</td>
<td>COASTAL SATELLITE</td>
<td>SIO</td>
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<td>296</td>
<td>0.02</td>
<td>0.3</td>
<td>D S</td>
<td>4,173</td>
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** NUMERALS DENOTE SCHEDULED EVENTS – DOTS DENOTE POTENTIAL SERVICE EVENTS – UNSCHEDULED

* D - DEPLOY
S - SERVICE
R - RETRIEVE

( ) NASA 1981 SYSTEMS TECHNOLOGY MODEL ID NO.
<table>
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<tr>
<th>ID</th>
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<th>OPERATIONS CODE</th>
<th>TRANSP CODE</th>
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<th>TRIP TIME</th>
<th>DELTA V/KM/S</th>
<th>MISSION FUNCTION</th>
<th>MASS</th>
<th>LENGTH M</th>
<th>DIA M</th>
<th>TRAFFIC</th>
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<tr>
<td>R8</td>
<td>SOIL MOISTURE (R10)</td>
<td>FL</td>
<td>FTU</td>
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<td>0.1 - 0.1</td>
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<td>OPERATIONAL LAND OBSERVATION SYSTEM (R6)</td>
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<td>700</td>
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<td>1,700 - 1,700</td>
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<tr>
<td>R58</td>
<td>ADV GEOLOGY SATELLITE (R5)</td>
<td>FL</td>
<td>FTU</td>
<td>700</td>
<td>98</td>
<td>0.04</td>
<td>0.2 - 0.2</td>
<td>D S R</td>
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<td>PRIVATE EARTH RESOURCE (COMMERCIAL)</td>
<td>FL</td>
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<td>700</td>
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<td>D S R</td>
<td>1,700 - 1,700</td>
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<td>2.2</td>
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<td>R6</td>
<td>ADV THERMAL MAPPING (R7)</td>
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<td>FTU</td>
<td>700</td>
<td>98</td>
<td>0.04</td>
<td>0.2 - 0.2</td>
<td>D S R</td>
<td>1,450 - 1,450</td>
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<td>FOU</td>
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<td>FL</td>
<td>FTU</td>
<td>700</td>
<td>57</td>
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<td>0.2 - 0.2</td>
<td>D S R</td>
<td>1,000 - 1,000</td>
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NUMERALS DENOTE SCHEDULE EVENTS - DOTS DENOTE POTENTIAL SERVICE EVENTS - UNSCHEDULED
DIRECT ORBITER LAUNCH & RECOVERY
NASA 1981 SYSTEMS TECHNOLOGY MODEL 10 NO.

R81-2100-072W
### TABLE 4.4-10 RESOURCE OBSERVATION MISSIONS (PART 2)

<table>
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<tr>
<th>ID NO.</th>
<th>ON-OPTION OPS TIME</th>
<th>NO. OF APPENDAGES</th>
<th>NO. OF MODULES</th>
<th>FAB TIME</th>
<th>MAINTENANCE &amp; REPAIR/RECONFIGURE/ RESUPPLY TIME</th>
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<tbody>
<tr>
<td>R2</td>
<td>*</td>
<td>3</td>
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<td>R4</td>
<td>*</td>
<td>3</td>
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<tr>
<td>R50</td>
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<td>2</td>
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<td>***</td>
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<tr>
<td>R51</td>
<td>*</td>
<td>2</td>
<td></td>
<td></td>
<td>***</td>
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<tr>
<td>R53</td>
<td>*</td>
<td>2</td>
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<td>**</td>
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<tr>
<td>R54</td>
<td>*</td>
<td>2</td>
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<td></td>
<td>**</td>
</tr>
<tr>
<td>R55</td>
<td>*</td>
<td>2</td>
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<tr>
<td>R56</td>
<td>*</td>
<td>2</td>
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<tr>
<td>R8</td>
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<td>R5</td>
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<td>R8</td>
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<td>**</td>
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<tr>
<td>R9</td>
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<td>2</td>
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</tr>
<tr>
<td>R6</td>
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<td>2</td>
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<td>**</td>
</tr>
<tr>
<td>R7</td>
<td>*</td>
<td>2</td>
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<td>**</td>
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<td>2</td>
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<td>**</td>
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* LAPSED TIME FOR POST DELIVERY, SEPARATION, AND CHECKOUT – ASSUME 0.12 DAYS
** LAPSED TIME FOR ON ORBIT SERVICE AND CHECKOUT OF SATELLITES ≤ kg ASSUME 0.3 DAY TOTAL OR 1 WORK SHIFT
*** LAPSED TIME FOR ON ORBIT SERVICE AND CHECKOUT OF SATELLITES > kg ASSUME 0.9 DAY TOTAL OR 2 WORK SHIFTS
<table>
<thead>
<tr>
<th>ID NO.</th>
<th>NAME</th>
<th>OPERATIONS CODE</th>
<th>TRANSPO CODE</th>
<th>ORBIT H I</th>
<th>TIME 0.03 DAYS</th>
<th>DELTA V Km/s</th>
<th>MISSION FUNCT</th>
<th>MASS 4,500</th>
<th>LENGTH 50</th>
<th>DIA 1</th>
<th>TRAFFIC</th>
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<tr>
<td>0110</td>
<td>LONG DURATION EXPOSURE</td>
<td>FTU</td>
<td>FTU</td>
<td>509</td>
<td>28.5</td>
<td>D</td>
<td>S R</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>FACILITY (O1-17)</td>
<td>SOC</td>
<td>FTU</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>012</td>
<td>INDUCED ENVIRONMENT</td>
<td>SOE-T</td>
<td>SOC</td>
<td>D</td>
<td>338</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td></td>
<td>CONTAMINATION (O1-11)</td>
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<tr>
<td>0157</td>
<td>LARGE DEPLOY ANTENNA DEMO</td>
<td>SOE-T</td>
<td>SOC</td>
<td>D</td>
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<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td></td>
<td>(O1-22+)</td>
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<td>1</td>
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<td>0159</td>
<td>STRUCTURAL ASSY DEMO</td>
<td>SOE-T</td>
<td>SOC</td>
<td>D</td>
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<td>1</td>
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<tr>
<td></td>
<td>(O1-21+)</td>
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<td>1</td>
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<tr>
<td>0160</td>
<td>DEPLOYABLE PLATFORM EXPERIMENT</td>
<td>SOE-T</td>
<td>SOC</td>
<td>D</td>
<td>1,500</td>
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<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td></td>
<td>(O1-23+)</td>
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<td></td>
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<td>1</td>
<td>1</td>
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<tr>
<td>0161</td>
<td>FLUID MECH &amp; HEAT XFER FACILITY</td>
<td>SOE-T</td>
<td>SOC</td>
<td>D</td>
<td>580</td>
<td></td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td></td>
<td>(O1-28)</td>
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<td>1</td>
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<td>0162</td>
<td>PACE EXMPTS (O1-26&amp;27)</td>
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<td>SOC</td>
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<td>0163</td>
<td>SCIENCE INSTRUMENT DEMO</td>
<td>SOE-T</td>
<td>SOC</td>
<td>D</td>
<td></td>
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<td></td>
<td>1</td>
<td>1</td>
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* D = DEPLOY
* S = SERVICE
* R = RETRIEVE

TABLE 4.4-11 SPACE TESTING MISSIONS PART 1

(1) NASA 1981 SYSTEMS TECHNOLOGY MODEL ID NO.
<table>
<thead>
<tr>
<th>ID NO.</th>
<th>ON-ORBIT OPS TIME</th>
<th>NO. OF APPENDAGES</th>
<th>NO. OF MODULES</th>
<th>FAB TIME</th>
<th>MAINTENANCE &amp; REPAIR/RECONFIGURE/ RESUPPLY TIME</th>
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<tbody>
<tr>
<td>OI-10</td>
<td>&lt;.1 DAYS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>***</td>
</tr>
<tr>
<td>OI-2</td>
<td>~ 30 DAYS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>**</td>
</tr>
<tr>
<td>OI-57</td>
<td>7-20 DAYS</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>**</td>
</tr>
<tr>
<td>OI-59</td>
<td>7-20 DAYS</td>
<td>&gt; 1</td>
<td>-</td>
<td>-</td>
<td>***</td>
</tr>
<tr>
<td>OI-60</td>
<td>7-20 DAYS</td>
<td>&gt; 1</td>
<td>-</td>
<td>-</td>
<td>**</td>
</tr>
<tr>
<td>OI-61</td>
<td>5-20 DAYS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>**</td>
</tr>
<tr>
<td>OI-62</td>
<td>7 DAYS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>**</td>
</tr>
<tr>
<td>OI-63</td>
<td>10-20 DAYS</td>
<td>NA</td>
<td>-</td>
<td>-</td>
<td>**</td>
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**LAPSED TIME FOR ON ORBIT SERVICE AND CHECKOUT OF SATELLITES < 3000 kg ASSUME 0.3 DAY TOTAL OR 1 WORK SHIFT**

***LAPSED TIME FOR ON ORBIT SERVICE AND CHECKOUT OF SATELLITES > 3000 kg ASSUME 0.9 DAY TOTAL OR 2 WORK SHIFTS***

NA NOT AVAILABLE
FSSUG - Space Based Unmanned Orbit Transfer Vehicle/GEO plus support capability

FGTUG - Ground Based Unmanned Orbit Transfer Vehicle/GEO plus support capability

SOC - Satellite maintenance/repair, reconfigure and resupply on SOC

SIC - SOC based satellite servicing in situ

SIO - Orbiter based satellite servicing in situ

SOE - On board SOC space tests

CAM - On orbit assembly - medium complexity

CGM - On orbit deploy and assembly - medium complexity

CGH - On orbit deploy and assembly - high complexity

CPM - On orbit deploy assembly and fabricate - medium complexity

CFH - On orbit deploy assembly and fabricate - high complexity

A capsule description is provided for each mission. Part 1 data (Tables 4.4-1, -3, -5, -7, -9, and -11) also characterizes each mission with its target orbit, estimated transfer time from a 400 km orbit, required delta vee, mass, size, and scheduled service events. The Part 2 sheets (Tables 4.4-2, -4, -6, -8, -10, and -12) provided additional information on the characteristics of each satellite and the estimated times for implementing on-orbit operations, on-orbit servicing and fabrication.

4.4.1.4 Co-orbiting Satellite Service Missions

Candidate services for satellites co-orbiting with the SOC are provided in Figure 4.4-15. These satellites, which are derived from the S/SUM data base, are nominally at 28.5 degrees inclination and orbital altitudes between 300 and 600 km. A few out-of-plane satellites within range of the MOTV core stage are also included. The
### Fig. 4.4-15 Co-Orbiting Satellites — Candidate Services for Space Operations Center — S/Sum Data

<table>
<thead>
<tr>
<th>SATELLITE</th>
<th>SPONSOR</th>
<th>ORBIT</th>
<th>MASS (kg)</th>
<th>CY - EVENTS</th>
<th>IN-ORBIT MAINTENANCE SUPPORT</th>
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<tr>
<td>ST - SPACE TELESCOPE</td>
<td>OSS</td>
<td>593</td>
<td>28.5</td>
<td>11,000</td>
<td>REPLACE S/I ORUs, SCI INSTR, GUID SENSOR, ANTENNA, RATE GYROS, STAR TRACKERS, SOLAR ARRAYS, ETC</td>
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<tr>
<td>LDEF - LONG DURATION EXPOSURE FACILITY</td>
<td>OAST</td>
<td>509</td>
<td>28.5</td>
<td>4,500</td>
<td>CHANGE EXPERIMENT TRAYS</td>
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<tr>
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<td>296</td>
<td>28.5</td>
<td>500</td>
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<td>AXAF - ADVANCED X-RAY ASTROPHYSICS FACILITY</td>
<td>OSS</td>
<td>450</td>
<td>28.5</td>
<td>10,000</td>
<td>REPLACE SUBSYS ORUs, SCI INSTR, GUID SENSOR, ANTENNA, ETC, RESUPPLY RADIATION DETECTOR GAS</td>
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<td>SOLAR CORONA EXPLORER</td>
<td>OSS</td>
<td>600</td>
<td>33.5</td>
<td>1,000</td>
<td>REPLACE SUBSYS ORUs, RESUPPLY RCS PROPellant</td>
</tr>
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<td>350</td>
<td>28.5</td>
<td>9,800</td>
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<td>LARGE AMBIENT DEPLOYABLE IR TELESCOPE</td>
<td>OSS</td>
<td>500</td>
<td>20.5</td>
<td>16,000</td>
<td>CHANGE SUBSYS UNITS</td>
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<td>IR INTERFEROMETER</td>
<td>OSS</td>
<td>400</td>
<td>28.5</td>
<td>22,500</td>
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<td>25,000</td>
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<td>LARGE OPTICAL/UV TELESCOPE</td>
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<td>28.5</td>
<td>22,800</td>
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<td>EUVE-EXTREME UV EXPLORER</td>
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<td>550</td>
<td>28.5</td>
<td>400</td>
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<td>HI-ENERGY EXPLORER</td>
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<td>463</td>
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<td>X-RAY TIMING EXPLORER</td>
<td>OSS</td>
<td>400</td>
<td>28.5</td>
<td>1,000</td>
<td>REPLACE FAILED SUBSYS MODULES — PWR, COMM/DATA &amp; ATT CTL</td>
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<td>SCADM — SOLAR CYCLE &amp; DYNAMICS MISSION</td>
<td>OSS</td>
<td>575</td>
<td>28.5</td>
<td>2,600</td>
<td>REPLACE FAILED SUBSYS MODULES, PWR, COMM/DATA &amp; ATT CTL</td>
</tr>
<tr>
<td>LAMAR — LARGE AREA MODULAR ARRAY REFLECTOR</td>
<td>OSS</td>
<td>400</td>
<td>28.5</td>
<td>5,200</td>
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<tr>
<td>GTE - GAMMA-RAY TRANSIENT EXPLORER</td>
<td>OSS</td>
<td>450</td>
<td>28.5</td>
<td>3,000</td>
<td>NOT DESIGNED FOR IN-ORBIT SERVICE</td>
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<td>OSS</td>
<td>400</td>
<td>28.5</td>
<td>545</td>
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### Fig. 4.4.15  Co-Orbiting Satellites — Candidate Services for Space Operations Center

<table>
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<th>ALT-km</th>
<th>INC-DEG</th>
<th>MASS-kg</th>
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<th>'88</th>
<th>'90</th>
<th>'92</th>
<th>'94</th>
<th>'96</th>
<th>'98</th>
<th>'00</th>
<th>IN-OBJECT MAINTENANCE SUPPORT</th>
<th>REF</th>
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<td>S-55  XRO – X-RAY OBSERVATORY</td>
<td>OSS</td>
<td>400</td>
<td>28.5</td>
<td>3,550</td>
<td>A</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>REPLACE FAILED SUBSYS MODULES PWR, COMM OR ATT CTL</td>
<td>1, 2, 10</td>
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<td>A-56  SXS – SOFT X-RAY SURVEY</td>
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<td>400</td>
<td>28.5</td>
<td>1,600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NOT DESIGNED FOR IN-OBJECT SERVICING</td>
<td>2, 11</td>
</tr>
<tr>
<td>A-57  MLS – MOLECULAR LINE SURVEY</td>
<td>OSS</td>
<td>600</td>
<td>28.5</td>
<td>1,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NOT DESIGNED FOR IN-OBJECT SERVICING</td>
<td>2, 12</td>
</tr>
<tr>
<td>A-55  XSM – X-RAY SPECTROSCOPY MISSION</td>
<td>OSS</td>
<td>400</td>
<td>28.5</td>
<td>1,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>REPLACE FAILED SUBSYS MODULES PWR, COMM &amp; ATT CTL</td>
<td>2, 13</td>
</tr>
<tr>
<td>E-4   ERSBS – EARTH RADIATION BUDGET SATELLITE</td>
<td>OSTA</td>
<td>600</td>
<td>46</td>
<td>1,150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>REPAIR IN SITU – REPLACE FAILED SUBSYS MODULES, ETC</td>
<td>2</td>
</tr>
<tr>
<td>A-15  VERY LONG BASELINE RADIO INTERFEROMETER</td>
<td>OSS</td>
<td>1000</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>REPAIR IN SITU – REPLACE FAILED SUBSYS MODULES, ETC</td>
<td>2</td>
</tr>
</tbody>
</table>

**LEGEND**

- ▲▼ SCHEDULED LAUNCH & RETURN
- △▼ ASSUMED LAUNCH & RETURN
- ○ SCHEDULED SERVICE EVENT
- O ASSUMED SERVICE EVENT
first 10 satellites, which have no self-propulsion capability, are listed in chronological order. The remaining satellites include a low energy propulsion system and are also listed in chronological order. Servicing events for launch and return are annotated to follow the approved/planned schedule and the assumed opportunity schedule described by Grumman's S/SUM data (Reference 4.4-2). The scheduled and assumed events for in-orbit maintenance resupply and reconfiguration are annotated in a like manner. Some satellites are not designed for in-orbit maintenance, such as the Gamma Ray Transient Explorer. Other satellites require periodic, resupply of cryogens (i.e., IR Interferometer) or changeout of scientific instruments (i.e., Space Telescope and AXAF). There are yet other satellites of short mission duration, such as the X-Ray Spectroscope Mission, which will only be serviced if needed.

Economic analysis of the co-orbiting satellites included in the S/SUM data has resulted in fewer programs in LEO which in turn has a moderate impact on SOC required service events. Figure 4.4-16 defines alternate service event schedules for these satellites from the high, medium and low economic models. The reference S/SUM service events are compared in Figure 4.4-17 with respect to the results of the high and low economic models. The in-orbit service events are denoted as scheduled maintenance and potential revisits. For LEO satellites "potential revisits" cover the possible need for more frequent on-orbit support and possible random failure situations which add to the schedule maintenance requirements. Both the high and low models include launch support for at least two co-orbiting satellites per year. The models also indicate that potential exists for on-orbit maintenance/resupply on three to four satellites per year. In addition, the SOC would have to support the retrieval of one or two satellites per year which are to be removed from orbit.

4.4.1.5 Satellite Service Missions In situ

Candidate satellites which can be serviced in situ, by SOC based vehicles, are identified in Figure 4.4-18. This includes satellites
Figure 4.4-16 Co-Orbiting Satellites for Servicing By Space Operations Center — Economic Mission Model

<table>
<thead>
<tr>
<th>SATELLITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-3</td>
</tr>
<tr>
<td>A-10</td>
</tr>
<tr>
<td>S-9</td>
</tr>
<tr>
<td>A-9</td>
</tr>
<tr>
<td>A-61</td>
</tr>
<tr>
<td>A-5</td>
</tr>
<tr>
<td>A-10</td>
</tr>
<tr>
<td>S-13</td>
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<tr>
<td>A-14</td>
</tr>
<tr>
<td>S-52</td>
</tr>
<tr>
<td>S-53</td>
</tr>
<tr>
<td>A-58</td>
</tr>
<tr>
<td>A-57</td>
</tr>
<tr>
<td>A-55</td>
</tr>
<tr>
<td>E-4</td>
</tr>
<tr>
<td>A-15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CY — HIGH MODEL EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>'86 '88 '90 '92 '94 '96 '98 '00</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>CY — MEDIUM MODEL EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>'86 '88 '90 '92 '94 '96 '98 '00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CY — LOW MODEL EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>'86 '88 '90 '92 '94 '96 '98 '00</td>
</tr>
</tbody>
</table>
Figure 4.4-17 LEO Co-Oribiting Satellite Service Mission Models for SOC – Non Dod & Non Foreign
### Fig. 4.4-18 Satellites for Servicing In-Situ By Vehicles Based at Space Operations Center

| SATELLITE                      | SPONSOR | ALT-km | INC-DEG | MASS-kg | '86 | '88 | '90 | '92 | '94 | '96 | '98 | '00 |
|--------------------------------|---------|--------|---------|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A-15 VERY LONG BASELINE INTERFEROMETER | OSS     | 1,000  | 45      | ND      |  A  |     |     |     |     |     |     |     |
| A-53 INTERNATIONAL UV EXPLORER      | FOREIGN | GEO    | 0       | 500     |  B  |     |     |     |     |     |     |     |
| A-59 SIMULTANEOUS ASTRONOMY MISSION | OSS     | GEO    | 0       | 2,080   |     |     |     |     |     |     |     |     |
| A-64 EXTREME UV SPECTROSCOPE       | OSS     | GEO    | 0       | 1,000   |     |     |     |     |     |     |     |     |
| A-18 IR INTERFEROMETER             | OSS     | 400    | 28.5    | 22,500  |     |     |     |     |     |     |     |     |
| A-19 GRAVITY WAVE INTERFEROMETER   | OSS     | GEO    | 0       | 11,250  |     |     |     |     |     |     |     |     |
| A-20 COSMIC COHERENT OPTICAL SYSTEM| OSS     | GEO    | 0       | 11,500  |     |     |     |     |     |     |     |     |
| A-22 100 M THIN APERTURE TELESCOPE | OSS     | GEO    | 0       | 10,600  |     |     |     |     |     |     |     |     |
| S-51 ASTRONOMY                     | OSS     | 5,000  | 28.5    | 950     |     |     |     |     |     |     |     |     |
| E-2 GEO OPERATING ENVIRONMENT SATELLITE | OSTA   | GEO    | 0       | 720     |     |     |     |     |     |     |     |     |
| E-4 ERBS - EARTH RADIATION BUDGET SAT | OSTA   | 600    | 46      | 1,150   |     |     |     |     |     |     |     |     |
| E-62 STORM SAT                     | NOAA    | GEO    | 0       | 1,600   |     |     |     |     |     |     |     |     |

R81-2100-078W(1)
Fig. 4.4-18 Satellites for Servicing In-Situ By Vehicles Based at SOC

<table>
<thead>
<tr>
<th>SATELLITE</th>
<th>SPONSOR</th>
<th>ORBIT</th>
<th>CY - EVENTS S/SUM DATA</th>
<th>CY - HIGH MODEL EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-53</td>
<td>EARTH OBSERVATION/COMM</td>
<td>OSTA GEO 0</td>
<td>943-2040</td>
<td></td>
</tr>
<tr>
<td>R-54</td>
<td>RESOURCES/POLLUTION</td>
<td>OSTA GEO 0</td>
<td>615-998</td>
<td></td>
</tr>
<tr>
<td>TELECOMMUNICATIONS (BOEING DATA)</td>
<td>COMM' L GEO 0</td>
<td>1000-10,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The diagram shows the expected events and high model events for each satellite over the years from 1986 to 2000.
in remote orbits (e.g., 46 degree inclination or at GEO) and a few co-orbiting satellites in LEO which are too large to return for servicing at SOC (i.e., IR Interferometer). Scheduled service events are shown for both the reference S/SUM data and the results of the high economic model analysis. The high model and the other economic model are dominated by the commercial telecommunication missions at GEO, which Boeing analyzed and defined. Telecommunication satellites are presently being designed for about 7 years. As stated above, it is assumed that all satellites will be designed for on-orbit maintenance after 1988. At that time, all communication satellites are assumed to be designed for a 10-year mission life, which is achieved by in-orbit maintenance and resupply after five years.

Cumulative yearly service events are shown in Figure 4.4-19 for these GEO satellites, which exclude DOD and foreign satellites, with respect to the three economic mission models (high, medium, and low). The progressive buildup of LEO SOC supported launch events is shown for each model. During the SOC era a large number of satellites will accumulate in GEO due to these launches alone. There will be more than 100 to 200 satellites, depending upon the model used, which will be repairable and operating in GEO at the same time. From this population alone, a sizeable number of satellites can be expected to have random failures before their end-of-mission or scheduled maintenance time. These failures are identified as part of the scheduled revisits for GEO satellite periodic maintenance. Between the low and the high model there are 8 to 18 scheduled revisits needed every year if each telecommunication satellite is serviced at least once after deployment. Otherwise 3 to 6 random failures per year, which may occur regardless, can be expected to occur. During this period 7 to 12 satellites per year will reach the end of their mission and should be removed from their orbital slots.
Figure 4.4-19  Geo Satellite Service Mission Models for SOC – Non Dod & Non-Foreign
4.4.2 BENEFITS OF USING SOC TO SERVICE SATELLITES

4.4.2.1 Potential Savings for LEO Satellite Users

Representative mission service costs are shown in Figure 4.4-20 for a large scientific observatory such as the Advanced X-ray Astrophysics Facility and a smaller MMS type satellite such as the Large Area Modular Array of Reflectors (LAMAR) spacecraft. The cost of replacing these spacecraft in event that they fail prematurely has been estimated at between $150 and 200 M. The direct charge to the user to repair these satellites with the Orbiter is estimated to be $16 to 19 M, or even higher if an OMS kit is required to reach the satellite. Nevertheless, to the user these costs are only 10% of the total replacement costs for a new satellite. The largest part of the Shuttle revisit cost results from the charge to carry the required service equipment (i.e., proximity operations, modules, handling/positioning aid, etc) to and from orbit. The SOC achieves its major cost advantage of $6 to 7 M, since these equipments are always left in orbit.

4.4.2.2 Potential Savings for GEO Communication Satellites

The telecommunication satellite community can derive considerable savings by using SOC based vehicles to maintain and support their satellites in GEO. Figure 4.4-21 shows the range of potential savings that can be accrued by either servicing all satellites once or only repairing those as needed.

Both strategies deal with communication satellites that are designed for a 10-year mission life with in-orbit servicing provisions. The full traffic model includes all the scheduled maintenance revisits as defined by the three GEO satellite service mission models shown in Figure 4.4-19. The partial traffic model only considers random failure situations which could have a 15% to 20% probability of occurrence. In both instances the total savings, which exceed $1 B by 2000, reflects the user's costs of transporting a new satellite to GEO, less the cost of satellite repair. Satellite replacement costs are based upon $50 M/tonne and $35 M was used to cover...
Figure 4.4-20  Representative Missions — Service Costs

- ESTIMATED COSTS FOR TOTAL SATELLITE REPLACEMENT
  - AXAF  $200 M
  - LAMAR  $150 M
Fig. 4.4-21 Potential Savings from Servicing Satellites in GEO With LEO-Based MOTV
the cost of transporting each satellite to orbit. Satellite servicing
costs, in turn, are based upon a four satellite service sortie mission
where each user shares the cost at $30 M per satellite. The total
satellite servicing cost also includes an allowance to cover satellite
related repair costs (i.e., 10% of new satellite cost).

4.4.2.3 **Summary of Benefits**

The major benefits of using SOC to service satellites in LEO & GEO
are that it provides a continuously manned transportation node, which
is decoupled from potential ground launch problems and/or mission con­
strains of the Space Shuttle. Figure 4.4-22 summarizes the major advan­
tages of using SOC to supplement the Orbiter for satellite ser­
vicing. By basing orbital service vehicles on the SOC it will be able
to provide a broad range of services (including launch, on-orbit sup­
port, and removal from orbit) to the satellite users when they are
needed. With advanced mission planning and early provisioning of
satellite replaceable items and supplies onboard, the SOC should be
immune to STS launch delays and vehicle availability problems. The
SOC, of course, is not constrained by the Orbiter mission duration
limits. By using the SOC to support satellite deployment and on-orbit
maintenance in LEO, the Orbiter will be free to support other mission
operations which are beyond its range. SOC accessible orbits extend
from LEO to GEO and include an out-of-plane sector at LEO which can be
±3 degrees with a Versatile Service Stage, or even ±20 degrees or
more with the core stage from a Manned Orbital Transfer Vehicle
(MOTV). Since it is continuously in orbit, the SOC offer greater
flexibility to deal with satellite deployment situations which may
require extended test and checkout operations with the Payload
Operations Control Center (POCC), extended calibration operations or
other contingencies that might arise. The SOC has the inherent cap­
ability for on-orbit storage, which can be used to deal with delays in
maintenance and repair, to maintain a cache for common modules/
equipment, or even as a depot for earth return spacecraft. By
operating in a 28.5 degree orbit the SOC will be able to service 50%
of the satellites in LEO, launch all GEO and planetary spacecraft, and
support MOTV satellite service at GEO.
<table>
<thead>
<tr>
<th>Major Advantages of Using SOC vs Orbiter for Satellite Servicing</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Decoupled from STS launch delays, mission limits and vehicle availability</td>
</tr>
<tr>
<td>- On-demand service to SOC accessible orbits</td>
</tr>
<tr>
<td>- LEO out of plane sector: ±3° VSS (TMS) ±20° MOTV core</td>
</tr>
<tr>
<td>- GEO altitudes and higher</td>
</tr>
<tr>
<td>- Flexibility in satellite deployment</td>
</tr>
<tr>
<td>- Extend test and checkout with POCC</td>
</tr>
<tr>
<td>- Extend calibration operations</td>
</tr>
<tr>
<td>- Contingencies</td>
</tr>
<tr>
<td>- On-orbit storage capability:</td>
</tr>
<tr>
<td>- Handle operational delays (maint/repair &amp; deploy)</td>
</tr>
<tr>
<td>- Maintain common module/equipment cache</td>
</tr>
<tr>
<td>- Return to Earth depot</td>
</tr>
<tr>
<td>- 28.5° SOC serves 50% LEO at SAT programs, all GEO and planetary launches, and all services in GEO</td>
</tr>
<tr>
<td>- Frees orbiter to support high incl LEO programs</td>
</tr>
<tr>
<td>- Maintain/repair LEO SATS at SOC $7M/USE vs STS $19.25M</td>
</tr>
<tr>
<td>- In situ maintain/repair 20% GEO COMM SAT saves $200M/YR (FY '95 LOW MODEL)</td>
</tr>
</tbody>
</table>

Fig. 4.4-22
It is estimated that servicing LEO satellites on SOC will save $12-18 M of related orbiter transportation costs for performing the same function.

Potential savings from the maintenance and repair of GEO communication satellites with a SOC based MOTV can also be quite substantial ($200 M/year for the low model if 20% are repaired due to random failures).
SUBSECTION 4.4 REFERENCES


4.4-3 Space Support Equipment, P-Wear Presentation, Lockheed Missiles and Space Corporation, CM-04, 24-25 May 1981

4.4-4 Advanced X-Ray Astrophysics Facility (AXAF) - Science Working Group Report NASA TM-78285 May 1980


4.4-6 Large Area Modular Array of Reflectors, NASA/GSFC White Paper, July 1980

4.4-7 Gamma-Ray Transient Explorer, NASA/GSFC White Paper, July 1980

4.4-8 Extreme Ultraviolet Explorer, NASA/GSFC White Paper, July 1980

4.4-9 Ultraviolet Photometric/Polarmetric Explorer, NASA/GSFC White Paper, July 1980

4.4-10 X-Ray Observatory, GSFC White Paper, July 1980

4.4-11 Soft X-Ray Survey, GSFC White Paper, July 1980

4.4-12 Molecular Line Survey, GSFC White Paper, July 1980

4.4-13 X-Ray Spectroscopy Mission, GSFC White Paper, July 1980


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| 4.4-16 | An Analytical Technique to Assess the Economic Impact of the Shuttle on Satellite Payloads. A. Salee, Grumman Aerospace Corporation, AIAA paper No. 71-807 July 1971 |
## 4.5 DIFFERENTIAL DRAG CONSIDERATIONS OF CO-ORBITING SATELLITES

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<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
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<td>4.5.2</td>
<td>Analytical Models</td>
<td>4-143</td>
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<tr>
<td>4.5.3</td>
<td>Results</td>
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</tbody>
</table>
4.5 DIFFERENTIAL DRAG CONSIDERATIONS OF CO-ORBITING SATELLITES

4.5.1 Introduction

Satellites co-orbiting with a Space Operations Center, so located for servicing reasons, will in general have different drag characteristics other than the SOC. At the flight altitude selected for the SOC (370 km), orbit decay rates due to differential drag are appreciable, 0.25 km/day being a typical figure for the SOC itself. Co-orbiting satellites will have drag characteristics ranging from greater decay rates than the SOC to no decay at all, in the case of a satellite that employs continuous orbit makeup.

Differential drag, and the changes in relative orbit location it causes, must be considered in (1) the selection of an orbit makeup strategy for SOC, (2) the selection of an orbit makeup strategy for co-orbiting satellites, and (3) the selection of propulsive means for accomplishing servicing.

If two spacecraft, initially co-orbital, experience differential drag, and do not compensate for it, they will become separated: (1) in altitude by the difference in orbit decay; (2) along the orbit track because the satellite at lower altitude will move faster; and (3) in plane, because of differential nodal regression resulting from the difference in altitude.

4.5.2 Analytical Models

To study this phenomena, an orbital simulation was employed using three different satellites. This simulation model contained a Jacchia dynamic atmospheric density model, effects due to the sun and moon, and harmonics of the Earth's gravitational field through the fourth order degree. The Science and Applications Space Platform (SASP) and the Advanced X-Ray Astronomy Facility (AXAF) were used as the SOC co-orbiting satellite models. These satellites were chosen on the basis that they represented a fairly wide range of ballistic coefficients (approximately 21 to 190 Kg/M^2). An operational SOC configuration was used for comparing the different orbit decay rates. It was assumed that SOC maintained its initial altitude by employing continuous orbit makeup since this will be quite likely. Two Jacchia models were used: the NASA Neutral Model with a value of
230 for the 10.7 near solar flux (F10.7) and a value of 20.3 for the geomagnetic index (Ap), and a Minimum Model using a F10.7 of 73.3 with an Ap of 10.9.

The results of these simulations are shown in Figures 4.5-1 and 4.5-2.

4.5.3 Results

As seen in these figures, the along-track separation develops more rapidly than the other separations. The "sinusodial" effects in the along-track separation are due to the fact that once the two satellites become 180 degrees out of phase, they begin to approach each other (i.e., one satellite "laps" the other).

If the same average altitude is maintained, the plane differences will approximately cancel out. A representative relative maneuver strategy for a co-orbiting satellite needing periodic service is illustrated in Figure 4.5-3. The orbit of the satellite experiencing the greatest decay rate is reboosted once per service interval. The reboost occurs halfway between intervals so that as the service time approaches, the satellite approaches the SOC with a low closing velocity. Terminal maneuvering can then be used to effect rendezvous and capture. The means of orbit makeup and maneuver are the subject of an investigation into satellite servicing transportation considerations.
Figure 4.5-1  Differential Drag Between Operational SOC (No Drag) and SASP ($C_D = 3.0$)

Figure 4.5-2  Differential Drag Between Operational SOC (No Drag) and UXAF ($C_D = 3.0$)
Figure 4.5-3  Differential Drag Orbit Makeup Strategy
4.6 SATELLITE SERVICING TRANSPORTATION CONSIDERATIONS

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4.6 SATELLITE SERVICING TRANSPORTATION CONSIDERATIONS

4.6.1 Performance Capability Analysis

Performance capabilities have been established for a space-based Orbital Transfer Vehicle (OTV) and a Teleoperator Maneuvering System (TMS). Assumptions used in the analysis are as follows:

1) All vehicle missions begin and end at the Space Operations Center (SOC), which is in circular orbit at 370 km.

2) Vehicle performance characteristics reflect all propulsive maneuvers up through plane changes of 28.5 degrees and altitude changes up to 7800 km for delivery, and a lower altitude for retrieval or round trip. The altitude for the latter types of missions depends on the payload weight inserted into LEO. Aeroassist below these altitudes is not beneficial on a cost basis.

3) OTV (normal growth technology) system characteristics as per the Future Orbital Transfer Vehicle Study (NAS1-16088). TMS system characteristics per Vought TMS book for NASA MSFC, 29-30 May 1980.

4) Vehicle Characteristics:

<table>
<thead>
<tr>
<th></th>
<th>FOTV</th>
<th>TMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Burnout Mass</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Propellant Mass</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Total Vehicle Mass</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Specific Impulse</td>
<td>seconds</td>
<td></td>
</tr>
</tbody>
</table>

The performance capabilities that have been defined include mission envelopes for three types of missions for each vehicle. The missions are:

a) Delivery. The vehicle takes a payload from the SOC and returns (empty).
b) Retrieval. The vehicle brings a payload to the SOC.
c) Round Trip. The vehicle takes a payload from the SOC and brings it back.
FOTV performance capability is presented in Figures 4.5-1 through -4 and TMS performance in Figures 4.5-5 through 4.5-9. The TMS data includes capability provided when using the standard propellant tank set as well as that available with dual and triple tank sets.

4.6.2 Results

The key observations resulting from this analysis are as follows:
- The FOTV is limited to less than 40 degrees plane change for altitude up to 2000 km above SOC
- The TMS is limited to less than 4 degrees plane change
- The TMS cannot perform any mission above 2800 km altitude
- For coplanar orbits with small (less than 100 km) altitude changes, neither vehicle is likely to be limited by the payload mass
Figure 4.5-1. FOTU Payload Delivery Capability—Low Altitudes
Figure 4.5-2. FOTU Payload Retrieval Capability—Low Altitudes
Figure 4.5-3. FOTU Round Trip Payload Capability—Low Altitudes
Figure 4.5-4. Performance—Off-Loaded Space Based \( \text{LO}_2/\text{LH}_2 \) OTV
Figure 4.5-5. TMS Payload Delivery Capability From SOC
Figure 4.5-6. TMS Payload Retrieval Capability To SOC
Figure 4.5-7. TMS Roundtrip Payload Capacities
Figure 4.5-8. Dual TMS Payload Delivery Capability From SOC
Figure 4.5-9. Triple TMS Payload Delivery Capability From SOC
End of Document