erations Analysis (Study 2.6) Final Report

Volume II
Analysis Results

Prepared by ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

15 September 1973

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

Contract No. NASW-2472

Systems Engineering Operations
THE AEROSPACE CORPORATION

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OPERATIONS ANALYSIS (Study 2.6)
FINAL REPORT

Volume II: Analysis Results

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FOREWORD

Study 2.6, Operations Analysis, has as its objective the assessment of the Space Transportation System (STS) relative to future NASA space program planning. Several options have been investigated to improve the efficiency of operations as a means of reducing future resource expenditures. The study has involved improvement in multiple payload deployment and retrieval operations, multiple orbit maneuvers, and alternate upper stage configurations. In addition, the study performed a preliminary estimate of space servicing for synchronous equatorial orbit satellites in the NASA mission model. These results indicate that space servicing offers an improvement in both logistic operations and payload procurement costs.

There are four volumes to this final report as listed below. The first volume provides an executive summary. The second volume provides an overall summary of the study results with comparisons between space servicing and ground refurbishment of payloads. The third volume provides all of the detailed payload design information developed for space-servicing configurations. The final volume provides a computer code specification which is proposed to be developed in a follow-on effort to support space-servicing tradeoffs.

Volume I	Executive Summary
Volume II	Analysis Results
Volume III	Payload Designs for Space Servicing
Volume IV	LOVES Computer Code Specification

Study 2.6, Operations Analysis, is one of several study tasks conducted under NASA Contract NASW-2472 in FY 1973. The NASA Study Director was Mr. V. N. Huff, NASA Headquarters, Code MTE.

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FIGURES

FIGURES (Continued)

TABLES

1. INTRODUCTION

In its evolution, the Space Transportation System (STS) may assume various roles depending upon future mission requirements and economic constraints. This study was originated to examine alternative operational concepts for the future which could be developed with some degree of economic benefit. The study examines the total concept at a system level involving mission requirements, payload design options, and logistic vehicle definitions. The problem is approached in a generic sense in that, in general, payloads and missions of the future can be assumed to be an extrapolation of today's missions, but detailed design information is beyond the realm of possibility. Even design information on the Shuttle and upper stage are fluid at this time. Consequently, although design information on vehicles and payloads is required, the emphasis of this study has been directed at assessing typical mission characteristics and searching for alternative means to improve the operational capability of the STS system as a whole. In this regard, this study has been unique in that alternate concepts could be considered without being inhibited by a specific design approach except for the Shuttle design which is considered to be relatively firm.

The emphasis has been placed first on improving utilization of the Shuttle and Tug upper stage for payload deployment and retrieval. This leads to increased multiple payload operations to maximize the loading efficiency of these vehicles. Further improvement was developed by modifying the payload design and operational approach to allow space servicing with the promise of further economic improvement. Multiple mission satellites and alternate upper stages were also examined, including a brief look at solar-electric propulsion stages (SEPS) and in-space warehousing of space replaceable payload modules. Each item has inherent benefits which must be traded off against cost of operations and design and some measure of risk associated with new developments. Because of the magnitude of the required effort to examine these concepts, it was possible only to expose the potential benefits and develop an analysis technique to support subsequent trade studies. However, although the results presented in this report are constrained by input assumptions and ground rules, the conclusions strongly point toward new space-servicing concepts which inherently improve the efficiency of future space operations.

The study approach was developed around the three major elements of the NASA space program as shown in Figure 1. The first element addresses the payload definitions as provided in the payload data books (Ref. 1 and 2) which describe candidate payload programs for the 1979 to 1990 time period. Rather than defining payloads in more detail, the objective of this study is to examine generic types of payload programs. This is based upon the belief that for an operational concept to be valid, it must be applicable to a whole class of payloads rather than any discrete entity. Specifically, the initial interest was directed at the compatibility of multiple payload logistic operations. As the study evolved, interest developed in space servicing as an operational concept and consequently payload modularization was employed based upon Lockheed Missile and Space Company, Inc. (LMSC) and Aerospace design approaches (Ref. 3 and Vol. III of this report).

The second step consisted of analyzing varying approaches for deploying and servicing multiple payload operations. This was based upon the 1971 NASA mission model and the 1972 excursion as described in References 4 and 5 respectively. In addition, the impulse required to phase from one position to another in the same orbit was determined. This includes consideration of weight and volume load factors of the Shuttle and upper stage as well as the impact of scar weights on the total system performance. This information has been documented as mission characteristics (Ref. 6). Additional information is provided in Reference 7 relative to velocity requirements to support synchronous equatorial orbit operations.

The third step addressed candidate logistic vehicle concepts. The Shuttle was assumed to be relatively fixed in concept as given in Reference 8. However, upper stage concepts vary considerably from low technology cryogenic stages to the Marshall Space Flight Center (MSFC) baseline Tug of Reference 9 and include also storable upper stages. In addition, when

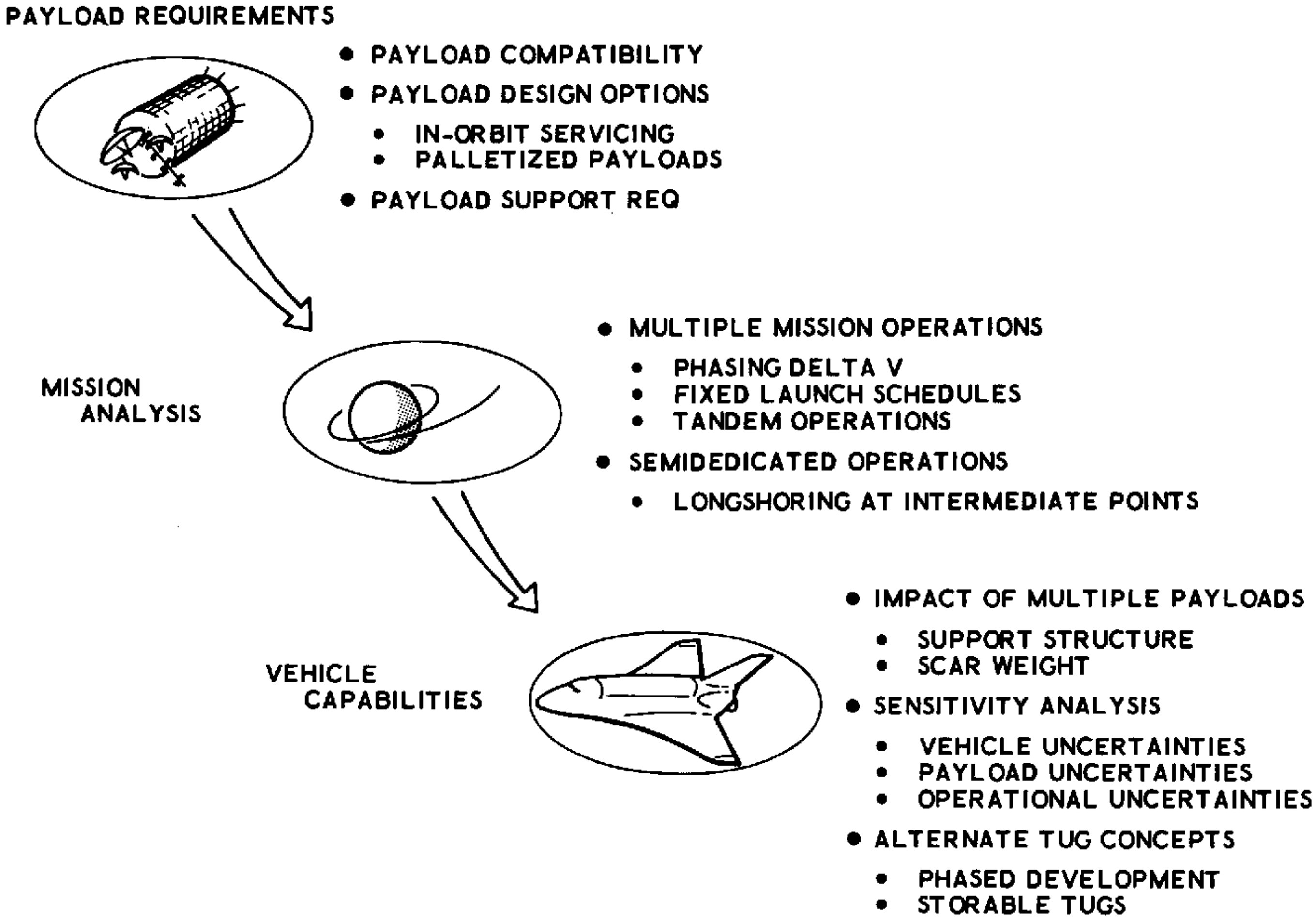


Figure 1. Operations Analysis Study Plan

considering space concepts, a solar-electric propulsion stage (SEPS) (Ref. 10) offers certain advantages. The basic tradeoffs between various upper stage options, including tandem Tug operations, are provided as a separate part of this study (Ref. 11). The dynamic operations requirements and cost analysis (DORCA) interactive computer program (Ref. 12 and 13) was employed for these tradeoffs.

The results of this study effort have exposed several new concepts which could provide cost benefits for future NASA operations. A broad range of concepts has been examined, limited in depth by the available resources. However, sufficient interest has been generated to consider improving the analysis technique and performing in-depth studies as a follow-on to this effort. Therefore, an adjunct to this effort was directed at developing a computer program specification which could be coded and employed in subsequent study efforts. This specification is identified as Vol. IV of this report.

In summary, the results of various tradeoffs performed during this study point to space servicing as a means of reducing overall program costs including payload acquisition and logistic vehicle operations. For the cases examined, the Tug operations were reduced by approximately 18% over ground refurbishment of payloads. Payload procurement was reduced approximately 10%. Space servicing also implies the use of standard modules for subsystems, although deviations can be tolerated in specific instances. This should provide further cost savings. A further extension of this concept leads to multi-mission satellites in which a common set of subsystems may support several payload programs simultaneously (time-sharing operations) or allow mission equipment changeout. This of particular interest because for many NASA payload programs the mission equipment is the major source of uncertainty in future planning rather than subsystems. Reliabilities of such mission equipment as multi-spectral scanners and similar sensors are relatively low and can be projected to have no more than a two-year operating life in the time period (1979-1990) of interest. Since these equipments are mechanical in nature, the failure modes exhibit wearout features rather than random failures and therefore, improvement through design redundancy may be difficult to achieve. Space servicing therefore offers a means of maintaining and upgrading mission equipment at a reduced program cost if standardization of the operating concept can be achieved; that is, commonality of payload design and efficient utilization of logistic vehicles.

Numerous space-servicing policies can be postulated as shown in subsequent sections, each exhibiting specific advantages. The key issue is that space servicing as a concept offers new insight into systems level requirements for payloads and logistic vehicles. It also offers a key to management of multi-faceted operations where subsystems can be relegated to standard components while still retaining flexibility in mission equipment applications.

2. BASIC DATA DEVELOPMENT

The basic information developed in support of space-servicing tradeoffs discussed in the next section is summarized here for information purposes. Examples of the type of information required are given along with some of the analysis results which led to space servicing as a concept. Detail information is provided under separate cover as listed in the references.

The information is separated into three principal subjects:

Mission Characteristics
Logistic Vehicle Options
Payload Design Options

A. MISSION CHARACTERIZATION

It is important in assessing operational concepts to determine if the results are overly sensitive to the initial mission model. In this case, the interest lies in the application of multiple payload logistic operations such as deployment, servicing, or retrieval of more than one payload on a given Tug flight. A measure of the efficiency with which the operations can be performed is the load factor achieved on each flight. This is defined as the ratio of the payload weight to the weight capability of the logistic vehicle (Shuttle, Tug, etc). A volume load factor is also useful to determine if payload length limits the loading of logistic vehicles. An overall length of 18.3 m (60 ft) is employed as a constraint to be compatible with the Shuttle payload bay. When a Tug is employed, the upper stage payload length is constrained to 7.6 m (25 ft), thus allowing the Tug/payload combination to meet the Shuttle constraint. The 1971 NASA mission model as defined in Reference 4 is used as a basis for this analysis. Excursions are then made to see if the logistics vary significantly. The following questions were addressed:

1. What load factor (and volume factor) was achieved for each logistic operation?
2. To what extent were multiple payload operations employed?

3. What potential exists for improving the efficiency of flight operations?

4. What uncertainties exist which may alter the derived results?

On the first leg of a synchronous equatorial mission, the Shuttle takes the payload and Tug to an orbit altitude of approximately 296 km (160 nmi) at 28.5 degrees inclination. In addition, there are other payloads; i.e., planetary, etc. which also require this first step. Combining these delivery and retrieval requirements for the 1971 mission model results in 331 Shuttle flights over the time period 1979 to 1997. The vast majority of these flights delivered and returned more than one payload. For example, 99 flights delivered two payloads (including the Tug as one payload) to the reference orbit and returned two payloads to the launch site for refurbishment. Each payload required an upper stage for subsequent operations but, in general, more than one automated payload was handled on each flight.

The average load factor was 80 percent of the total of 331 flights. No significant problems were encountered due to Shuttle bay volume constraints. Continuing this example to the next leg resulted in 191 Tug and 10 tandem Tug flights to synchronous equatorial orbit. The average load factor for Tug operations was only 67 percent with approximately 50 percent of the flights handling a single payload up and a single payload down. Forty flights had a load factor less than 30 percent with several flights below 10 percent. A detailed analysis is provided in Reference 6. In summary, improved utilization of the Tug is needed and further improvement of Shuttle flights is desirable. Some of this improvement can be achieved by improved loading, adjustment of the individual flight schedule or, in other cases, adjustment of the mission orbit. The reduction in flights may only be 10 to 20 percent overall, but the operations cost allocated to certain classes of payloads could be substantially reduced.

Although improved weight load factors for the Tug can be achieved in some cases, a further look at the results shows that the volume load factor will become dominant. Consequently, repackaging of the payloads to improve the packing density in the Shuttle is a significant factor for improved vehicle utilization. One way is to take advantage of the 4.6-m (15-ft) diameter by placing payloads in the bay like pineapple slices. This approach is discussed in more detail in Section 3 and is especially appropriate for space replaceable units.

An overall comparison of vehicle utilization is provided in Table 1 for the 1971 mission model (Case 403.) A second model (Case 506) developed in Reference 5 as an excursion to the 1971 model is also shown. The overall Shuttle utilization has a weight load factor of 75 percent which drops to 58 percent for Case 506 due to the extensive number of flights for space station and sortie operations. A better comparison is achieved by considering automated payloads only, in which the Shuttle weight load factor for both cases is within five percentage points (71 percent vs 66 percent). The improved Tug utilization shown stems from redefined payloads which enhance the loading capability. It is also seen that in either case, Tug operations at the western launch site, Vandenburg Air Force Base (VAFB), have a low efficiency and should be improved. In summary, the mission model provides sufficient traffic in each year that a mix of payloads can be accommodated with approximately the same efficiency from model to model. Hence, the average operations cost allocated to a payload program should remain relatively constant, unless a drastic redesign of the payloads occurs to improve the packing density.

This does not obviate the fact that further improvement in vehicle utilization is needed. Operations from the western launch site have been shown to be very inefficient when the Tug is required. Also, the Shuttle performance is marginal for payload deployment and/or retrieval at 926 km (500 nmi). One option is to use a smaller Tug, since the baseline Tug must be off-loaded for these flights anyway. Another is to use a storable stage, more in line with the impulsive velocity requirements. These options were examined briefly as reported in Reference 11, but further work is required. Another option to improve the Tug utilization for polar orbits is multiple-orbit operations including plane change maneuvers of a few degrees. If the Tug, off-loaded to meet Shuttle constraints, could deploy or service payloads in one orbit and then transfer to a second orbit, the cost of operations could be apportioned between the payload programs. To examine

Table 1. Mission Characterization Summary

VEHICLES	CASE 403		CASE 506*	
SHUTTLE	520	75%	562	58%
TUG (ETR)	251	57%	182	71%
TANDEM TUGS	16	64% (96%)**	5	86%
TUG (WTR)	51	17%	72	7%
CENTAUR	13	82%	36	52%
AGENA	-0-	---	3	78%

* INCLUDES SPACE STATION AND SORTIE MISSIONS

** APPLICABLE TO TEN SYNC EQ MISSIONS

this point, the orbits of interest are grouped into three sets: one set of eliptical orbits at 90-degrees inclination; a second set of two 926 km (500 nmi) circular orbits at 98 degrees and 99.2 degrees inclination, respectively; and, a third set with various inclinations and altitudes. Table 2 defines the mission orbits and candidate combinations investigated. Typical results are shown in Figures 2, 3, and 4 indicating the Tug has sufficient capability to service up to 726 kg (1,600 lb) in each of the orbits shown. A minor adjustment in mission launch dates for the three payloads (NP2-13 Explorers, NC2-48 Small Applications Technology Satellites (ATS), NP2-14 Explorers) makes these three operations compatible for multiple operations. The total number of Shuttle flights is reduced by 30 percent, and consequently, the cost of operations to be absorbed by the payloads is also reduced.

The same approach was applied to several candidate missions to determine the feasibility of combined operations. The results are summarized in Table 3. Nodal regression precludes the Tug from servicing more than two orbits at low altitude and low inclinations. Even less capability exists with the Shuttle and the overall load factors indicate a need for improvement. This leads to consideration of multi-mission satellites wherein a single satellite, which can be readily serviced, could perform a majority of the mission functions currently scheduled for separate payloads and separate orbits. This point is discussed further in subsequent sections.

B. LOGISTIC VEHICLE OPTIONS

A brief review of logistic vehicle options is provided here to indicate the type of data which must be developed to support space servicing. A more complete description including tradeoff results is presented in Reference 11. In addition, during the course of this study, it was determined that differences existed between NASA MSFC and NASA Johnson Space Center (JSC) relative to the velocity requirements to service synchronous equatorial operations. Reference 7 documents this information and provides the Aerospace approach which is used in the space-servicing tradeoffs. The differences in velocity requirements varied by as much as 70 mps (200 fps)

Table 2. Candidate Mission Orbits for Multiple Operations

Orbit Inclination	Initial Orbit, km (nmi)	Altitude Final Orbit, km (nmi) Apogee	Altitude Final Orbit, km (nmi) Perigee	Notes
28.5°	278 (150)	463 (250) 551 (297) 556 (300) 611 (330) 741 (400)	463 (250) 551 (297) 556 (300) 611 (330) 741 (400)	Examine Transfers for various combinations
0° to 28.5°	278 (150)	35,786 (19,323) 35,786 (19,323)	35,780 (19,323) 35,780 (19,323)	Change inclinations at synchronous altitude
55°	185 (100)	500 (270) 12,800 (6,900)	500 (270) 12,800 (6,900)	
90°	185 (100)	333 (180) 556 (300) 1,889 (1,020)	3,333 (1,800) 5,556 (3,000) 37,040 (20,000)	Examine transfer for various combinations
98° to 99.2°	185 (100)	926 (500) 926 (500)	926 (500) 926 (500)	Plane change maneuver
99.2 100.9 103	185 (100)	926 (500) 1.296 (700) 1,678 (906)	926 (500) 1,296 (700) 1,678 (906)	Plane change and orbit altitude change

Table 3. Tug Payload Capabilities

Orbit Inclination	Initial and Final Orbit, km (nmi)	Payload Serviced Altitude, km (nmi) 1	2	3	Launch Window (Days)	(Unavail. (Days)	Operations Service	Payload kg (lb)
28.5°	278 (150)	463 (250)	551 (297)	---	546	668	No	726 (1,600)
↓	↓	↓	611 (330)	---	325	400	No	↓
			741 (400)	---	183	220	No	
		551 (297)	611 (330)	---	833	980	No	
		↓	741 (400)	---	275	330	No	
		556 (300)	741 (400)	---	417	493	No	
		463 (250)	611 (330)	400	15	2,800	No	
28.5°	278 (150)	35,786-0° (19,323)	35,786-29° (19,323)	---	∞	-0-	Yes	340 (750)
55°	185 (100)	500 (270)	12,800 (6,900)	---	23	61	Yes	726 (1,600)
90°	185 (100)	333 × 3,333 (180 × 1,800)	556 × 5,556 (300 × 3,000)	---	∞	-0-	Yes	1,000 (2,200)
↓	↓	333 × 3,333 (180 × 1,800)	1,889 × 37,040 (1,020 × 20,000)	---	∞	-0-	Yes	↓
		556 × 5,556 (300 × 3,000)	1,889 × 37,040 (1,020 × 20,000)	---	∞	-0-	Yes	
		333 × 3,333 (180 × 1,800)	556 × 5,556 (300 × 3,000)	1,889 × 37,040 (1,020 × 20,000)	500	90	Yes	726 (1,600)
98° 99.2°	185 (100)	926 × 926 (500 × 500) →	926 × 926 (500 × 500)		375	6 Years	No	---
99.2° 100.9° 103°	185 (100)	926 × 926 (500 × 500) →	1,296 (700) →	1,678 (906)	∞	-0-	Yes	726 (1,000)

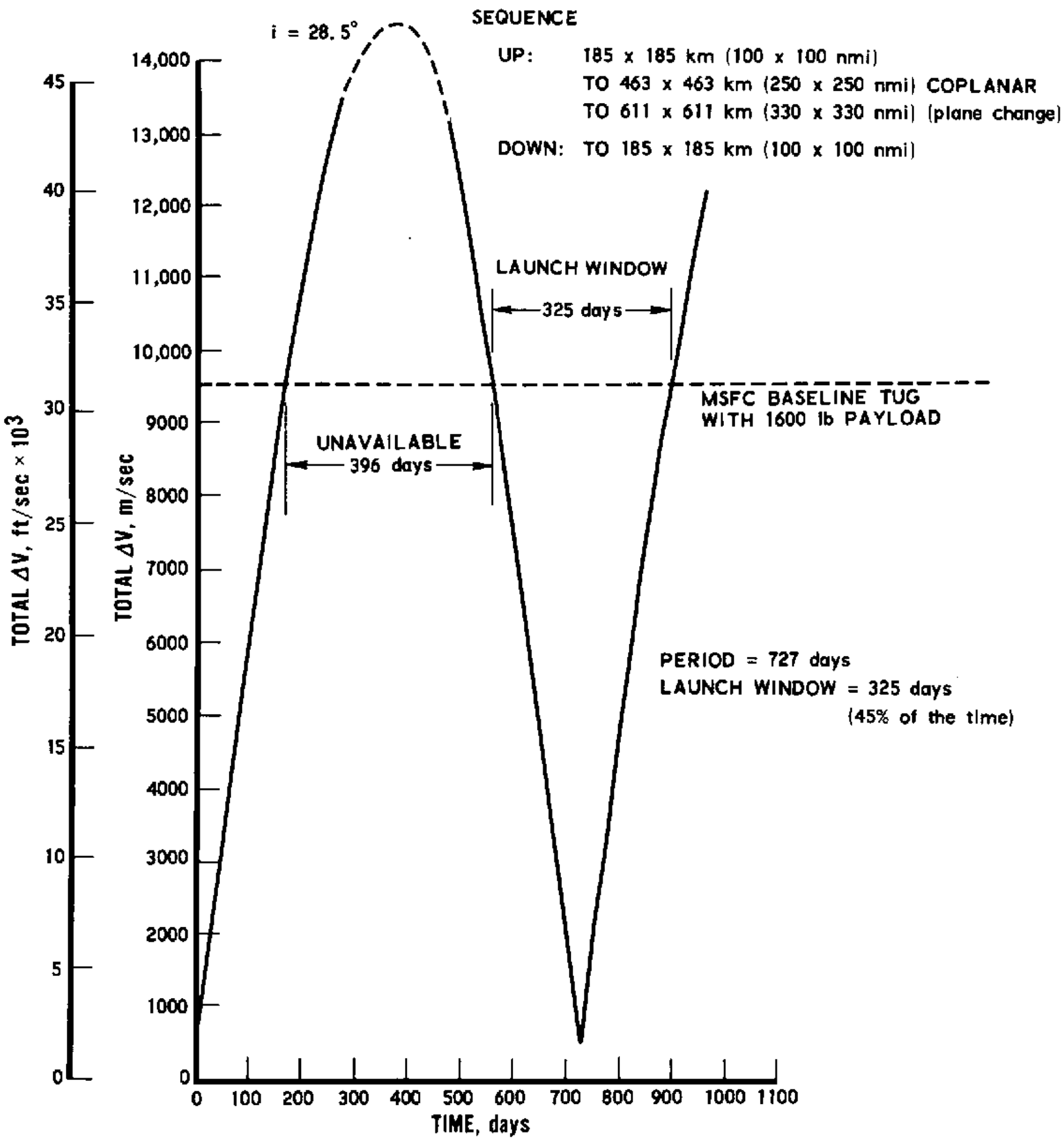


Figure 2. Velocity Requirements to Service Two Orbits at 28.5 deg Inclination

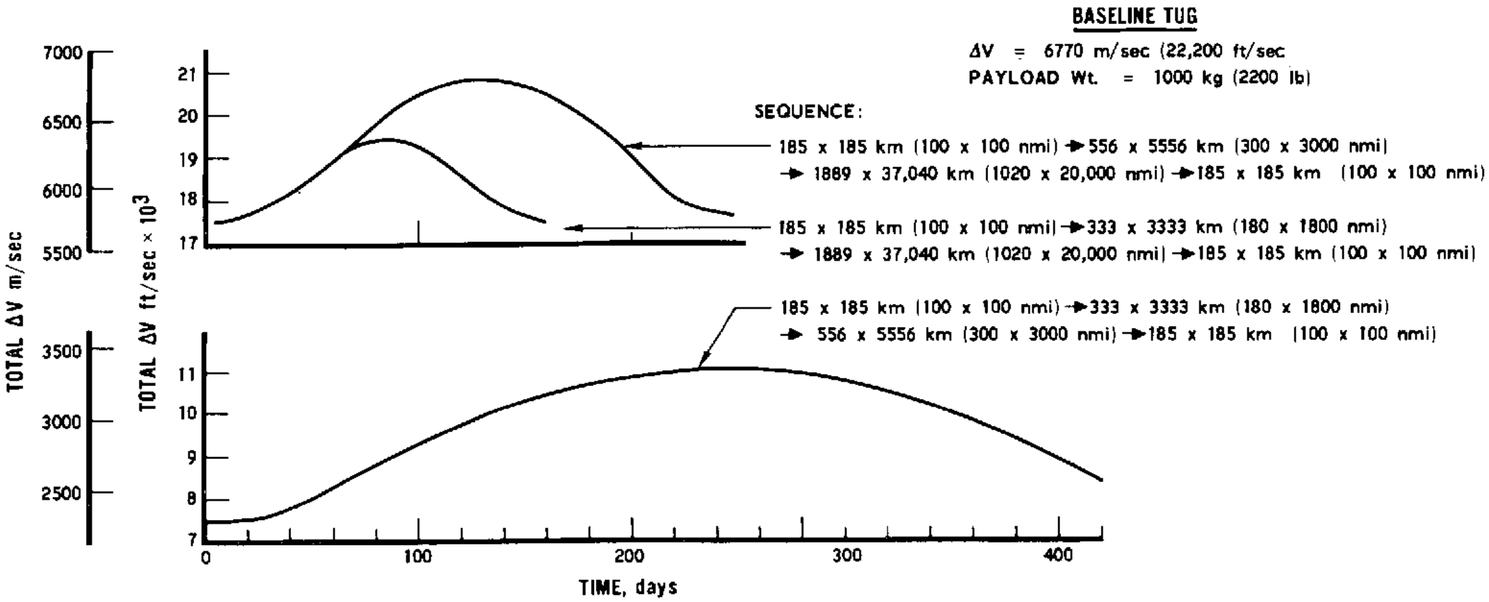


Figure 3. Velocity Requirements to Service Two Elliptical 90-deg Orbits

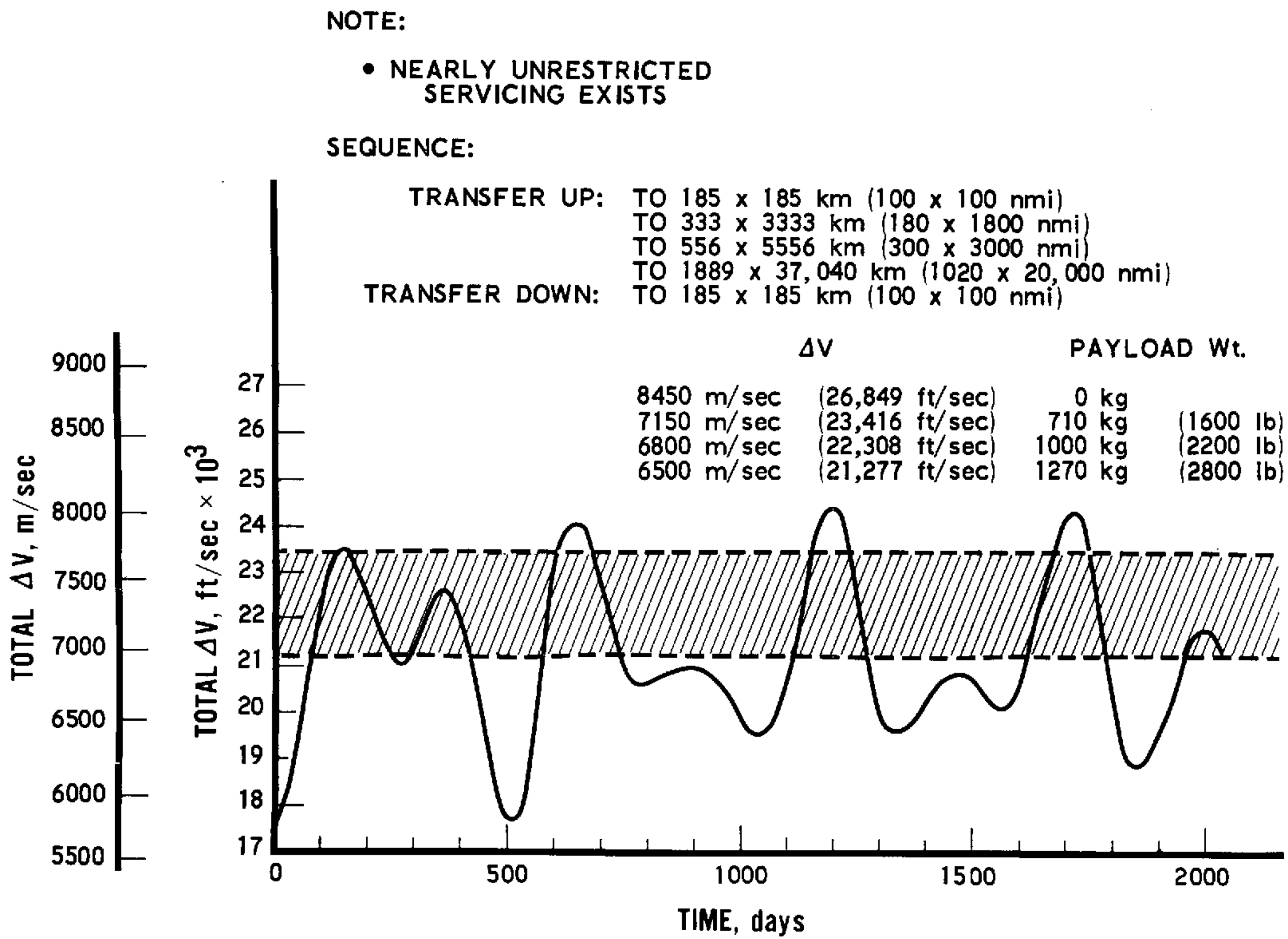


Figure 4. Payload Capabilities of Off-Loaded Tug for Servicing Three Elliptical 90-deg Orbits

which is significant relative to phasing increments at synchronous altitudes. The value selected for transfer from 296 km (160 nmi) orbit to synchronous equatorial orbit, including losses, yaw steering, and longitude placement is 4,309 mps (14,138 fps) (one way). This value was then used consistantly for all operations under consideration.

The space-servicing results presented in Section 3 utilize the NASA MSFC baseline cryogenic Tug as defined in Reference 9. Alternate upper stage configurations also considered in tradeoffs based upon the 1971 mission model (ground-refurbishable payloads) are shown in Figure 5. The performance capabilities, including a preliminary description of the NASA JSC storable Tug (model 025) are shown in Figure 6. Within the limits of the ground rules in Reference 11, it was shown retrieval of payloads was an important factor in reducing overall program costs, but having selected a retrieval Tug design, the relative cost difference was small. The higher cost of developing the baseline Tug was offset by the increased payload benefits. The reduced cost of the low technology Tug (with retrieval capability) was offset by the loss in performance increasing the operations costs.

An alternate means of deploying and retrieving payloads was examined using the baseline Tug equipped with a solar-electric propulsion stage (SEPS). The impact of various options is shown in Figure 7. The SEPS can more than double the performance capability of the Tug alone, if the operation time period can be relaxed to 200 days. Constraining the time to approximately three months still provides a significant improvement. This may be acceptable considering the fact that current programs, after initial insertion in synchronous equatorial orbit, may be allowed to drift for 30 to 45 days before final stabilization. Since the Tug is restricted to a seven-day operation, it is necessary for the SEPS, after initial deployment, to return to the changeover orbit and rendezvous with a second Tug. The SEPS acquires the payload and transfers back to synchronous altitude. The current design based on Reference 10 is capable of four round trips of this type. Although the operations achieve an additional degree of complexity, the increased performance is sufficiently attractive to warrant further

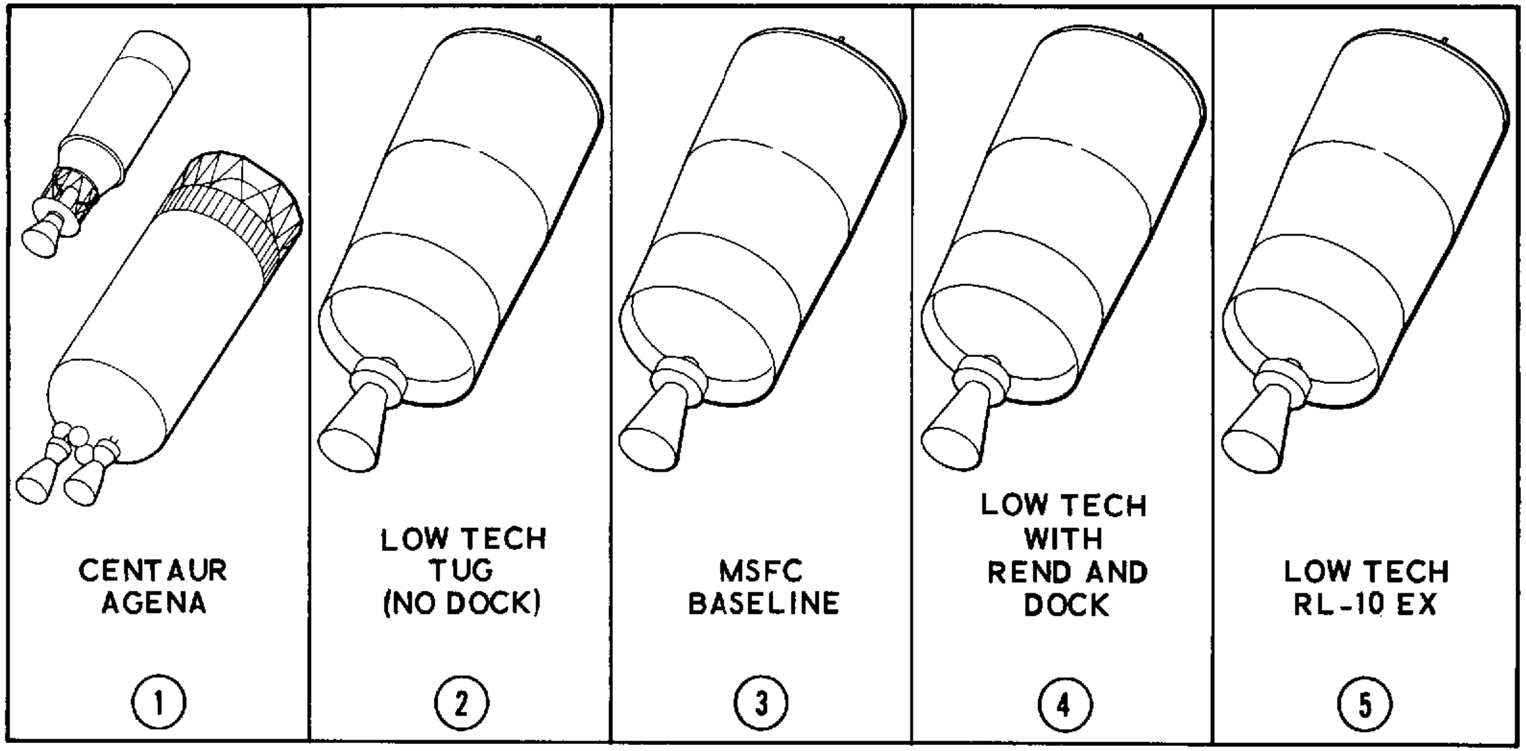


Figure 5. Phased Development Lug Options

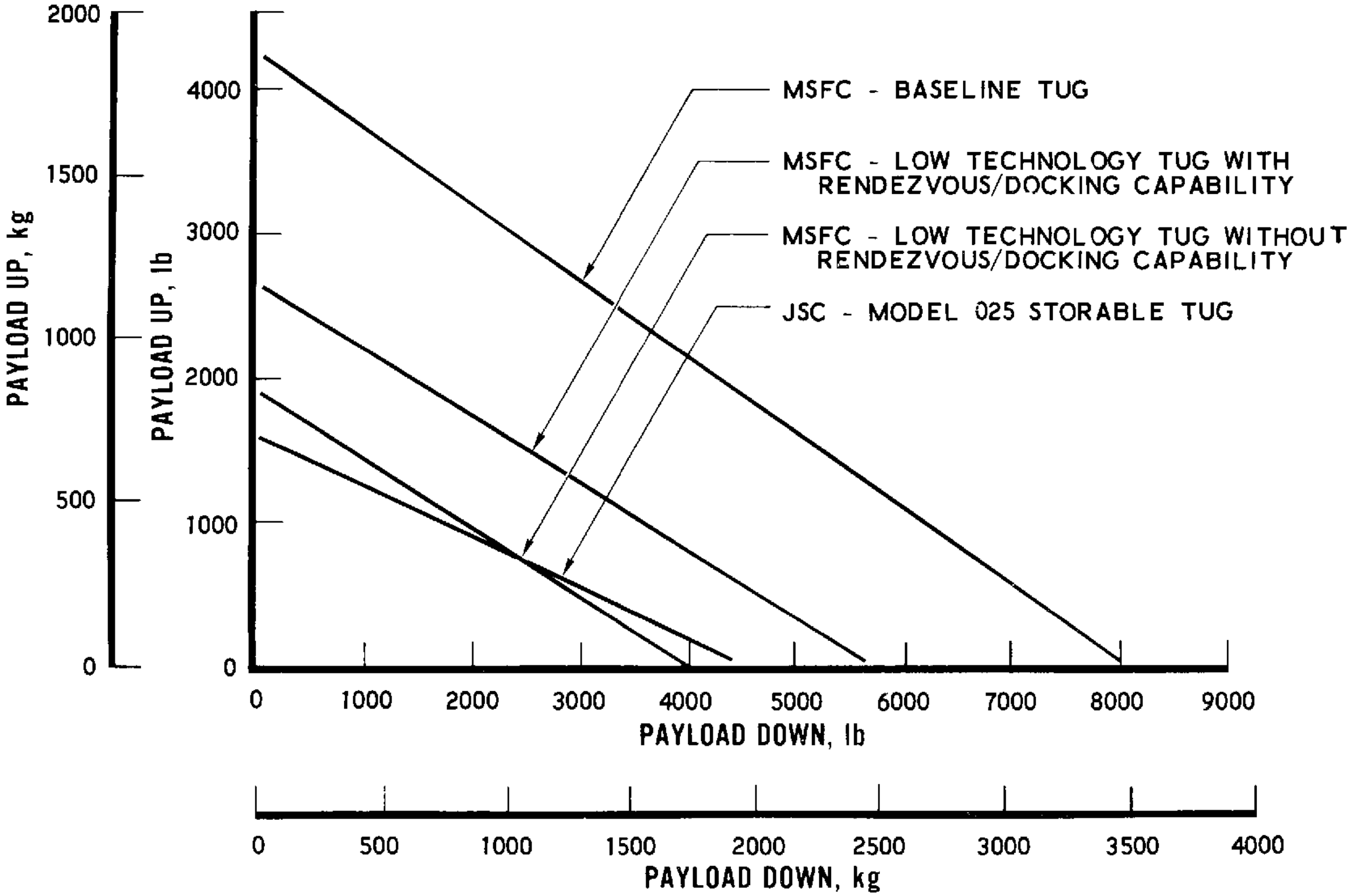


Figure 6. Performance Capabilities of Tug Options

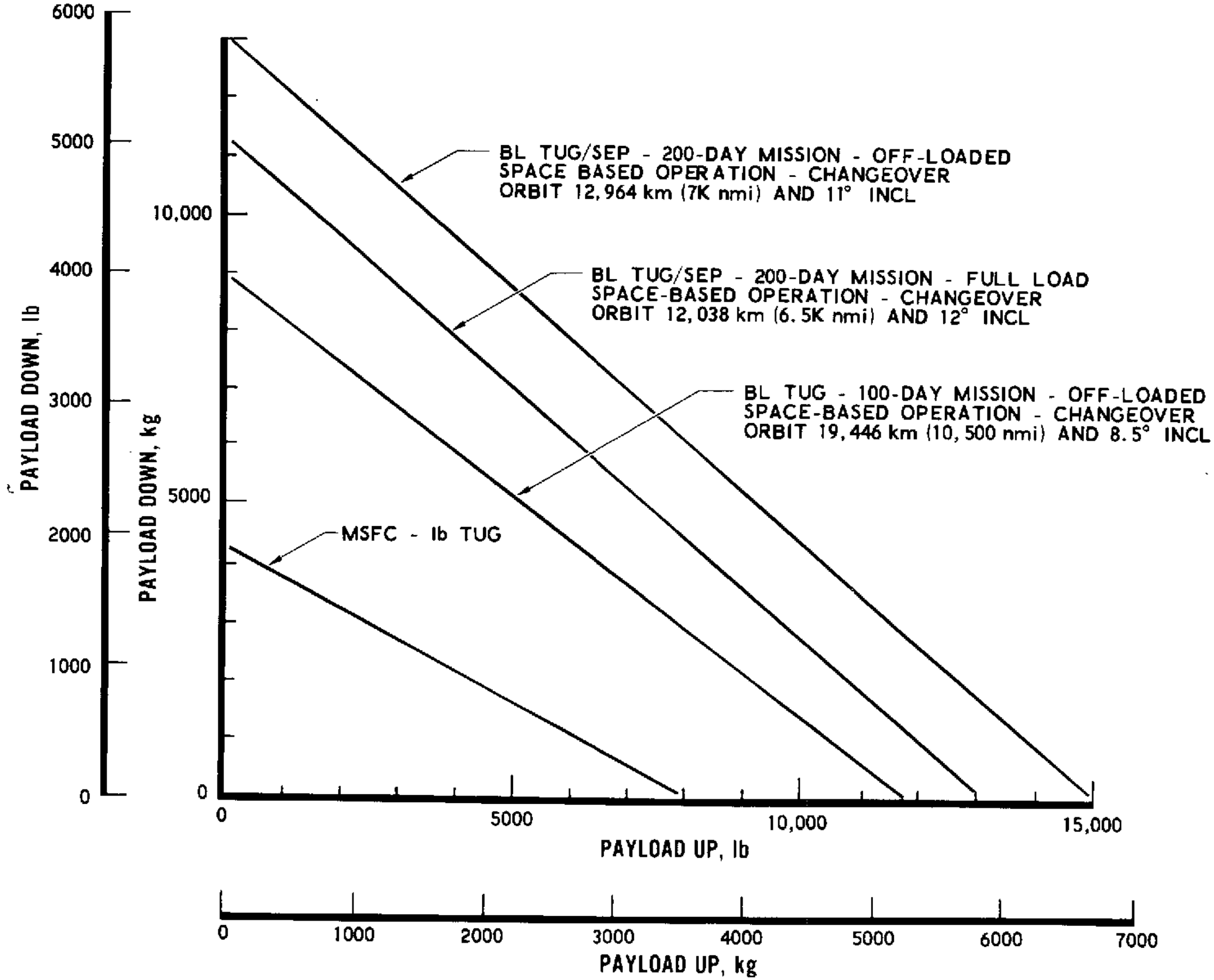


Figure 7. Performance Capabilities of Tug/SEPS Options

analysis at a later date. Further benefits may be derived when considering space servicing of multiple payloads as an operational concept.

Space servicing of multiple payloads in a given orbit requires the logistic vehicle to transfer from one payload to another, exchanging modules or performing some other service. Particular interest lies in synchronous equatorial orbit where a majority of the projected payload programs will be deployed. For the purpose of example cases in Section 3, it has been assumed that the servicing weight is constant for the entire operation. That is, if a module is taken to a satellite, the module removed is equivalent and consequently the weight remains constant. This represents a conservative assumption but eases the interpretation by allowing parametric data to be developed.

The baseline Tug capability to perform servicing is shown in Figure 8 restricted to a seven-day mission duration. The number of satellites to be serviced are distributed equally over the total phase angle being considered. The Tug mission duration is highly restrictive due to the long period of the transfer orbits required to change longitude placement. However, even with this restriction, the Tug could service three to four payloads if the satellites were clustered over a limited phase angle, say 120 degrees. Allowing 91 kg (200 lb) for a servicing unit, the Tug could replace 204 kg (450 lb) of equipment in each of four satellites. This is not realistic considering the distribution of payloads in orbit as shown in Figure 9.

Extending the Tug mission life to 21 days provides a substantial improvement in servicing capability as shown in Figure 10. The initial capability is lower due to the increase in consumables required for attitude control, power, and boiloff. As many as six or more payloads could be serviced over a 300-deg phase angle. Over 113 kg (250 lb) could be transported to each payload. It will be shown in Section 3 that this weight represents a reasonable value of space-serviceable modules.

Applying this same idea to the use of a SEPS stationed at synchronous equatorial orbit results in a further increase in capability within reasonable time constraints. As shown in Figure 11, the SEPS can

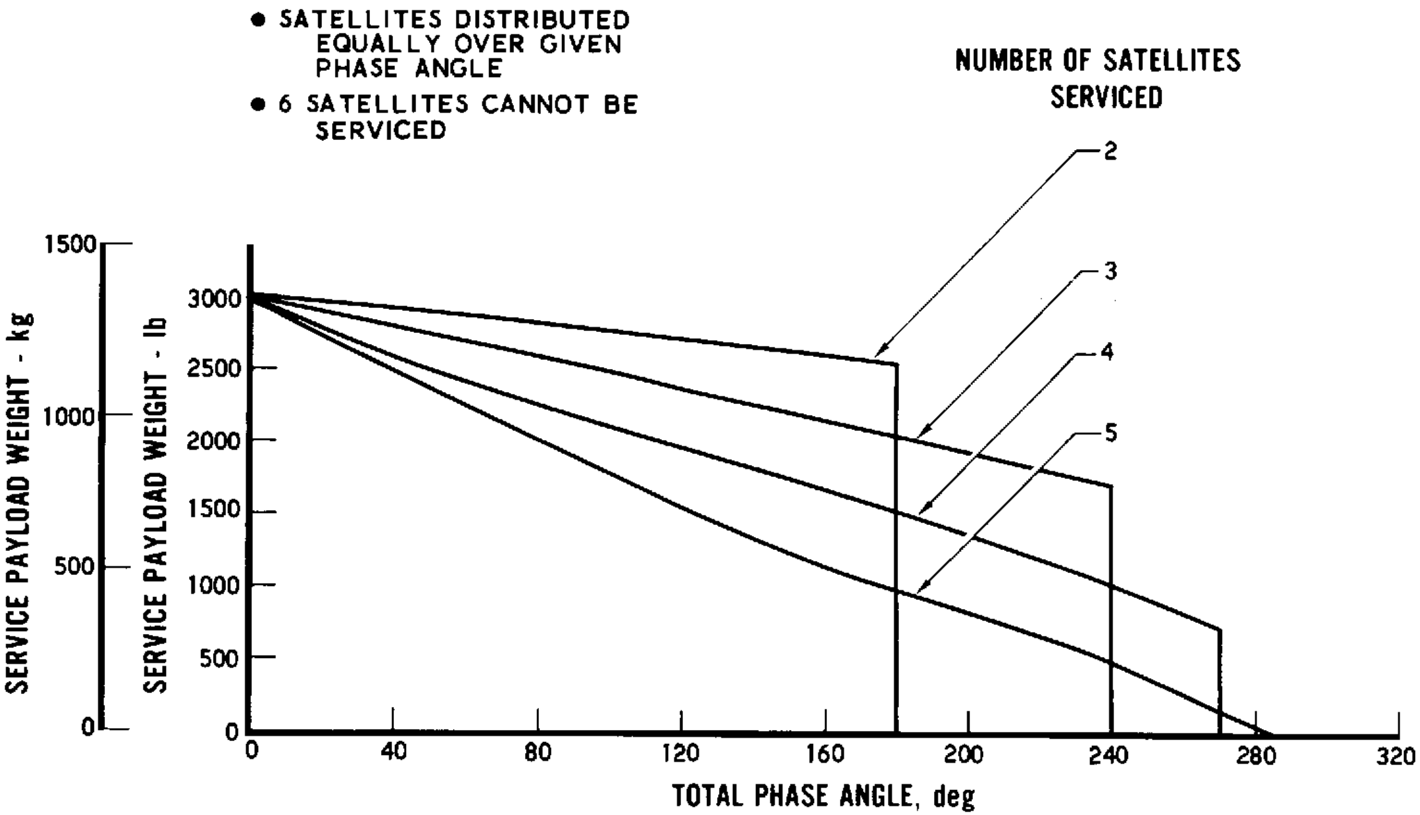
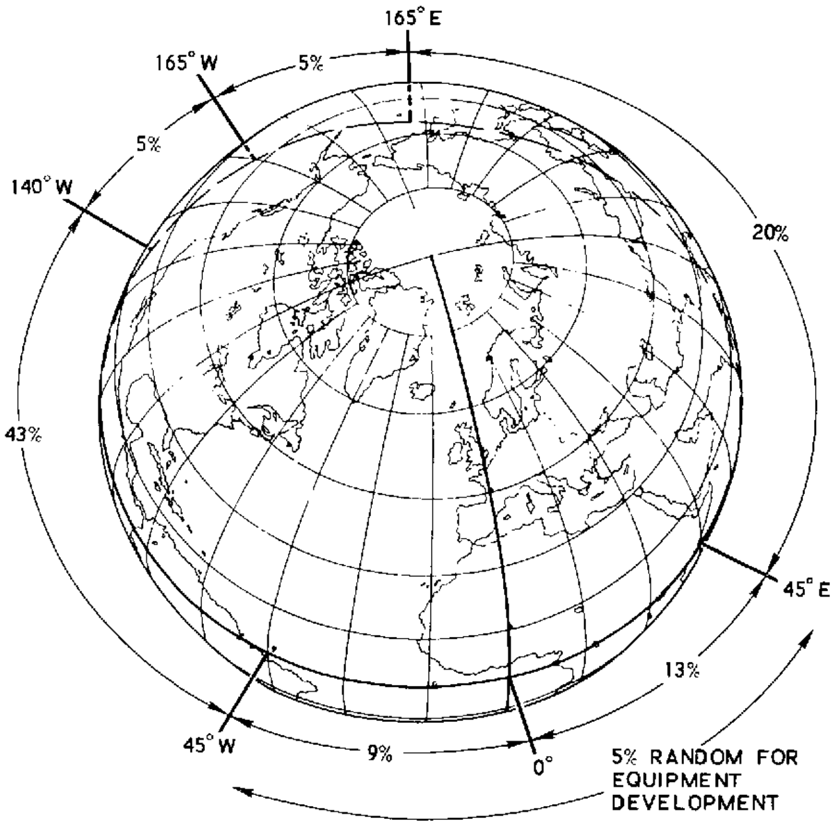


Figure 8. Tug Service Capabilities for Seven-Day Operating Period



- BASED UPON NAR GSPS
- AT LEAST 70% OF PROGRAMS HAVE 2 OR MORE SATELLITES IN SYSTEM

- PAYLOAD PROGRAMS
  - NC2-46 ATS SYNC
  - NC2-51 SYSTEM TEST SATELLITE
  - NC2-47 SMALL ATS
  - NCN-7 COMSAT
  - NCN-8 U.S. DOMESTIC
  - NCN-9 FOREIGN DOMESTIC SAT.
  - NC2-49 TDRS
  - NC2-50 DISASTER WARNING
  - NE2-43 SYNC EARTH OBS
  - NE2-39 SYNC EARTH RES
  - NEO-11 SYNC EARTH RES
  - NE2-41 SYNC MET SAT.
  - NEO-15 SYNC MET SAT.
- TOTAL SATELLITE IN SERVICE = 37

Figure 9. Distribution of Satellites in Synchronous Equatorial Orbit

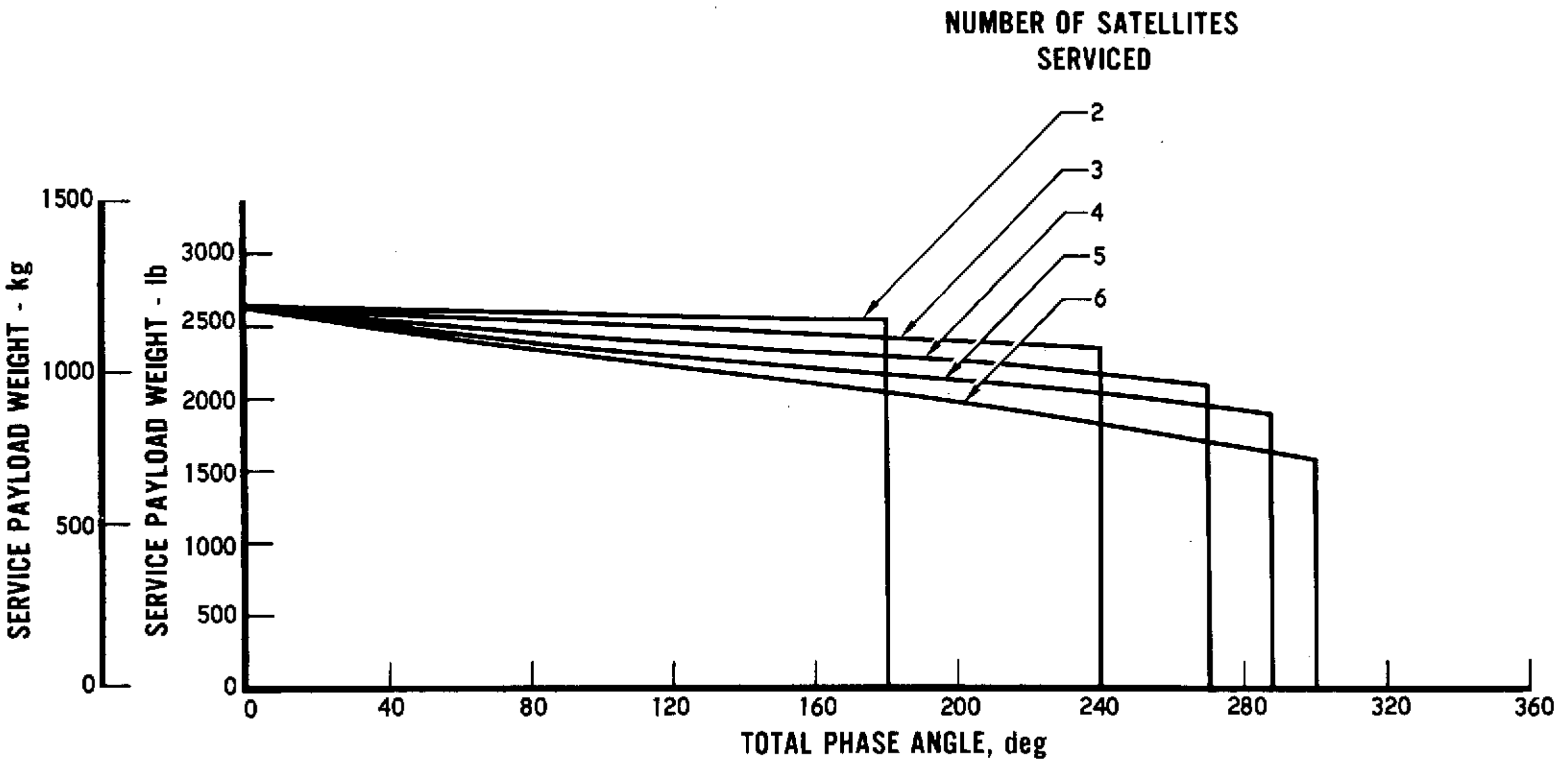


Figure 10. Tug Service Capabilities for 21-Day Operating Period

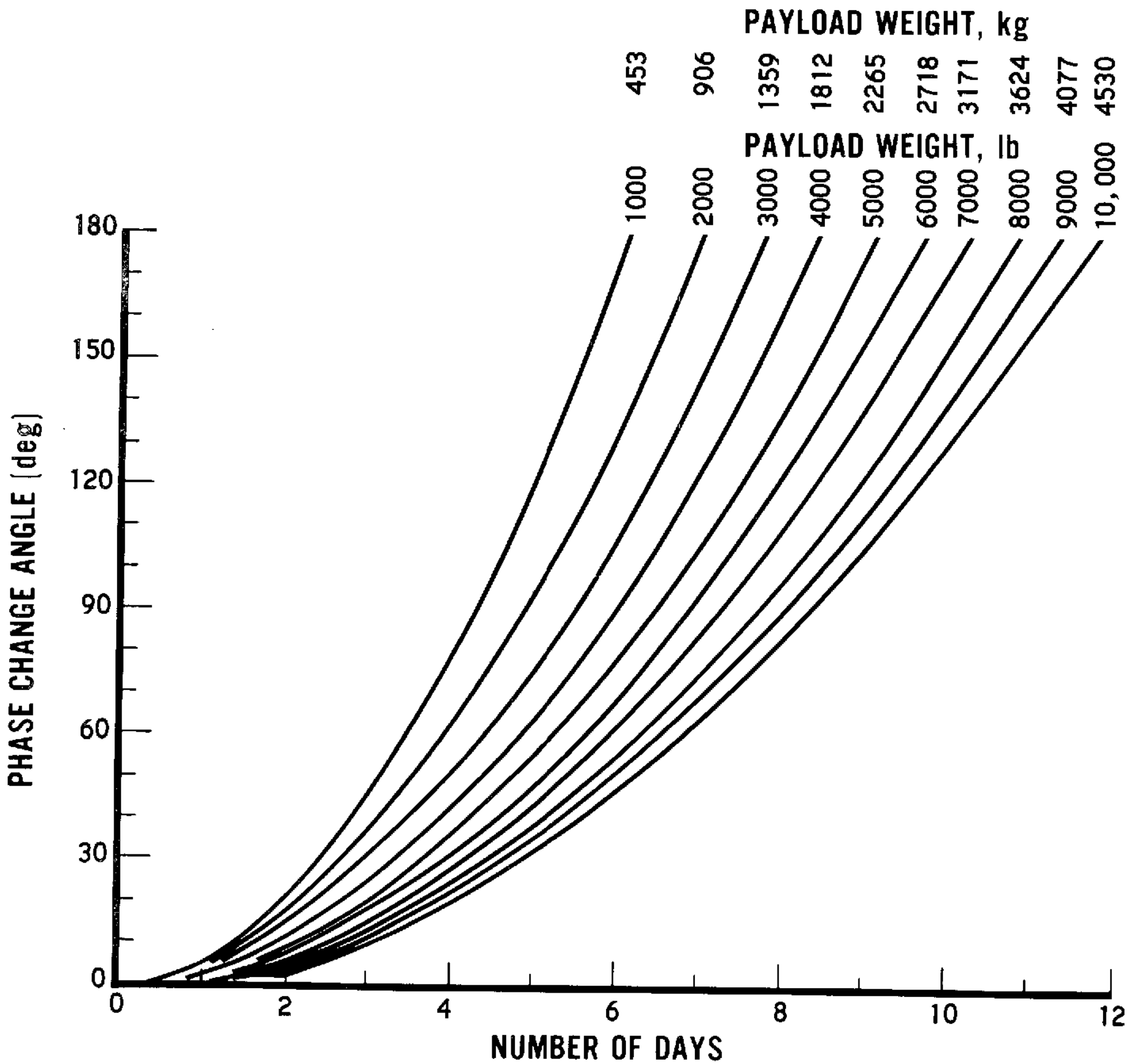


Figure 11. Service Capability of SEPS in Synchronous Equatorial Orbit

translate 4,536 kg (10,000 lb) of payload through a phase angle of 180 deg in approximately 12 days. It can service 3 payloads at 90-deg positions with 4,536 kg (10,000 lb) in 16 days. Obviously if space replaceable units (SRUs) could be warehoused in-orbit (i.e., deployed by a tandem Tug), the SEPS has sufficient capability to service payloads with a faster response than ground-oriented Tug operations. Detailed tradeoffs were not possible within the current study, but this concept deserves consideration in any follow-on efforts.

C PAYLOAD DESIGN OPTIONS

Payload design has been considered only to the point that sufficient information can be developed to support system level tradeoffs. The desired information must be generic in nature, allowing extrapolation to all the payload programs of interest. In particular, space servicing or any other operations concept may be attractive for any single payload program, but unless it can be applied to the total mission model, the results are inconclusive. The data summarized here are provided in depth in Volume III. The payload configurations evolve from a conceptual design study performed at Aerospace for SAMSO. Data from other payload programs within Aerospace were also employed in developing reliability and weight characteristics. For the most part, all the design information employed should be considered conservative in that further refinement can be expected to produce lower weights and higher reliabilities. As an initial case for the purpose of developing the analysis technique discussed in Section 3, the LMSC standardized module definitions of Reference 3 were employed.

A brief review of payload failure histories (Ref. 14) was conducted to aid in selecting the levels of redundancy to be considered. Of the failures presented, 93 percent represented a condition classed as small to negligible degradation, 5 percent represented a significant degradation, and 2 percent resulted in loss of the spacecraft. Where redundancy was employed, it contributed nearly as many anomalies as it protected against. Consequently, experience indicates that redundancy as a means of achieving an operation lifetime is not altogether effective. This implies that a majority of failures are not random but rather are design deficiencies, either due to improper design or a poor knowledge of the environment. Although the reliability of satellites should continue to improve with experience, it can be expected that these two factors will continue to influence the failure characteristics.

Space servicing provides one means by which satellites can be maintained in an operational condition. If the failure occurrence of a particular element is determined to be a design deficiency, the design can be corrected and then be installed in all satellites with common equipment. Redundancy would not necessarily provide the same operational capability. It is prudent, however, to maintain a minimal level of redundancy or redundant modes to support serviceability if required. As an example, backup attitude stabilization should be provided to allow docking. Backup transmitters should also be provided to support diagnosis of the failure condition. Therefore, for the current study, redundancy of satellite components has been minimized as will be shown later.

Another key item in considering space servicing as an operational concept relates to payload availability. This term represents the ratio of the time the payload is operating on orbit to the design life of the satellite. A 95 percent availability inplies that 5 percent of the time the satellite is not functioning as desired or to minimum specification. If a failure occurs which interrupts payload operations until the failure can be repaired, this represents the unavailable time; that is, the satellite is unavailable to the user. The user requirements are unknown but would obviously vary over a wide range depending upon the value of the data being obtained. The Aerospace studies performed for SAMSO were directed at maintaining a high availability for national security. Non-NASA domestic satellites desire a high availability because of a direct relationship to revenues. However, NASA experimental and developmental satellite programs may not require a high availability due to the associated logistics costs. Since a valid criterion does not exist, this parameter will be treated as a variable in subsequent analyses. Because of its importance to the servicing policy, the term will be repeatedly mentioned.

Payload design information evolved from several sources. In the final selection of data, it should be recognized that a certain degree of engineering judgment was required to compile a sufficiently complete set of data to support trade studies. The major source of payload design information was developed by reconfiguring the NASA Earth Observatory Satellite (NE2-38 EOS) to be space serviceable. This satellite is sufficiently large and complex that design envelopes based upon modularization will encompass a majority of the remaining satellites. Consequently, extrapolation to other satellites should inherently be conservative. The reconfiguration was based upon the initial work performed by Aerospace on the Defense Support Program Satellite, utilizing detail design approaches where applicable. The principal reason for this selection is that the payloads are modularized around a 3.0-m (10-ft) diameter ring frame. The entire payload will fit into a volume of 4.6 m (15 ft) in diameter by approximately 1.5 to 2.4 m (5 to 8 ft) in depth. With this approach, the payloads can be assembled in the Shuttle payload bay as shown in Figure 12. This should improve the logistic vehicle utilization mentioned previously. Other payload data from previous analyses of SAMSO programs was used in arriving at reliability and weight estimates.

A view of the baseline EOS (Ref. 15) is shown in Figure 13. The reconfigured EOS is shown in Figures 14 and 15. The mission equipment sensors have been packaged as independent modules. The remaining modules accommodate subsystems. Several alternatives are available in terms of new mission equipment, alternate attitude control systems, etc., but for the purpose of this study, this design is sufficient to bracket module sizes and weights. The payload weight increased from 1,724 to 2,313 kg (3,800 to 5,100 lb). A more compact design could be achieved, but this approach was considered to be reasonable and conservative. A schematic of the data bus interfaces is shown in Figure 16. Each module was defined to the component level to allow development of reliability block diagrams. An example is shown as Figure 17. The Weibull parameters shown are used in Section 3 to predict the random failure times.

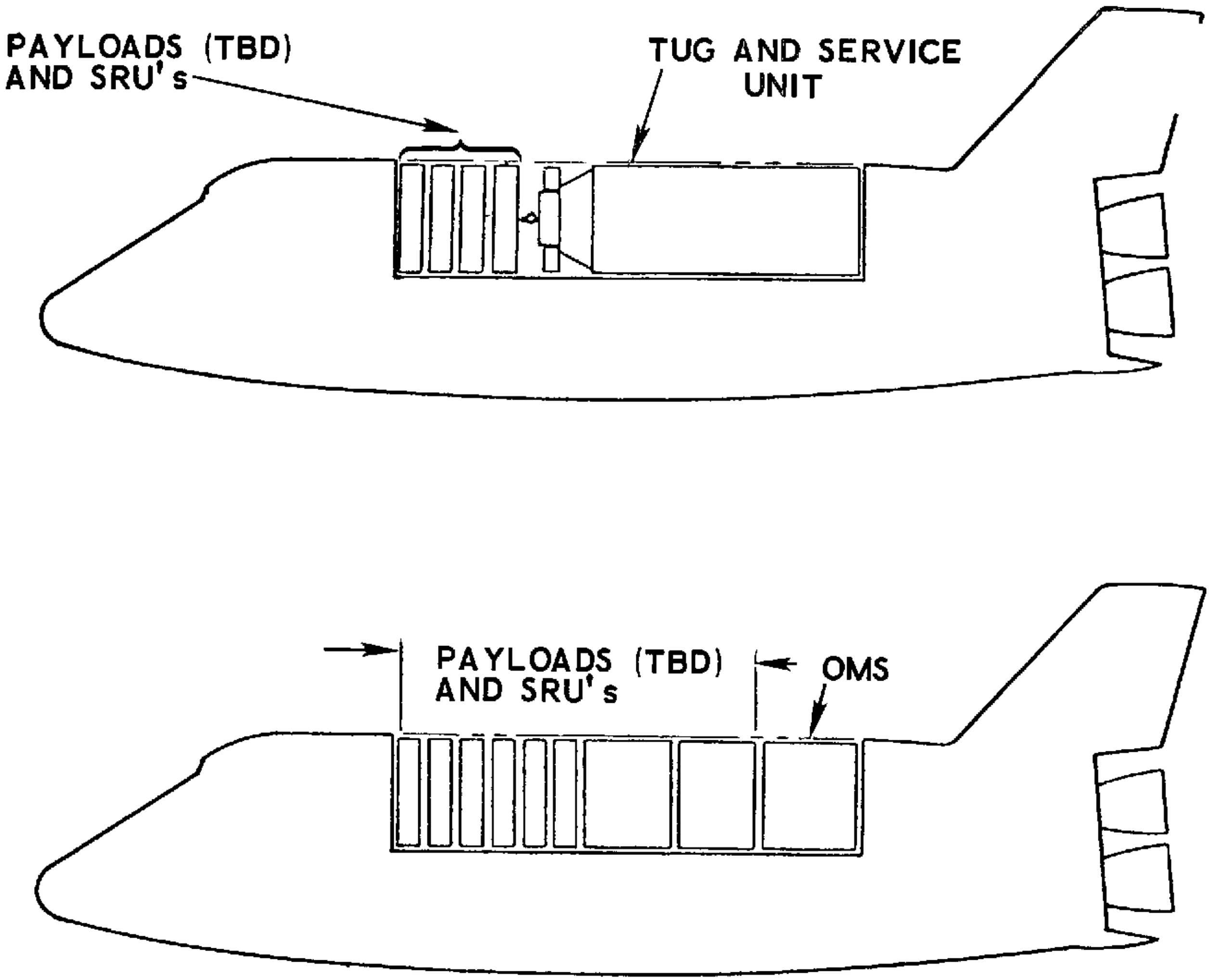


Figure 12. Shuttle Payload Bay Considerations

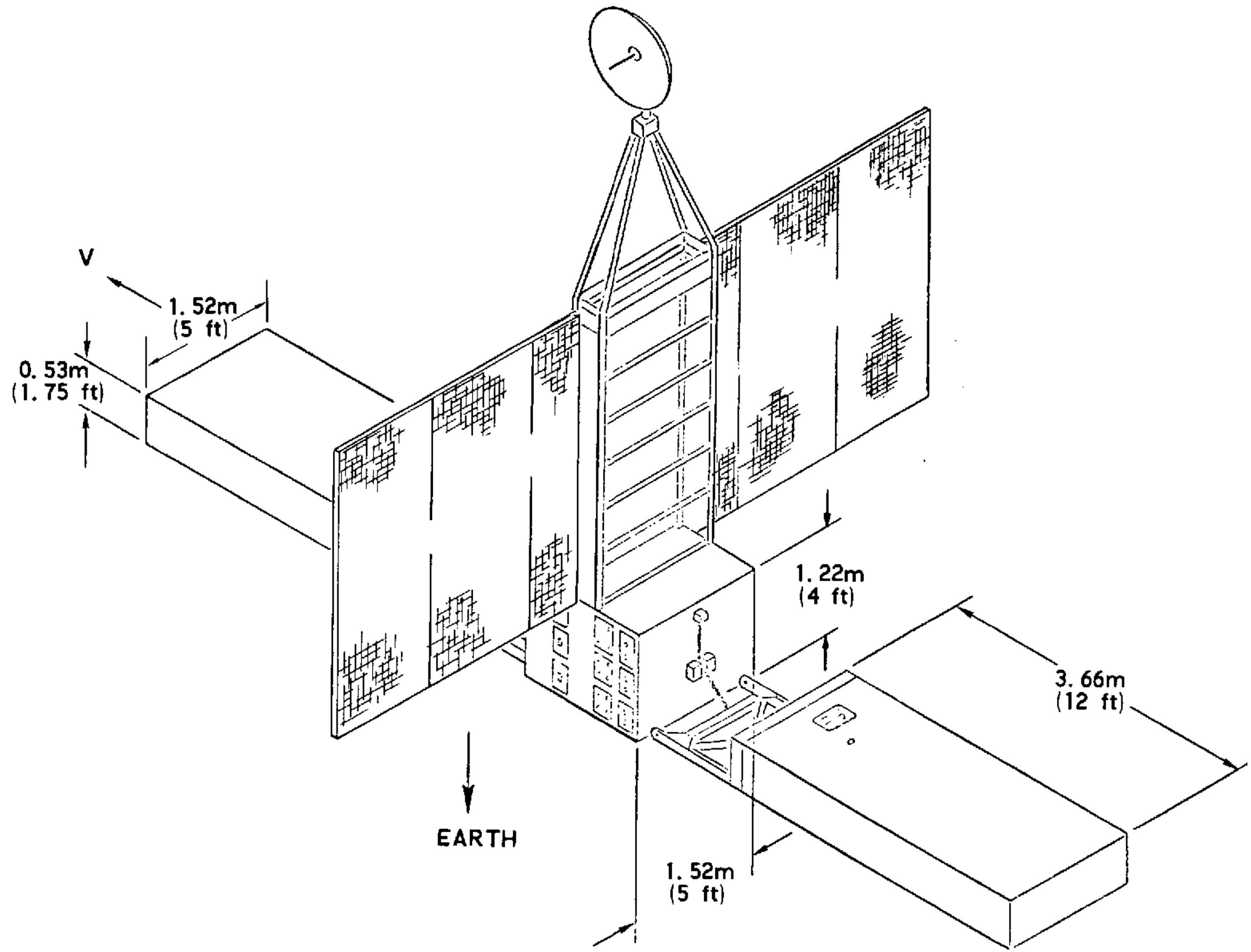


Figure 13. Baseline EOS Design

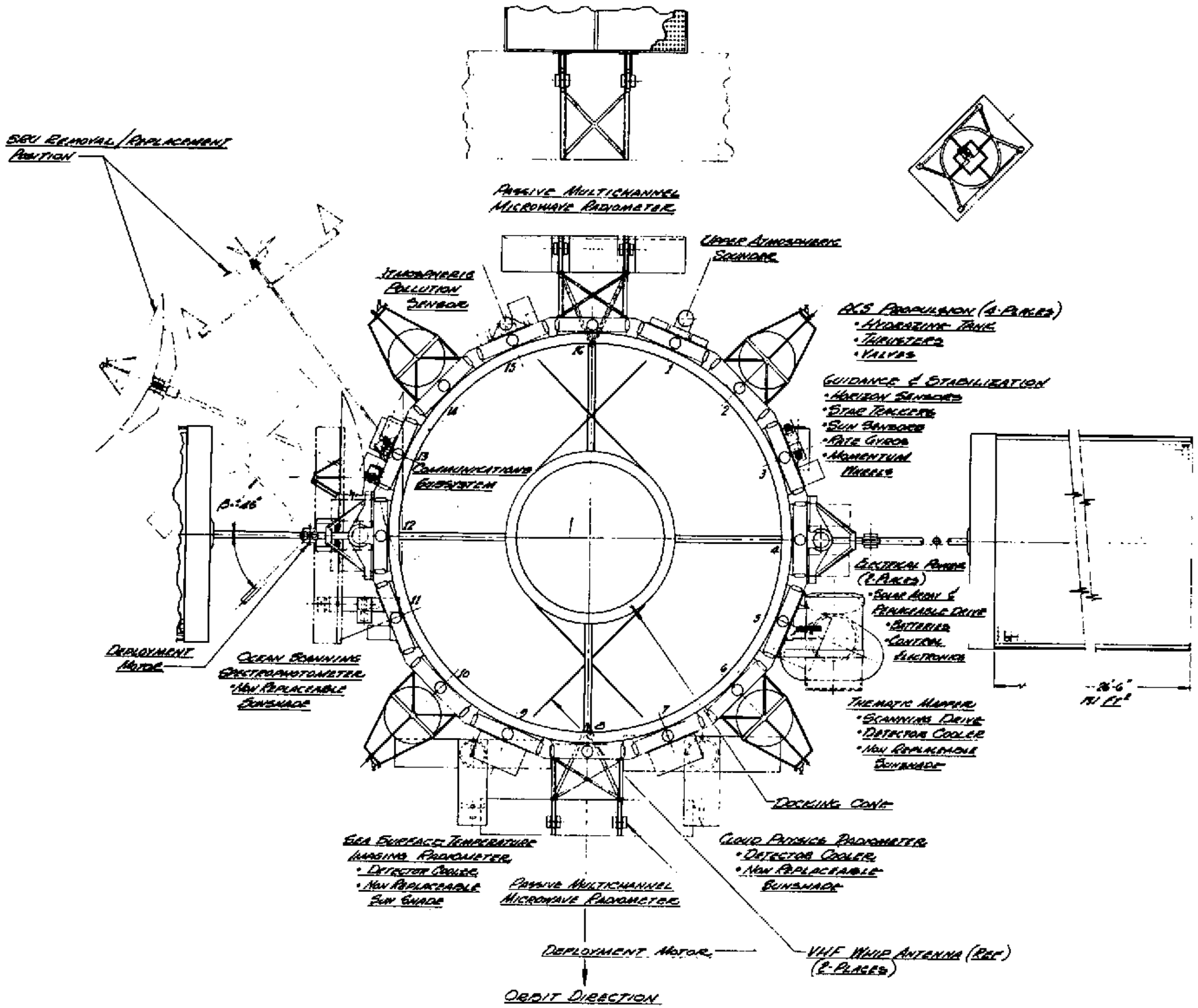


Figure 14. Space-Serviceable EOS (Top View)

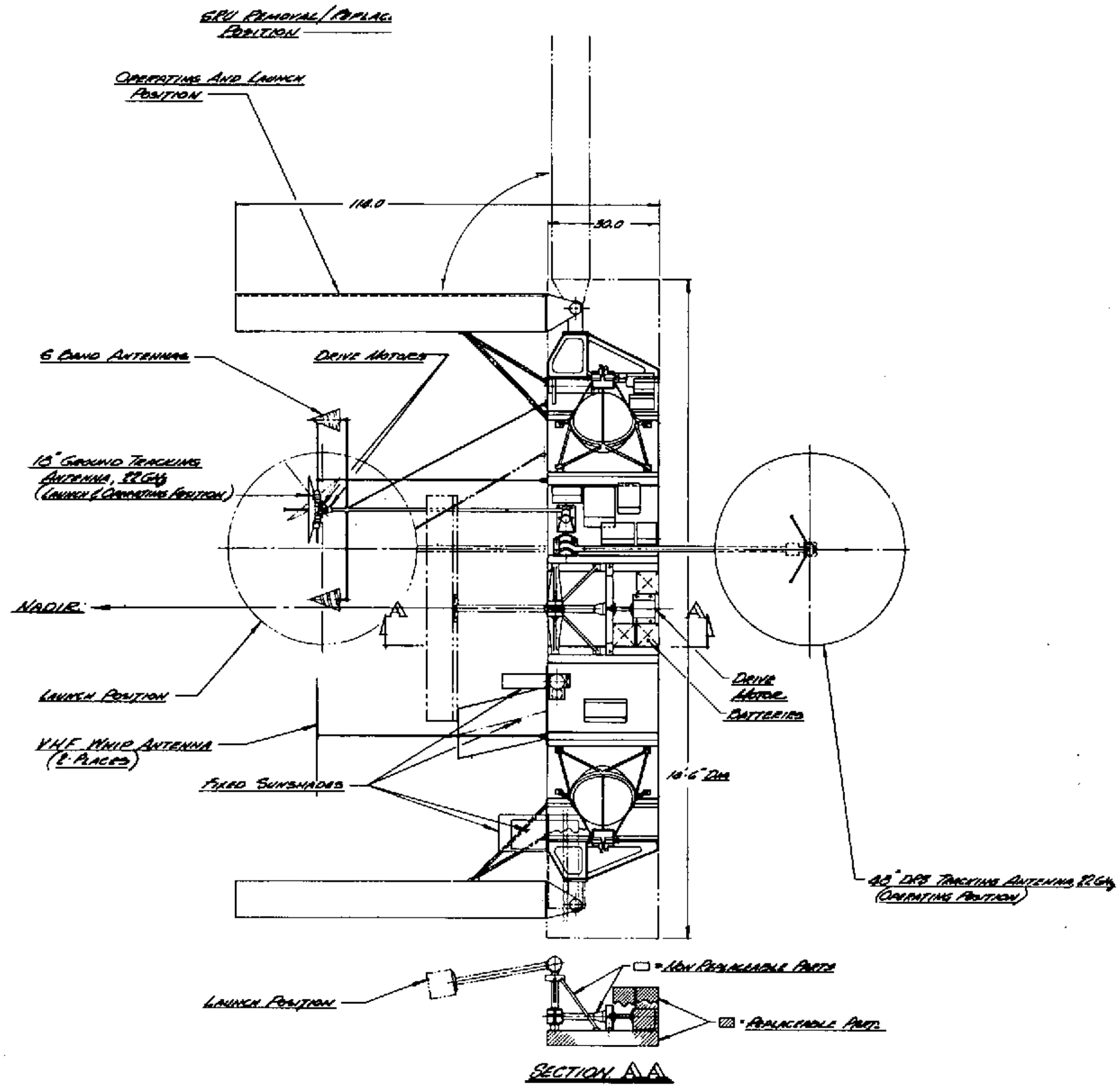


Figure 15. Space-Serviceable EOS (Side View)

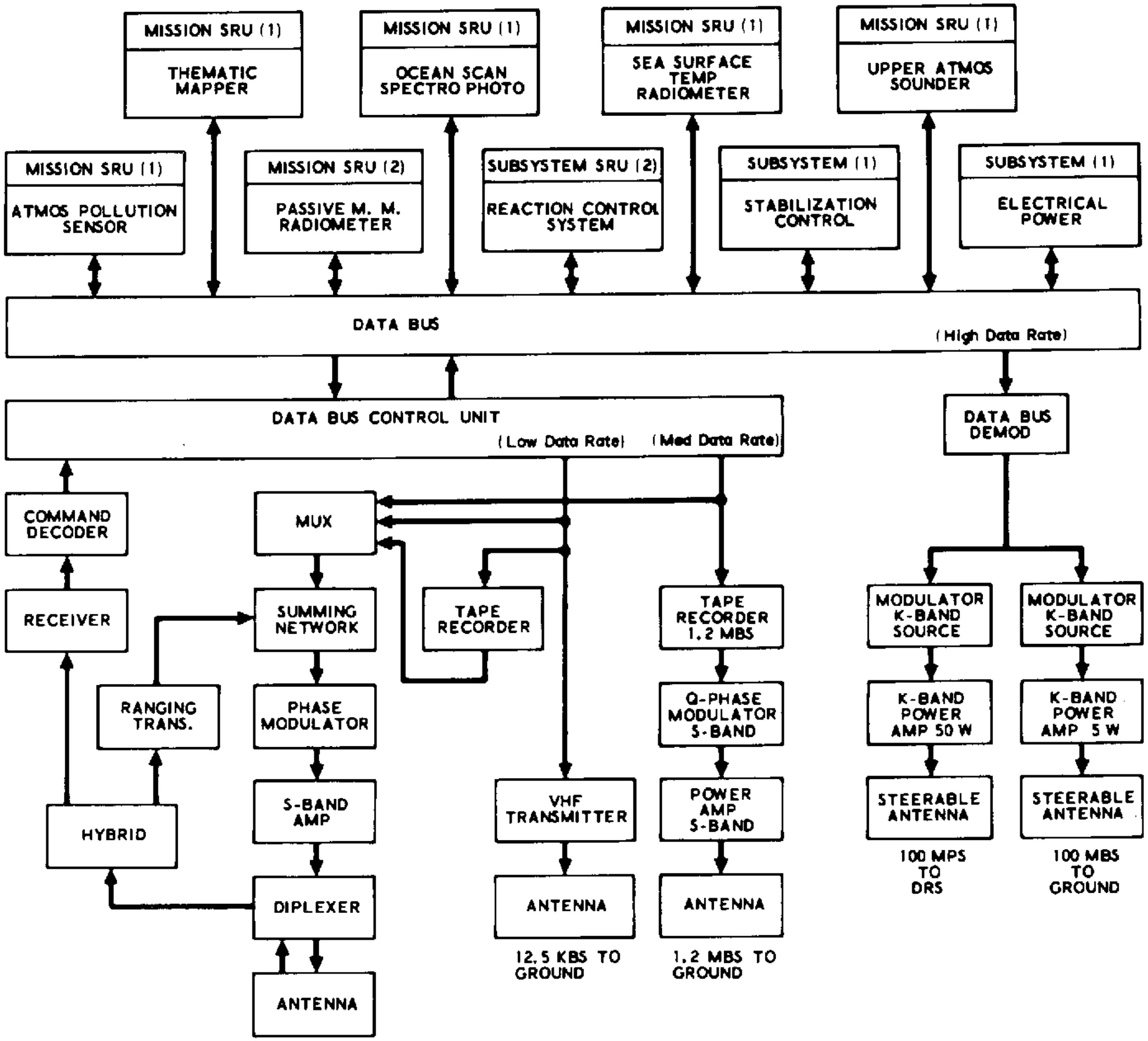
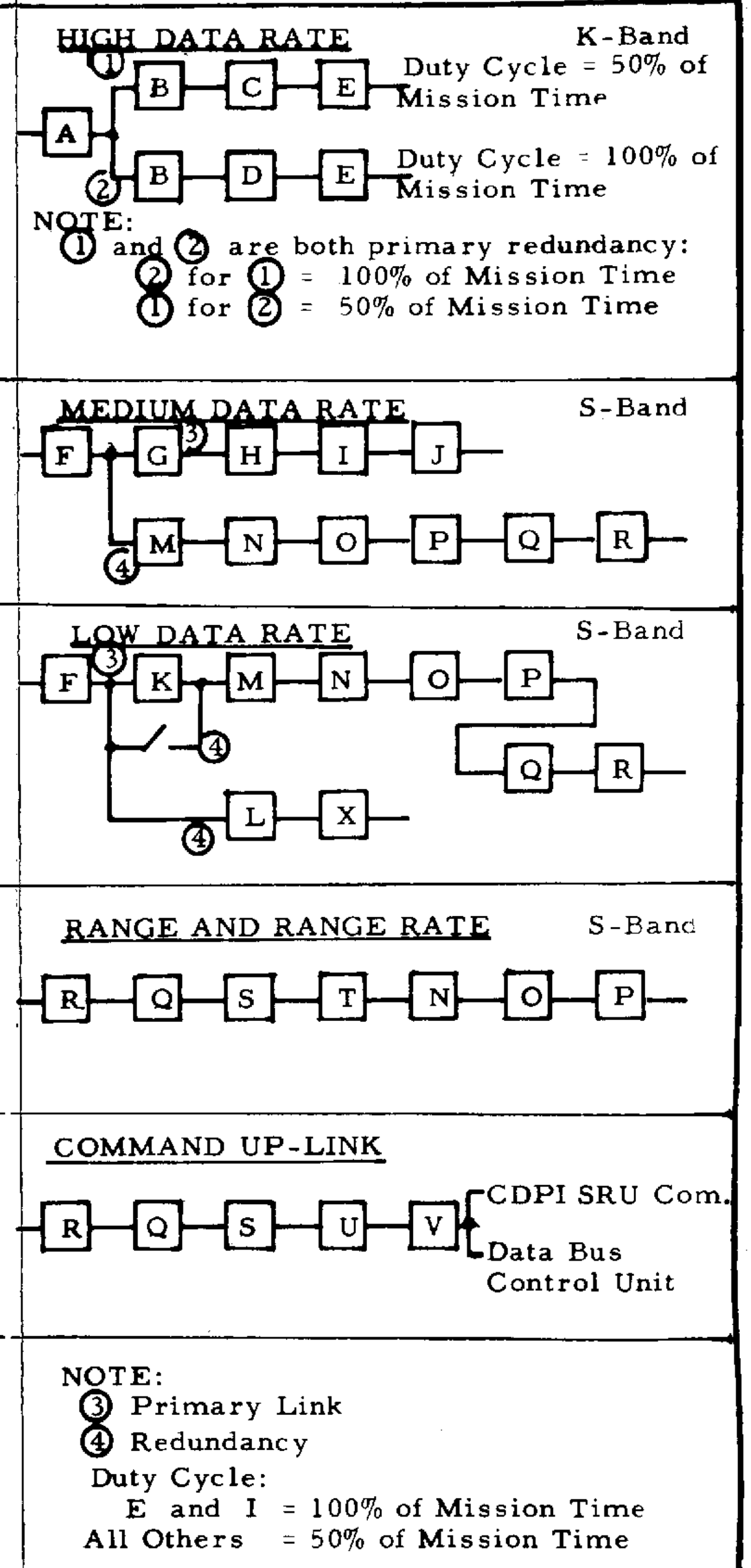


Figure 16. EOS Data Bus Schematic

(A) CODE	LMSC CODE	MODULE NAME	ITEM	EQUIPMENT	QNTY	WEIGHT (LBS) Item / Total	FAILURE RATE (X 10^{-9})	WEIBULL PARAMETER α	β	DESIGN LIFE (Yrs)	REL (at Design Life)
		Command, Data Processing, Instrumentation Subsystem	A	Data Bus Demodulator	1	1.0	4,000(1)	5.74	1.1004	7	.2864
			B	Quadriphase Modulator and K-Band Source	2		4,000(1) ea				
			C	K-Band Power Amplifier, 5 Watts	1	93.0	8,000(1)				
			D	K-Band Power Amplifier, 50 Watts	1		14,000(3)				
			E	Steerable K-Band Antenna Incl Servo & Electronics	2		5,600(3) ea				
			F	Data Bus Control Unit	1	12.0	7,000(1)				
			C	Tape Recorder, 1.2 M Bit/Sec and Control Unit	1	30.0	14,000(2)				
			H	Quadriphase Modulator and S-Band Source	1		1,000(1)	7.0306	1.0098	7	.3692
			I	Power Amplifier, S-Band	1	17.5	1,500(1)				
			J	Antenna, S-Band	1		100(1)				
			K	Tape Recorder, Low Data Rate, and Control Unit	1	10.0	14,000(2)				
			L	VHF Transmitter	1	4.0	2,000(4)	7.2083	.9534	7	.3625
			X	VHF Antenna	1	0.5	100(4)				
			M	Multiplexer	1		1,500(4)				
			N	Summing Network	1		1,500(4)				
			O	Phase Modulator	1		1,000(1)				
			P	Power Amplifier, S-Band	1	38.5	1,500(1)				
			Q	Diplexer	1		200(1)				
			R	Antenna, S-Band	1		100(1)				
			S	Hybrid	1		40(1)				
			T	Transponder, Range & Range Rate	1		1,500(1)	19.5	1.0008	7	.6989
			U	Receiver, S-Band and Signal Conditioner	1		6,500(1)				
			V	Command Decoder	1	2.5	5,000(1)				
				Mounting and Wiring		29.0					
				Total:		238.0					
								9.6507	.9990	7	.4840

BLOCK DIAGRAM



(1)SSDSP (2)HEAO (3)TRW DSP ØIIB Study (4)Estimate (5)PRC D-1864 (6)TRW In-Space Servicing Study (7)FLEETSATCOM

Figure 17. Typical SRU Reliability Data

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Before going into the mission equipment modularization, it is necessary to identify those payloads which may benefit by use of space servicing. A typical set of missions is shown in Figure 18. This figure identifies the payload, when it is deployed, when block changes have been scheduled, and when the payload is to be retrieved for refurbishment. This schedule was developed from the information in Reference 5. The satellites of interest can be further subdivided into generic design groups as shown in Table 4. Eight programs are of the ComSat type, having characteristics similar to Intelsat IV. Ten programs fall in the earth observations earth resources group, each having similar equipment. Seven programs are primarily scientific in nature and must be treated on an individual basis, although there are direct similarities within this set. Four additional programs use small satellites, scheduled on one- to two-year launch centers. These can be treated as single modules to be deployed with other modules but not to be serviced if a failure occurs.

Allocation of mission equipment modules to these payloads has been performed based upon the available information in References 1 and 2. A typical set of assignments is shown in Table 5. Although similar equipment may be employed, it is reasonable to expect the users to be interested in different applications such as number and type of spectral bands. A thermal analysis indicated that solid cryogenic cooling was preferred to allow flexibility in module applications. This has been included in the module weights. However, an additional weight for base plate, interconnects, tracks, etc. of 22 kg (48 lb) must be added to each module shown to arrive at the total weight to be serviced.

The reliability definitions are the major point of concern. The sophisticated sensors employed for earth observations have a current operating life approximating six months. Extrapolating to the time period of 1980 may support an upper bounds judgment of a two-year design life. It appears impractical to expect longer time periods. It also is impractical to enhance this life by adding redundancy, because of the wearout nature of the failure modes. Deterioration of the mission data simply progresses to the point of being unusable. Redundant modules (sensors) could be employed

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Table 4. NASA/Non-NASA Space-Servicing Candidate Payloads

- SINGLE MODULE SATELLITES

  / NC2-47 ONE/YR - EACH SATELLITE UNIQUE
  / NC2-48
  / NA2-1
  / NA2-2

- SATELLITES WITH RELATED CHARACTERISTICS

INTELSAT - IV TYPE (60)	EARTH OBS/RESOURC.(10)	SCIENTIFIC (UNIQUE) (7)
NCN-7	NE2-38	NA2-11
NCN-8	NE2-40	NP2-13
NCN-9	NE2-41	NP2-14
NCN-10	NE2-42	NP2-16
NC2-49	NE2-43	NP2-18
NC2-50	NE2-39	NP2-19
NC2-46	NEO-15	NE2-45
NC2-51	NEO-11	
	NEO-16	
	NEO-7	

OPERATIONS ANALYSIS

SATELLITE OPERATIONAL PERIODS - I

PAYLOAD					OPERATING PERIOD		
CODE	NAME	ORBIT	WT(LB)	NO.	79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97	REL SAT	NOTES
NC2-46	ATS-SYNC	19.3/0	3000	1		NC2-51	R&D PROGRAM - EACH PAYLOAD IS DIFFERENT. MISSION EQUIPMENT CHANGED EVERY TWO TO THREE YEARS.
NC2-51	SYSTEM TEST SATELLITE	19.3/0	2860	2	1 1 1 1	NC2-46	SYSTEM DEMONSTRATION AND OPERATION
NC2-47	SM APP TECH	19.3/0	300	1		NC2-48	EXP EQUIP DEV - 1 YR LIFE
NC2-48	SM EARTH APPL	300/3000 90°	300	1		NC2-47	EXP EQUIP DEV - 1 YR LIFE
NCN-7	COMSAT	19.3/0	1420	3			INTELSAT IV - OPERATIONAL 3 SAT DEPLOYED 1978
NCN-8	U.S. DOMSAT	19.3/0	3425	3	1 2 1 2 1	NCN-7	2 DEPLOYED IN 78, 1 DEPLOYED IN 79 - SUB-SEQUENT DEPLOYMENT SHOWN
NCN-9	FOREIGN DOMSAT	19.3/0	1000	2	2 6 2 2 2	NCN-7 NCN-8	2 SAT/COUNTRY AT VARIOUS INCLINATIONS 0 TO 28° MISSION EQUIP SIMILAR TO INTELSAT IV
NCN-10	NAV & TRAFFIC CONTROL	19.3/5 A 16-30/29 B	700 EA	5	3 A B	NCN-7	5 SAT REQ WITH 2 DIFF ORBITS - 4 - A, 1 - B.
NC2-49	TDRS	19.3/0	1760	3	3	NCN-7	OPERATIONAL IN 78
NC2-50	DISASTR WARN	19.3/0	1760	2	1 2	NCN-7	DEPLOY ONE SAT IN 78

○ INITIAL SATELLITE DEPLOYMENT - NUMBER
△ PROGRAMMED CHANGE OF MISSION EQUIPMENT

Figure 18. Typical Satellite Operational Periods

FOLDOUT FRAME

FOLDOUT FRAME 2

Table 5. Typical Mission Equipment Assignments

MISSION CODE NUMBER	PAYLOAD	TYPE OF SENSOR	SENSOR CODE NUMBER	WEIGHT kg (lb)	COMPLEXITY	STATE OF DEVELOPMENT	WEIBULL PARAMETERS α (YR)	β	DESIGN LIFE (YRS)	RELIABILITY AT DESIGN LIFE
NE2-43	Sync Earth Ob Satellite/Proto	IR & Visible Radiometer	NE2-431	155 (343)	3	4	2.70	1.0	2	.475
		Vert Temp Profile Rad	NE2-432	116 (257)	2	4	3.84	1.0		.600
		Space Environ Sensor	NE2-433	39 (86)	2	3	4.00	1.0		.625
		Data Collection System	NE2-434	65 (143)	1	3	6.77	1.0		.750
		High Spectral Resol Rad	NE2-435	259 (571)	3	5		1.0		.450
NE2-45	GEOPAUSE	Radar Altimeter	NE2-451	18 (40)	2	3	6.25	1.0	3	.625
		Triaxial Magnetometers	NE2-452	18 (40)	2	3	6.25	1.0		.625
		Transponder Package	NE2-453	20 (45)	2	3	6.25	1.0		.625
NP2-13	Explorers-Upper Atmosphere	Electron Multiplier, Current Collector & Electric Field Detector	NP2-131	11 (25)	2	4	1.96	1.0	1	.600
		UV Dectector	NP2-132	7 (15)	2	4	1.96	1.0		.600
		VLF Radio Receiver	NP2-133	7 (15)	2	3	2.08	1.0		.625
		Mass Spectrometer	NP2-134	7 (15)	2	2	2.32	1.0		.650
		Magnetometer	NP2-135	7 (15)	2	2	2.32	1.0		.650
		Pressure Sensor & Drag Device	NP2-136	7 (15)	2	3	2.08	1.0		.625
NP2-14	Explorers-Medium Altitude	Electron Multiplier, Current Collector & Electric Field Detector	NP2-141	11 (25)	2	4	1.96	1.0	1	.600
		UV Detector	NP2-142	7 (15)	2	4	1.96	1.0		.600
		VLF Radio Receiver	NP2-143	7 (15)	2	3	2.08	1.0		.625
		Mass Spectrometer	NP2-144	7 (15)	2	2	2.32	1.0		.650
		Magnetometer	NP2-145	7 (15)	2	2		1.0		.650
		Pressure Sensors & Drag Device	NP2-146	7 (15)	2	3	2.08	1.0		.625
NP2-16	Gravity & Relatively Set-LEO	Precession Gyros	NP2-161	23 (50)	3	4	1.33	1.0	1	.475
		Star Telescope	NP2-162	68 (150)	2	4	1.96	1.0		.600
		Magnetometers	NP2-163	11 (25)	2	3	2.08	1.0		.625
		Star Trackers	NP2-164	11 (25)	2	3	2.08	1.0		.625

on high priority satellites, but the dormant failure rates have been estimated to be between 25 and 50 percent of the active failure rate (Ref. 16). Consequently, redundancy might add one more year of operation at best. Therefore, the mission equipment was treated as non-redundant modules. Mission equipment definitions for ComSats were developed based upon experience with in-house Aerospace programs.

The LMSC standard subsystem modules were also investigated to provide a basis of comparison with this design effort. Reliability block diagrams were prepared and the estimated reliability developed. Application of the modules to individual payload programs was taken from the LMSC reports (Ref. 3). Combining these with the mission modules provided the definition of each complete payload to be used in the space-servicing analysis of Section 3.

The final element in the design process is the service unit attached to the front of the Tug. This design was developed for the Defense Support Program (DSP) study and has been adapted in toto here. A detailed description is given in Volume III of this report. The service unit is shown in Figure 19, consisting of replacement modules around the periphery of an indexing ring frame. At least one spare slot exists to accommodate the failed module. After removing the failed module, the ring frame indexes such that the replacement module is aligned properly with the payload. The module is then translated into the payload, automatically engaging electrical contacts. The design approach is shown in Figures 20 and 21. Numerous design approaches by other contractors have been postulated, but in general for the purpose here, the only important factor is the weight. The design weight for this approach has been estimated at 91 kg (200 lb).

Whatever design is selected should provide for a mixture of module installations or one cannot take advantage of multiple servicing operations. This particular design uses very little Shuttle payload bay volume, and could, if necessary, be collapsed further. In addition, the layout is such that if redundancy of any actuation mechanisms is required there is adequate space available. A further extension of this design deserves consideration to allow both payload deployment and servicing functions to

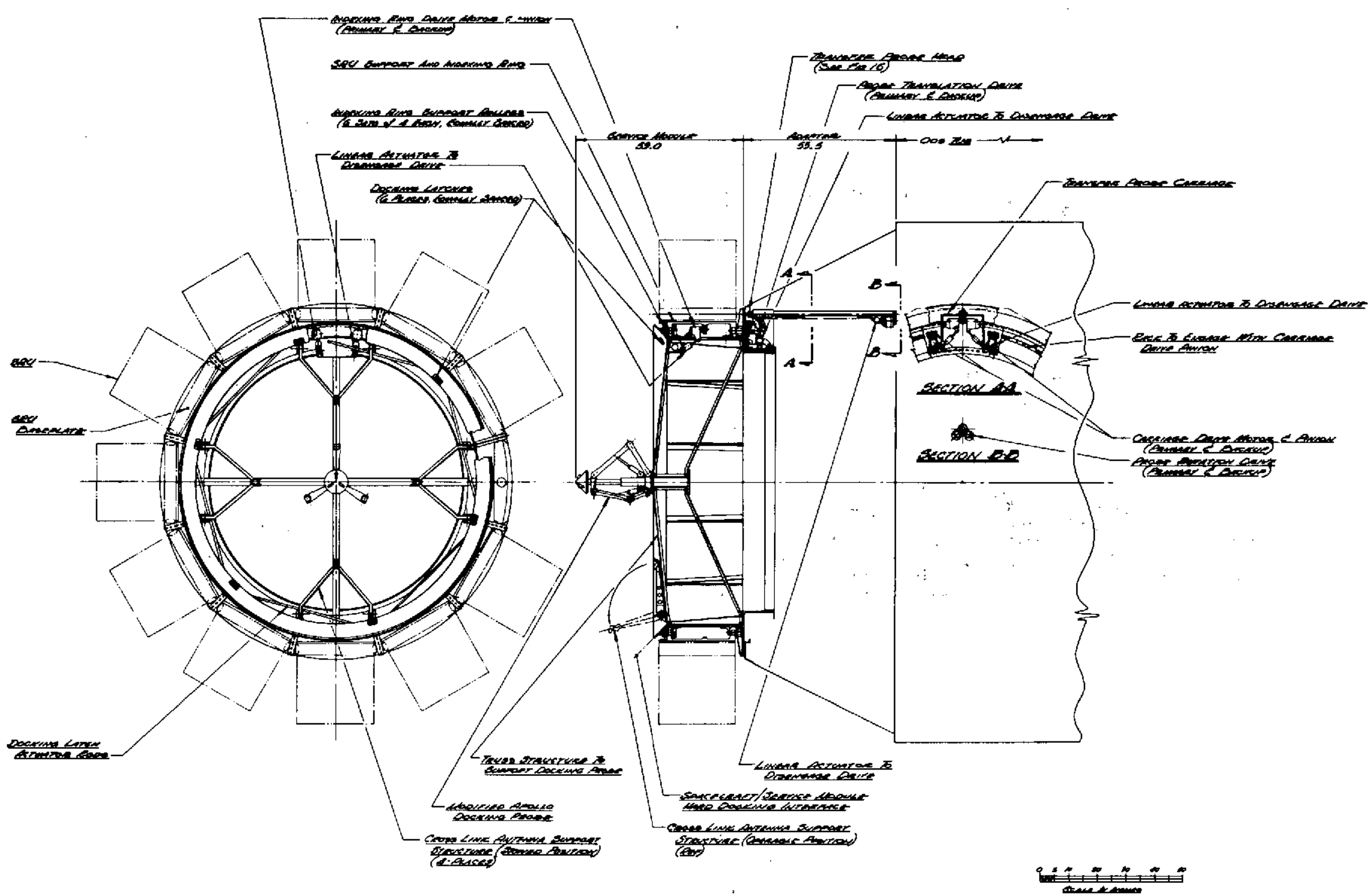

Figure 19. Space-Servicing Unit/Lug Arrangement

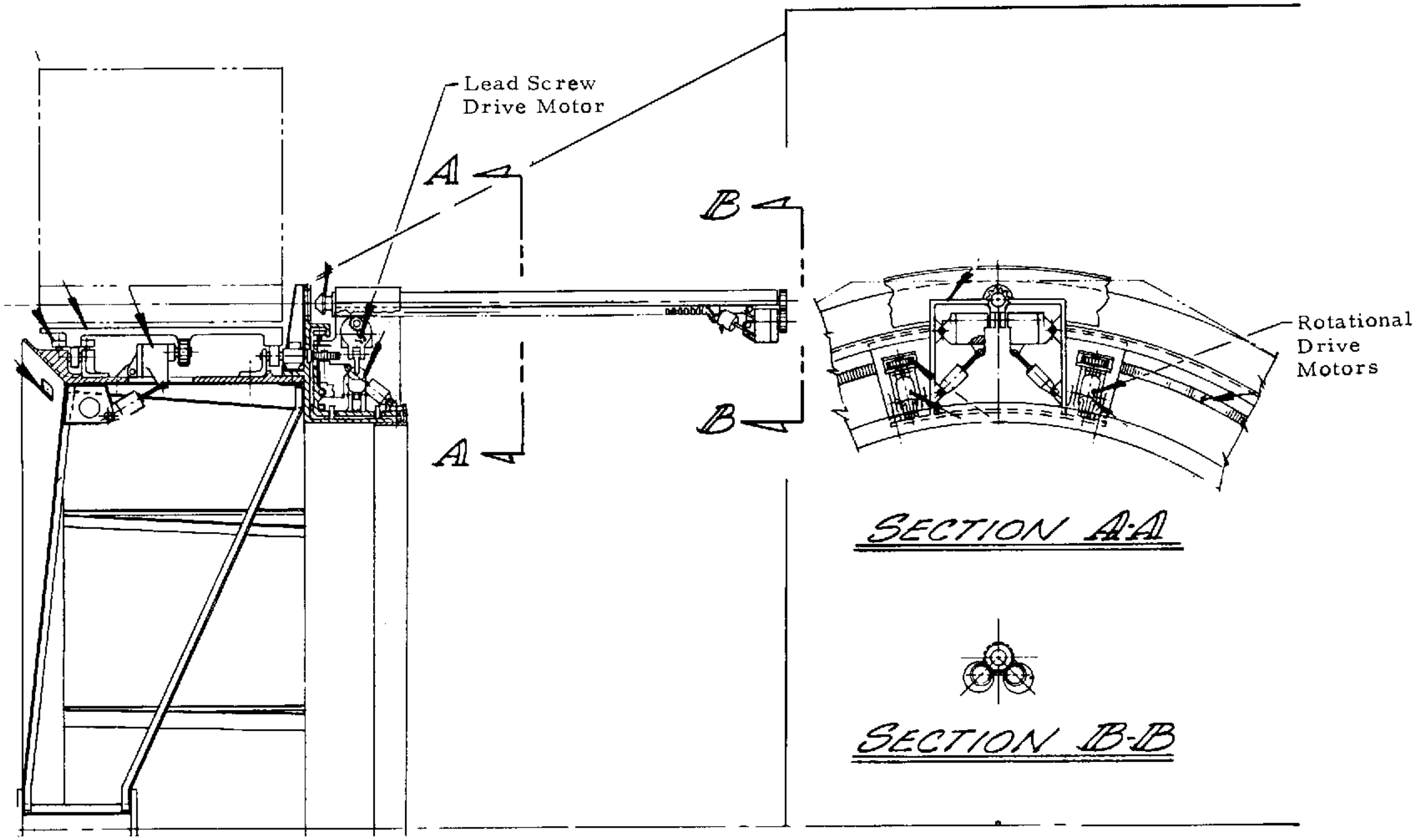

Figure 20. Detail of Ram Mechanism

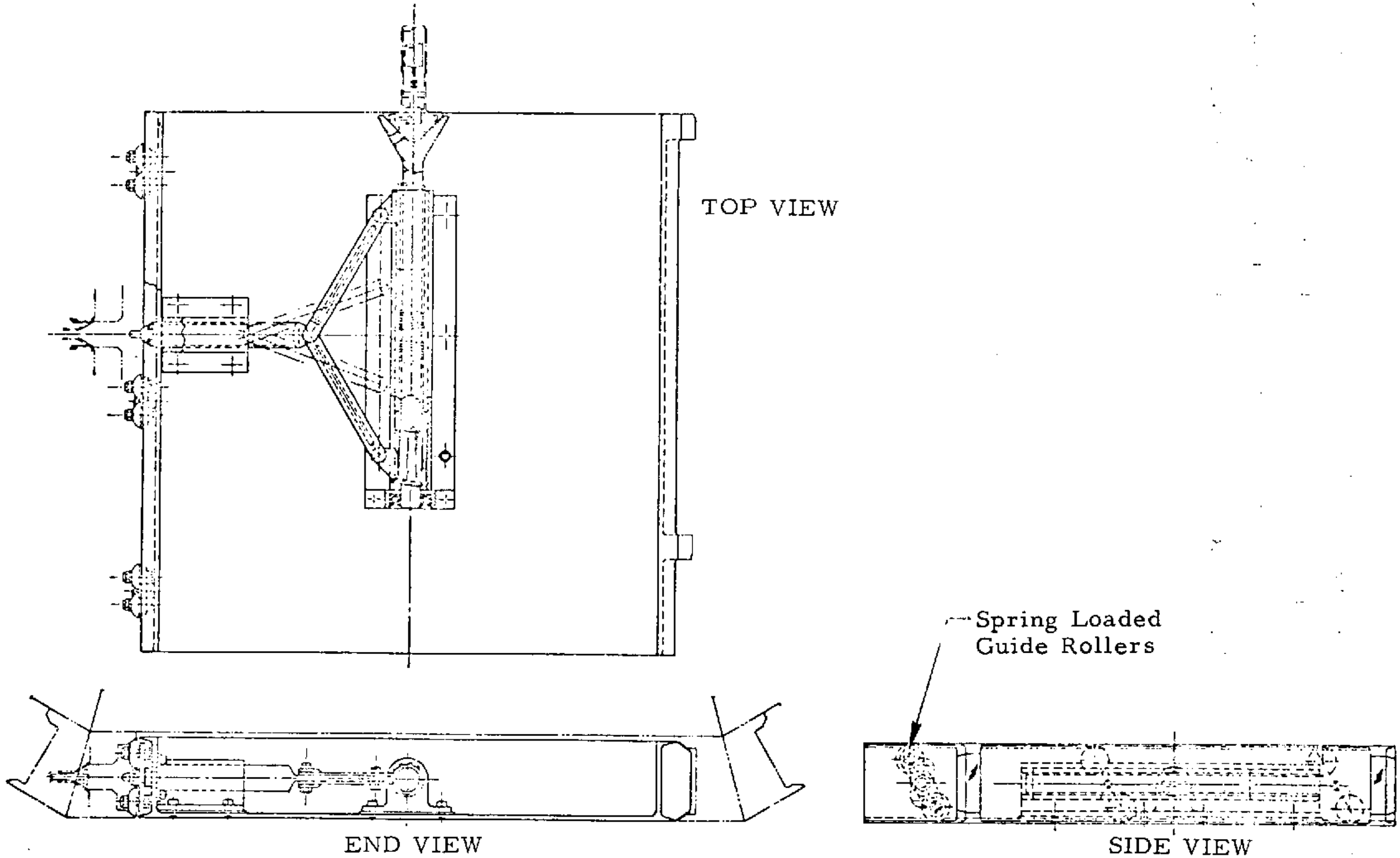

Figure 21. Detail of Baseplate Mechanism

be performed by the same mission. This has not been addressed as yet but there is no obvious reason why a payload could not be mounted on the front of the servicing unit by one of several means. The new payload would be deployed first, leaving the service module unhindered for servicing operations.

3. SPACE-SERVICING CONCEPTS

Numerous approaches to space servicing can be postulated depending upon such factors as availability, logistics costs, standardization of SRUs, etc. The purpose of this section is to describe the analysis technique for addressing the parameters and to define the ground rules used in the two cases analyzed in this study. An extensive amount of work is yet to be performed; consequently the information developed under this study can only point toward trends relative to the cost of future operations if space servicing is employed. The major points of concern can be summarized by the following questions.

Will total program costs be reduced by space servicing?

Will individual payload program costs be reduced by space servicing?

Can system availability be maintained?

Space servicing will have a major impact on payload and logistic vehicle designs. This impact in risk and cost must be weighed against potential gains. The approach taken to perform this analysis is shown schematically in Figure 22. This is a simplification of a rather complex process but should serve as a basis for the results presented in Section 4. The basic payload data obtained as the first step was described in Section 2. This information is used to develop generic sets of subsystem and mission equipment modules, weight, reliability, and costs. Candidate payloads from the NASA mission model are then constructed from the module inventory, allowing for basic structure, consumables, etc. as necessary to achieve a representative weight for each payload program. The estimated time to failure is then developed for each module, both space replaceable and non-replaceable, by a random number process. For the space replaceable unit, this defines when servicing is needed, and the replacement module is then placed on the manifest to be shipped to orbit. When a sufficient load has been established, the failed module is replaced and returned for refurbishment. The cycle is repeated over the time period of interest.

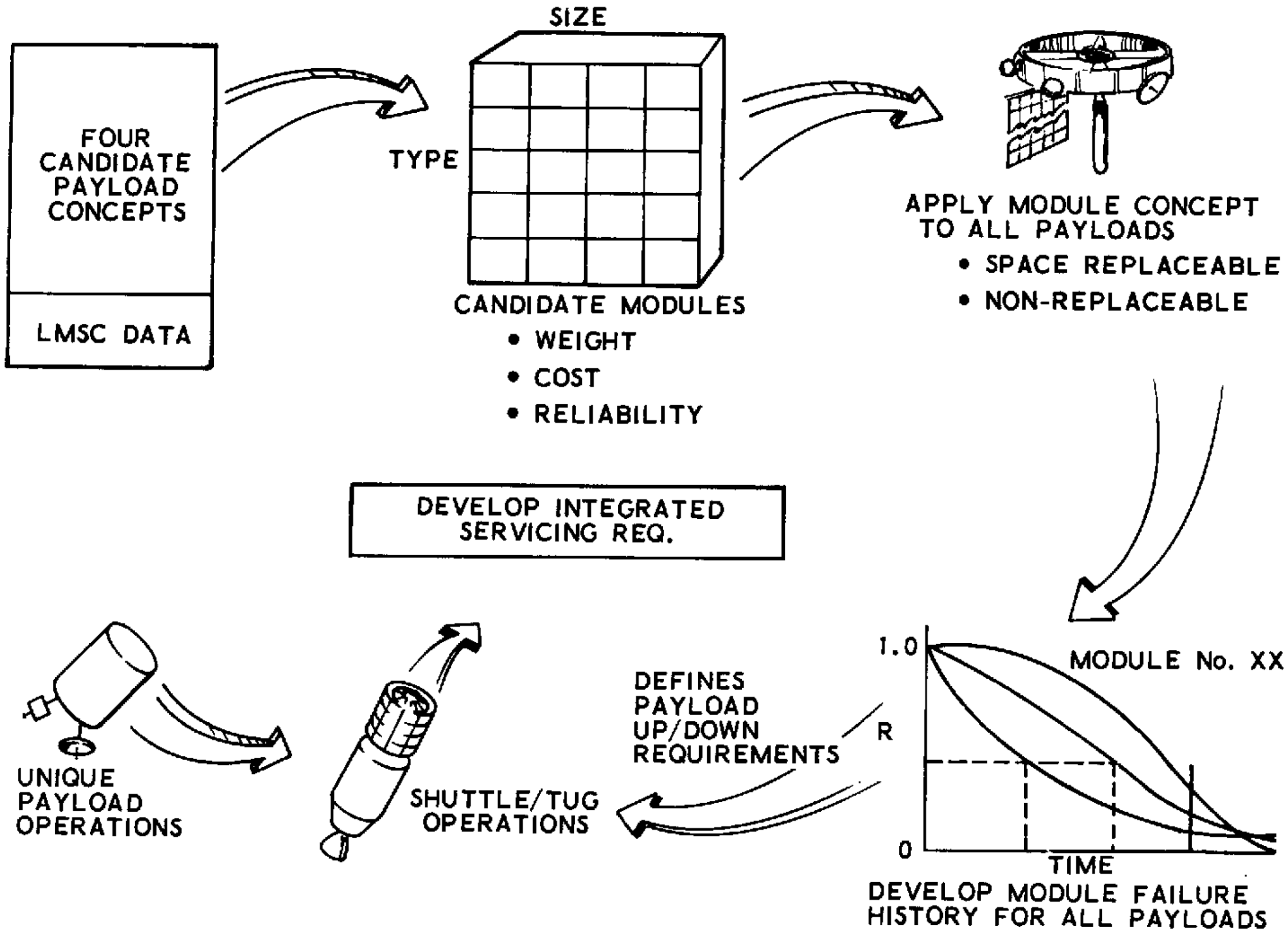

Figure 22. Space-Servicing Analysis Approach

The results are integrated with other payload programs which are not space serviceable to obtain total traffic requirements. The logistic costs can then be apportioned between the various programs according to weight or volume criteria. Further, although some payloads may not be serviceable, they may be modularized. The integrated number of modules, by type, is required to develop the cost profile and production rate.

Certain ground rules have been employed in the process of selecting candidate payloads for space servicing. Planetary payloads have been excluded for obvious reasons; however, if cost benefits accrue, the payloads could be modularized. Man-tended programs such as High Energy Astronomical Observatory (HEAO) and the Large Stellar Telescope (LST) were excluded because dedicated servicing has been scheduled a priori. Also there is little commonality in the design approach with automated payloads. Space station and sortie modules have been excluded for the same reasons. Finally, small payloads such as Explorers which weigh approximately 136 kg (300 lb) have been treated as single modules and in general will not be serviced. In the sample cases analyzed under this study, the payloads were further restricted to synchronous equatorial orbit to keep the effort within scope. A complete analysis would encompass the total set of candidate payloads.

The next point to be considered is the selection of a space-servicing policy. This is in effect a definition of criteria to be employed to decide when and what satellites are to be serviced. Various policies have been postulated, each having certain benefits, but until they can be applied to a specific mission model, it is not possible to judge their merits. The simplest policy is to replace modules after a failure has occurred and only replace the failed SRUs. In this event, a large number of logistic flights would be required with inefficient load factors.

It can also be anticipated that two to four weeks of satellite down-time (unavailability) will occur before servicing can be effected. This assumes that replacement modules are available in stock and that the next available launch date can be scheduled for servicing.

This policy can be extended further by stipulating a loading policy for the logistic vehicle. For example, Tug operations can be constrained until a weight load factor equals or exceeds 80 percent of the vehicle's performance capability. This improves the efficiency of Tug operations, but the first satellite to experience a failure may wait months or years before other random failures accumulate modules sufficient to initiate a flight. Another alternative is to impose no longer than a defined unavailability, such as six months. At this time, if the load factor has not been achieved, the service operation is initiated anyway. It can also be assumed that servicing of existing satellites can be coupled with the initial deployment of a new satellite.

Other policies point toward preventive maintenance servicing. Satellites to be serviced are designed to provide a warning signal prior to an outage occurrence. This triggers the service operation. In this way there is a high probability that at least one string of modules in a satellite is functioning continuously. This requires a high degree of redundancy, imposing higher weights and cost, but may be justified where high availability is required.

Further application can be made to a system of satellites. If a failure or warning signal occurs in one satellite, it is reasonable to expect the same condition to propagate to the remaining satellites in the system. Consequently, when one satellite is serviced, all satellites in the system are serviced. This generally results in a high availability but increases the number of modules in the inventory. If, however, the failure is not a design problem but is random in nature, a large number of modules would be replaced unnecessarily.

The ultimate in redundancy is achieved when, instead of spare modules, a spare satellite is placed in orbit. As an example, a system requiring three at all times would be composed of four. When one satellite fails, the spare is employed until servicing of the failure has been completed. The initial deployment results in higher costs but availability approaches 100 percent provided the spare satellite is in the correct orbital position to assume the activity of the failed satellite.

The options available for space servicing are extensive and probably in the final analysis will be some mix of criteria which reflects the availability requirements of each payload program. The final judgment has to revert to economics to the payload user. For this reason, it has been proposed that a statistical computer program be developed for use in performing tradeoffs of servicing policies. A specification for this program was prepared (Vol. IV) for implementation as a follow-on effort. The current study was limited to the following two cases, performed manually.

A CASE 1: LMSC STANDARD MODULES

The candidate set of payloads to be serviced was limited to those shown in Table 6. The modular composition of the payloads is provided in Table 7 and based upon LMSC data (Ref. 3). The MSFC baseline Tug was used with a 91 kg (200-lb) servicing unit and assuming an availability in 1979. The mission model of Reference 5 was modified to reflect operating time periods rather than launch and retrieval schedules. The defined periods are provided in Appendix A and reflect in general a seven- to nine-year operational period for each payload program. The minimum time between Tug operations is assumed to be one month, and the Tug is limited to a mission time of seven days. When new satellites are specified for deployment in a given year, the satellites are assumed to be available on one-month centers beginning 1 January of that year. Propulsion units have been specified as having three years of propellant available. If the unit has not failed previously, it will be truncated at that time.

The servicing policy is based on replacing modules upon identification of a failure. No redundancy in the payload designs exists. The replacement SRUs will be loaded onto a Tug on a first-come first serve basis until the maximum number of modules are loaded consistent with the performance capabilities. In any event, if a full load is not available, the Tug will be launched no later than six months after the first module failure is identified. Service flights take priority over deployment of new satellites; however, where schedules permit, the two functions can be combined.

Table 6. Space-Servicing Candidate Payloads

SYNCHRONOUS EQUATORIAL ORBIT PAYLOADS					
NUMBER	CODE	NAME	NUMBER IN ORBIT	NASA	NON-NASA
1	NC2-46	Application Technology Satellite	1	X	
2	NC2-51	System Test Satellite	2	X	
3	NC2-47	Small Application Technology Satellite	1	X	
4	NCN-7	COMSAT	3	X	
5	NCN-8	U.S. Domestic COMSAT	3		X
6	NCN-9	Foreign DOMSAT	2 → 12		X
7	NC2-49	Tracking Data Relay Satellite	3	X	
8	NC2-50	Disaster Warning Satellite	2	X	
9	NE2-43	Synchronous Earth Observations (Photo)	1	X	
10	NE2-39	Synchronous Earth Observations	1	X	
11	NEO-11	Synchronous Earth Resources	4		X
12	NE2-41	Synchronous Meteorological Satellite	2	X	
13	NEO-15	Synchronous Meteorological Satellite	2		X

Table 7. Selected Spacecraft Module Assignments, Case 1

CODE NUMBER	PAYLOAD	SUBSYSTEMS (MODULES)								MISSION EQUIP		GROSS SPCRFT WT kg (lb)
		S&C		CDPI		ELEC POWER		ATT CONTROL		SENSOR		
		ITEM	QTY	ITEM	QTY	ITEM	QTY	ITEM	QTY	ITEM	QTY	
NC2-46 (NO TRUNC)	Application Technology	S&C-1	2	C-1	1	EP-1	2	AC-1	2	NC2-461 NC2-462 NC2-463	1 1	1, 674 (3, 690)
NC2-51	System Test	S&C-2	2	C-1	1	EP-2	2	AC-2	2	NC2-511 NC2-512	1	1, 172 (2, 583)
NC2-47 (NO SERV)	Small Appl Tech - Sync	S&C-3	1	C-2	1	EP-3	2	AC-3	2	NC2-471	1	577 (1, 271)
NCN-7	COMSAT	S&C-4	1	C-3	1	EP-4	2	AC-4	2	NCN-71 NCN-72	1	1, 100 (2, 425)
NCN-8	U. S. Domestic	S&C-5	1	C-4	1	EP-5	2	AC-5	4	NCN-81 NCN-82 NCN-83 NCN-84 NCN-85	1 1 1 1 1	2, 082 (4, 591)
NCN-9	Foreign Domestic	S&C-6	1	C-5	1	EP-6	2	AC-6	2	NCN-91 NCN-92	1 1	872 (1, 923)
NC2-49	Tracking Data Relay	S&C-7	1	C-6	1	EP-7	2	AC-7	2	NC2-491 NC2-492	1 1	786 (1, 732)
NC2-50	Disaster Warning	S&C-8	2	C-7	1	EP-8	2	AC-1	2	NC2-501 NC2-502 NC2-503	1 1 1	1, 132 (2, 496)
NE2-43	Sync Earth Obs/Photo	S&C-9	2	C-8	1	EP-9	2	AC-8	2	NE2-431 NE2-432 NE2-433 NE2-434 NE2-435	1 1 1 1 1	1, 566 (3, 453)
NE2-39	Sync Earth Obs	S&C-6	1	C-9	1	EP-10	2	AC-9	2	NE2-391 NE2-392 NE2-393 NE2-394 NE2-395	1 1 1 1 1	1, 574 (3, 471)
NEO-11	Sync Earth Resources	S&C-6	1	C-9	1	EP-11	2	AC-10	2	NEO-111 NEO-112 NEO-113 NEO-114 NEO-115	1 1 1 1 1	

Table 7. Selected Spacecraft Module Assignments, Case 1 (Continued)

CODE NUMBER	PAYLOAD	SUBSYSTEMS (MODULES): S&C ITEM	S&C QTY	CDPI ITEM	CDPI QTY	ELEC POWER ITEM	ELEC POWER QTY	ATT CONTROL ITEM	ATT CONTROL QTY	MISSION EQUIP: SENSOR ITEM	SENSOR QTY	GROSS SPCRFT WT kg (lb)
NE2-39	Sync Earth Obs	[S&C-1 S&C-2] 1 S&C-3	2 1 1	[CDPI-1 CDPI-4-1] 1	1 1	[EPS-1-2 EPS-5] 2 EPS-6 EPS-7	2 2 1 1	ACS-2	4	NE2-391 NE2-392 [NE2-393 NE2-394] 1 NE2-395	1 1 1 1 1	1,902 (4,193)
NEO-11	Sync Earth Resources	[S&C-1 S&C-2] 1 S&C-3	2 1 1	[CDPI-1 CDPI-4-1] 1	1 1	[EPS-1-2 EPS-5] 2 EPS-6 EPS-7	2 2 1 1	ACS-2	4	[NEO-111 NEO-112 NEO-113 NEO-114] 1 NEO-115	1 1 1 1 1	1,715 (3,781)
NE2-41	Synchronous Meteorological	[S&C-1 S&C-2] 1 S&C-3	2 1 1	[CDPI-2 CDPI-3] 1	1 1	[EPS-1-3 EPS-5] 2 EPS-6 EPS-7	2 2 1 1	ACS-2	4	[NE2-411 NE2-412 NE2-413 NEw-414] 1	1 1 1 1	1,548 (3,413)
NEO-15	Synchronous Meteorological	[S&C-1 S&C-2] 1 S&C-3	2 1 1	[CDPI-2 CDPI-3] 1	1 1	[EPS-1-2 EPS-5] 2 EPS-6-1 EPS-7	2 2 1 1	ACS-2	4	[NEO-151 NEO-152 NEO-153 NEO-154 NEO-155] 1	1 1 1 1 1	1,557 (3,432)

B. CASE 2: AEROSPACE MODULARIZATION

The same set of satellites are assumed as in Case 1; however, the modular composition is modified as shown in Table 8. Total system weights are changed considerably. The reliability estimates also differ from those of Case 1 as shown by comparison in Table 9 for representative subsystems. The fact that differences exist reflects the need for further analysis as no attempt has been made to resolve these differences due to budgetary constraints. In general, the LMSC modules tended to be higher in reliability and weight. Each satellite for this case was truncated at nine years, except for NC2-46 (ATS) which is assumed to operate over the full 1979-1997 time period. The small ATS (NC2-47) is assumed to be deployed as an expendable satellite on a yearly basis. Failure times were tracked for reference only. Truncation time for propulsion units was three years and for power units, five years. In addition, longitude placement of the satellites was assumed, based on Reference 17, to take advantage of the performance benefits of servicing payloads over limited phase angles. The assumed longitudes listed in Table 10 are reasonably representative of key placements at synchronous equatorial orbit (SEO).

The servicing policy is similar to Case 1 with minor variation. If a module of a given satellite fails within the last year of the stated service life of the satellite, the module is not replaced. The satellite was assumed inoperative until the replacement satellite was deployed the following year. Also, all replacement satellites were placed in the loading queue two months prior to the scheduled launch. In both Cases 1 and 2, retrieval of satellites at the end of their operational period was ignored to ease the burden of calculation. A gross approximation of the Tug flights required to perform this function was made for the purpose of comparing results with previous analyses which employed ground refurbishment of payloads.

Table 8. Selected Spacecraft Module Assignments, Case 2

CODE NUMBER	PAYLOAD	SUBSYSTEMS (MODULES) S&C ITEM	S&C QTY	CDPI ITEM	CDPI QTY	ELEC POWER ITEM	ELEC POWER QTY	ATT CONTROL ITEM	ATT CONTROL QTY	MISSION EQUIP SENSOR ITEM	SENSOR QTY	GROSS SPCRFT WT kg (lb)
NC2-46 (NO TRUNC)	Application Technology	S&C-2-1 S&C-4	1 1	[CDPI-1-1 CDPI-4] 1	1 1	[EPS-2-1 EPS-5] 2 EPS-6 EPS-7	2 2 2 1	[ACS-2] 1	4	NC2-461 NC2-462 NC2-463	1 1 1	1, 825 (4, 023)
NC2-51	System Test	S&C-2-1 S&C-4	1 1	CDPI-4	1	[EPS-1-7 EPS-5] 2 EPS-6 EPS-7	2 2 2 1	[ACS-2] 1	4	NC2-511 NC2-512	1 1	1, 608 (3, 545)
NC2-47	Small Appl Tech - Sync	[S&C-1 S&C-2] 1 S&C-3	1 1 1	[CDPI-2 CDPI-3] 1	1 1	[EPS-1-3 EPS-5] 2 EPS-6 EPS-7	2 2 1 1	[ACS-2] 1	4	NC2-471	1	1, 422 (3, 136)
NCN-7	COMSAT	S&C-2-1 S&C-4	1 1	CDPI-4	1	[EPS-1-5 EPS-5] 2 EPS-6 EPS-7	2 2 1 1	[ACS-2] 1	4	NCN-71 NCN-72	1 1	1, 497 (3, 301)
NCN-8	U.S. Domestic	S&C-2-1 S&C-4	1 1	CDPI-4	1	[EPS-2-1 EPS-5] 2 EPS-6 EPS-7	2 2 2 1	[ACS-2] 1	4	NCN-81 NCN-82 NCN-83 NCN-84 NCN-85	1 1 1 1 1	2, 009 (4, 428)
NCN-9	Foreign Domestic	S&C-2-1 S&C-4	1 1	CDPI-4	1	[EPS-1-4 EPS-5] 2 EPS-6 EPS-7	2 2 1	[ACS-1] 1	4	NCN-91 NCN-92		1, 185 (2, 612)
NC2-49	Tracking Data Relay	[S&C-1 S&C-2] 1 S&C-3	2 1 1	CDPI-4	1	[EPS-1-5 EPS-5] 2 EPS-6 EPS-7	2 2 1 1	[ACS-2] 1	4	[NC2-491 NC2-492] 1		1, 522 (3, 356)
NC2-50	Disaster Warning	S&C-2-1 S&C-4	1 1	CDPI-4	1	[EPS-1-7 EPS-5] 2 EPS-6 EPS-7-1	2 2 2 1	[ACS-2] 1	4	NCN-501 NCN-502 NCN-503	1 1 1	1, 701 (3, 750)
NE2-43	Sync Earth Obs/Proto	[S&C-1 S&C-2] 1 S&C-3	2 1 1	[CDPI-1 CDPI-4-1] 1	1 1	[EPS-1-2 EPS-5] 2 EPS-6 EPS-7	2 2 1 1	[ACS-2] 1	4	NE2-431 NE2-432 [NE2-433 NE2-434] 1 NE2-435	1 1 1 1 1	2, 154 (4, 748)

[ ] Modules combined into single unit

Table 8. Selected Spacecraft Module Assignments, Case 2 (Continued)

CODE NUMBER	PAYLOAD	SUBSYSTEMS (MODULES) S&C ITEM	S&C QTY	CDPI ITEM	CDPI QTY	ELEC POWER ITEM	ELEC POWER QTY	ATT CONTROL ITEM	ATT CONTROL QTY	MISSION EQUIP SENSOR ITEM	SENSOR QTY	GROSS SPCRFT WT kg (lb)
NE2-41	Sync Meteorological	S&C-10	1	C-10	1	EP-3	2	AC-11	2	NE2-411 NE2-412 NE2-413 NE2-414	1 1 1 1	823 (1,814)
NEO-15	Sync Meteorological	S&C-11	1	C-11	1	EP-12	2	AC-12	2	NEO-151 NEO-152 NEO-153 NEO-154 NEO-155	1 1 1 1 1	1,010 (2,226)

Table 9. EOS Subsystem Reliability Comparison

SUBSYSTEM MODULE	BASELINE EOS		CASE 1		CASE 2	
	WEIGHT, kg (lb)	RELIABILITY	WEIGHT, kg (lb)	RELIABILITY	WEIGHT, kg (lb)	RELIABILITY
Guidance and Stabilization	102 (255)	0.5656	216 (477)	0.6820	123 (271)	0.2578
Attitude Control	39 (85) Dry	0.7329	247 (544) Dry	0.7273	48 (106) Dry*	0.8586
Communication Data Processing	163 (360)	0.1719	149 (329)	0.3354	108 (238)**	0.2537
Electrical Power	238 (525)	0.5726	580 (1,278)	0.9887	383 (844)	0.3949

*BASED UPON 4 YEARS DESIGN LIFE DUE TO FUEL LIMIT

**DATA PROCESSING INCORPORATED IN SENSOR

NOTE: ALL RELIABILITIES NORMALIZED TO A 2-YEAR DESIGN LIFE CONDITION.

Table 10. Case 2 Satellite Longitude Placement

NO.	SATELLITE	UNIT	LONGITUDE		NOTES *
1	NC2-46 ATS Sync		90°W		
2	NC2-51 Sys Test Sat	A B	70°W 140°W		Two in system
3	NC2-47 Sm Appl Tech	A→S			No longitude constraint; deploy at first opportunity; no servicing
4	NCN-7 COMSAT	A B C	6°W 68°E 172°E		Three in system
5	NCN-8 U.S. DOMSAT	A B C	140°W 70°W 100°W		Three in system
6	NCN-9 Foreign DOMSAT	A B C, I D, J E, K F, L G H	0° 30°E 70°W 140°W 60°E 100°E 45°W 75°W	1 2, 5 3, 6 4	Two in system for each of six countries
7	NC2-49 TDRS	A B C	6°W 80°W 140°W		Three in system
8	NC2-50 Disaster Warn	A B	60°W 135°W		Two in system
9	NE2-43 Sync Earth Obs (Proto)		100°W		One in system
10	NE2-39 Sync Earth Res		100°W		One in system
11	NEO-11 Sync Earth Res	A B C D	30°E 105°E 75°W 150°W		Four in system
12	NE2-41 Sync Met Sat	A B	75°W 135°W		Two in system
13	NEO-15 Sync Met Sat	A B	75°W 30°E		Two in system

*REF NAR STUDY GEOSYNCHRONOUS PLATFORM, APRIL 73

4. SPACE-SERVICING RESULTS

Since there has been no previous analysis of space servicing, there is no valid means of comparing the results of the two cases analyzed. However, some understanding can be achieved by comparing in a gross sense these results with ground refurbishment of payloads as analyzed in Reference 5. A sample case of a single satellite program (NC2-51, System Test Satellite) is described first. This is followed by a summary of the results of Case 1 which is based upon LMSC standardized modules. The results of Case 2 based upon Aerospace data are then presented and a comparison of the two provided. Further details on input data and sequence of events are provided in the appendix section.

The current effort was restricted to synchronous equatorial orbit for the missions defined in Reference 5. Table 6 has already listed this set, including the number of satellites required to comprise an operational system. When ground refurbishment is considered, the total mission operations require 182 Tug flights over the 1979 to 1997 time period based upon a Tug availability in 1983. Of this amount, 130 flights are required to support synchronous equatorial operations for the 13 payload programs considered in this study. This is further reflected in 158 Shuttle flights to support the Tug and payload operations. A detailed break down of the flight operations is given in Table 7. A direct comparison will be difficult, however, because of different ground rules and assumptions and basic input data.

Of the 130 Tug flights supporting synchronous operations, 10.5 were allocated to the sample payload program NC2-51 which has two satellites operating simultaneously for 18 years. The equivalent charge for deployment prior to the Tug IOC was 1.7 Centaur flights. Also, there were two tandem Tug flights in which this payload shared the ride. It should be recognized that some of these charges are for retrieval since ground refurbishment was an objective. The flight rate was established based upon a mean mission duration of five years which has no corollary in the space-servicing study. The satellite weight was given as 1,896 kg (4,181 lb) when designed for ground refurbishment.

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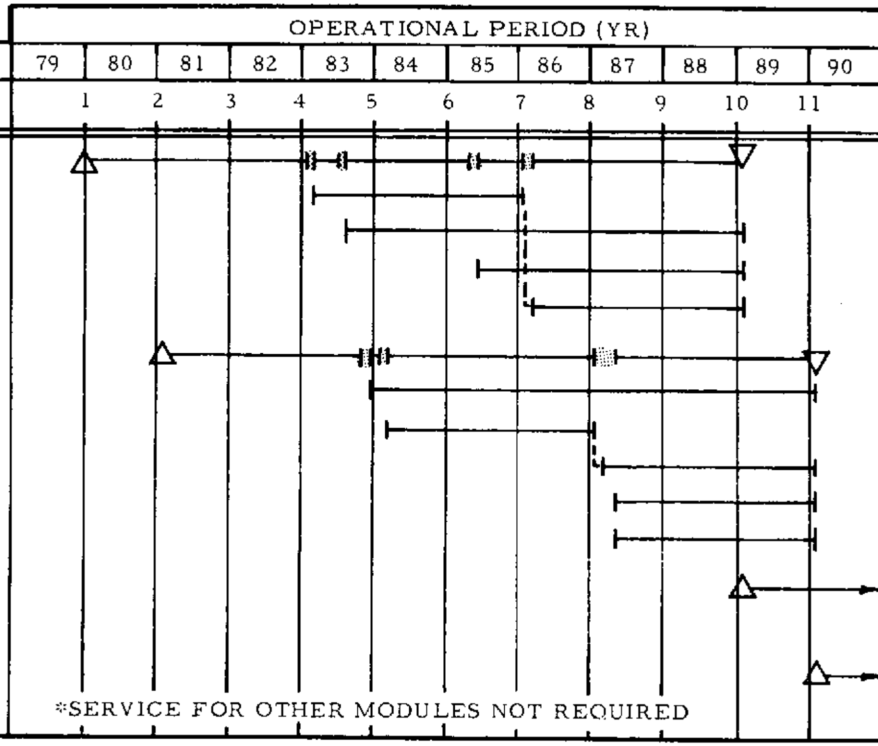
By comparison, when modularized in this study, the NC2-51 satellite weight is estimated as 1,608 kg (3,545 lb). A breakdown of the individual module failures is shown in Figure 23. This figure shows how each module performed over the period of interest for the two satellites required in the system. The first satellite (NC2-51A) is to be in-orbit and operating before launching the second payload (NC2-51B). The satellites are truncated at a nine-year life and replaced with a new series, NC2-51C and NC2-51D.

The Tug launch schedule is also shown. The initial deployment absorbs the major charge for Tug operations, because of the high weight and low traffic at this time. As module failures randomly occur in time, a demand for support flights is made. The modules for NC2-51 are combined with other satellite requirements and consequently share the flight expense.

The first assignment to NC2-51A was scheduled as the fourth Tug flight in the sequence of events. The assigned Tug flights are listed in Table 12. The previous three Tug flights supported other payload deployments. In addition to the module weight, it is necessary to include a service unit weight of 91 kg (200 lb). It is seen that the utilization of the Tug varies over a wide range. The excess performance capability ranged from 32 to 907 kg (70 to 2,000 lb). It is not possible to always use the full capability. If additional payload is required at one of the existing satellites already assigned to the Tug, this capability could be utilized. If transfer to another satellite position is required, as often occurs, this excess is absorbed by the transfer maneuver. The additional weight beyond NC2-51 assigned to the Tug flights is shown for reference.

Ten Tug flights were required to service NC2-51 over the 10 years of interest. However, because support to other payload programs was also required, the NC2-51 program only absorbed the equivalent of 3.81 flights in logistic charges for the first system, and a total of 7.6 flights for 18 years of operation. If it is necessary to recover the satellites at the end of their useful life, costs could be increased by 1.7 flights. A total of 9.3 Tug flights are required to deploy, service, and retrieve the NC2-51

SATELLITE UNIT	SATELLITE MODULE	TUG ASSIGNMENT NO.	SLOT	LOADED (YR)	LAUNCH (YR)	DELAYED (YR)
A*		4	2	1.00	1.08	----
	ACS-2(4)	22	3	4.08	4.16	0.08
	NC2-512	26	2	4.50	4.53	0.03
	CDPI-4	45	1	6.30	6.40	0.10
	ACS-2(4)	51	1	7.08	7.14	0.06
B*		7	1	2.00	2.08	----
	NC2-511	30	1	4.90	4.98	0.08
	ACS-2(4)	31	2	5.08	5.16	0.08
	ACS-2(4)	56	3	8.08	8.16	0.08
	CDPI-4	58	1	8.09	8.32	0.23
	NC2-512	58	2	8.12	8.32	0.20
C	DEPLOY	74	2	10.00	10.08	----
D	DEPLOY	78	2	11.00	11.08	----



AVAILABILITY OVER NINE-YEAR PERIOD:
SATELLITE A 97%
SATELLITE B 96%

LAUNCH DELAYS:
AVERAGE DELAY 0.09 YR (33 DAYS)
MAXIMUM DELAY 0.23 YR (84 DAYS)

Figure 23. Schedule of Operations NC2-51 System Test Satellite

satellites with the system still operational at the end of 18 years. This is compared favorably with ground refurbishment as shown in Table 11. If retrieval of the satellites at the end of the operational period is not required, further savings would be realized. Further refinements could reduce the number of Tug operations to service NC2-51 but are not justified for this example.

Looking further at the results (Table 12) shows a rather high availability for each individual satellite with a system availability of 93 percent. The longest period of down time is three months in 1986. Otherwise, the nominal traffic is such that servicing can be achieved within one to two months after a failure occurs. It can also be seen that some modules did not fail within the time period of interest. These were primarily the LMSC electrical power modules. The LMSC data indicates a very high reliability for this subsystem. The ACS modules on the other hand are limited by the propellant quantity and therefore are truncated at three years. Obviously the satellite design should be reoptimized for space servicing before valid comparisons with alternate concepts can be made.

Integrated across the total mission model, it should be possible to improve the Tug and Shuttle utilization. However, the potential savings are dependent upon valid SRU designs and phasing definitions. Since these are highly subjective, it is necessary to perform a sensitivity analysis. This implies running numerous cases varying the SRU failure parameters to determine if the distribution of service operations varies significantly. Also, further work could be devoted toward standardizing SRUs to reduce overall costs and examine varying degrees of redundancy. This was not possible during this study effort, but the following two cases provide insight into the potential use of space servicing as an operational concept.

A CASE 1: LMSC STANDARD MODULES

The payload programs will be discussed first, followed by the logistic operations. Servicing includes replacement of SRUs due to failures and truncation as well as mission equipment updates which are inherent in many designs. The block changes in mission equipment are based upon the

Table 11. Case 506 Synchronous Equatorial Operations

SATELLITE			NUMBER DEPLOYED	NUMBER RETRIEVED	LOGISTIC TRAFFIC (FLIGHTS)					TOTAL
CODE	TYPE	WT kg (lb)			TUG	TD TUG**	CENTAUR	AGENA	TITAN III	
NC2-46	LCR	2,900 (6,394)	10	0	6.7	----	2.0	----	----	8.7
NC2-51	LCR	1,897 (4,181)	14	5	10.5	0.6	1.7	----	----	12.8
NC2-47	LCR	374 (824)	19	13	5.1	----	0.4	----	0.6	6.1
NCN-7	CR	800 (1,764)	16	12	8.7	0.2	----	1.0	2.4	12.3
NCN-8	CR	1,631 (3,595)	33	23	37.6	----	5.0	----	----	42.6
NCN-9	LCR	925 (2,040)	45	34	27.8	----	4.4	1.0	----	33.2
NC2-49	CR	994 (2,191)	9	6	6.1	----	----	----	----	6.1
NC2-50	LCR	1,515 (3,339)	1	0	----	----	----	----	1.0	1.0
NE2-43	LCR	1,798 (3,964)	4	3	3.3	1.0	----	----	----	4.3
NE2-39	LCR	2,511 (5,536)	8	5	2.1	6.2	1.4	----	----	9.7
NEO-11	LCR	913 (2,013)	16	8	10.8	----	----	----	----	10.8
NE2-41	CE	270 (596)	4	0	0.2	----	0.3	----	----	0.5
NEO-15	LCR	1,151 (2,537)	19	15	11.5	2.2	2.3	----	----	16.0
TOTAL			198	124	130.4	10.2	17.5	2.0	4.0	164.1
NCN-10B*	LCR	784 (1,729)	10	8	6.8	----	0.5	----	1.0	8.3

*REF ONLY; DELETED FROM SPACE SERVICING CASES

**TANDEM TUG FLIGHTS DOUBLED TO REFLECT EQUIVALENT TUG FLIGHTS

Table 12. NC2-51 System Test Satellite Servicing Operations

FLIGHT NUMBER	PAYLOAD SERVICED NC2-51	MODULE SERVICED	MODULE WEIGHT kg (lb)	SERVICE UNIT CHARGE % 91 kg (200 lb)	TOTAL WEIGHT ASSIGNED kg (lb)	EXCESS CAPABILITY kg (lb)	PAYLOAD LAUNCH COST PERCENT
4	A	DEPLOY	1,608 (3,545)	----	1,853 (4,093)	419 (923)	85
7	B	DEPLOY	1,608 (3,545)	----	3,032 (6,681)	145 (319)	52
22	A	ACS-2(4)	272 (600)	50	1,878 (4,139	54 (118)	17
26	A	NC2-512	93 (205)	33-1/3	382 (841)	199 (439)	32
30	B	NC2-511	93 (206)	50	214 (473)	875 (1,927)	75
31	B	ACS-2(4)	272 (600)	100	1,786 (3,936)	506 (1,113)	20
45	A	CDPI-4	30 (67)	100	1,832 (4,048)	404 (890)	7
51	A	ACS-2(4)	272 (600)	33-1/3	523 (1,150)	55 (120)	63
56	B	ACS-2(4)	272 (600)	50	1,879 (4,144)	32 (70)	17
58	B	[CDPI-4 NC2-512]	123 (272)	100	1,713 (3,773)	457 (1,008)	13

EQUIVALENT SYSTEM LAUNCH COST: 3.81 TUG FLIGHTS

AVERAGE LOAD FACTOR: 79%

data of Reference 5. These service flights (for block changes) represent dedicated operations to be conducted in the initial period of the year programmed. A detailed breakdown of servicing parameters is given in Table 13. System availability ranges from a low of 27 percent for NEO-11 Synchronous Earth Resources to a high of 92 percent for NC2-50 Disaster Warning Satellites. The Small Application Technology Satellite (NC2-47) has a 99 percent availability but this is due to yearly launches and not servicing. In this particular case, two random failures occurred just prior to the scheduled launch of a follow-on satellite resulting in a very minor down time period. In general, the COMSAT-type satellites have a high availability as individual units, but the system as a whole (as defined here) is probably unsatisfactory for commercial usage. Resource satellites tend to be relatively low in availability with a large number of SRU replacements caused by sensor limitations.

The number of modules defined for each satellite of interest ranged from 7 to 13, averaging approximately 10 modules for the 13 satellites. Module replacements of each satellite tended to be in the range of three to six SRUs over the operational life of the satellite, approximately nine years. Some cases, where extensive changeout of mission equipment (NC2-46) was defined, the number of SRU replacements was high (19). The average number of SRU replacements per satellite was found to be 5.6 over the total time period of 1979 through 1997. Therefore, since there was an average of 10 modules per satellite, approximately 56 percent of each satellite was replaced over the 19-year time period. However, this does not reflect a 56 percent first unit cost increment. The major contributor was the attitude control system SRUs due primarily to the truncation time of three years to account for propellant usage. This SRU accounted for 36 percent of the changeout requirements. Several alternatives are available to improve this design. An additional 35 percent of SRU replacements was allocated to mission equipment modules including estimated changes. This can be improved in COMSAT-type satellites by redundancy, but for the remaining programs, some major breakthrough will be required to improve the basic equipment reliability. The remainder of the SRU replacements is

Table 13. Case 1 Synchronous Equatorial Orbit Servicing

PAYLOAD					SCHEDULE (FROM 1979)		SERVICE OPERATIONS			AVAIL. %		LOGISTICS FLIGHT	
CODE NUMBER	NAME	WEIGHT kg (lb)	NO. IN SYSTEM	UNIT	DEPLOY YR	TRUNC YR	NUMBER MODULES SERVICED	MAX DELAY YRS	AVG DELAY YRS	SAT UNIT	SYST	TUG FLIGHTS	TOTAL FOR SYSTEM
NC2-46	ATS Sync.	1,825 (4,023)	1	A	-0-	-----	18	0.25	0.14	87	87	7.46	7.46
NC2-51	System Test Satellite	1, 608 (3, 545)	2	A	1.08	10.08	4	0.10	0.07	97	93	2.04	7.56
				B	2.08	11.08	5	0.23	0.13	96		1.77	
				C	10.08	-----	3	0.21	0.13	96	90	2.14	
				D	11.08	-----	4	0.18		94		1.61	
NC2-47	Small ATS	1,422 (3,136)	1	A-S	1 Per YR	-----	19	----	----	--	99	13.28	13.28
NCN-7	COMSAT	1, 491 (3, 301)	3	A	-1.0	8.0	3	0.18	0.14	95	84	1.25	12.64
				B	-1.0	8.0	5	0.16	0.10	94		1.42	
				C	-1.0	8.0	5	0.11	0.09	95		1.30	
				D	8.32	17.32	4	0.24	0.13	94	86	1.91	
				E	8.40	17.40	3	0.20	0.12	96		2.66	
				F	8.48	17.48	3	0.16	0.12	96		2.30	
				G	17.64	-----	--	----	----	--		0.80	
				H	17.72	-----	--	----	----	--		0.50	
				I	17.72	-----	--	----	----	--		0.50	
NCN-8	U.S. Domestic	2, 009 (4, 428)	3	A	-1.0	8.0	8	0.13	0.10	91	76	1.57	18.77
				B	-1.0	8.0	5	0.20	0.13	93		1.80	
				C	+0.08	9.08	7	0.16	0.10	92		2.94	
				D	8.56	17.56	2	0.10	0.10	98	87	3.23	
				E	8.64	17.64	4	0.23	0.15	93		3.86	
				F	9.24	18.24	3	0.16	0.13	96		2.59	
				G	17.80	-----	--	----	----	--		0.92	
				H	17.97	-----	--	----	----	--		0.94	
				I	18.24	-----	--	----	----	--		0.92	
NCN-9	Foreign Domestic Sat	1, 185 (2, 612)	2	A	1.24	10.24	5	0.20	0.11	94	89	2.05	8.68
				B	1.24	10.24	4	0.15	0.10	95		2.40	
				C	10.24	-----	5	0.16	0.10	94	86	1.75	
				D	10.32	-----	4	0.32	0.17	92		2.48	

Table 13. Case 1 Synchronous Equatorial Orbit Servicing (Continued)

PAYLOAD					SCHEDULE (FROM 1979)		SERVICE OPERATIONS			AVAIL. %		LOGISTICS FLIGHT	
CODE NUMBER	NAME	WEIGHT kg (lb)	NO. IN SYSTEM	UNIT	DEPLOY YR	TRUNC YR	NUMBER MODULES SERVICED	MAX DELAY YRS	AVG DELAY YRS	SAT UNIT	SYST	TUG FLIGHTS	TOTAL FOR SYSTEM
NC2-49	TDRS	1,522 (3,356)	3	A	-1.0	8.0	7	0.21	0.14	89		2.68	
				B	-1.0	8.0	6	0.46	0.18	88	72	1.63	
				C	-1.0	8.0	4	0.18	0.12	95		1.60	
				D	8.72	17.72	6	0.18	0.13	91		2.63	16.36
				E	8.80	17.80	7	0.24	0.12	91	76	2.84	
				F	8.88	17.88	4	0.16	0.15	94		2.43	
				G	17.32	-----	--	----	----	--		0.93	
				H	17.40	-----	--	----	----	--		0.79	
				I	17.48	-----	--	----	----	--		0.83	
NC2-50	Disaster Warning	1,701 (3,750)	2	A	-1.0	8.0	4	0.42	0.19	91	86	1.35	
				B	0.50	9.50	4	0.14	0.11	95		1.68	
				C	8.96	17.96	3	0.15	0.12	96	92	2.01	8.83
				D	9.32	18.32	2	0.24	0.16	96		1.91	
				E	17.24	-----	--	----	----	--		1.00	
				F	18.40	-----	--	----	----	--		0.88	
NE2-43	Sync Earth Obs	2,154 (4,748)	1	A	11.32	-----	8	0.28	0.16	71	71	4.61	4.61
NE2-39	Sync Earth Res.	1,902 (4,193)	1	A	1.82	10.82	14	0.19	0.10	85	85	5.63	9.91
				B	10.61	-----	10	0.27	0.19	78	78	4.28	
NEO-11	Sync Earth RE	1,715 (3,781)	4	A	6.24	15.24	7	0.28	0.16	95		2.54	
				B	6.32	15.32	7	0.24	0.13	90	68	2.73	
				C	6.40	15.39	7	0.17	0.11	91		2.68	
				D	6.56	15.56	6	0.23	0.13	91		2.80	17.81
				E	15.24	-----	4	0.32	0.21	77		1.92	
				F	15.32	-----	2	0.24	0.23	88	27	1.48	
				G	15.48	-----	2	0.24	0.18	90		1.93	
				H	15.56	-----	3	0.25	0.22	82		1.73	
NE2-41	Sync Met Sat	1,548 (3,413)	2	A	2.20	11.20	8	0.20	0.12	90	82	2.03	
				B	3.29	12.29	5	0.22	0.14	92		2.12	9.84
				C	11.40	-----	6	0.18	0.05	88	75	1.96	
				D	12.20	-----	6	0.24	0.15	87		3.73	

Table 13. Case 1 Synchronous Equatorial Orbit Servicing (Continued)

PAYLOAD					SCHEDULE (FROM 1979)		SERVICE OPERATIONS			AVAIL, %		LOGISTICS FLIGHT	
CODE NUMBER	NAME	WEIGHT kg (lb)	NO. IN SYSTEM	UNIT	DEPLOY YR	TRUNC YR	NUMBER MODULES SERVICED	MAX DELAY YRS	AVG DELAY YRS	SAT UNIT	SYST	TUG FLIGHTS	TOTAL FOR SYSTEM
NEO-15	Sync Met Sat	1,557 (3,432)	2	A	-1.0	8.00	10	0.16	0.11	88	75	2.97	
				B	0.50	9.50	8	0.58	0.14	87		3.06	
				C	8.24	17.08	8	0.41	0.14	88	75	3.03	14.72
				D	9.40	18.40	8	0.22	0.15	87		3.85	
				E	17.16	-----	--	----	----	--	--	1.00	
				F	18.48	-----	--	----	----	--	--	0.81	

distributed among the other subsystems and does not reflect any definite pattern.

Tug utilization is the next subject of interest. Simplifying assumptions were employed relative to the performance penalty for phasing in the synchronous equatorial orbit. No attempt was made to represent the actual longitude placement of the satellites; consequently, the loss in payload capability was developed only on the number of payloads to be serviced. The Tug can service 1,361 kg (3,000 lb) of weight at one satellite station (discounting 91 kg (200 lb) for the service unit). If two stations are to be serviced, the service capability is estimated as 1,089 kg (2,400 lb), losing 272 kg (600 lb) for the transfer maneuver. If three stations are serviced, the payload capability is further reduced to 576 kg (1,270 lb). This represents the upper bounds on the number of satellites to be visited, because the performance capability for four stations is only 227 kg (500 lb) which must include the service unit weight.

A total of 150 Tug flights are required to service the 13 payload programs over the 19-year time period. This can be compared with the results for ground refurbishment previously mentioned (130 Tug operations, 5 tandem Tug flights, 18 Centaur flights, and 2 Agena flights). A breakdown of the Tug utilization is provided in Table 14. The majority of Tug operations were restricted to servicing two and three satellites on each flight. The low effective load factor of 56 percent is due primarily to the performance loss associated with transfer maneuvers. When deployment operations are included, the effective load factor increases substantially such that an overall average of 75 percent is achieved. This compares favorably with ground refurbishment operations for the same payload set and time period, which averages 82 percent. Further comparison of the yearly flight rate is provided in Figure 24. The flight rate tends to average around eight flights per year.

Tug utilization for ground refurbishment of payloads represents a reasonable upper bounds, since this has previously been analyzed in detail (Ref. 5). However, there is considerable room for improvement using space servicing by altering the servicing policy. In this particular case,

Table 14. Case 1 Tug Operations

TUG OPERATIONS		WEIGHT TO SYNC EQ ORBIT (1979-1997)					PERFORMANCE		
TYPE	FLIGHTS	DEPLOYED WEIGHT kg (lb)	SERVICE #1	SERVICE #2	SERVICE #3	TOTAL WEIGHT kg (lb)*	EXCESS kg (lb)	AVERAGE LOAD kg (lb)/FLT	LOAD FACTOR PERCENT
DEPLOY ONLY	10	24, 295 (53, 562)	------	------	------	24, 296 (53, 563)	10, 332 (22, 779)	2, 429 (5, 356)	73
SERVICE ONLY	82	------	------	22, 543 (49, 699)	10, 615 (23, 403)	40, 597 (89, 502)	31, 700 (69, 886)	495 (1, 091)	56
DEPLOY & SERVICE	58	94, 666 (208, 703)	6, 540 (14, 419)	5, 069 (11, 175)	------	111, 355 (245, 496)	17, 236 (38, 000)	1, 921 (4, 235)	87
TOTAL	150					176, 248 (388, 561)	59, 268 (130, 665)	1, 175 (2, 592)	75

*91-KG (200-LB) SERVICE UNIT WEIGHT INCLUDED WHERE REQUIRED

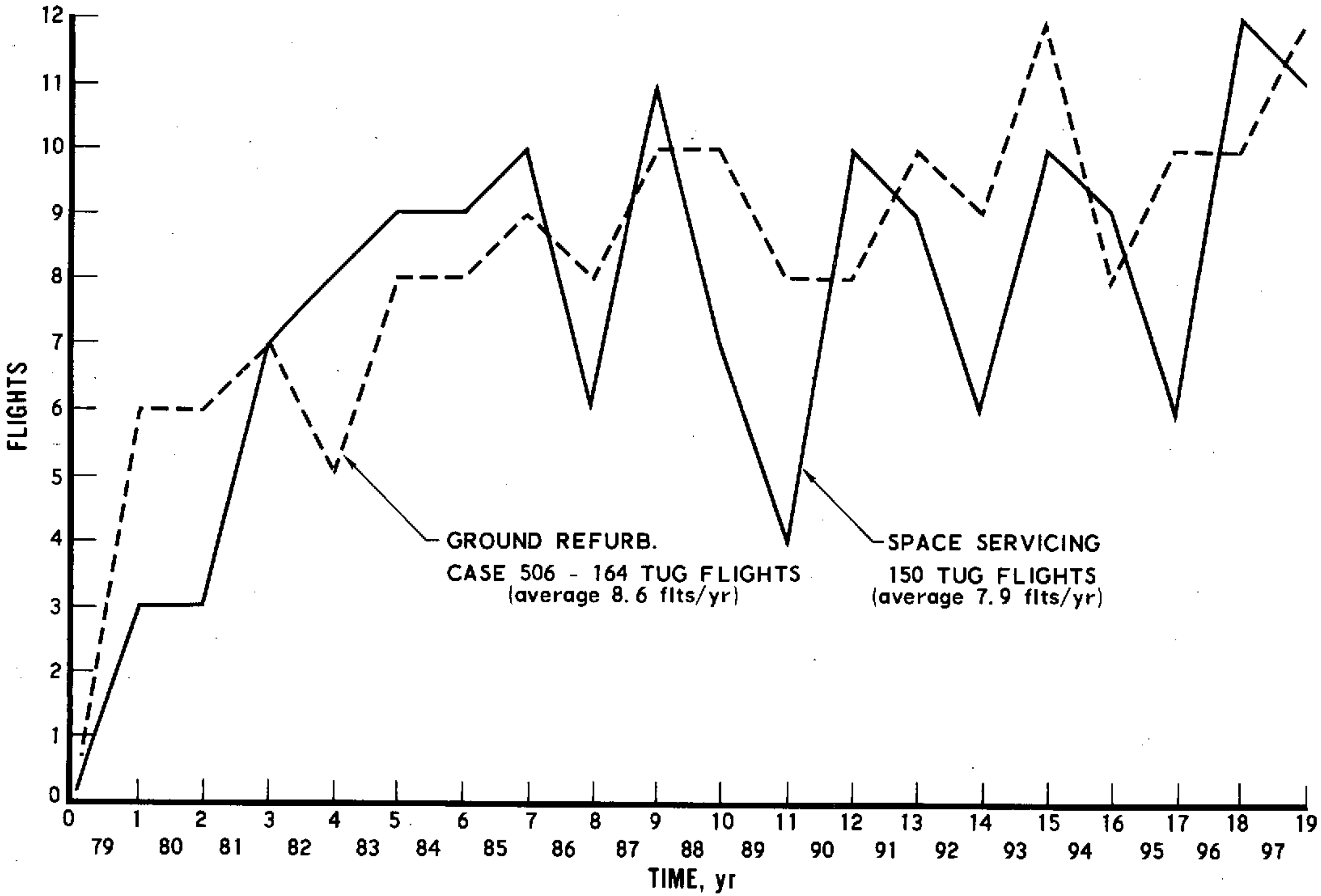


Figure 24. Synchronous Equatorial Traffic, Case 506 vs Case 1

the replacement SRUs were loaded as they were identified, and the launch delay was maintained relatively low (30 days). If, however, a launch delay of 60 or 90 days was allowed, it would be possible to select payloads to be serviced which are close to the same station on orbit. Further definition of SRUs would probably result in lower weights which should also improve the load factor. Finally, it was assumed that the attitude control modules (ACS-2) were truncated at three years. This forced an abnormally high number of flights just to service this SRU. Extending the operating life of this SRU should reduce the number of flights and improve the Tug utilization. Further consideration of these points is provided by Case 2 to be discussed next.

In summary, the results of Case 1 using LMSC subsystem module definitions are comparable with ground refurbishment of payloads, at least to the extent of operational consideration. Payload costs including DDT&E have not been developed, but since both approaches employ modular designs, the costs should be comparable. Recurring payload costs could possibly be lower, since on the average, only 50 percent of the modules were replaced on orbit as opposed to refurbishing the entire satellite.

B. CASE 2: AEROSPACE MODULAR DESIGNS

The major difference between Case 1 and Case 2 exists in the definition of subsystem modules. However in addition, the Tug performance relative to phasing at synchronous equatorial orbit is more accurately represented along with the satellite longitude placement. One other difference is that deployment of the Foreign DOMSAT payloads was increased from 2 to 12 satellites to be in agreement with the ground refurbishment study (Case 506). This provides for two satellites in a system supporting six different foreign countries. One final point is that the electrical power modules were truncated at five years, representing an upper bound on battery life. All other ground rules are essentially unchanged.

A comparison of the relative satellite weights is provided in Table 15 for four different conditions. There are numerous variances between the conditions due to the payload design approach chosen. Case 2 is in

Table 15. Space-Servicing Design Weight Comparison

SATELLITE		DESIGN WEIGHTS kg (lb)			
CODE	NAME	CUR. EXPN. *	CASE 506	CASE 1	CASE 2
NC2-46	Appl Tech. Sat.	1,361 (3,000)	2,900 (6,394)	1,825 (4,023)	1,674 (3,690)
NC2-51	System Test Sat.	1,297 (2,860)	1,896 (4,181)	1,608 (3,545)	1,172 (2,583)
NC2-47	Small ATS	136 (300)	374 (824)	1,423 (3,136)	577 (1,271)
NCN-7	COMSAT	644 (1,420)	800 (1,764)	1,497 (3,301)	1,100 (2,425)
NCN-8	U.S. DOMSAT	1,554 (3,425)	1,631 (3,595)	2,009 (4,428)	2,082 (4,591)
NCN-9	Foreign DOMSAT	454 (1,000)	925 (2,040)	1,185 (2,612)	872 (1,923)
NC2-49	Track Data Relay	798 (1,760)	994 (2,191)	1,522 (3,356)	786 (1,732)
NC2-50	Disaster Warning	798 (1,760)	1,515 (3,339)	1,701 (3,750)	1,132 (2,496)
NE2-43	Sync Earth Obs/Pr	1,198 (2,640)	1,798 (3,964)	2,154 (4,748)	1,566 (3,453)
NE2-39	Sync Earth Obs	1,134 (2,500)	2,511 (5,536)	1,902 (4,193)	1,574 (3,471)
NEO-11	Sync Earth Res.	454 (1,000)	913 (2,013)	1,715 (3,781)	1,006 (2,218)
NE2-41	Sync Met. Sat.	243 (535)	270 (596)	1,548 (3,413)	823 (1,814)
NEO-15	Sync Met Sat.	494 (1,000)	1,151 (2,537)	1,557 (3,432)	1,010 (2,226)

*NASA PAYLOAD DATA BOOK

general lighter weight than Case 1, both of which exceed the current design estimates. The reduced weight will be reflected in some measure in the number of Tug operations, but the integrated effect should be small because the satellites represent incremental loads on the Tug. Consequently, there is always some reserve performance remaining on each flight which can be absorbed without increasing the flight rate. The weights are considered to be realistic for the design concept (ring frame) and module breakout selected.

The results of the manual analysis for all 13 payload programs are shown in Table 16. This shows when each satellite was deployed, how long it was on station, and what its availability was. In addition, the delay between failure occurrence and the Tug service is shown. It is very interesting to find that sufficient traffic exists such that, in general, the downtime on any given satellite is less than two months. Considering the ground rule that this also includes a 30-day preparation on the ground if a flight was not previously scheduled, it indicates very good accessibility to the failed satellite. The availability of any given satellite is also relatively high. The system availability drops significantly, because it is assumed that all satellites in the system must be operational. If two out of three satellites in a system would be acceptable for short periods of time, the overall availability would increase sharply. This is particularly noticeable with NEO-11, Synchronous Earth Resources Satellite, where four satellites are required in the system. The average for all the programs is approximately 81 percent availability. The logistic flight charges allocated to each payload program are also shown.

A comparison of Tug operations is provided in Table 17. Case 2 has 10 percent less flights than Case 1, in spite of the fact that more payloads and modules were deployed (NCN-9). Case 2 further represents a 18-percent reduction in flights over ground refurbishment. One simplification exists however; the satellites for Case 1 and Case 2 were not retrieved at the end of their useful life (nine years). The option remains open to the payload user, since it is assumed that after this time the payload has no value; consequently, a $5- to $10-million retrieval cost may not be tolerable. However, if retrieval were employed, an additional 20 to 30 flights would be

Table 16. Case 2 Synchronous Equatorial Orbit Servicing

PAYLOAD					SCHEDULE (FROM 1979)		SERVICE OPERATIONS			AVAIL. %		LOGISTICS FLIGHT	
CODE NUMBER	NAME	WEIGHT Kg (lb)	NO. IN SYSTEM	UNIT	DEPLOY YR	TRUNC YR	NUMBER MODULES SERVICED	MAX DELAY YRS	AVG DELAY YRS	SAT UNIT	SYST	TUG FLIGHTS	TOTAL FOR SYSTEM
NC2-46	ATS Sync	1,674 (3,690)	1	A	0.16	18.84	23	0.35	0.14	89	89	4.42	4.42
NC2-51	System Test Satellite	1,172 (2,583)	2	A	1.16	10.16	7	0.19	0.12	95	87	1.31	
				B	2.08	11.08	8	0.22	0.15	92		1.66	5.68
				C	10.07	-----	9	0.17	0.10	95	91	2.04	
				D	11.07	-----	6	0.16	0.13	96		0.67	
NC2-47	Small ATS	577 (1,271)	1	A S	1 Per Yr	-----	19	0.49	----	91	91	8.22	8.22
NCN-7	COMSAT	1,100 (2,425)	3	A	- 1.0	8.00	6	0.16	0.13	95		0.82	
				B	- 0.92	8.08	10	0.21	0.13	89	75	1.70	
				C	- 0.84	8.16	7	0.24	0.18	91		1.30	
				D	7.91	16.91	8	0.16	0.14	92		1.46	
				E	7.91	16.91	9	0.24	0.12	95	82	1.41	10.30
				F	8.00	17.00	6	0.16	0.15	95		1.61	
				G	16.74	-----	--	----	----	--		0.76	
				H	16.85	-----	--	----	----	--	100	0.48	
				I	16.97	-----	--	----	----	--		0.76	
NCN-8	U. S. DOMSAT	2,082 (4,591)	3	A	- 0.76	8.24	12	0.39	0.20	88		1.67	
				B	- 0.68	8.32	11	0.24	0.12	94	74	1.44	
				C	0.32	9.32	11	0.32	0.17	92		2.08	
				D	8.07	17.07	11	0.22	0.18	92		2.61	
				E	8.24	17.24	14	0.16	0.12	91	73	2.91	16.43
				F	9.24	18.24	15	0.16	0.13	90		3.18	
				G	17.07	-----	--	----	----	--		0.92	
				H	17.23	-----	--	----	----	--	100	0.84	
				I	18.09	-----	--	----	----	--		0.78	

Table 16. Case 2 Synchronous Equatorial Orbit Servicing (Continued)

PAYLOAD					SCHEDULE (FROM 1979)		SERVICE OPERATIONS			AVAIL. %		LOGISTICS FLIGHT	
CODE NUMBER	NAME	WEIGHT Kg (lb)	NO. IN SYSTEM	UNIT	DEPLOY YR	TRUNC YR	NUMBER MODULES SERVICED	MAX DELAY YRS	AVG DELAY YRS	SAT UNIT	SYST	TUG FLIGHTS	TOTAL FOR SYSTEM
NCN-9	Foreign DOMSAT	872 (1,923)	2 Per Country	A	1.16	10.16	10	0.23	0.14	88	84	1.45	
				B	1.48	10.48	7	0.13	0.09	96		1.45	
				C	2.24	11.24	8	0.17	0.14	92	87	1.77	
				D	2.40	11.40	6	0.16	0.14	95		1.73	
				E	2.48	11.48	9	0.22	0.15	89	83	1.76	
				F	2.48	11.48	8	0.24	0.11	94		1.89	
				G	2.64	11.64	8	0.17	0.12	94	84	1.99	
				H	2.72	11.72	8	0.26	0.16	90		1.42	
				I	3.08	12.08	7	0.24	0.14	94	84	1.29	
				J	3.24	12.24	9	0.27	0.14	90		1.74	
				K	4.16	13.16	7	0.34	0.18	92	72	1.18	
				L	4.24	13.24	11	0.51	0.23	80		2.13	36.62
				M	9.40	18.40	7	0.18	0.13	94	88	1.70	
				N	10.15	-----	9	0.18	0.10	94		1.79	
				O	11.23	-----	8	0.16	0.10	94	89	1.13	
				P	10.64	-----	6	0.20	0.15	95		1.38	
				Q	11.23	-----	7	0.32	0.16	92	80	1.15	
				R	11.47	-----	8	0.24	0.17	88		2.00	
				S	11.55	-----	9	0.21	0.14	90	86	1.53	
				T	10.99	-----	6	0.16	0.11	96		1.36	
				U	12.07	-----	7	0.24	0.17	90	81	1.36	
				V	12.16	-----	7	0.19	0.14	91		1.38	
				W	13.07	-----	5	0.17	0.14	93	90	1.03	
				X	13.15	-----	4	0.08	0.08	97		1.01	
NC2-49	TDRS	786 (1,732)	3	A	- 0.60	8.40	8	0.17	0.13	92		0.86	
				B	- 0.52	8.48	8	0.16	0.07	96	80	0.93	
				C	- 0.44	8.56	8	0.24	0.13	92		1.12	
				D	8.32	17.32	7	0.16	0.16	93		1.36	
				E	8.47	17.47	9	0.24	0.14	91	73	1.52	9.01
				F	8.47	17.47	9	0.29	0.16	89		1.66	
				G	17.31	-----	--	----	----	--		0.68	
				H	17.39	----	--	----	----	--	100	0.44	
				I	17.39	----	--	----	----	--		0.44	

Table 16. Case 2 Synchronous Equatorial Orbit Servicing (Continued)

PAYLOAD					SCHEDULE (FROM 1979)		SERVICE OPERATIONS			AVAIL. %		LOGISTICS FLIGHT	
CODE NUMBER	NAME	WEIGHT Kg (lb)	NO. IN SYSTEM	UNIT	DEPLOY YR	TRUNC YR	NUMBER MODULES SERVICED	MAX DELAY YRS	AVG DELAY YRS	SAT UNIT	SYST	TUG FLIGHTS	TOTAL FOR SYSTEM
NC2-50	Disaster Warning	1,132 (2,496)	2	A	-0.36	8.64	7	0.33	0.19	91	84	0.93	
				B	0.32	9.32	7	0.24	0.15	93		1.25	
				C	8.55	17.55	8	0.29	0.16	91	83	1.82	7.15
				D	9.32	18.32	8	0.23	0.14	92		1.76	
				E	17.47	-----	--	----	----	--	100	0.66	
				F	18.01	-----	--	----	----	--		0.73	
NC2-43	Sync Earth Observ.	1,566 (3,453)	1	A	11.23	-----	15	0.24	0.11	83	83	3.33	3.33
NE2-39	Sync Earth Resources	1,574 (3,471)	1	A	1.48	10.48	16	0.22	0.12	82	82	3.89	7.55
				B	10.32	19.32	13	0.25	0.14	83	83	3.66	
NEO-1	Sync Earth Resources	1,006 (2,218)	4	A	6.24	15.24	8	0.25	0.16	90		1.54	
				B	6.28	15.29	8	0.20	0.16	91	57	1.75	
				C	6.36	15.36	7	0.35	0.22	89		1.40	
				D	6.45	15.45	9	0.35	0.17	87		1.92	11.68
				E	14.55	-----	4	0.30	0.22	85		1.23	
				F	15.31	-----	3	0.25	0.20	89	54	1.23	
				G	14.63	-----	4	0.24	0.17	88		1.38	
				H	14.79	-----	3	0.27	0.18	92		1.23	
NE2-41	Sync Met Sat	823 (1,814)	2	A	2.72	11.72	8	0.19	0.15	92	81	1.20	
				B	3.40	12.40	9	0.25	0.16	89		1.39	5.43
				C	11.64	-----	8	0.15	0.10	93	80	1.28	
				D	12.31	-----	7	0.28	0.22	87		1.56	
NEO-15	Sync Met Sat	1,010 (2,226)	2	A	-0.28	8.72	10	0.26	0.14	89	79	1.61	
				B	0.16	9.16	10	0.21	0.13	90		1.89	
				C	7.91	16.91	12	0.25	0.14	86	78	2.29	9.18
				D	8.99	17.99	11	0.17	0.09	92		2.30	
				E	16.85	-----	--	----	----	--	100	0.44	
				F	18.01	-----	--	----	----	--		0.65	

Table 17. Comparison of Upper Stage Logistics

PAYLOAD	UPPER STAGE FLIGHTS CASE 506	TUG FLIGHTS CASE 1	TUG FLIGHTS CASE 2
NC2-46	8.7	7.46	4.4
NC2-51	12.8	7.56	5.7
NC2-47	6.1	13.28	8.2
NCN-7	12.3	12.64	10.3
NCN-8	42.6	18.77	16.4
NCN-9	33.2	8.68	36.6
NC2-49	6.1	16.36	9.0
NC2-50	1.0	8.83	7.2
NE2-43	4.3	4.61	3.3
NE2-39	9.7	9.91	7.6
NEO-11	10.8	17.81	11.7
NE2-41	0.5	9.84	5.4
NEO-15	16.0	14.72	9.2
TOTAL	164.0	150.0	135.0

required over the 19-year time period or approximately 1 to 2 per year. The flight rate profiles are shown in Figure 25. The only significant points are the dip in flight rate in 1989 due to the replacement of a number of satellites in 1988. Modules have not had time to reach a failure state, and consequently the flight rate is reduced. Prudent adjustment of the operational periods could alleviate this characteristic.

A further consideration is the efficiency in loading the Tug. A summary of the Tug operations and associated load factors is provided in Table 18. It was possible to service up to five satellites on a single Tug flight; however, this did not occur often. The total weight carried to orbit over this time period was 162,000 kg (357,206 lb), including the 91 kg (200 lb) service unit when required. This is essentially equivalent to the payload deployment of Case 506 (161,100 kg (355,167 lb)). The excess performance capability shown (35,737 kg (78,786 lb)) can probably be reduced with further analysis, because smaller increments of weight are being shipped. Even so, a load factor of 82 percent was achieved which is comparable to Case 506.

In a gross sense, the payload procurement requirements can also be established for each payload program. Table 19 summarizes the equivalent procurement of payloads for Case 506 ground refurbishment and the two space-servicing cases. Ground-refurbishment costs are estimated to average one-third of the basic unit cost. Space-servicing costs are based upon replacing a certain percentage of the modules making up a satellite. The estimated number of modules per satellite varies from 8 to 13. On this basis, space servicing required 25 percent more payload procurement, although the total number of satellites deployed was reduced by 50 percent. It is therefore necessary to look at the nature of the modules being serviced to determine the driving factors involved.

Of the 598 modules serviced on-orbit, 50 percent were propulsion modules which were replaced because of fuel depletion (3 years truncation). As pointed out previously, this is highly conservative, and the module life could be extended without compromising reliability. Twenty-three percent of the modules replaced were electrical power modules. This also was due

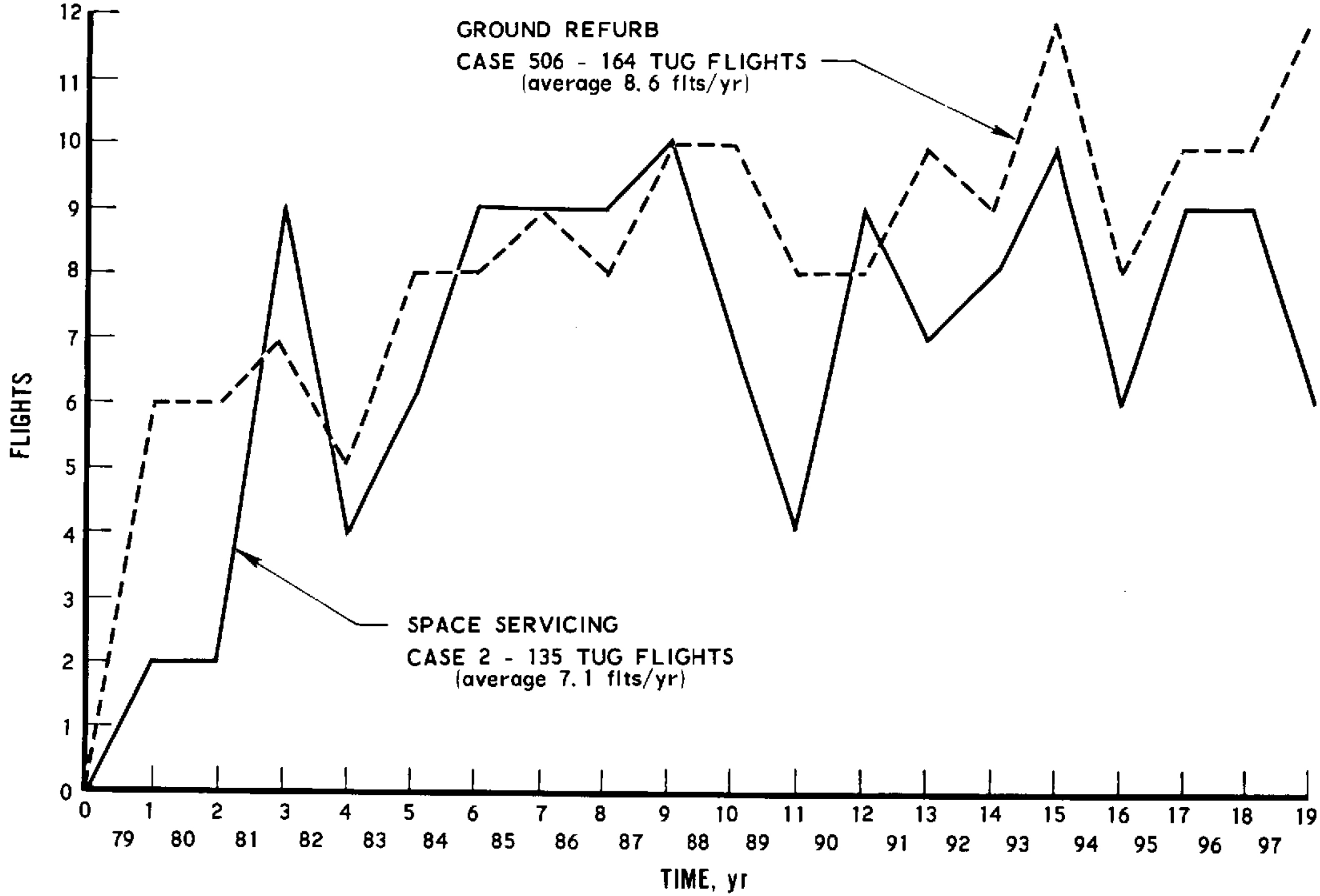


Figure 25. Synchronous Equatorial Traffic, Case 2

Table 18. Case 2 Tug Operations

TUG OPERATIONS		WEIGHT TO SYNCHRONOUS EQUATORAL ORBIT (1979-97)						PERFORMANCE		
TYPE	FLIGHTS	DEPLOYED WEIGHT Kg (lb)	SERVICE #2 Kg (lb)	SERVICE #3 Kg (lb)	SERVICE #4 Kg (lb)	SERVICE #5 Kg (lb)	TOTAL WEIGHT Kg (lb)*	EXCESS Kg (lb)	AVERAGE LOAD Kg (lb)/FLT	LOAD FACTOR PERCENT
DEPLOY ONLY	7	19,723 (43,482)	-----	------	------	-----	19,723 (43,482)	4,091 (9,018)	3,472 (7,655)	83
SERVICE ONLY	64	------	748 (1,648)	17,748 (39,128)	16,403 (36,163)	3,230 (7,122)	43,935 (96,861)	15,151 (33,403)	686 (1,513)	74
DEPLOY 1 & SERVICE	54	54,019 (119,091)	2,950 (6,503)	10,011 (22,071)	6,414 (14,140)	635 (1,400)	78,927 (174,005)	12,757 (28,125)	1,461 (3,220)	86
DEPLOY 2 & SERVICE	10	17,161 (37,834)	1,372 (3,024)	------	------	-----	19,441 (42,858)	3,738 (8,240)	1,944 (4,286)	84
TOTAL	135						162,026 (357,206)	35,737 (78,786)	1,198 (2,645)	82

*91-KG (200-LB) SERVICE UNIT WEIGHT INCLUDED WHERE REQUIRED

Table 19. Payload Program Procurement Requirements

PAYLOAD CODE	CASE 506		CASE 1			CASE 2			
	NUMBER DISPLAYED	EQUIV. PROCUR	NUMBER DEPLOYED	MODULES SERV.	EQUIV. PROCUR	NUMBER DEPLOYED	MODULES PER SAT	MODULES SERV.	EQUIV. PROCUR
NC2-46	10	10.0	1	18	2.6	1	10	23	3.3
NC2-51	14	10.7	4	16	5.6	4	9	30	7.3
NC2-47	19	11.0	19	0	19.0	19	7	0	19.0
NCN-7	16	9.3	9	23	11.3	9	8	46	14.7
NCN-8	33	19.0	9	29	11.2	9	13	74	14.7
NCN-9	45	24.3	4	18	5.8	24	8	181	46.6
NC2-49	9	6.3	9	34	12.8	9	8	49	15.1
NC2-50	1	1.0	6	13	7.2	6	10	30	9.0
NE2-43	4	2.7	1	8	1.7	1	12	15	2.25
NE2-39	8	4.7	2	24	4.0	2	11	29	4.6
NEO-11	16	12.0	8	38	11.8	8	11	46	12.2
NE2-41	4	4.0	4	25	6.8	4	10	32	7.2
NEO-15	19	10.3	6	34	9.8	6	10	43	10.3
TOTAL	198	125.3	82	280	109.6	102	127	598	166.3

to truncation at five years, but this appears to be a reasonable upper bound. The next major replacement (22 percent) was for mission equipment, including blockchanges defined in Case 506. The remaining module replacements were 4 percent for communications and one percent for stabilization and control. It is obvious that the module serviced most often is also the lowest cost relative to the payload design. Therefore, it may be more appropriate to use a weighted value of cost per module in estimating the overall procurement requirements.

The weighted cost factors are estimates as shown in the table below for the replacement modules. On the average, there are 10 modules per satellite. Also on the average, 7.2 modules were serviced over the 9-year operational period. These factors then result in a weighted average replacement cost of 13 percent for the failures of this case. This reduced the effective procurement to approximately 112 equivalent payloads as compared with the gross estimate of 166 previously discussed providing a 10 percent improvement over ground refurbishment. The weighting factors can vary significantly over a wide range with little effect, since a majority of the cost must inherently be in the mission equipment modules. These uncertainties dictate the need for valid costing information. As a result, an effort was initiated to develop an overall cost comparison of Case 2 space servicing with Case 506 ground refurbishment. The results of this task are discussed below.

MODULE	PERCENT OF COST
Propulsion	10
Electrical Power	10
Communications	15
Stabilization and Control	20
Mission Equipment	45

Cost estimate data was developed using the Aerospace Payload Program Cost model. Factors were developed for each subsystem of the 13 payload programs to reflect the effect on cost of modular designs. These factors range from zero to over 100 percent in terms of subsystem cost increases. The results of the Aerospace DSP design study were used in developing these factors along with other historical data. All costs are in 1973 dollars and reflect the uncertainty inherent in such a cursory analysis.

Three conditions were analyzed to provide a comparison of payload costs and overall program costs. Payload costs include RDT&E, investment, and support operations costs. Launch vehicle costs consider only operations since RDT&E and recurring investment would have to be spread across the total space program. Case 506, ground refurbishment, provides a basis for cost comparison with space servicing. It was necessary to adjust the flight schedules of this case to reflect the payload mean mission duration provided in the NASA Payload Data Book, such that the results would be comparable to space servicing. In addition, in a few cases the launch schedules were adjusted to reflect the extended operational time periods used for the space servicing analysis. In general, these changes provide a reasonable basis for comparison between space servicing of payloads and ground refurbishment, however, at this time the results only suggest trends. An in-depth analysis should be performed in the future to verify preliminary conclusions.

The cost estimates for Case 2, space servicing, reflect modularization of payloads without standardization. The estimates associated with Case 506, ground refurbishment, include low-cost payload design concepts, which as pointed out previously, define satellites that are heavier in weight. A cost comparison by payload program of Case 506 and Case 2 is provided in Table 20. In addition, the cost benefits of using standardized subsystem modules is shown by a third case. For this particular set of conditions, ground refurbishment compared to space servicing is lower in cost by approximately $300 million. This is caused by the large amount of spares required for space servicing which varied between one and two equivalent satellites worth. Such spare modules would be procured at the

Table 20. Payload Program Costs ($M 1973)

PAYLOAD		CASE 506 GROUND REFURB				CASE 2 SPACE SERVICE				CASE 2A SPACE SERVICE – STANDARD			
CODE	NAME	RDTE	INVEST	OPS	TOTAL	RDTE	INVEST	OPS	TOTAL	RDTE	INVEST	OPS	TOTAL
NC2-46	ATS	136	192	46	374	102	34	94	230	102	34	85	221
NC2-51	SYS TEST	247	227	66	540	234	120	103	457	152	120	71	343
NC2-47	SML ATS SYN	100	39	29	168	105	125	11	241	105	125	11	241
NCN-7	COMSAT	0	112	92	204	0	134	92	226	0	134	61	195
NCN-8	U. S. DOMSAT	34	209	170	413	34	242	117	393	34	242	72	348
NCN-9	FORE. DOMSAT	101	195	139	435	76	445	162	683	76	445	131	652
NC2-49	TDRS	82	59	27	168	78	83	43	204	55	83	26	164
NC2-50	DISAST. WARN	69	125	11	205	76	120	47	243	42	120	25	187
NE2-43	SYN EAR OBS	101	62	39	202	103	40	48	191	65	40	40	145
NE2-39	SYN EAR RES	211	84	64	359	233	61	99	393	165	61	90	316
NEO-11	SYN EAR RES	136	150	77	363	158	179	113	450	98	179	94	371
NE2-41	SYN MET SAT	68	62	17	147	83	63	41	187	55	63	29	147
NEO-15	SYN MET SAT	70	75	112	257	66	113	101	280	66	113	79	258
TOTAL		1355	1591	889	3835	1348	1759	1071	4178	1015	1759	814	3588

initiation of a payload program. When the programs were reinstituted after nine years of operation, such spares would again be procurred. If standardized modules can be realized, the improved use of spares would result in approximately equal payload costs for space servicing compared to ground refurbishment.

The third case shown in Table 20, which reflects the benefits of standardized subsystems, reduces RDT&E as well as the number of spares. The net effect is a savings of $247 million over ground refurbishment of approximately 6 percent.

These results are then integrated into the total program including launch vehicle cost and summarized in Table 21. Space servicing shows an overall saving, over ground refurbishment, of approximately 4 percent. Standardization increases this savings to 14 percent or $818 million. The figures suggest that space servicing may offer economic benefits for space programs. The savings illustrated are only approximate but are felt to be achievable and should be conservative. In-depth analyses should be performed and cost estimating techniques should be improved to help diminish uncertainty regarding the concept of space servicing.

Table 21. Total Program Costs ($M1973)

PAYLOAD		CASE 506 GROUND REFURB			CASE 2 SPACE SERVICEABLE			CASE 2A SPACE SERVICE – STANDARD		
CODE	NAME	PAYLOAD	LAUNCH OPS	TOTAL	PAYLOAD	LAUNCH OPS	TOTAL	PAYLOAD	LAUNCH OPS	TOTAL
NC2-46	ATS	374	85	459	230	54	284	221	54	275
NC2-51	SYS TEST	540	140	680	457	69	526	343	69	412
NC2-47	SML ATS SYN	168	160	328	241	100	341	241	100	341
NCN-7	COMSAT	204	265	469	226	125	351	195	125	320
NCN-8	U. S. DOMSAT	413	391	804	393	199	592	348	199	547
NCN-9	FORE. DOMSAT	435	532	967	683	410	1093	652	410	1062
NC2-49	TDRS	168	71	239	204	109	313	164	109	273
NC2-50	DISAST. WARN	205	42	247	243	87	330	187	87	274
NE2-43	SYN EAR OBS	202	42	244	191	40	231	145	40	185
NE2-39	SYN EAR RES	359	97	456	393	92	485	316	92	408
NEO-11	SYN EAR RES	363	117	480	450	142	592	371	142	513
NE2-41	SYN MET SAT	147	33	180	187	66	253	147	66	213
NEO-15	SYN MET SAT	257	200	457	280	111	391	258	111	369
TOTAL		3835	2175	6010	4178	1604	5782	3588	1604	5192

5. SUMMARY AND CONCLUSIONS

This study was originated to examine alternative operational concepts for the Space Transportation System which could improve the operational efficiency and provide some degree of economic benefit. The study examined the total concept at a system level involving mission requirements, payload design options, and logistic vehicle definitions. The problem was approached in a generic sense in that payloads and missions of the future are assumed to be an extrapolation of today's missions. Although detail design information for each payload program cannot be specified, descriptions can be developed to bound the weight and volume considerations which impact on the STS system. Emphasis was placed first on improving utilization of the Shuttle and Tug upper stage for payload deployment and retrieval. After this, alternate upper stages were evaluated relative to overall program costs including solar electric propulsion (SEP). The analysis was then expended to include space servicing as an operational concept in an effort to improve logistic operations.

The STS logistic operations have several areas needing improvement. Low altitude operations using the Shuttle for payload deployment or sortie operations show a load factor (based upon weight) of approximately 50 percent. In a few cases, this occurs because of large volume requirements imposed by the payload, but in general it can be laid to poor utilization of the Shuttle. The traffic requirements are so unique that multiple payload operations cannot be exploited. In many cases, this is attributed to a lack of appreciation of the flight requirements by the payload programs. It is not apparent why specific altitudes are required when a shift of 93 km (50 nmi) in apogee could allow deployment of multiple payloads. The cost benefits to the payload programs are such that a reconsideration of the mission requirements should be undertaken. Also, the projected resupply traffic to the space station at 55 deg inclination utilizes only 25 percent of the Shuttle capacity. There are a few payloads in this same inclination at 12,800 km (6,900 nmi) altitude, which require an upper stage. However, ground rules to date have precluded inclusion of upper stages on manned resupply missions as a safety precaution. An alternate approach is to save the operations cost through better utilization of the Shuttle and apply these funds toward reducing the hazards. There are also numerous polar missions for earth observations. It is recommended that these be examined to determine the degradation in mission data which might occur if they utilized a 55-deg inclined orbit. Recognizing the benefits of operations cost sharing should have some influence, since a majority of the earth surface can still be observed by this orbit.

Tug operations to synchronous equatorial orbit were found to be relatively efficient with a load factor of 82 percent. Also, approximately 70 percent of the operations employed both deployment and retrieval indicating that ground refurbishment of payloads is feasible without numerous retrieval-only flights. Only two payloads were heavy enough to force dedicated retrieval flights. These payloads (NE2-39, LCR Synchronous Earth Observations, and NC2-46, LCR Applications Technology Satellite) should be reevaluated to determine if the low cost design approach is valid in these cases. It may also be possible to break down the mission objectives into separate smaller payloads which could be absorbed into the normal traffic flow.

Polar missions were found to result in poor utilization of the Tug. The Tug load factor on the average was less than 7 percent. Several options are available. The orbital requirements are such that (unless there is some mission constraint) up to three payloads could be deployed or retrieved on a single Tug flight. The operation becomes compounded, but the logistic cost is reduced to one-third the cost previously considered. The fundamental launch schedule of three such payloads is reasonably compatible for multiple use of the Tug. This deserves more effort relative to the actual operations involved to assure that the complexities involved can be accepted. Another alternative is to use a smaller Tug which is more compatible with the mission requirements. The logistics could be reduced some, because the Shuttle would have the capacity to deploy other payloads at low altitude on the same flights. Development costs would obviously increase over the baseline Tug; however, joint use of subsystems and powerplants could minimize this effect. A two-stage operation could then be employed for retrieval of the two synchronous satellites previously mentioned.

Another alternative which was investigated involved the use of a solar electric propulsion stage (SEPS) in conjunction with a Tug. A preliminary analysis indicated minor cost savings, considering the DDT&E of the SEPS. However, a significant gain in deployment and retrieval can be realized for those unique payloads which exceed the Tug alone capability. This effort is reported in detail in an Aerospace report (Ref. 11). The report includes a tradeoff of various Tug sizes and shows the impact on the total program costs. In summary, the cost variance between viable Tug options, including phased deployment was less than 5 percent of the total program costs. Spread over the 19-year program, it appears that cost itself should not be the principal parameter in selecting a Tug configuration.

In an effort to improve the overall utilization of resources, space servicing of payloads was analyzed as an operational concept. In-depth analysis of a single program in synchronous equatorial orbit (DSP) indicated a potential benefit approximating 20 to 45 percent of the program cost, depending upon the servicing policy. However, it was not obvious that these savings could be extrapolated to the full spectrum of payloads in the NASA mission model. There are 13 payload programs at synchronous equatorial orbit with 1 to 4 satellites in each program. This amounts to a total of 37 satellites at various longitude placements. The baseline MSFC Tug was found to have the performance capability to service up to 5 satellites distributed over 270 deg of longitude within a 7-day mission period.

The results are based upon a statistical distribution of failures in the candidate satellites which then forces a random loading of space replaceable units (SRUs) on the Tug. The results are preliminary in that only two sample cases could be analyzed, using a manual computation technique. However, several points can be inferred as compared to ground refurbishment of the same payloads.

a. Tug flight operations were reduced by 18 percent.

b. Tug utilization (load factor) averaged 82 percent which is equivalent to ground refurbishment operations.

c. Total equivalent procurement of payloads was reduced approximately 10 percent. Integrated cost benefit is 14 percent.

d. Average availability of the satellite systems was 81 percent.

The results point favorably toward space servicing along with other factors which may be just as important. The mission equipment on many of the earth observation satellites has a typically short lifetime of approximately one year. Consequently, equipment changeout or block changes in design can be expected for some time in the future. An operational concept which allows this flexibility without having to replace the entire satellite should be a distinct improvement. In addition, the total satellite weight is not constrained to a retrieval condition of 1,814 kg (4,000 lb), allowing some relaxation of the design effort. Once the payload is deployed, the concern focuses on the individual module weights.

The same servicing results may not be possible with low altitude satellites due to orbital regression and reduced traffic to specific orbits. In this case, a multi-mission satellite offers the potential to reduce program costs. A single satellite stationed in a compromise orbit could have the same mission equipment of several satellites in different orbits. In this way, the multi-mission satellite could be serviced by a single Tug or Shuttle operation replacing failed components and changing out mission equipment. It is recommended that this concept be pursued in future studies as a means of reducing overall system costs.

Further analysis is required to assess various space-servicing options. Manual calculations are too time-consuming to produce enough data for a statistically acceptable answer. Consequently, a computer program has been considered for future efforts. The computer specification is included as Volume IV of this report. It is recommended that coding of this program be initiated as early as possible in any follow-on study of space servicing.

In summary, this study effort has assessed several operational approaches which could reduce future resource expenditures. Several options appear promising and deserve further investigation. Also, there is always a need to improve the input data upon which these tradeoffs are made. Improved utilization of the Tug, especially for VAFB operations, should be pursued to assure a viable alternative to the current launch vehicles. The analysis of space servicing must be continued along with standardization of design approaches. Standardization can be developed without compromising the mission objectives and should provide substantial cost benefits. It appears to date that, irrespective of common hardware, if the SRUs can be designed for handling with a common servicing unit, space servicing offers cost reductions over ground refurbishment.

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APPENDIX A

CASE 1 GROUND RULES AND MANIFEST

APPENDIX A

This appendix provides the detailed launch schedules for deployment and servicing of the thirteen synchronous equatorial payload programs based upon a LMSC module composition. Allocation of the modules to the spacecraft designs is provided in Section 3.0 of this volume. A summary of the modules employed, defining weight and reliability characteristics is contained in Table A-1.

The launch schedule (Table A-2) provides a flight-by-flight manifest of the payloads being transported to orbit by the Tug. The total payload weight is identified along with the remaining margin in Tug performance which cannot be utilized. The weight of the servicing unit (91 kg, 200 lbs), where required has been added to the payload weight to reflect the impact on the Tug performance. The time of preparing payloads for launch and time at which launched occurred is also provided. This shows the delay time between a failure occurrence and when repair can be affected. The maximum delays associated with each flight load are given for reference purposes.

The Tug is assumed to be available on 1 January 1979. The Tug performance, as a function of the number of satellites to be serviced, is assumed as follows:

Satellites Serviced	Service Payload	
1	1,360 kg	3,000 lbs
2	1,088 kg	2,400 lbs
3	576 kg	1,270 lbs
4	227 kg	500 lbs
5	-0-	-0-

The service payload weight is assumed to be carried round trip and remains constant. That is, the module to be replaced is assumed to weigh the same as the new module. This total weight must also include the 91 kg (200 lb) servicing unit. It is assumed that payloads can be deployed on the same mission that other payloads can be serviced. Deployment always occurs first, with the remaining performance used for servicing. The minimum time between Tug operations is assumed to be 30 days (0.08 yrs). Satellites to be deployed in a given year are assumed to be available on one month centers, starting 1 January -- no priority of operations is assumed for new payload deployments. If after placing the first SRU in the loading que, a full load is not achieved within six months, the TUG flight is to be performed regardless. No satellite is to wait more than six months for servicing. Further it is assumed that some time delay is required between identifying a failed module and preparing a new one for flight. This time was taken as 30 days.

Table A-1. Case 1 Module Definitions

MODULE TYPE	CODE (LMSC)	WEIGHT kg (lb)	WEIBULL PARAM α (YR)	β	TRUNC TIME (YR)
Stabilization & Control	S&C-2-1	40 (88)	7.6774	1.1102	N/A
	S&C-4	103 (228)	37.004	.9994	
	S&C-1	48 (105)	15.828	1.0113	
	S&C-2	29 (64)	10.0012	1.1535	
	S&C-3	92 (203)	6.4099	.9986	
Communications, Data Processing & Instru	CDPI-1-1	54 (120)	16.4234	1.1771	N/A
	CDPI-4	30 (67)	6.6073	1.0946	
	CDPI-2	35 (78)	3.2319	.9998	
	CDPI-3	41 (91)	10.7912	1.002	
	CDPI-1	39 (85)	8.0422	1.1057	
	CDPI-4-1	25.7 (56.7)	3.8409	1.0009	
Electrical Power	EPS-2-1	91 (200)	1085.74	1.0751	N/A
	EPS-5	34 (76)	475.677	.9998	
	EPS-6	106 (234)	1562.46	1.2363	
	EPS-7	54 (120)	208.929	1.056	
	EPS-1-7	65 (144)	1407.83	1.0392	
	EPS-1-3	52 (114)	1407.83	1.0392	
	EPS-1-5	56 (123)	1407.83	1.0392	
	EPS-1-4	54 (120)	1407.83	1.0392	
	EPS-7-1	74 (164)	1811.45	1.0453	
	EPS-1-2	50 (111)	1407.83	1.0392	
	EPS-6-1	81 (178)	1562.46	1.2363	
Attitude Control	ACS-2	44 (97)	10.1074	1.1116	3
	ACS-1	46 (101)	5.4473	1.0134	3

Table A-2. Case 1 Manifest

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
1	1	NC2-46		1, 825 (4, 023)	-0-	-0-	-0-	576 (1, 270)
	2	NC2-47(A)		1, 423 (3, 136)	-0-			163 (360)
2	1	NCN-8(C)		2, 009 (4, 428)	.08	.08	-0-	522 (1, 150)
3	1	NC2-50(B)		1, 701 (3, 750)	.50	.50	-0-	612 (1, 350)
	2	NEO-15(B)		1, 557 (3, 432)	.50			163 (360)
4	1	NEO-15(A)	NEO-151	136 (300)	.93	1.08	.15	1. 225 (2, 700)
	2	NC2-51(A)		1, 608 (3, 545)	1.00			408 (900)
5	1	NCN-9(A)		1, 185 (2, 612)	1.16	1.24	.08	762 (1, 680)
	2	NCN-9(B)		1, 185 (2, 612)	1.24			436 (960)
6	1	NE2-39(A)		1, 902 (4, 193)	1.32	1.82	.50	544 (1, 200)
	2	NCN-8(A)	CDPI-4	30 (67)	1.78			286 (630)
	3	NCN-8(A)	ACS-2(4)	272 (600)	1.82			-0-
7	1	NC2-51(B)		1, 608 (3, 545)	2.0	2.08	.08	
	2	NC2-47(C)		1, 423 (3, 136)	2.08			-0-
8	1	NE2-41(A)		1, 548 (3, 413)	2.16	2.2	.06	
	2	NC2-49(B)	ACS-2(4)	272 (600)	2.2			483 (1, 065)
9	1	NC2-49(B)	NC2-49	121 (267)	1.81	2.28	.47	
	2	NC2-50(A)	CDPI-4	30 (67)	1.86			
	3	NC2-49(A)	ACS-2(4)	272 (600)	2.1			62 (136)
10	1	NCN-8(B)	ACS-2(4)	272 (600)	2.2	2.36	.16	
	2	NC2-49(C)	ACS-2(4)	272 (600)	2.3			454 (1, 000)
11	1	NCN-7(A)	ACS-2(4)	272 (600)	2.3	2.42	.12	
	2	NCN-7(B)	ACS-2(4)	272 (600)	2.4			454 (1, 000)
12	1	NC2-50(A)	ACS-2(4)	272 (600)	2.4	2.50	.10	
	2	NC2-49(C)	S&C-3	92 (203)	2.40			635 (1, 400)
	3	NC2-49(A)	NC2-491, 2	121 (267)	2.42			-0-

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
13	1	NEO-15(A)	NEO-151, 2, 3, 4, 5	136 (300)	2.44	2.58	.14	
	2	NEO-15(A)	ACS-2(4)	272 (600)	2.5			862 (1,900)
	3	NCN-7(C)	ACS-2(4)	272 (600)	2.5			318 (700)
14	1	NEO-15(B)	NEO-151, 2, 3, 4, 5	136 (300)	2.55	3.05	.50	
	2	NC2-46	NC2-461	95 (210)	2.79			771 (1,700)
	3	NCN-8(C)	ACS-2(4)	272 (600)	3.05			-0-
15	1	NCN-8(B)	CDPI-4	30 (67)	3.029	3.13	.10	
	2	NC2-46	ACS-2(4)	272 (600)	3.10			695 (1,533)
16	1	NC2-47(D)		1,423 (3,137)	3.13	3.21	.08	
	2	NEO-15(A)	NEO-151, 2 3, 4, 5	113 (250)	3.16			505 (1,113)
	3	NEO-15(B)	NEO-151, 2 3, 4, 5	113 (250)	3.16			32 (70)
17	1	NE2-41(B)		1,548 (3,413)	3.21	3.29	.08	
	2	NE2-39(A)	NE2-395	67 (147)	3.234			461 (1,017)
18	1	NE2-39(A)	NE2-391	160 (353)	3.295	3.486	.19	
	2	NE2-41(A)	CDPI-2, 3	77 (169)	3.413			739 (1,630)
	3	NCN-8(B)	NCN-85	91 (200)	3.486			114 (252)
19	1	NEO-15(B)	ACS-2(4)	272 (600)	3.5	3,566	.07	
	2	NC2-50(B)	ACS-2(4)	272 (600)	3.5			454 (1,000)
20	1	NCN-8(C)	CDPI-4	30 (67)	3.694	3.771	.08	
	2	NEO-15(B)	CDPI-2, 3	76 (167)	3.739			891 (1,964)
	3	NCN-8(C)	S&C-2-1	40 (88)	3.771			338 (746)
21	1	NE2-39(A)	NE2-392	120 (265)	3.896	3.925	.03	
	2	NC2-46	NC2-463	74 (162)	3.896			782 (1,725)
	3	NE2-39(A)	CDPI-1-4	64 (142)	3.925			206 (453)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
22	1	NC2-49(B)	S&C-3	92 (203)	3.993	4.08	.09	
	2	NC2-47(E)		1,423 (3,137)	4.00			505 (1, 113)
	3	NC2-51(A)	ACS-2(4)	272 (600)	4.08			54 (118)
23	1	NC2-50(B)	CDPI-4	30 (67)	4.114	4.246	.13	
	2	NC2-46	NC2-461,2,3	221 (488)	4.24			
	3	NCN-8(C)	NCN-82	91 (200)	4.246			99 (219)
24	1	NC2-49(A)	NC2-491, 2	99 (219)	4.32	4.369	.05	
	2	NE2-39(A)	NE2-395	67 (147)	4.362			
	3	NCN-7(B)	CDPI-4	30 (67)	4.369			245 (541)
25	1	NC2-50(A)	S&C-2-1	40 (88)	4.382	4.449	.07	
	2	NCN-8(C)	NCN-84	91 (200)	4.384			
	3	NC2-49(B)	NC2-491, 2	99 (219)	4.40			343 (755)
26	1	NC2-49(C)	NC2-491, 2	99 (219)	4.48	4.529	.05	
	2	NC2-51(A)	NC2-512	71 (157)	4.502			
	3	NEO-15(A)	CDPI-2-3	77 (169)	4.506			216 (477)
27	1	NC2-49(A)	S&C-1-2	77 (169)	4.615	4.74	.12	
	2	NE2-41(A)	NE2-411, 2, 3, 4	73 (160)	4.63			
	3	NCN-9(A)	ACS-1(4)	272 (600)	4.74			42 (93)
28	1	NE2-39(A)	NE2-391	160 (353)	4.742	4.82	.08	
	2	NCN-9(B)	ACS-1(4)	272 (600)	4.76			544 (1, 199)
29	1	NCN-8(A)	ACS-2	272 (600)	4.8	4.90	.10	
	2	NE2-39(A)	ACS-2	272 (600)	4.82			454 (1, 000)
30	1	NC2-51(B)	NC2-511	72 (158)	4.896	4.98	.08	
	2	NCN-7(A)	CDPI-4	30 (67)	4.917			874 (1, 927)
31	1	NC2-47(F)		1,423 (3,137)	5.0	5.08	.08	
	2	NC2-51(B)	ACS-2(4)	272 (600)	5.08			505 (1, 113)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			MARGIN kg (lb)
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	
32	1	NCN-8(D)		2,009 (4,428)	5.08	5.16	.08	280 (617)
	2	NCN-7(B)	NCN-72	80 (177)	5.14			
33	1	NCN-8(E)		2,009 (4,428)	5.16	5.24	.08	302 (665)
	2	NE2-41(A)	ACS-2(4)	272 (600)	5.2			
34	1	NC2-49(B)	ACS-2(4)	272 (600)	5.2	5.32	.10	24 (53)
	2	NCN-8(A)	NCN-85	91 (200)	5.248			
	3	NEO-15(A)	S&C-1, 2	77 (169)	5.259			
35	1	NE2-39(A)	NE2-393, 4	107 (235)	5.289	5.40	.11	597 (1, 317)
	2	NCN-8(B)	ACS-2(4)	272 (600)	5.3			
36	1	NC2-49(A)	ACS-2(4)	272 (600)	5.3	5.48	.18	454 (1, 000)
	2	NC2-49(C)	ACS-2(4)	272 (600)	5.3			
37	1	NCN-7(A)	ACS-2(4)	272 (600)	5.4	5.56	.16	454 (1, 000)
	2	NCN-7(B)	ACS-2(4)	272 (600)	5.4			
38	1	NC2-50(A)	ACS-2(4)	272 (600)	5.502	5.64	.14	454 (1, 000)
	2	NCN-7(C)	ACS-2(4)	272 (600)	5.582			
39	1	NEO-15(A)	ACS-2(4)	272 (600)	5.582	5.72	.14	118 (261)
	2	NCN-9(A)	CDPI-4	30 (67)	5.599			
	3	NE2-39(A)	CDPI-1, -4 -1	64 (142)	5.717			
40	1	NC2-49(B)	S&C-1, 2	77 (169)	5.756	6.0	.24	144 (318)
	2	NC2-47(G)		1,423 (3,137)	6.0			
	3	NE2-39(A)	NE2-391, 2, 3, 4, 5	454 (1,000)	6.0			
41	1	NCN-8(C)	ACS-2(4)	272 (600)	6.05	6.08	.03	302 (665)
	2	NCN-8(F)		2,009 (4,428)	6.08			
42	1	NC2-46	ACS-2(4)	272 (600)	6.13	6.16	.03	591 (1, 302)
	2	NEO-15(B)	NEO-151, 2, 3, 4, 5	113 (250)	6.145			

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
43	1	NEO-15(B)	S&C-3	92 (203)	6.147	6.24	.09	
	2	NEO-11(A)		1,715 (3,781)	6.16			404 (890)
44	1	NEO-11(B)		1,715 (3,781)	6.24	6.32	.08	
	2	NE2-41(B)	ACS-2(4)	272 (600)	6.29			404 (890)
45	1	NC2-51(A)	CDPI-4	30 (67)	6.302	6.40	.10	
	2	NEO-11(C)		1,715 (3,781)	6.32			404 (890)
46	1	NEO-15(A)	NEO-151, 2 3, 4, 5	113 (250)	6.321	6.48	.16	
	2	NCN-9(B)	143	2,869 (6,325)				
	3	NCN-7(C)	NCN-71	81 (178)	6.37			204 (450)
47	1	NEO-11(D)		1,715 (3,781)	6.40	6.56	.16	
	2	NCN-8(C)	NCN-85	91 (200)	6.526			404 (890)
48	1	NC2-50(B)	ACS-2 (4)	272 (600)	6.566	6.64	.07	
	2	NEO-15(B)	ACS-2(4)	272 (600)	6.566			454 (1,000)
49	1	NEO-15(A)	CDPI-2, 3	79 (169)	6.569	6.72	.15	
	2	NCN-8(A)	CDPI-4	30 (67)	6.632			
	3	NCN-9(B)	NCN-92	65 (143)	6.661			292 (643)
50	1	NC2-47(H)		1,423 (3,136)	7.0	7.0	-0-	
	2	NEO-15(A)	NEO-151, 2, 3, 4, 5	113 (250)	7.0			
	3	NEO-15(B)	NEO-151, 2 3, 4, 5	113 (250)	7.0			32 (70)
51	1	NC2-51(A)	ACS-2(4)	272 (600)	7.08	7.142	.06	
	2	NE2-39(A)	NE2-391	107 (235)	7.09			
	3	NC2-49(A)	CDPI-4	30 (67)	7.142			54 (120)
52	1	NCN-8(B)	S&C-2-1	40 (88)	7.145	7.273	.13	
	2	NCN-7(B)	S&C-2-1	40 (88)	7.159			
	3	NC2-49(A)	NC2-491, 2	99 (219)	7.273			284 (627)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
53	1	NCN-7(C)	S&C-2-1	40 (88)	7.365	7.745	.38	
	2	NCN-9(A)	ACS-1(4)	272 (600)	7.74			
	3	NEO-15(B)	CDPI-2, 3	77 (169)	7.745			97 (213)
54	1	NEO-11(A)	CDPI-1, 4-1	64 (142)	7.80	7.845	.05	
	2	NCN-9(B)	ACS-1(4)	272 (600)	7.82			
	3	NCN-8(A)	NCN-84	91 (200)	7.845			36 (80)
55	1	NCN-8(A)	S&C-2-1	40 (88)	7.85	7.98	.13	
	2	NE2-39(A)	CDPI-1, 4-1	64 (142)	7.889			
	3	NCN-8(A)	ACS-2(4)	91 (200)	7.90			
	4	NE2-39	ACS-2(4)	272 (600)	7.90			531 (1, 170)
56	1	NE2-41(B)	NE2-411, 2,	73 (160)	7.942	8.16	.22	
	2	NC2-47(I)	3, 4	1,423 (3,137)	8.0			
	3	NC2-51(B)	ACS-2(4)	272 (600)	8.08			32 (70)
57	1	NEO-15(C)		1,557 (3,432)	8.08	8.24	.16	
	2	NE2-41(A)	NE2-411, 2 3, 4	73 (160)	8.092			437 (962)
58	1	NC2-51(B)	CDPI-4	30 (67)	8.094	8.32	.23	
	2	NC2-51(B)	NC2-512	71 (157)	8.12			
	3	NCN-7(D)		1,497 (3,301)	8.16			457 (1, 008)
59	1	NCN-7(E)		1,497 (3,301)	8.24	8.40	.16	
	2	NE2-41(A)	ACS-2(4)	272 (600)	8.24			479 (1, 056)
60	1	NCN-7(F)		1,497 (3,301)	8.32	8.48	.16	
	2	NC2-46	CDPI-1, 1-4	85 (187)	8.351			479 (1, 056)
61	1	NCN-8(D)		2,009 (4,428)	8.40	8.56	.16	
	2	NCN-9(A)	NCN-92	65 (143)	8.453			280 (617)
62	1	NCN-8(E)		2,009 (4,428)	8.48	8.64	.16	
	2	NEO-11(B)	CDPI-1-4-1	64 (142)	8.56			302 (665)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
63	1	NC2-49(D)		1,522 (3,356)	8.56	8.72	.16	1,361 (3,000)
64	1	NC2-49(E)		1,522 (3,356)	8.64	8.80	.16	
	2	NC2-50(B)	NC2-502	76 (167)	8.682			
	3	NEO-11(C)	CDPI-1, 4-1	64 (142)	8.71			2 (4)
65	1	NC2-49(F)		1,522 (3,356)	8.72	8.88	.16	
	2	NE2-41(B)	S&C-1, 2	77 (169)	8.80			470 (1,037)
66	1	NC2-50(C)		1,701 (3,750)	8.80	8.96	.16	
	2	NCN-9(A)	CDPI-4	30 (67)	8.863			408 (900)
67	1	NC2-47(J)		1,423 (3,137)	9.0	9.08	.08	
	2	NEO-11(D)	CDPI-1, 4-1	64 (142)	9.0			
	3	NE2-39(A)	NE2-395	67 (147)	9.0			32 (70)
68	1	NCN-8(F)		2,009 (4,428)	9.08	9.24	.16	
	2	NC2-46	ACS-2(4)	272 (600)	9.16			302 (665)
69	1	NC2-50(D)		1,701 (3,750)	9.16	9.32	.16	
	2	NE2-41(B)	CDPI-2, -3	77 (169)	9.161			408 (900)
70	1	NC2-46	S&C-2-1	40 (88)	9.188	9.40	.21	
	2	NEO-11(A)	ACS-2(4)	272 (600)	9.24			
	3	NEO-15(D)		1,557 (3,432)	9.24			13 (29)
71	1	NE2-41(A)	S&C-1, 2	77 (169)	9.276	9.48	.20	
	2	NE2-41(B)	ACS-2(4)	272 (600)	9.32			649 (1,431)
72	1	NEO-11(B)	ACS-2(4)	272 (600)	9.32	9.56	.24	
	2	NEO-11(C)	ACS-2(4)	272 (600)	9.40			454 (1,000)
	3	NEO-11(C)	NEO-115	64 (142)	9.47			367 (809)
73	1	NEO-11(D)	ACS-2(4)	272 (600)	9.56	9.79	.23	
	2	NE2-39(A)	NE2-391	160 (353)	9.71			544 (1,199)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
74	1	NEO-11(A)	S&C-3	98 (203)	9.80	10.08	.28	
	2	NC2-51(C)		1,608 (3,545)	10.0			440 (971)
75	1	NC2-47(K)		1,423 (3,136)	10.08	10.24	.16	
	2	NCN-9(C)		1,185 (2,612)	10.16			568 (1,252)
76	1	NEO-15(C)	CDPI-2, 3	77 (169)	10.199	10.32	.12	
		NCN-9(D)		1,185 (2,612)	10.24			587 (1,295)
77	1	NE2-39(B)		1,902 (4,193)	10.32	10.607	.29	
	2	NE2-41(A)	CDPI-2, 3	77 (169)	10.527			
	3	NE2-41(A)	S&C-3	92 (203)	10.527			339 (747)
78	1	NEO-11(B)	NEO-111, 2, 3, 4	94 (207)	10.90	11.08	.18	
	2	NC2-51(D)		1,608 (3,545)	11.0			419 (923)
79	1	NEO-11(C)	CDPI-1-4-1	64 (142)	11.026	11.16	.13	
	2	NC2-47(L)		1,423 (3,136)	11.08			505 (1,113)
80	1	NE2-43		2,154 (4,748)	11.16	11.32	.16	
	2	NEO-15(C)	NEO-111, 2, 3, 4, 5	113 (250)	11.226			
	3	NEO-15(C)	ACS-2(4)	272 (600)	11.24			230 (506)
81	1	NE2-41(C)		1,548 (3,413)	11.24	11.40	.16	
	2	NCN-7(D)	ACS-2(4)	272 (600)	11.32			461 (1,017)
82	1	NEO-11(D)	NEO-111, 2, 3, 4	94 (207)	11.38	11.48	.10	
	2	NCN-7(E)	ACS-2(4)	272 (600)	11.4			610 (1,345)
83	1	NEO-15(D)	NEO-151, 2, 3, 4, 5	113 (250)	11.404	11.56	.16	
	2	NEO-11(B)	NEO-111, 2 3, 4	94 (207)	11.43			768 (1,693)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
84	1	NCN-7(F)	ACS-2(4)	272 (600)	11.48	11.64	.16	
	2	NEO-11(B)	CDPI-1, 4-1	64 (142)	11.488			661 (1, 458)
85	1	NCN-8(D)	ACS-2(4)	272 (600)	11.56	11.656	.10	
	2	NC2-49(E)	CDPI-4	30 (67)	11.576			695 (1, 533)
86	1	NCN-8(E)	ACS-2(4)	272 (600)	11.64	11.79	.15	
	2	NEO-11(C)	S&C-3	92 (203)	11.71			634 (1, 397)
87	1	NC2-49(D)	ACS-2(4)	272 (600)	11.72	11.88	.16	
	2	NC2-49(E)	ACS-2(4)	272 (600)	11.80			454 (1, 000)
88	1	NC2-49(F)	ACS-2(4)	272 (600)	11.88	12.04	.16	
	2	NC2-50(C)	ACS-2(4)	272 (600)	11.96			454 (1, 000)
89	1	NC2-47(M)		1,423 (3,136)	12.0	12.12	.12	
	2	NC2-46	NC2-461, 2, 3	221 (488)	12.0			
	3	NEO-15(C)	NEO-151, 2, 3, 4, 5	113 (250)	12.0			32 (70)
90	1	NC2-49(D)	NC2-491, 2	99 (219)	12.056	12.20	.14	
	2	NE2-41(D)		1,548 (3,413)	12.08			438 (966)
91	1	NE2-39(B)	NE2-391	160 (353)	12.088	12.32	.23	
	2	NCN-8(F)	ACS-2(4)	272 (600)	12.24			544 (1, 199)
92	1	NC2-46	ACS-2(4)	272 (600)	12.24	12.40	.16	
	2	NC2-50(D)	ACS-2(4)	272 (600)	12.32			454 (1, 000)
93	1	NEO-11(A)	CDPI-1, 4-1	64 (142)	12.371	12.48	.11	
	2	NEO-11(A)	ACS-2(4)	272 (600)	12.40			
	3	NEO-15(D)	ACS-2(4)	272 (600)	12.40			389 (858)
94	1	NEO-15(C)	S&C-3	92 (203)	12.429	12.56	.13	
	2	NEO-11(B)	ACS-2(4)	272 (600)	12.56			634 (1, 397)
95	1	NEO-11(C)	ACS-2(4)	272 (600)	12.56	12.734	.17	
	2	NE2-43	NE2-431	156 (343)	12.654			548 (1, 209)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
96	1	NC2-49(F)	S&C-3	91 (200)	12.746	12.89	.14	
	2	NEO-11(D)	ACS-2(4)	272 (600)	12.79			
	3	NEO-11(D)	S&C-1, 2	77 (169)	12.81			555 (1, 223)
97	1	NCN-9(D)	NCN-91	65 (143)	12.994	13.08	.09	
	2	NC2-47(N)		1,423 (3,136)	13.0			
	3	NC2-49(D)	NC2-491, 2	99 (219)	13.0			32 (70)
98	1	NC2-49(F)	NC2-491, 2	99 (219)	13.0	13.16	.16	
	2	NC2-49(F)	NC2-491, 2	99 (219)	13.0			
	3	NEO-15(D)	NEO-151, 2 3, 4, 5	113 (250)	13.0			152 (334)
99	1	NE2-39(B)	NE2-392	120 (265)	13.069	13.272	.20	
	2	NC2-51(C)	ACS-2(4)	272 (600)	13.08			
	3	NCN-9(C)	NCN-91	65 (143)	13.192			6 (14)
100	1	NCN-9(C)	ACS-1(4)	272 (600)	13.24	13.40	.16	
	2	NCN-9(D)	ACS-1(4)	272 (600)	13.32			45 (100)
101	1	NE2-39(B)	NE2-395	67 (147)	13.353	13.62	.27	
	2	NE2-39(B)	NE2-393, 4	107 (235)	13.36			
	3	NEO-11(D)	CDPI-1, 4-1	64 (142)	13.442			
	4	NEO-11(C)	NEO-111, 2, 3, 4	113 (250)	13.54			113 (248)
102	1	NE2-39(B)	ACS-2(4)	272 (600)	13.607	13.872	.27	
	2	NC2-49(D)	S&C-3	92 (203)	13.721			
	3	NCN-7(D)	CDPI-4	30 (67)	13.792			91 (200)
103	1	NC2-46	CDPI-1-1, 4	85 (187)	13.862	14.064	.20	
	2	NEO-11(A)	NEO-111, 2, 3, 4	94 (207)	13.87			
	3	NC2-51(D)	NC2-512	71 (157)	13.984			214 (471)
104	1	NC2-47(O)		1,423 (3,137)	14.0	4.263	.26	
	2	NC2-51(D)	ACS-2(4)	272 (600)	14.08			
	3	NEO-15(C)	NEO-111, 2, 3, 4	113 (250)	14.183			32 (70)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
105	1	NEO-11(A)	CDPI-1, 4-1	64 (142)	14.198	14.358	.36	
	2	NEO-11(B)	S&C-1, -2	77 (169)	14.27			
	3	NE2-41(D)	CDPI-2, -3	77 (169)	14.278			268 (590)
106	1	NE2-43	ACS-2(4)	272 (600)	14.32	14.438	.12	
	2	NEO-15(C)	ACS-2(4)	272 (600)	14.32			454 (1,000)
107	1	NCN-7(D)	ACS-2(4)	272 (600)	14.40	14.518	.12	
	2	NE2-41(C)	ACS-2(4)	272 (600)	14.40			454 (1,000)
108	1	NC2-50(C)	CDPI-4	30 (67)	14.451	14.598	.15	
	2	NE2-43	NE2-435	259 (571)	14.473			687 (1,514)
109	1	NCN-7(E)	ACS-2(4)	272 (600)	14.48	14.678	.20	
	2	NC2-46	NC2-462	74 (163)	14.487			630 (1,389)
110	1	NCN-7(F)	ACS-2(4)	272 (600)	14.64	14.758	.12	
	2	NCN-8(D)	ACS-2(4)	272 (600)	14.656			454 (1,000)
111	1	NCN-8(E)	ACS-2(4)	272 (600)	14.79	14.885	.10	
	2	NCN-7(F)	CDPI-4	30 (67)	14.805			698 (1,538)
112	1	NC2-49(E)	ACS-2(4)	272 (600)	14.88	14.965	.09	
	2	NC2-49(D)	ACS-2(4)	272 (600)	14.88			454 (1,000)
113	1	NE2-41(C)	S&C-3	92 (203)	14.897	15.08	.18	
	2	NC2-47(D)		1,423 (3,137)	15.0			
	3	NE2-39(B)	NE2-391, 2, 3, 4, 5	454 (1,000)	15.0			32 (70)
114	1	NC2-50(C)	ACS-2(4)	272 (600)	15.04	15.16	.12	
	2	NC2-49(F)	ACS-2(4)	272 (600)	15.04			454 (1,000)
115	1	NE2-41(C)	NE2-411, 2, 3, 4	73 (160)	15.059	15.24	.18	
	2	NEO-11(E)		1,715 (3,781)	15.08			392 (842)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
116	1	NEO-15(D)	NEO-151, 2 3, 4, 5	113 (250)	15.133	15.32	.19	
	2	NEO-11(F)		1,715 (3,781)	15.16			382 (842)
117	1	NCN-7(D)	NCN-72	80 (177)	15.161	15.40	.24	
	2	NE2-41(D)	ACS-2(4)	272 (600)	15.20			624 (1,375)
118	1	NEO-11(G)		1,715 (3,781)	15.24	15.48	.24	
	2	NCN-8(F)	ACS-2(4)	272 (600)	15.32			404 (890)
119	1	NEO-11(H)		1,715 (3,781)	15.32	15.56	.24	
	2	NC2-46	ACS-2(4)	272 (600)	15.4			404 (890)
120	1	NC2-50(D)	ACS-2(4)	272 (600)	15.4	15.74	.34	
	2	NEO-15(D)	ACS-2(4)	272 (600)	15.48			454 (1,000)
121	1	NCN-8(E)	CDPI-4	30 (67)	15.492	15.72	.23	
	2	NEO-15(D)	S&C-3	92 (203)	15.503			
	3	NE2-43	S&C-3	92 (203)	15.528			
	4	NCN-8(E)	NCN-83	91 (200)	15.601			158 (349)
122	1	NEO-15(C)	CDPI-2, 3	77 (169)	15.615	16.034	.42	
	2	NCN-9(D)	NCN-91	65 (143)	15.714			
	3	NEO-15(D)	CDPI-2, 3	77 (169)	15.954			245 (541)
123	1	NC2-47(Q)		1,423 (3,137)	16.0	16.192	.19	
	2	NC2-46	NC2-461, 2, 3	221 (488)	16.0			
	3	NC2-49(E)	S&C-1, 2	77 (169)	16.112			32 (70)
124	1	NC2-51(C)	ACS-2(4)	272 (600)	16.272	16.48	.21	
	2	NCN-9(C)	ACS-2(4)	272 (600)	16.40			454 (1,000)
125	1	NCN-9(D)	ACS-2(4)	272 (600)	16.40	16.589	.19	
	2	NC2-49(D)	S&C-1, 2	77 (169)	16.412			
	3	NC2-49(E)	S&C-1, 2	77 (169)	16.509			60 (132)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
126	1	NC2-49(E)	NC2-491, 2	99 (219)	16.509	16.745	.24	
	2	NC2-46	S&C-2, 1	40 (88)	16.565			
	3	NE2-41(C)	S&C-1, 2	77 (169)	16.595			
	4	NE2-39(B)	NE2-392	120 (265)	16.665			128 (281)
127	1	NC2-46	NC2-463	74 (162)	16.747	16.952	.21	
	2	NC2-51(C)	NC2-512	71 (157)	16.854			
	3	NE2-39(B)	ACS-2(4)	272 (600)	16.872			47 (103)
128	1	NCN-7(E)	NCN-71	81 (178)	16.995	17.076	.08	
	2	NEO-15(C)	NEO-151, 2 3, 4, 5	113 (250)	16.996			79 (174)
129	1	NEO-15(E)		1,557 (3,432)	17.0	17.156	.16	1,618 (3,568)
130	1	NC2-50(E)		1,701 (3,750)	17.08	17.236	.16	1,474 (3,250)
131	1	NC2-49(G)		1,522 (3,356)	17.16	17.316	.16	
	2	NC2-51(D)	CDPI-4	30 (67)	17.235			470 (1,037)
132	1	NC2-49(H)		1,522 (3,356)	17.24	17.396	.16	
	2	NC2-51(D)	ACS-2(4)	272 (600)	17.263			
	3	NCN-9(C)	S&C-2, 1	40 (88)	17.285			24 (52)
133	1	NE2-39(B)	NE2-391	160 (353)	17.286	17.476	.19	
	2	NC2-49(I)		1,522 (3,356)	17.32			449 (989)
134	1	NC2-47(R)		1,423 (3,136)	17.40	17.556	.16	
	2	NE2-43	ACS-2(4)	272 (600)	17.438			505 (1,113)
135	1	NCN-7(G)		1,497 (3,301)	17.48	17.636	.16	
	2	NE2-41(C)	ACS-2(4)	272 (600)	17.518			479 (1,056)
136	1	NCN-7(H)		1,497 (3,301)	17.56	17.72	.16	
	2	NCN-7(I)		1,497 (3, 301)	17.64			181 (398)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
137	1	NE2-41(C)	CDPI-2, 3	77 (169)	17.683	17.80	.12	
	2	NCN-8(G)		2,009 (4,428)	17.72			302 (665)
138	1	NE2-43	CDPI-1, 4-1	64 (142)	17.732	17.88	.15	
	2	NC2-46	NC2-461	74 (163)	17.77			838 (1,847)
139	1	NCN-8(H)		2,009 (4,428)	17.80	17.973	.17	
	2	NCN-9(C)	CDPI-4	30 (67)	17.893			302 (665)
140	1	NE2-41(D)	S&C-1, 2	77 (169)	17.928	18.082	.15	
	2	NCN-8(F)	CDPI-4	30 (67)	17.94			
	3	NEO-15(D)	NEO-151, 2, 3, 4, 5	113 (250)	17.942			356 (784)
141	1	NC2-47(S)		1,423 (3,136)	18.0	18.162	.16	
	2	NEO-11(E)	NEO-115	65 (143)	18.068			483 (1,065)
142	1	NCN-8(I)		2,009 (4,428)	18.08	18.244	.16	
	2	NE2-41(D)	NE2-411, 2, 3, 4	73 (160)	18.084			280 (617)
143	1	NEO-11(F)	CDPI-1, 4-1	64 (142)	18.101	18.324	.22	
	2	NE2-43	NE2-431	246 (543)	18.141			665 (1,467)
144	1	NC2-50(F)		1,701 (3,750)	18.16	18.404	.24	
	2	NE2-39(B)	NE2-392	120 (265)	18.181			387 (852)
145	1	NE2-43	NE2-435	259 (571)	18.199	18.484	.28	
	2	NEO-15(F)		1,557 (3,432)	18.24			436 (962)
146	1	NEO-11(E)	ACS-2(4)	272 (600)	18.24	18.564	.32	
	2	NEO-11(E)	NEO-111, 2, 3, 4	94 (207)	18.25			
	3	NEO-11(F)	ACS-2(4)	272 (600)	18.32			338 (745)
147	1	NEO-11(H)	S&C-3	92 (203)	18.391	18.644	.25	
	2	NE2-41(D)	ACS-2(4)	272 (600)	18.40			634 (1,397)

Table A-2. Case 1 Manifest (Continued)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
148	1	NEO-11(G)	ACS-2(4)	272 (600)	18.48	18.724	.24	
	2	NEO-11(H)	NEO-111,2,3,4		207	18.553		519 (1,145)
149	1	NC2-46	ACS-2(4)	272 (600)	18.56	18.804	.44	
	2	NEO-11(H)	ACS-2(4)	272 (600)	18.56			454 (1,000)
150	1	NEO-11(E)	NEO-115	65 (143)	18.854	18.982	.13	
	2	NEO-11(G)	NEO-115	65 (143)	18.865			
	3	NE2-41(D)	CDPI-2, 3	77 (169)	18.902			319 (703)

APPENDIX B

CASE 2 GROUND RULES AND MANIFEST

I

APPENDIX B

This appendix provides the detailed launch schedules for deployment and servicing of synchronous equatorial payloads composed of modular designs developed by Aerospace. The type of modules and their reliability characteristics are included in Table B-1. The launch schedule and payload manifest are shown in Table B-2.

The significant differences between this case (Case 2) and Appendix A (Case 1) are listed below.

(a) Tug phasing performance in orbit accurately represented.

(b) Subsystem modules are Aerospace design rather than LMSC standard modules. This results in heavier payloads with slightly less reliability.

(c) The payload program NCN-9, Foreign DOMSAT, was expanded from one system of two satellites to six systems of two satellites each for compatibility with the ground refurbishment reference case.

(d) Electrical power modules were truncated at five years to represent reasonable battery life. Attitude control modules reduced from four (LMSC) to two per satellite.

Table B-1 provides a list of all subsystem used to compose the thirteen satellite programs. No attempt was made to develop common or standard modules. The mission equipment module definitions are identical to Case 1 as defined in Section 3.

Table B-1. Case 2 Module Definitions

MODULE TYPE	SRU CODE NUMBER	WEIGHT kg (lb)	WEIBULL PARAM α (YR)	WEIBULL PARAM β	TRUNC TIME (YR)
Electrical Power	EP-1	181 (400)	60.6	1.54	5
	EP-2	116 (255)	60.6	1.54	
	EP-3	46 (101)	60.6	1.54	
	EP-4	136 (300)	60.6	1.54	
	EP-5	133 (294)	60.6	1.54	
	EP-6	84 (186)	60.6	1.54	
	EP-7	65 (144)	60.6	1.54	
	EP-8	85 (187)	60.6	1.54	
	EP-9	82 (181)	60.6	1.51	
	EP-10	169 (372)	60.6	1.51	
	EP-11	66 (146)	60.6	1.51	
	EP-12	74 (163)	60.6	1.51	
Communications	C-1	125 (276)	11.6	1.87	N/A
	C-2	48 (106)	11.6	1.87	
	C-3	58 (127)	11.6	1.87	
	C-4	80 (176)	11.6	1.87	
	C-5	78 (171)	11.6	1.87	
	C-6	45 (100)	11.6	1.87	
	C-7	89 (196)	11.6	1.87	
	C-8	116 (256)	7.0	1.62	
	C-9	78 (171)	7.0	1.62	
	C-10	53 (116)	7.0	1.62	
	C-11	80 (176)	7.0	1.62	
Attitude Control	AC-1	90 (198)	27.8	1.66	3
	AC-2	95 (209)	27.8	1.66	
	AC-3	112 (247)	27.8	1.66	
	AC-4	158 (348)	27.8	1.66	
	AC-5	108 (238)	27.8	1.66	
	AC-6	85 (188)	27.8	1.66	
	AC-7	82 (181)	27.8	1.66	
	AC-8	70 (155)	27.8	1.64	
	AC-9	91 (200)	27.8	1.64	
	AC-10	95 (210)	27.8	1.64	
	AC-11	77 (169)	27.8	1.64	
	AC-12	105 (232)	27.8	1.64	

MODULE TYPE	SRU CODE NUMBER	WEIGHT kg (lb)	WEIBULL PARAM α (YR)	β	TRUNC TIME (YR)
Stability and Control	S&C-1	103 (226)	30.4	1.59	N/A
	S&C-2	113 (248)	30.4	1.59	
	S&C-3	44 (96)	15.2	1.59	
	S&C-4	67 (147)	15.2	1.59	
	S&C-5	103 (226)	15.2	1.59	
	S&C-6	64 (141)	15.2	1.59	
	S&C-7	50 (110)	15.2	1.59	
	S&C-8	62 (136)	30.4	1.59	
	S&C-9	69 (151)	30.4	1.59	
	S&C-10	39 (86)	15.2	1.59	
	S&C-11	66 (146)	15.2	1.59	

Table B-2. Case 2 Manifest

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
1	1	NC2-47(A)		577 (1,271)	-0-			
	2	NC2-46		1,674 (3,690)	.08			
	3	NEO-15(B)		1,010 (2,226)	.16	.16	.16	142 (313)
2	1	NC2-50(B)		1,132 (2,496)	.24			
	2	NCN-8(C)		2,082 (4,591)	.32	.32	.08	187 (413)
3	1	NC2-51(A)		1,172 (2,583)	1.0			
	2	NC2-47(B)		577 (1,271)	1.08			
	3	NCN-9(A)		872 (1,923)	1.16	1.16	.16	782 (1,723)
4	1	NE2-39(A)		1,574 (3,471)	1.24			
	2	NCN-9(B)		872 (1,923)	1.32			
	3	NC2-49(A)	NC2-491,2	99 (219)	1.40	1.48	.24	61 (134)
5	1	NC2-51(B)		1,172 (2,583)	2.0			
	2	NCN-7(A)	AC-4	158 (348)	2.0			
	3	NCN-7(A)	AC-4	158 (348)	2.0	2.08	.08	364 (803)
6	1	NC2-47(C)		577 (1,271)	2.08			
	2	NCN-7(B)	AC-4	158 (348)	2.08			
	3	NCN-7(B)	AC-4	158 (348)	2.08	2.16	.08	728 (1,605)
7	1	NE2-39(A)	NE2-391	160 (353)	2.14			
	2	NCN-9(C)		872 (1,923)	2.16	2.24	.10	724 (1,597)
8	1	NCN-7(C)	AC-4	158 (348)	2.16			
	2	NCN-7(C)	AC-4	158 (348)	2.16			
	3	NCN-8(A)	AC-5	108 (238)	2.24			
	4	NCN-8(A)	AC-5	108 (238)	2.24			
	5	NCN-8(A)	AC-5	108 (238)	2.24			
	6	NCN-8(A)	AC-5	108 (238)	2.24	2.32	.16	459 (1,012)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
9	1	NCN-9(D)		872 (1,923)	2.24			
	2	NCN-8(B)	AC-5	108 (238)	2.32			
	3	NCN-8(B)	AC-5	108 (238)	2.32			
	4	NCN-8(B)	AC-5	108 (238)	2.32			
	5	NCN-8(B)	AC-5	108 (238)	2.32	2.40	.16	427 (942)
10	1	NCN-9(E)		872 (1,923)	2.32			
	2	NC2-49(A)	AC-7	82 (181)	2.40			
	3	NC2-49(A)	AC-7	82 (181)	2.40			
	4	NCN-9(F)		872 (1,923)	2.40	2.48	.16	216 (476)
11	1	NCN-9(G)		872 (1,923)	2.48			
	2	NC2-49(B)	AC-7	82 (181)	2.48			
	3	NC2-49(B)	AC-7	82 (181)	2.48			
	4	NCN-8(B)	NCN-84	91 (200)	2.56			
	5	NC2-49(C)	AC-7	82 (181)	2.56			
	6	NC2-49(C)	AC-7	82 (181)	2.56	2.64	.16	134 (296)
12	1	NCN-9(H)		872 (1,923)	2.56			
	2	NC2-50(A)	AC-1	90 (198)	2.64			
	3	NC2-50(A)	AC-1	90 (198)	2.64			
	4	NE2-41(A)		823 (1,814)	2.64	2.72	.16	419 (923)
13	1	NEO-15(A)	AC-12	105 (232)	2.72			
	2	NEO-15(A)	AC-12	105 (232)	2.72			
	3	NCN-8(A)	NCN-84	91 (200)	2.78			
	4	NE2-39(A)	NE2-391	160 (353)	2.90	2.98	.26	624 (1,375)
14	1	NC2-47(D)		577 (1,271)	3.0			
	2	NC2-49(B)	NC2-491, 2	99 (219)	3.07			
	3	NCN-9(I)		872 (1,923)	3.08	3.08	.08	581 (1,281)
15	1	NCN-9(J)		872 (1,923)	3.16			
	2	NEO-15(B)	AC-12	105 (232)	3.16			
	3	NEO-15(B)	AC-12	105 (232)	3.16			
	4	NC2-46	AC-1	90 (198)	3.16			
	5	NC2-46	AC-1	90 (198)	3.16	3.24	.08	151 (332)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
16	1	NE2-41(B)		823 (1,814)	3.24			
	2	NEO-15(A)	NEO-151, 2, 3, 4, 5	113 (250)	3.28			
	3	NC2-50(B)	AC-1	90 (198)	3.32			
	4.	NC2-50(B)	AC-1	90 (198)	3.32			
	5	NCN-8(C)	AC-5	108 (238)	3.32			
	6	NCN-8(C)	AC-5	108 (238)	3.32			
	7	NCN-8(C)	AC-5	108 (238)	3.32			
	8	NCN-8(C)	AC-5	108 (238)	3.32	3.40	.16	20 (43)
17	1	NCN-9(A)	NCN-92	65 (143)	3.53			
	2	NC2-46	NC2-461	74 (163)	3.56			
	3	NEO-15(A)	C-11	80 (176)	3.60			
	4	NE2-39(A)	NE2-395	67 (147)	3.68	3.76	.23	489 (1,077)
18	1	NC2-47(E)		577 (1,271)	4.0			
	2	NC2-46	NC2-461	221 (488)	4.0			
	3	NEO-15(B)	NEO-151, 2, 3, 4, 5	113 (250)	4.0	4.08	.08	373 (823)
19	1	NCN-7(A)	EP-4	136 (300)	4.0			
	2	NCN-7(A)	EP-4	136 (300)	4.0			
	3	NCN-9(K)		872 (1,923)	4.08			
	4	NCN-7(B)	EP-4	136 (300)	4.08			
	5	NCN-7(B)	EP-4	136 (300)	4.08	4.16	.16	223 (491)
20	1	NCN-9(L)		872 (1,923)	4.16			
	2	NC2-51(A)	AC-2	95 (209)	4.16			
	3	NC2-51(A)	AC-2	95 (209)	4.16			
	4	NCN-9(A)	AC-6	85 (188)	4.16			
	5	NCN-9(A)	AC-6	85 (188)	4.16	4.24	.08	181 (398)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
21	1	NCN-7(C)	EP-4	136 (300)	4.16			
	2	NCN-7(C)	EP-4	136 (300)	4.16			
	3	NCN-8(A)	EP-5	133 (294)	4.24			
	4	NCN-8(A)	EP-5	133 (294)	4.24			
	5	NCN-8(B)	EP-5	133 (294)	4.32			
	6	NCN-8(B)	EP-5	133 (294)	4.32	4.40	.24	174 (384)
22	1	NC2-49(A)	EP-7	65 (144)	4.40			
	2	NC2-49(A)	EP-7	65 (144)	4.40			
	3	NC2-49(B)	EP-7	65 (144)	4.48			
	4	NC2-49(B)	EP-7	65 (144)	4.48			
	5	NE2-39(A)	AC-9	91 (200)	4.48			
	6	NE2-39(A)	AC-9	91 (200)	4.48			
	7	NCN-9(B)	AC-6	85 (188)	4.48			
	8	NCN-9(B)	AC-6	85 (188)	4.48	4.56	.16	4 (8)
23	1	NCN-9(H)	NCN-91	65 (143)	4.54			
	2	NC2-49(C)	EP-7	65 (144)	4.56			
	3	NC2-49(C)	EP-7	65 (144)	4.56			
	4	NE2-39(A)	NE2-395	67 (147)	4.58			
	5	NC2-50(A)	EP-8	85 (187)	4.64			
	6	NC2-50(A)	EP-8	85 (187)	4.64			
	7	NEO-15(A)	EP-12	74 (163)	4.72			
	8	NEO-15(A)	EP-12	74 (163)	4.72	4.80	.26	193 (426)
24	1	NCN-8(A)	NCN-83	91 (200)	4.77			
	2	NC2-47(F)		577 (1,271)	5.00			
	3	NC2-51(B)	AC-2	95 (209)	5.08			
	4	NC2-51(B)	AC-2	95 (209)	5.08			
	5	NCN-7(A)	AC-4	158 (348)	5.08	5.16	.39	67 (148)
25	1	NCN-7(A)	AC-4	158 (348)	5.08			
	2	NCN-7(B)	AC-4	158 (348)	5.16			
	3	NCN-7(B)	AC-4	158 (348)	5.16			
	4	NC2-46	EP-1	181 (400)	5.16			
	5	NC2-46	EP-1	181 (400)	5.16	5.24	.16	57 (126)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
26	1	NEO-15(B)	EP-12	74 (163)	5.16			
	2	NEO-15(B)	EP-12	74 (163)	5.16			
	3	NCN-7(C)	NCN-72	80 (177)	5.18			
	4	NEO-15(B)	NEO-151,2 3,4,5	113 (250)	5.18			
	5	NCN-8 (B)	C-4	80 (176)	5.21	5.32	.16	302 (665)
27	1	NCN-9(J)	NCN-91	65 (143)	5.21			
	2	NC2-49(A)	NC2-491,2	99 (219)	5.23			
	3	NCN-9(C)	NCN-92	65 (143)	5.23			
	4	NCN-9(C)	AC-6	85 (188)	5.24			
	5	NCN-9(C)	AC-6	85 (188)	5.24			
	6	NC2-49(B)	NC2-491,2	99 (219)	5.31	5.40	.19	162 (358)
28	1	NCN-7(C)	AC-4	158 (348)	5.32			
	2	NCN-7(C)	AC-4	158 (348)	5.32			
	3	NCN-8(A)	AC-5	108 (238)	5.32			
	4	NCN-8(A)	AC-5	108 (238)	5.32			
	5	NCN-8(A)	AC-5	108 (238)	5.32			
	6	NCN-8(A)	AC-5	108 (238)	5.32			
	7	NCN-8(C)	EP-5	133 (294)	5.32			
	8	NCN-8(C)	EP-5	133 (294)	5.32	5.48	.16	38 (84)
29	1	NC2-50(B)	EP-8	85 (187)	5.32			
	2	NC2-50(B)	EP-8	85 (187)	5.32			
	3	NCN-7(B)	NCN-72	80 (177)	5.35			
	4	NC2-49(C)	NC2-491,2	99 (219)	5.39			
	5	NCN-9(D)	AC-6	85 (188)	5.40			
	6	NCN-9(D)	AC-6	85 (188)	5.40	5.56	.24	122 (268)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
30	1	NCN-8(B)	AC-5	108 (238)	5.40			
	2	NCN-8(B)	AC-5	108 (238)	5.40			
	3	NCN-8(B)	AC-5	108 (238)	5.40			
	4	NCN-8(B)	AC-5	108 (238)	5.40			
	5	NCN-9(E)	NCN-92	65 (143)	5.46			
	6	NC2-49(A)	AC-7	82 (181)	5.48			
	7	NC2-49(A)	AC-7	82 (181)	5.48			
	8	NCN-9(E)	AC-6	85 (188)	5.48			
	9	NCN-9(E)	AC-6	85 (188)	5.48	5.64	.24	99 (219)
31	1	NCN-9(F)	AC-6	85 (188)	5.48			
	2	NCN-9(F)	AC-6	85 (188)	5.48			
	3	NCN-9(G)	AC-6	85 (188)	5.64			
	4	NCN-9(G)	AC-6	85 (188)	5.64			
	5	NC2-49(B)	AC-7	82 (181)	5.64			
	6	NC2-49(B)	AC-7	82 (181)	5.64			
	7	NC2-49(C)	AC-7	82 (181)	5.64			
	8	NC2-49(C)	AC-7	82 (181)	5.64	5.72	.24	188 (414)
32	1	NCN-9(H)	AC-6	85 (188)	5.72			
	2	NCN-9(H)	AC-6	85 (188)	5.72			
	3	NE2-41(A)	AC-11	77 (169)	5.72			
	4	NE2-41(A)	AC-11	77 (169)	5.72			
	5	NC2-50(A)	AC-1	85 (188)	5.72			
	6	NC2-50(A)	AC-1	85 (188)	5.72			
	7	NCN-9(I)	NCN-91	65 (143)	5.83	5.91	.19	410 (904)
33	1	NCN-9(F)	NCN-92	65 (143)	5.87			
	2	NCN-9(J)	NCN-92	65 (143)	5.90			
	3	NCN-7(B)	S&C-4	67 (147)	5.92			
	4	NE2-39(A)	NE2-393,4	107 (235)	5.92	6.00	.13	181 (398)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
34	1	NC2-51(B)	NC2-512	71 (157)	5.98			
	2	NEO-15(A)	AC-12	135 (298)	5.98			
	3	NEO-15(A)	AC-12	135 (298)	5.98			
	4	NC2-47(G)		577 (1,271)	6.0			
	5	NC2-49(C)	S&C-7	50 (110)	6.0			
	6	NEO-15(A)	NEO-151, 2 3, 4, 5	113 (250)	6.02			
	7	NCN-9(H)	NCN-92	65 (143)	6.07	6.15	.17	81 (179)
35	1	NEO-11(A)		1,006 (2,218)	6.08			
	2	NCN-9(I)	AC-6	85 (188)	6.08			
	3	NCN-9(I)	AC-6	85 (188)	6.08			
	4	NCN-9(A)	EP-6	84 (186)	6.16			
	5	NCN-9(A)	EP-6	84 (186)	6.16			
	6	NC2-51(A)	EP-2	116 (255)	6.16			
	7	NC2-51(A)	EP-2	116 (255)	6.16	6.24	.16	89 (195)
36	1	NEO-11(B)			6.16			
	2	NE2-39(A)	NE2-391, 2,	1,006 (2,218)	6.20	6.28	.12	237 (523)
			3, 4, 5	454 (1,000)				
37	1	NEO-11(C)			6.24			
	2	NCN-9(J)	AC-6	1,006 (2,218)	6.24			
	3	NCN-9(J)	AC-6	85 (188)	6.24			
	4	NC2-46	AC-1	85 (188)	6.24			
	5	NC2-46	AC-1	90 (198)	6.24	6.36	.12	392 (864)
				90 (198)				
38	1	NEO-15(B)	AC-12		6.24			
	2	NEO-15(B)	AC-12	105 (232)	6.24			
	3	NEO-11(D)		105 (232)	6.32			
	4	NCN-9(A)	NCN-92	1,006 (2,218)	6.37	6.45	.21	174 (383)
				85 (143)				

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
39	1	NCN-7(B)	C-3	58 (127)	6.37			
	2	NCN-8(C)	AC-5	108 (238)	6.40			
	3	NCN-8(C)	AC-5	108 (238)	6.40			
	4	NCN-8(C)	AC-5	108 (238)	6.40			
	5	NCN-8(C)	AC-5	108 (238)	6.40			
	6	NC2-50(B)	AC-1	90 (198)	6.40			
	7	NC2-50(B)	AC-1	90 (198)	6.40	6.53	.16	129 (285)
40	1	NCN-9(E)	NCN-91	65 (143)	6.45			
	2	NE2-39(A)	EP-10	169 (372)	6.48			
	3	NE2-39(A)	EP-10	169 (372)	6.48			
	4	NCN-9(B)	EP-6	84 (186)	6.48			
	5	NCN-9(B)	OP-6	84 (186)	6.48	6.61	.16	296 (653)
41	1	NC2-50(A)	NC2-501	76 (167)	6.53			
	2	NCN-8(C)	S&C-5	103 (226)	6.54			
	3	NC2-51(A)	NC2-511	72 (158)	6.67			
	4	NEO-15(B)	NEO-151, 2, 3, 4, 5	113 (250)	6.78	6.86	.23	333 (735)
42	1	NCN-7(B)	NCN-71	81 (178)	6.86			
	2	NC2-46	NC2-461	74 (163)	6.89			
	3	NCN-9(L)	NCN-91	65 (143)	6.99			
	4	NE2-41(B)	AC-11	77 (169)	6.99			
	5	NE2-41(B)	AC-11	77 (169)	6.99	7.07	.21	15 (34)
43	1	NC2-47(H)		577 (1,271)	7.0			
	2	NC2-51(B)	EP-2	116 (255)	7.08			
	3	NC2-51(B)	EP-2	116 (255)	7.08			
	4	NCN-9(K)	AC-6	85 (188)	7.16			
	5	NCN-9(K)	AC-6	85 (188)	7.16			
	6	NCN-9(K)	NCN-92	65 (143)	7.22	7.30	.30	84 (184)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
44	1	NE2-39(A)	NE2-395	67 (147)	7.23			
	2	NC2-51(A)	AC-2	95 (209)	7.24			
	3	NC2-51(A)	AC-2	95 (209)	7.24			
	4	NCN-9(A)	AC-6	85 (188)	7.24			
	5	NCN-9(A)	AC-6	85 (188)	7.24			
	6	NCN-9(C)	EP-6	84 (186)	7.24			
	7	NCN-9(C)	EP-6	84 (186)	7.24	7.38	.15	222 (489)
45	1	NCN-9(L)	AC-6	85 (188)	7.24			
	2	NCN-9(L)	AC-6	85 (188)	7.24			
	3	NCN-9(A)	NCN-91	65 (143)	7.25			
	4	NC2-46	C-1	125 (276)	7.25	7.46	.22	443 (977)
46	1	NCN-9(D)	EP-6	84 (186)	7.40			
	2	NCN-9(D)	EP-6	84 (186)	7.40			
	3	NC2-50B	NC2-501	76 (167)	7.42			
	4	NCN-9(E)	EP-6	84 (186)	7.48			
	5	NCN-9(E)	EP-6	84 (186)	7.48	7.56	.16	370 (816)
47	1	NCN-9(F)	EP-6	84 (186)	7.48			
	2	NCN-9(F)	EP-6	84 (186)	7.48			
	3	NC2-49(C)	NC2-419, 2	99 (219)	7.52			
	4	NCN-9(B)	AC-6	85 (188)	7.56			
	5	NCN-9(B)	AC-6	85 (188)	7.56	7.64	.16	256 (565)
48	1	NE2-39(A)	AC-9	91 (200)	7.61			
	2	NE2-39(A)	AC-9	91 (200)	7.61			
	3	NCN-9(G)	EP-6	84 (186)	7.64			
	4	NCN-9(G)	EP-6	84 (186)	7.64			
	5	NCN-9(B)	NCN-92	65 (143)	7.67			
	6	NCN-9(C)	C-5	78 (171)	7.67	7.75	.14	243 (536)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
49	1	NC2-51(B)	NC2-511	72 (158)	7.67			
	2	NE2-41(A)	EP-3	46 (101)	7.72			
	3	NE2-41(A)	EP-3	46 (101)	7.72			
	4	NCN-9(H)	EP-6	84 (186)	7.72			
	5	NCN-9(H)	EP-6	84 (186)	7.72			
	6	NEO-15(A)	NEO-151, 2 3, 4, 5	113 (250)	7.81	7.89	.22	473 (1,042)
50	1	NCN-7(D)		1,100 (2,425)	7.83			
	2	NEO-15(C)		1,010 (2,226)	7.88			
	3	NCN-7(E)		1,100 (2,425)	7.91	7.91	.08	192 (424)
51	1	NCN-7(F)		1,100 (2,425)	7.99			
	2	NC2-46	NC2-461, 2, 3	221 (488)	7.98			
	3	NC2 -47(I)		577 (1,271)	8.00	8.00	.21	217 (479)
52	1	NCN-8(D)		2,082 (4,591)	8.07			
	2	NCN-9(I)	EP-6	84 (186)	8.08			
	3	NCN-9(I)	EP-6	84 (186)	8.08	8.16	.09	272 (599)
53	1	NEO-15(B)	NEO-151, 2, 3, 4, 5	113 (250)	8.10			
	2	NCN-8(E)		2,082 (4,591)	8.15	8.24	.14	270 (595)
54	1	NC2-51(B)	AC-2		8.16			
	2	NC2-51(B)	AC-2	95 (209)	8.16			
	3	NC2-49(D)		95 (209)	8.23			
	4	NCN-9(J)	EP-6	786 (1,732)	8.24			
	5	NCN-9(J)	EP-6	84 (186)	8.24	8.32	.16	297 (655)
				84 (186)				
55	1	NE2-41(B)	C-10		8.27			
	2	NC2-49(E)		117 (116)	8.31			
	3	NC2-49(F)		786 (1,732)	8.39	8.47	.20	743 (1,639)
				786 (1,732)				

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
56	1	NCN-9(C)	AC-6	85 (188)	8.40			
	2	NCN-9(C)	AC-6	85 (188)	8.40			
	3	NE2-41(B)	EP-3	46 (101)	8.40			
	4	NE2-41(B)	EP-3	46 (101)	8.40			
	5	NC2-50(C)		1,132 (2,496)	8.47	8.55	.15	413 (910)
57	1	NCN-9(F)	NCN-92	65 (143)	8.56			
	2	NCN-9(D)	AC-6	85 (188)	8.56			
	3	NCN-9(D)	AC-6	85 (188)	8.56			
	4	NE2-39(A)	C-9	78 (171)	8.58			
	5	NCN-9(G)	NCN-91	65 (143)	8.59	8.67	.11	14 (31)
58	1	NE2-41(B)	NE2-411, 2, 3, 4	73 (160)	8.60			
	2	NCN-9(G)	NCN-92	65 (143)	8.61			
	3	NCN-9(J)	NCN-92	65 (143)	8.61			
	4	NCN-9(E)	AC-6	85 (188)	8.64			
	5	NCN-9(E)	AC-6	85 (188)	8.64	8.75	.15	369 (814)
59	1	NCN-9(F)	AC-6	85 (188)	8.72			
	2	NCN-9(F)	AC-6	85 (188)	8.72			
	3	NCN-9(G)	AC-6	85 (188)	8.72			
	4	NCN-9(G)	AC-6	85 (188)	8.72			
	5	NEO-11(D)	NEO-111, 2, 3, 4	94 (207)	8.81	8.89	.17	314 (693)
60	1	NE2-41(A)	C-10	53 (116)	8.84			
	2	NEO-15(C)	NEO-151, 2, 3, 4, 5	113 (250)	8.88			
	3	NE2-41(A)	AC-11	77 (169)	8.91			
	4	NE2-41(A)	AC-11	77 (169)	8.91			
	5	NCN-9(H)	AC-6	85 (188)	8.91			
	6	NCN-9(H)	AC-6	85 (188)	8.91			
	7	NEO-15(D)		1,010 (2,226)	8.99	8.99	.15	16 (36)
61	1	NC2-47(J)		577 (1,271)	9.0			
	2	NE2-41(A)	NE2-411, 2, 3, 4	73 (160)	9.01			
	3	NEO-11(B)	NEO-115	65 (143)	9.08	9.16	.16	426 (940)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
62	1	NE2-39(A)	NE2-392	120 (265)	9.08			
	2	NE2-39(A)	NE2-395	67 (147)	9.08			
	3	NCN-8(F)		2,082 (4,591)	9.15	9.24	.16	293 (645)
63	1	NC2-50(D)		1,132 (2,496)	9.15			
	2	NCN-9(K)	EP-6	85 (188)	9.16			
	3	NCN-9(K)	EP-6	85 (188)	9.16	9.32	.17	453 (999)
64	1	NCN-9(M)		872 (1,923)	9.18			
	2	NCN-9(L)	EP-6	84 (186)	9.24			
	3	NCN-9(L)	EP-6	84 (186)	9.24			
	4	NEO-11(A)	AC-10	95 (210)	9.24			
	5	NEO-11(A)	AC-10	95 (210)	9.24	9.40	.22	347 (764)
65	1	NCN-9(I)	AC-6	85 (188)	9.24			
	2	NCN-9(I)	AC-6	85 (188)	9.24			
	3	NEO-11(B)	AC-10	95 (210)	9.28			
	4	NEO-11(B)	AC-10	95 (210)	9.28			
	5	NEO-11(D)	C-9	78 (171)	9.35	9.48	.24	396 (873)
66	1	NEO-11(C)	AC-10	95 (210)	9.36			
	2	NEO-11(C)	AC-10	95 (210)	9.36			
	3	NC2-46	AC-1	90 (198)	9.36			
	4	NC2-46	AC-1	90 (198)	9.36			
	5	NCN-9(J)	AC-6	85 (188)	9.36			
	6	NCN-9(J)	AC-6	85 (188)	9.36			
	7	NEO-11(D)	AC-10	95 (210)	9.45			
	8	NEO-11(D)	AC-10	95 (210)	9.45			
	9	NEO-11(C)	C-9	78 (171)	9.55	9.63	.27	117 (257)
67	1	NCN-9(L)	NCN-91	65 (143)	9.56			
	2	NCN-9(E)	NCN-91	65 (143)	9.85			
	3	NC2-51(C)		1,172 (2,583)	9.99	10.07	.51	264 (581)
68	1	NCN-47(K)		577 (1,271)	10.00			
	2	NCN-9(N)		872 (1,923)	10.05	10.15	.15	1,953 (4,306)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
69	1	NE2-41(B)	AC-11	77 (169)	10.07			
	2	NE2-41(B)	AC-11	77 (169)	10.07			
	3	NE2-41(B)	NE2-411,2 3,4	73 (160)	10.16			
	4	NE2-39(B)		1,574 (3,471)	10.22			
	5	NC2-46	EP-1	181 (400)	10.24			
	6	NC2-46	EP-1	181 (400)	10.24	10.32	.25	5 (12)
70	1	NCN-9(K)	AC-6	85 (188)	10.30			
	2	NCN-9(K)	AC-6	85 (188)	10.30			
	3	NCN-9L)	AC-6	85 (188)	10.46			
	4	NCN-9(L)	AC-6	85 (188)	10.46			
	5	NCN-9(L)	C-5	78 (171)	10.48			
	6	NCN-9(P)		(1,923)	10.64	10.64	.34	146 (321)
71	1	NCN-9(T)		872 (1,923)	10.71			
	2	NEO-11(A)	C-9	78 (171)	10.85			
	3	NEO-15(C)	AC-12	105 (232)	10.91			
	4	NEO-15(C)	AC-12	105 (232)	10.91	10.99	.28	406 (895)
72	1	NC2-51(D)		1,172 (2,583)	10.91			
	2	NCN-7(D)	AC-4	158 (348)	10.91			
	3	NCN-7(D)	AC-4	158 (348)	10.91			
	4	NCN-7(E)	AC-4	158 (348)	10.91	11.07	.16	48 (106)
73	1	NCN-7(E)	AC-4	158 (348)	10.91			
	2	NCN-7(F)	AC-4	158 (348)	11.0			
	3	NCN-7(F)	AC-4	158 (348)	11.0			
	4	NC2 -47(L)		577 (1,271)	11.0	11.15	.24	325 (716)
74	1	NE2-43		1,566 (3,453)	11.0			
	2	NCN-9(Q)		872 (1,923)	11.0			
	3	NCN-9(O)		872 (1,923)	11.07	11.23	.23	91 (201)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
75	1	NEO-11(D)	NEO-111, 2, 3, 4	94 (207)	11.12			
	2	NCN-8(E)	NCN-82	91 (200)	11.15			
	3	NCN-8(D)	AC-5	108 (238)	11.16			
	4	NCN-8(D)	AC-5	108 (238)	11.16			
	5	NCN-8(D)	AC-5	108 (238)	11.16			
	6	NCN-8(D)	AC-5	108 (238)	11.16	11.31	.19	411 (905)
76	1	NEO-11(A)	EP-11	66 (146)	11.24			
	2	NEO-11(A)	EP-11	66 (146)	11.24			
	3	NCN-8(E)	AC-5	108 (238)	11.24			
	4	NCN-8(E)	AC-5	108 (238)	11.24			
	5	NCN-8(E)	AC-5	108 (238)	11.24			
	6	NCN-8(E)	AC-5	108 (238)	11.24			
	7	NEO-15(D)	NEO-151, 2, 3, 4, 5	113 (250)	1.28	11.39	.15	326 (718)
77	1	NEO-11(B)	EP-11	66 (146)	11.28			
	2	NEO-11(B)	EP-11	66 (146)	11.28			
	3	NEO-11(B)	NEO-111, 2, 3, 4	94 (207)	11.30			
	4	NCN-9(R)		872 (1,923)	11.31			
	5	NC2-49(D)	AC-7	82 (181)	11.32			
	6	NC2-49(D)	AC-7	82 (181)	11.32	11.47	.19	268 (590)
78	1	NEO-11(C)	EP-11	66 (146)	11.36			
	2	NEO-11(C)	EP-11	66 (146)	11.36			
	3	NEO-11(D)	EP-11	66 (146)	11.45			
	4	NEO-11(D)	EP-11	66 (146)	11.45			
	5	NCN-9(S)		872 (1,923)	11.47			
	6	NC2-49(E)	AC-7	82 (181)	11.47			
	7	NC2-49(E)	AC-7	82 (181)	11.47	11.55	.19	108 (237)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
79	1	NC2-49(F)	AC-7	82 (181)	11.47			
	2	NC2-49(F)	AC-7	82 (181)	11.47			
	3	NE2-41(C)		369 (814)	11.55			
	4	NC2-50(C)	AC-1	90 (198)	11.55			
	5	NC2-50(C)	AC-1	90 (198)	11.55			
	6	NCN-8(E)	NCN-81	91 (200)	11.56	11.64	.17	194 (428)
80	1	NCN-9(L)	NCN-92	65 (143)	11.63			
	2	NCN-9(L)	S&C-6	64 (141)	11.73			
	3	NEO-15(C)	NEO-151, 2 3, 4, 5	113 (250)	11.74			
	4	NCN-9(M)	NCN-91	65 (143)	11.85			
	5	NC2-50(C)	NC2-503	75 (166)	11.86	11.94	.31	161 (355)
81	1	NCN-9(U)		872 (1,923)	11.91			
	2	NC2-46	NC2-461, 2, 3	221 (488)	11.99			
	3	NEO-15(D)	AC-12	105 (232)	11.99			
	4	NEO-15(D)	AC-12	105 (232)	11.99	12.07	.16	205 (452)
82	1	NC2-47(M)		577 (1,271)	12.0			
	2	NCN-9(V)		872 (1,293)	12.07			
	3	NE2-43	NE2-431	156 (343)	12.08	12.16	.16	455 (1,002)
83	1	NCN-9(N)	NCN-91	65 (143)	12.13			
	2	NE2-41(D)		823 (1,814)	12.23			
	3	NCN-8(E)	NCN-85	91 (200)	12.23	12.31	.18	371 (817)
84	1	NCN-8(F)	AC-5	108 (238)	12.24			
	2	NCN-8(F)	AC-5	108 (239)	12.24			
	3	NCN-8(F)	AC-5	108 (238)	12.24			
	4	NCN-8(F)	AC-5	108 (238)	12.24			
	5	NEO-11(A)	NEO-111, 2, 3, 4	94 (207)	12.28			
	6	NC2-50(D)	AC-1	90 (198)	12.32			
	7	NC2-50(D)	AC-1	90 (198)	12.32	12.40	.16	337

TUG ASSIGNMENT					SCHEDULE			MARGIN kg (lb)
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	
85	1	NEO-11(A)	AC-10	95 (210)	12.40			
	2	NEO-11(A)	AC-10	95 (210)	12.40			
	3	NEO-11(B)	AC-10	95 (210)	12.48			
	4	NEO-11(B)	AC-10	95 (210)	12.48			
	5	NEO-15(C)	C-11	80 (176)	12.56			
	6	NEO-15(D)	NEO-151, 2, 3, 4, 5	113 (250)	12.57	12.65	.25	133 (294)
86	1	NEO-11(C)	AC-10	95 (210)	12.63			
	2	NEO-11(C)	AC-10	95 (210)	12.63			
	3	NEO-11(D)	AC-10	95 (210)	12.63			
	4	NEO-11(D)	AC-10	95 (210)	12.63			
	5	NC2-46	AC-1	90 (198)	12.63			
	6	NC2-46	AC-1	90 (198)	12.63			
	7	NE2-43	NE2-435	259 (571)	12.90	12.98	.35	268 (590)
87	1	NEO-15(C)	EP-12	74 (163)	12.91			
	2	NEO-15(C)	EP-12	74 (163)	12.91			
	3	NCN-7(D)	EP-4	136 (300)	12.91			
	4	NCN-7(D)	EP-4	136 (300)	12.91			
	5	NCN-7(E)	EP-4	136 (300)	12.91			
	6	NCN-7(E)	EP-4	136 (300)	12.91	12.99	.08	179 (394)
88	1	NCN-9(Q)	NCN-92	65 (143)	12.98			
	2	NCN-9(W)		872 (1,923)	12.99			
	3	NC2-47(N)		577 (1,271)	13.0	13.07	.09	638 (1,406)
89	1	NCN-7(F)	EP-4	136 (300)	13.0			
	2	NCN-7(F)	EP-4	136 (300)	13.0			
	3	NCN-9(X)		872 (1,923)	13.07			
	4	NC2-51(C)	AC-2	95 (209)	13.07			
	5	NC2-51(C)	AC-2	95 (209)	13.07	13.15	.15	201 (444)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
90	1	NCN-8(E)	NCN-83	91 (200)	13.11			
	2	NC2-49(F)	NC2-491, 2	99 (219)	13.12			
	3	NCN-9(N)	AC-6	85 (188)	13.15			
	4	NCN-9(N)	AC-6	85 (188)	13.15			
	5	NE2-43	NE2-433, 4	136 (299)	13.15	13.23	.12	136 (300)
91	1	NCN-8(D)	EP-5	133 (294)	13.16			
	2	NCN-8(D)	EP-5	133 (294)	13.16			
	3	NCN-8(E)	EP-5	133 (294)	13.24			
	4	NCN-8(E)	EP-5	133 (294)	13.24			
	5	NEO-15(D)	C-11	80 (176)	13.25	13.33	.17	253 (558)
92	1	NE2-39(B)	AC-9	91 (200)	13.32			
	2	NE2-39(B)	AC-9	91 (200)	13.32			
	3	NC2-49(D)	EP-7	65 (144)	13.32			
	4	NC2-49(D)	EP-7	65 (144)	13.32			
	5	NEO-15(C)	NEO-151, 2 3, 4,	113 (250)	13.37			
	6	NE2-39(B)	NE2-393, 4	107 (235)	13.40			
	7	NCN-9(M)	AC-6	85 (188)	13.40	13.48	.16	51 (113)
93	1	NCN-9(M)	AC-6	85 (188)	13.40			
	2	NC2-49(F)	EP-7	65 (144)	13.47			
	3	NC2-49(F)	EP-7	65 (144)	13.47			
	4	NC2-49(E)	EP-7	65 (144)	13.47			
	5	NC2-49(E)	EP-7	65 (144)	13.47			
	6	NCN-9(N)	NCN-91	65 (143)	13.50	13.58	.18	233 (513)
94	1	NC2-50(C)	EP-8	85 (187)	13.55			
	2	NC2-50(C)	EP-8	85 (187)	13.55			
	3	NCN-9(P)	AC-6	85 (188)	13.64			
	4	NCN-9(P)	AC-6	85 (188)	13.64			
	5	NCN-8(F)	NCN-83	91 (200)	13.65			
	6	NCN-9(R)	NCN-91	65 (143)	13.69	13.77	.22	10 (21)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
95	1	NE2-39(B)	NE2-392	120 (265)	13.73			
	2	NCN-7(D)	NCN-72	81 (178)	13.83			
	3	NC2-49(E)	NC2-491, 2	99 (219)	13.85			
	4	NEO-15(D)	NEO-151, 2 3, 4, 5	113 (250)	13.89	13.97	.24	257 (566)
96	1	NEO-15(D)	EP-12	74 (163)	13.99			
	2	NEO-15(D)	EP-12	74 (163)	13.99			
	3	NEO-15(C)	AC-12	105 (232)	13.99			
	4	NEO-15(C)	AC-12	105 (232)	13.99			
	5	NCN-9(T)	AC-6	85 (188)	13.99			
	6	NCN-9(T)	AC-6	85 (188)	13.99	14.07	.08	483 (1,064)
97	1	NC2-47(O)		577 (1,271)	14.0			
	2	NCN-7(D)	AC-4	158 (348)	14.07			
	3	NCN-7(D)	AC-4	158 (348)	14.07			
	4	NCN-7(E)	AC-4	158 (348)	14.07			
	5	NC2-50(C)	C-7	89 (196)	14.13			
	6	NCN-7(E)	AC-4	158 (348)	14.15	14.23	.23	84 (186)
98	1	NC2-47(D)	NC2-491, 2	89 (219)	14.15			
	2	NCN-7(F)	AC-4	158 (348)	14.15			
	3	NCN-7(F)	AC-4	158 (348)	14.15			
	4	NE2-43	AC-8	70 (155)	14.23			
	5	NE2-43	AC-8	70 (155)	14.23	14.31	.16	298 (657)
99	1	NCN-9(O)	AC-6	85 (188)	14.23			
	2	NCN-9(O)	AC-6	85 (188)	14.23			
	3	NCN-9(Q)	AC-6	85 (188)	14.23			
	4	NCN-9(Q)	AC-6	85 (188)	14.23			
	5	NCN-8(F)	EP-5	133 (294)	14.24			
	6	NCN-8(F)	EP-5	133 (294)	14.24	14.39	.16	281 (620)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
100	1	NC2 49(E)	NC2-491, 2	99 (219)	14.30			
	2	NC2-49(F)	NC2-491, 2	99 (219)	14.30			
	3	NCN-8(D)	AC-5	108 (238)	14.31			
	4	NCN-8(D)	AC-5	108 (238)	14.31			
	5	NCN-8(D)	AC-5	108 (238)	14.31			
	6	NCN-8(D)	AC-5	108 (238)	14.31			
	7	NC2-50(D)	EP-8	85 (187)	14.32			
	8	NC2-50(D)	EP-8	85 (187)	14.32			
	9	NE2-41(C)	NE2-411, 2, 3, 4	73 (160)	14.37	14.47	.17	45 (100)
101	1	NCN-8(E)	AC-5	108 (238)	14.39			
	2	NCN-8(E)	AC-5	108 (238)	14.39			
	3	NCN-8(E)	AC-5	108 (238)	14.39			
	4	NCN-8(E)	AC-5	108 (238)	14.39			
	5	NEO-11(E)		1,006 (2,218)	14.41	14.55	.16	464 (1,022)
102	1	NEO-11(G)		1,006 (2,218)	14.44			
	2	NCN-9(S)	AC-6	85 (188)	14.47			
	3	NCN-9(S)	AC-6	85 (188)	14.47			
	4	NC2-49(D)	AC-7	82 (181)	14.47			
	5	NC2-49(D)	AC-7	82 (181)	14.47	14.63	.19	384 (846)
103	1	NCN-9(R)	AC-6	85 (188)	14.47			
	2	NCN-9(R)	AC-6	85 (188)	14.47			
	3	NC2-50(D)	NC2-501	76 (167)	14.48			
	4	NEO-15(C)	NEO-151, 2 3, 4, 5	113 (250)	14.49			
	5	NCN-9(R)	NCN-92	65 (143)	14.50	14.71	.24	236 (520)
104	1	NEO-11(H)		1,006 (2,218)	14.54			
	2	NE2-43	NE2-435	259 (571)	14.55			
	3	NC2-49(E)	AC-7	82 (181)	14.55			
	4	NC2-49(E)	AC-7	82 (181)	14.55			
	5	NE2-41(C)	AC-11	77 (169)	14.64			
	6	NE2-41(C)	AC-11	77 (169)	14.64	14.79	.25	8 (17)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
105	1	NC2-49(F)	AC-7	82 (181)	14.64			
	2	NC2-49(F)	AC-7	82 (181)	14.64			
	3	NC2-50(C)	AC-1	90 (198)	14.64			
	4	NC2-50(C)	AC-1	90 (198)	14.64			
	5	NE2-39(B)	C-9	78 (171)	14.70			
	6	NCN-9(O)	NCN-92	65 (143)	14.79			
	7	NCN-7(E)	NCN-72	81 (178)	14.85	14.93	.29	206 (454)
106	1	NC2-47(P)		577 (1,271)	15.0			
	2	NC2-51(C)	EP-2	116 (255)	15.07			
	3	NC2-51)C)	EP-2	116 (255)	15.07			
	4	NEO-15(D)	AC-12	105 (232)	15.07			
	5	NEO-15(D)	AC-12	105 (232)	15.07			
	6	NCN-9(W)	AC-6	85 (188)	15.07			
	7	NCN-9(W)	AC-6	85 (188)	15.07	15.15	.15	46 (101)
107	1	NCN-9(S)	NCN-91	65 (143)	15.12			
	2	NE2-39(B)	NE2-391, 2, 3, 4, 5	453 (1,000)	15.15			
	3	NCN-9(N)	EP-6	84 (186)	15.15			
	4	NCN-9(N)	EP-6	84 (186)	15.15	15.23	.11	222 (489)
108	1	NEO-11(F)		1,006 (2,218)	15.16			
	2	NCN-9(V)	AC-6	85 (188)	15.16			
	3	NCN-9(V)	AC-6	85 (188)	15.16			
	4	NCN-7(D)	C-3	58 (127)	15.17	15.31	.15	89 (197)
109	1	NE2-41(D)	AC-11	77 (169)	15.31			
	2	NE2-41(D)	AC-11	77 (169)	15.31			
	3	NC2-46	EP-1	181 (400)	15.32			
	4	NC-246	EP-1	181 (400)	15.32			
	5	NE2-39(B)	EP-10	169 (372)	15.32			
	6	NE2-39(B)	EP-10	169 (372)	15.32			
	7	NE2-43	C-8	116 (256)	15.38	15.46	.17	83 (182)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
110	1	NCN-8(F)	AC-5	108 (238)	15.40			
	2	NCN-8(F)	AC-5	108 (238)	15.40			
	3	NCN-8(F)	AC-5	108 (238)	15.40			
	4	NCN-8(F)	AC-5	108 (238)	15.40			
	5	NC2-50(D)	AC-1	90 (198)	15.40			
	6	NC2-50(D)	AC-1	90 (198)	15.40			
	7	NCN-9(M)	EP-6	84 (186)	15.40			
	8	NCN-9(M)	EP-6	84 (186)	15.40	15.56	.16	163 (360)
111	1	NC2-51(C)	NC2-511	72 (158)	15.58			
	2	NCN-9(P)	EP-6	84 (186)	15.64			
	3	NCN-9(P)	IP-6	84 (186)	15.64			
	4	NCN-8(F)	NCN-84	91 (200)	15.65			
	5	NC2-49(F)	C-6	45 (100)	15.67			
	6	NE2-39(B)	NE2-391	160 (353)	15.67	15.75	.17	269 (593)
112	1	NCN-8(D)	NCN-81	91 (200)	15.85			
	2	NC2-46	AC-1	90 (198)	15.98			
	3	NC2-46	AC-1	90 (198)	15.98			
	4	NC2-46	NC2-471, 2, 3	221 (488)	15.99			
	5	NCN-9(T)	EP-6	84 (186)	15.99			
	6	NCN-9(T)	EP-6	84 (186)	15.99	16.07	.22	258 (568)
113	1	NEO-15(C)	NEO-151, 2, 3, 4, 5	113 (250)	15.90			
	2	NC2-47(Q)		577 (1,271)	16.0			
	3	NCN-9(W)	AC-6	85 (188)	16.07			
	4	NCN-9(W)	AC-6	85 (188)	16.07	16.15	.25	420 (925)
114	1	NE2-39(B)	NE2-391	160 (353)	16.1			
	2	NCN-9(X)	AC-6	85 (188)	16.15			
	3	NCN-9(X)	AC-6	85 (188)	16.15			
	4	NC2-51(C)	AC-2	95 (209)	16.15			
	5	NC2-51(C)	AC-2	95 (209)	16.15			
	6	NC2-51(C)	NC2-512	71 (157)	16.15	16.23	.13	190 (418)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
115	1	NCN-9(Q)	EP-6	84 (186)	16.23			
	2	NCN-9(O)	EP-6	84 (186)	16.23			
	3	NCN-9(N)	AC-6	85 (188)	16.23			
	4	NCN-9(N)	AC-6	85 (188)	16.23			
	5	NCN-9(O)	EP-6	84 (186)	16.23			
	6	NCN-9(O)	EP-6	84 (186)	16.23			
	7	NE2-43	#P-9	82 (181)	16.23			
	8	NE2-43	EP-9	82 (181)	16.23	16.31	.08	4 (8)
116	1	NC2-51(C)	C-1	125 (276)	16.41			
	2	NC2-49(E)	C-6	45 (100)	16.42			
	3	NE2-43	NE2-435	259 (571)	16.43			
	4	NCN-9(R)	EP-6	84 (186)	16.47	16.55	.14	13 (29)
117	1	NCN-9(R)	EP-6	84 (186)	16.47			
	2	NE2-39(B)	AC-9	91 (200)	16.48			
	3	NE2-39(B)	AC-9	91 (200)	16.48			
	4	NCN-9(M)	AC-6	85 (188)	16.48			
	5	NCN-9(M)	AC-6	85 (188)	16.53			
	6	NCN-9(S)	EP-6	84 (186)	16.55	16.63	.16	28 (62)
118	1	NCN-9(S)	EP-6	84 (186)	16.55			
	2	NE2-41(C)	EP-3	46 (101)	16.64			
	3	NE2-41(C)	EP-3	46 (101)	16.64			
	4	NCN-9(O)	NCN-92	65 (143)	16.72			
	5	NCN-7(G)		1,145 (2,525)	16.74	16.74	.19	334 (736)
119	1	NCN-7(H)		1,100 (2,425)	16.74			
	2	NEO-15(E)		1,010 (2,226)	16.74			
	3	NCN-9(P)	AC-6	85 (188)	16.77	16.85	.11	5 (11)
120	1	NCN-9(P)	AC-6	85 (188)	16.77			
	2	NCN-7(I)		1,100 (2,425)	16.82			
	3	NC2-50(D)	C-7	89 (196)	16.87			
	4	NCN-9(S)	NCN-92	65 (143)	16.89	16.97	.20	51 (112)

TUG ASSIGNMENT					SCHEDULE			MARGIN kg (lb)
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	
121	1	NCN-8(G)		2,082 (4,591)	16.99			
	2	NE2-41(C)	NE2-411, 2, 3, 4	73 (160)	16.99	17.07	.08	352 (776)
122	1	NEO-15(D)	NEO-151, 2, 3, 4, 5	113 (250)	16.99			
	2	NCN-8(F)	NCN-82	91 (200)	16.99			
	3	NC2-47(R)		577 (1,271)	17.00	17.15	.16	395 (871)
123	1	NCN-8(H)		2,082 (4,591)	17.07			
	2	NCN-9(T)	AC-6	85 (188)	17.07			
	3	NCN-9(T)	AC-6	85 (188)	17.07			
	4	NCN-9(W)	EP-6	84 (186)	17.07			
	5	NCN-9(W)	EP-6	84 (186)	17.07	17.23	.16	172 (379)
124	1	NC2-49(G)		786 (1,732)	17.15			
	2	NEO-11(F)	NEO-111, 2, 3, 4	94 (207)	17.16			
	3	NCN-9(V)	EP-6	84 (186)	17.16			
	4	NCN-9(V)	EP-6	84 (186)	17.16	17.31	.16	109 (241)
125	1	NC2-49(H)		786 (1,732)	17.30			
	2	NC2-49(I)		789 (1,732)	17.30			
	3	NE2-43	AC-8	70 (155)	17.31			
	4	NE2-43	AC-8	70 (155)	17.31	17.39	.09	403 (889)
126	1	NE2-41(D)	EP-3	46 (101)	17.31			
	2	NE2-41(D)	EP-3	46 (101)	17.31			
	3	NC2-50(E)		1,132 (2,496)	17.38			
	4	NCN-9(O)	AC-6	85 (188)	17.39			
	5	NCN-9(O)	AC-6	85 (188)	17.39			
	6	NCN-8(F)	EP-5	133 (294)	17.39			
	7	NCN-8(F)	EP-5	133 (294)	17.39	17.47	.16	34 (74)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
127	1	NCN-9(Q)	AC-6	85 (188)	17.39			
	2	NCN-9(Q)	AC-6	85 (188)	17.39			
	3	NEO-11(E)	NEO-111, 2 3, 4	94 (207)	17.41			
	4	NCN-9(W)	NCN-91	65 (143)	17.54			
	5	NEO-11(E)	AC-10	95 (210)	17.55			
	6	NEO-11(E)	AC-10	95 (210)	17.55			
	7	NCN-9(S)	AC-6	85 (188)	17.63			
	8	NCN-9(S)	AC-6	85 (188)	17.63	17.71	.32	5 (12)
128	1	NEO-11(G)	AC-10	95 (210)	17.63			
	2	NEO-11(G)	AC-10	95 (210)	17.63			
	3	NE2-43	NE2-431	156 (343)	17.67			
	4	NE2-39(B)	NE2-392	120 (265)	17.70			
	5	NC2-46	S&C-1	103 (226)	17.70	17.79	.16	534 (1,170)
129	1	NCN-9(R)	AC-6	85 (188)	17.71			
	2	NCN-9(R)	AC-6	85 (188)	17.71			
	3	NE2-41(C)	AC-11	77 (169)	17.79			
	4	NE2-41(C)	AC-11	77 (169)	17.79			
	5	NEO-11(H)	AC-10	95 (210)	17.79			
	6	NEO-11(H)	AC-10	95 (210)	17.79	17.87	.16	320 (706)
130	1	NCN-9(S)	C-5	78 (171)	17.80			
	2	NE2-43	NE2-435	259 (571)	17.81			
	3	NEO-15(F)		1,010 (2,226)	17.82			
	4	NCN-9(N)	C-5	78 (171)	17.93	18.01	.21	-0-
131	1	NC2-47(S)		577 (1,271)	18.0			
	2	NCN-8(I)		2,082 (4,591)	18.07	18.09	.09	743 (1,638)
132	1	NCN-9(W)	EP-6	84 (186)	18.07			
	2	NCN-9(W)	EP-6	84 (186)	18.07			
	3	NC2-50(F)		1,132 (2,496)	18.15			
	4	NCN-9(X)	EP-6	84 (186)	18.15			
	5	NCN-9(X)	EP-6	84 (186)	18.15	18.23	.16	43 (94)

TUG ASSIGNMENT					SCHEDULE			
FLT NO.	SLOT NO.	CODE	MODULE NUMBER	WEIGHT kg (lb)	LOAD (YR)	LAUNCH (YR)	DELAY (YR)	MARGIN kg (lb)
133	1	NCN-9(W)	AC-6	85 (188)	18.15			
	2	NCN-9(W)	AC-6	85 (188)	18.15			
	3	NCN-9(W)	NCN-92	65 (143)	18.18			
	4	NEO-11(E)	NEO-115	65 (143)	18.19			
	5	NCN-9(V)	AC-6	85 (188)	18.31			
	6	NCN-9(V)	AC-6	85 (188)	18.31	18.39	.24	352 (776)
134	1	NEO-11(F)	AC-10	95 (210)	18.31			
	2	NEO-11(F)	AC-10	95 (210)	18.31			
	3	NEO-11(G)	NEO-111, 2 3, 4	94 (207)	18.32			
	4	NCN-9(V)	NCN-92	65 (143)	18.37			
	5	NEO-11(G)	NEO-115	65 (143)	18.45			
	6	NE2-41(D)	AC-11	77 (169)	18.48	18.56	.25	43 (94)
135	1	NE2-41(D)	AC-11	77 (169)	18.48			
	2	NE2-41(D)	NE2-411, 2 3, 4	73 (160)	18.48			
	3	NEO-11(H)	NEO-111, 2, 3, 4	94 (207)	18.49			
	4	NE2-43	C-8	116 (256)	18.68	18.76	.28	740 (1,632)