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SPACE OPERATIONS CENTER
SHUTTLE INTERACTION STUDY EXTENSION

FINAL REPORT, EXECUTIVE SUMMARY

Contract No. NAS9-16153
DRL T-1626
Line Item 3

February 1982

Approved by
A. J. Stefan

Space Operations/Integration & Satellite Systems Division
Rockwell International

N83-13142

FOREWORD

This report contains the results of the analysis of the additional issues identified in the SOC/Shuttle Interaction Study extension. This data supplements the SOC/Shuttle Interactions identified in the original contracted effort.

This effort was performed under Contract Number NAS9-16153, by the Space Operations and Satellite Systems Division of Rockwell International for the National Aeronautics and Space Administration, Johnson Space Center. The study was administered under the technical direction of the Contracting Officers Representative (COR), Mr. S. H. Nassiff, Program Development Office, Engineering and Development Directorate, Johnson Space Center.

The study was performed under the direction of A. J. Stefan, Study Manager. The following persons made significant contributions to the completion of the analysis.

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INTRODUCTION

The Space Operations Center (SOC) is conceived as a permanent facility in low earth orbit incorporating capabilities for space systems construction; space vehicle assembly, launching, recovery and servicing; and the servicing of co-orbiting satellites.

The Shuttle Transportation System (STS) is an integral element of the SOC concept. It will transport the various elements of the SOC into space and support the assembly operation. Subsequently, it will regularly service the SOC with crew rotations, crew supplies, construction materials, construction equipment and components, space vehicle elements, and propellants and spare parts.

This report contains the results of the study that analyzed in greater detail the implications to the SOC as a consequence of the Shuttle supporting operations. The study also addressed programmatic influences associated with propellant deliveries, spacecraft servicing, and total shuttle flight operations.

STUDY TASKS

Four tasks were identified for this contract extension effort. The four tasks and the study objective of each task is listed in Table I-1.

SPACE OPERATIONS CENTER CONFIGURATION

The configuration of the space operations center that was utilized for reference during the study is illustrated in Figure I-1. This configuration is a modification of the configuration supplied by NASA/JSC at the start of this study. The modification is principally concerned with the facility configuration for spacecraft servicing operations.

REPORT ORGANIZATION

This report is organized into four basic sections that correspond to the four tasks previously described. Supporting reference data is contained in the appendix which constitutes the second volume of this report.

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TABLE I-1 STUDY EXTENSION TASKS

TASK 1.0 SHUTTLE FLEET UTILIZATION & PROGRAMMATICS OBJECTIVE: DETERMINE SHUTTLE FLEET UTILIZATION REQUIREMENTS & RELATED PROGRAMMATICS DATA FOR SOC/SHUTTLE OPERATIONS IN LEO
TASK 2.0 SOC ASSEMBLY OPERATIONS OBJECTIVE: TO CONFIRM THE CAPABILITY OF THE RMS TO ASSEMBLE THE SOC, & TO DETERMINE THE ASSEMBLY OPERATIONAL IMPLICATIONS & THE IMPLICATIONS TO THE SOC MODULES
TASK 3.0 SHUTTLE SYSTEM PROPELLANT SCAVENGING OBJECTIVE: DETERMINE PRINCIPAL FUNCTIONAL IMPACTS ON THE SOC DUE TO PROPELLANT SCAVENGING
TASK 4.0 FLIGHT SUPPORT FACILITY OBJECTIVE: TO COMPARE THE SERVICING/CHECKOUT LOGIC & COSTS ASSOCIATED WITH PERFORMING FLIGHT SUPPORT SERVICES ON FREE-FLYING SATELLITES & OTV'S AT THE SOC, ON THE GROUND & FROM THE ORBITER

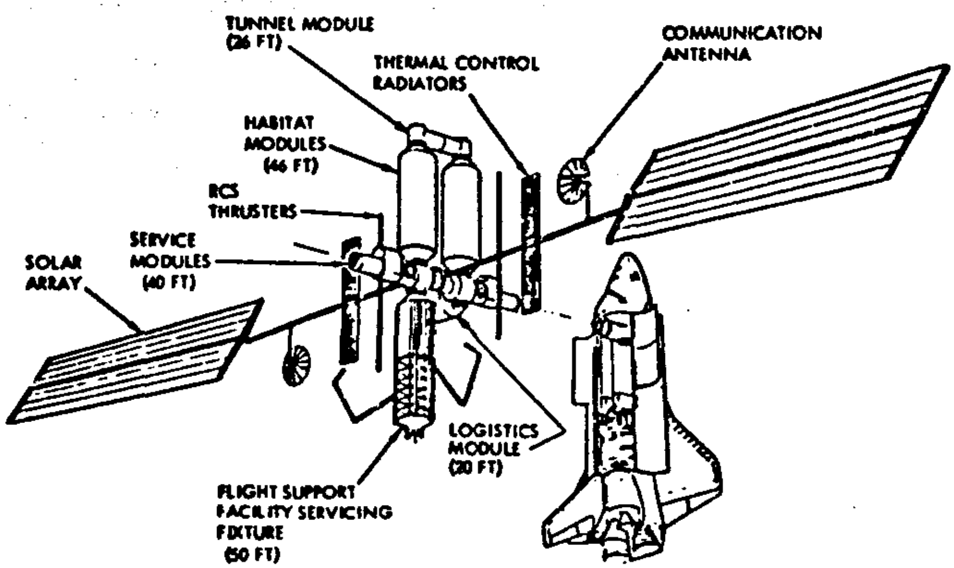

FIGURE I-1 SPACE OPERATIONS CENTER REFERENCE CONFIGURATION

1.0 SHUTTLE FLEET UTILIZATION & PROGRAMMATICS

This task determines the key interrelationships among the main STS utilization variables, with particular emphasis on the differences between SOC and "non-SOC" scenarios. The analysis investigated the interacting effects of cargo density, OTV performance models, and Shuttle logistics performance for their effects on fleet utilization and fleet size requirements. In particular, the analysis examined the potential benefits within the SOC scenario of increasing Shuttle load factors by adding high-density propellants to low-density cargo manifests to always fly the orbiter near its 65K lb payload capacity.

The further fleet utilization benefits of scavenging ET residual propellants have also been investigated. This technique is particularly suited to the SOC scenario where propellant storage capability in space would be provided as part of the SOC flight support activity.

The potential ground turnaround benefits which can be attained with an orbiter dedicated to SOC resupply missions was also investigated. The task focus is on traffic analyses based on a mission model derived with Rockwell discretionary resources. Each major sector of the mission model (commercial communications, NASA R&D, DOD, etc.) has been analyzed to synthesize representative spacecraft and/or STS manifest elements for later conversion into STS flight rates. The total mission model has been screened to catalog missions into candidate SOC related and non-SOC missions.

The representative manifest data is utilized to determine the amount of unused cargo bay space and payload weight capability that could exist on each SOC delivery flight. Further analyses determined how much propellant could be delivered to the SOC on these missions using payload top-off and propellant scavenging techniques. Payload top-off involves bringing the orbiter up to its maximum payload capability by adding propellants in the unused space of the various flight manifests. Propellant scavenging refers to the concept of recovering unused propellants from the ET and the main propulsion system before ET jettison. This includes propellant amounts ranging from the 9500 lbs associated with maximum payload launches to the 70,000 lb plus value associated with the "dry launch" concept for a tanker flight (orbiter is launched with an empty tank as its only payload which results in approximately 70,000 lbs of unused propellants).

The total propellants per year delivered to the SOC in this way are compared to the OTV propellant requirements to determine how many tanker flights are required to support the mission model previously defined.

The representative manifest data is further used to derive standard equipment sets suitable for use with an orbiter dedicated to SOC resupply mission.

The mission needs, when analyzed in conjunction with mission satellites defined, generates the payload and orbit transfer vehicle (OTV) requirements defining the mission model. The STS traffic models are developed for three accommodation modes, one which utilizes the SOC with a space based reusable OTV and two options without a SOC utilizing a ground based reusable OTV or a ground design expendable OTV. These accomodation modes together with the constraints of shuttle crew task and hours requirements, shuttle cargo manifesting limitations, and logistic support requirements established the shuttle and OTV traffic models. One model was defined for each of the three accommodation modes. These three traffic models were then evaluated to determine the required amounts of support system hardware (Shuttles, OTV's, Logistic Modules, etc.) to complete the Shuttle Fleet Utilization Studies and provide the basis to complete the basic trade analysis of execution of the mission model either with or without incorporation of a SOC.

1.1 MISSION MODEL DESCRIPTION

The establishment of the traffic models begins with an analysis of user needs to determine their demands and launch frequency requirements reflecting mission models. Each mission area was reviewed individually to establish the most reasonable grouping of mission needs into low, medium, and high mission area requirements from which a solid medium mission model was projected.

The mission model assembled defines all STS spacecraft launches for KSC and VAFB thru the year 2000, those missions which go to GEO or to LEO at 28.5 inclination (to the GEO Node) and are; therefore, candidates for interfacing with the initial SOC; were defined in more detail.

The mission model schedule for various mission areas is shown in Figure 1-1. With the SOC IOC of 1990, all affected mission areas are shown to be fully on line with the exceptions of space processing and space construction. Space processing is still in the process development phase and operational space construction missions are not shown to begin until 1995.

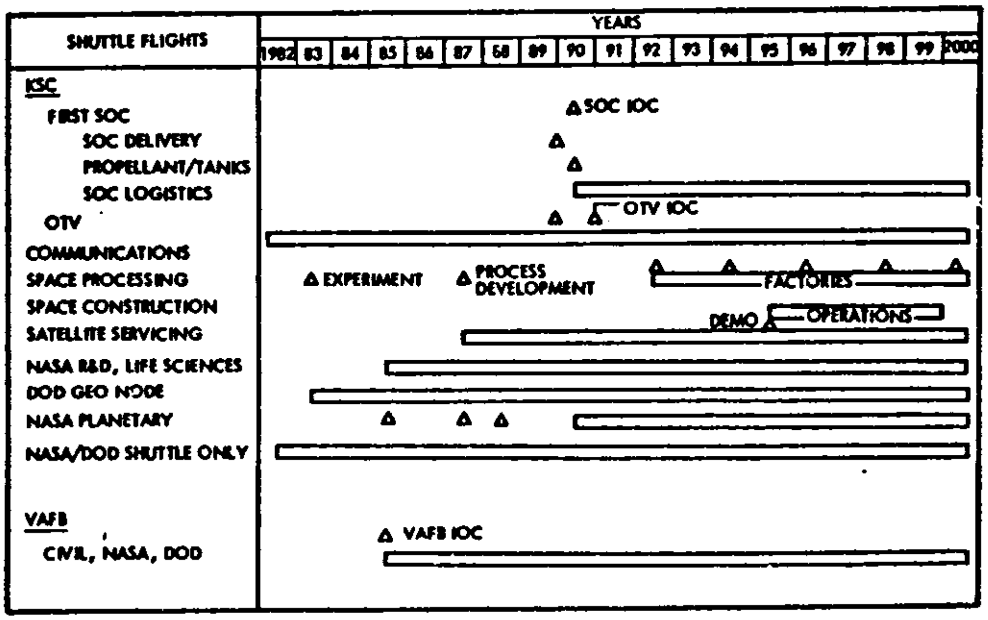

FIGURE 1.1. MISSION MODEL SCHEDULE

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The resulting GEO Node Mission Model is summarized in Table 1-1 for the SOC operational era under analysis (1990-2000). These data are shown for the SOC and No SOC Accommodation Options. Included are the total number of mission payloads for each mission area as well as the total number of STS flights and extended mission flights required in these years in order to accomplish the mission defined. As can be seen, the SOC offers a considerable reduction in the number of STS flights required as well as the added advantage of none of these flights being required to be extended mission flights. The advantage of reduced STS flights shown for the SOC accommodation option is considerable despite the fact that SOC element delivery and logistics missions are included in these requirements. The increased number of U.S. and foreign commercial communication payloads shown for no SOC accommodation option C-2 is because of the reduced payload capability of the ground design reusable OTV which leads to more (smaller) communication spacecraft being required in order to meet the transponder demand identified.

TABLE 1.1 MEDIUM MISSION MODEL SUMMARY

• 1990-2000 STS FLIGHTS AND MISSION PAYLOADS TO GEO NODE	OPTIONS A SOC + SPACE-BASED REUSABLE OTV	C-1 NO SOC EXPENDABLE OTV	C-2 NO SOC GROUND-BASED REUSABLE OTV
• STS FLIGHTS			
• TOTAL FLIGHTS	247	380	460
• 10 DAY MISSION FLIGHTS	0	279	437
• GEO NODE MISSION AREA S/C PAYLOADS			
• U.S. COMMERCIAL COMM	61	61	167
• FOREIGN COMMERCIAL COMM	31	31	84
• DoD PAYLOADS (GEO)	74	74	74
• NASA PLANETARY	12	12	12
• SPACE PROCESSING	285	285	285
• NASA R&D, LIFE SCIENCE	25	25	25
• SATELLITE SERVICING	40	40	40
• SPACE CONSTRUCTION	2	2	2
• TOTAL MISSION S/C PAYLOADS	530	530	689

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The objective of the GEO node missions is to deliver selected spacecraft to specific locations in a geosynchronous equatorial orbit.This delivery task requires the interaction of several space elements, e.g., Shuttle and OTV.

Two delivery modes have been considered, (1) the use of Shuttle for LEO delivery with some form of second stage for delivery to GEO, and (2) the use of a space operations center. Utilizing the space operations center provides the capability to decouple various mission elements of a GEO node mission. Thus, spacecraft of differing missions can be delivered to the SOC on a single, high-density, STS mission, mated with an OTV that was delivered by a separate Shuttle mission, or reused after refurbishment, and transferred to GEO orbit at a time compatible with the specific mission(s). The net effect is that, with careful attention, it is possible to obtain Shuttle launches with mass density factors (actual delivered mass divided by theoretical loads) approaching 95 percent.

1.1.1 GEO Node Payloads Mission Models Description

The rationale associated with the development of the number of payloads for each category as listed in Table 1-1 is described in the following section.

Communications Mission Model

Communication satellites are a profitable reality today and as such can provide a known data point of departure for projections into the future. Therefore, it was only natural that communication mission scenarios be developed and used to show programmatics comparisons and potential benefits of Space Base operations. Table 1-2 provides a comparison of present and future system characteristics for space communication satellites.

TABLE 1-2. U.S. SPACE COMMUNICATIONS
PRESENT AND FUTURE SYSTEM CHARACTERISTICS

U.S. SPACE COMMUNICATIONS TODAY	FUTURE (2030 A.D.)
9 DOMESTIC SATELLITES IN ORBIT	50-100
24 TRANSPONDERS/SATELLITE	150-240
191 TRANSPONDERS IN GEO, 30 TO 35% GROWTH RATE PER YEAR	10,000 20%-30%
4° SPACING OF SATELLITES	1°-3°
500 TO 600 TWO-WAY TELEPHONE CALLS PER TRANSPONDER	1500
28,000 SIMULTANEOUS LONG DISTANCE CALLS ~1.5% OF ALL U.S. LONG DISTANCE TELEPHONE TRAFFIC	30%-40% OF ALL U.S. LONG DISTANCE TELEPHONE TRAFFIC
C-BAND, Ku-BAND, 2-4 MULTI-BEAMS PER ANTENNA	Ka-BAND, 25 TO 100 MULTI-BEAMS PER ANTENNA
150 LB/TRANSPONDER (TOTAL S.C.)	50
1200 TO 4000 LB SPACECRAFT	8000 TO 12,000 LB
1 KW TO 2.5 KW CONT. POWER	7 KW TO 14 KW
5 TO 7.5 YEAR LIFETIME	7.5 TO 20 YEARS
2 TO 3 METER DIAMETER ANTENNAS	UP TO 30-METER DIAMETER
USERS: COMSAT/AT&T/GTE 3 SATELLITES WESTERN UNION 3 SATELLITES RCA 2 SATELLITES SBS 1 SATELLITE	

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No single communications demand model is available. Projections of future demand vary with individuals. A medium mission model was defined for the period from 1980 through the year 2000 to show anticipated demand in equivalent transponders required to provide voice, data, video distribution, and video teleconferencing services (Figure 1-2). This model was selected as the basis for determining the annual buildup rate, the replacement requirements, and the number and type of satellites required. Based on this demand, communication missions scenarios were developed for the three space support system options:

The traditional functions which the scenario addresses are satellite launching, LEO checkout and deployment, and satellite transfer to geostationary orbit. In this scenario, a communication satellite and/or OTV is launched from KSC aboard the Shuttle space vehicle into a low earth orbit inclined at 28° and at an altitude of 200 nmi. After checkout, OTV mating, and deployment (from the orbiter or Space Base), the satellite is transferred by the OTV to a geostationary equatorial orbit located at 110° west longitude.

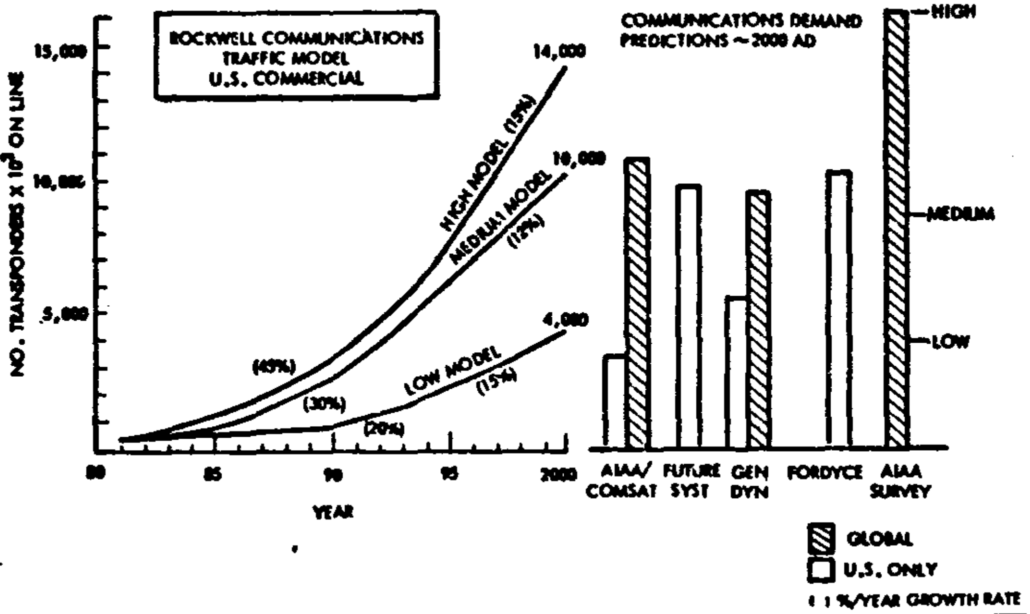

FIGURE 1-2. COMMUNICATION DEMAND PROJECTIONS

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The communication requirements were established by combining the U.S. commercial requirements with the foreign communication requirements (assumed to be 50% of U.S. requirements). A total of 142 satellites were included to meet the medium demand over the 1982-2000 time frame. This total was determined by utilizing the available satellite options/capability in Table 1-3 to provide yearly buildup rate of transponders consistent with mission requirements, including replacements due to lifetime expiration. A summary of these 142 satellites is provided in Table 1-4.

Increasing service life of a communication satellite can have very large economical benefits. Initial analysis has defined potential satellite servicing concepts.

Satellite design philosophy for incorporating servicing capability includes the replacement of "life-limiting" components on a scheduled basis or accommodating failure by replacement of failed subsystems as required.

TABLE 1-3. CANDIDATE SPACECRAFT OPTIONS

TYPE	IOC	LIFE (yr)	MASS (lb)	TRANSPONDERS NO.	TRANSPONDERS BAND	SPACING	MAX NO. SATELLITES IN ORBIT	MAX NO. TRANSPONDERS/ SATELLITE TYPE
0	'81	5	1,000	12	12 C - 12 Ku	4°	18	216
I	'85	5	2,200	24	24 C - 24 Ku	3°	24	576
II/IIa	'85/'90	5/8	5,000	96	48 C + 48 Ku	3°	24	2,304
III	'90	8	12,000	240	24 C, 96 Ku, 120 Ka	3°	24	5,760
IV	'90	8	12,000	240	72 C, 132 Ku, 36 Ka	3°	24	5,760
V	'90	8	12,000	240	Ka ONLY	1°	72 (48)	17,280 (11,520)
VI/VIa	'87/'90	5/8	6,000	80	Ka (+) OR Ka (-)	1°	144	11,520

TABLE 1-4. SUMMARY OF SATELLITE REQUIREMENTS

SATELLITE TYPE	YEARS																			NO. S/C BY TYPE
	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	
TYPE *	4	5	4																	13
TYPE II				8	8	9	7	5												37
TYPE IV									7	8	6	6	6	3	0	0	8	7	6	57
TYPE V									2	2	1	2	1	5	3	4	6	8	1	35
TOTAL																				142

D.O.D. Mission Model

The DOD Mission Model had to be handled in a more general way, since the payload information is secret. The Air Force provided the source materials and Rockwell reasoned adaptations to eliminate obvious duplications. Adjustments were also incorporated to make the traffic model consistent with the existence of a space base. The number of Shuttle flights was derived from payload manifest lengths as given in Air Force sources.

The Rockwell derived mission model is intended to be representative and not official. In aggregate, it reflects masses and rates sufficient for the transportation requirements analysis. Rockwell "growth" versions were incorporated into the model to explore the effects growth would have on space transporation requirements.

Table 1-5 illustrates the growth of DOD traffic vs. transportation system improvements. The deltas which characterize each level of growth are identified.

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TABLE 1.5. PAYLOAD MODEL GROWTH SUMMARY

TRAFFIC GROWTH	TRANSPORTATION SYSTEM IMPROVEMENTS		
	BASIC SHUTTLE AND IUS	ADD GROUND-BASED OTV	ADD SOC SPACE-BASED OTV
LOW	• CURRENT GENERIC MISSION SET WITH SOME BLOCK CHANGES • INCLUDES MILSTAR		
MEDIUM		• NEW SURVEILLANCE & COMM APPLICATIONS • SATELLITES EXPLOIT ADDED MASS-TO-ORBIT CAPABILITY	• ADD SERVICING AND REPAIR • SPACE-BASED OTV ALLOWS MORE MULTIPLE PAYLOAD DELIV. BY ORBITER
HIGH		• ADD NEW SPACE DEFENSE MISSIONS • INCREASE SURVEIL. CAPABILITY	• ADD SERVICING AND REPAIR CAPABILITY • INCREASED STS EFFICIENCY
HIGH HIGH		• ADD NEW SPACE DEFENSE MISSION	• SAME AS ABOVE

More specifically, military missions and cost effectiveness can be expected to benefit from increases in spacecraft mass and volume. It is interesting that many of today's spacecraft have already grown to the limits of the transportation capacity available. Consider the options that would become available to the satellite designer if mass and volume constraints were relaxed: for existing missions, most are low technology, life-extending, and cost-avoidance in nature. Our projection to the mid-1990's shows where we believe current military spacecraft could benefit most from reduced transportation constraints. Addition of new missions such as ASAT, space-based radar, and space-based laser would add to the mass-to-orbit requirements. (See Figure 1.-3)

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TRANSPORTATION NODE	1981 NUMBER MISSIONS	1981 MASS (LB)	GROWTH POTENTIAL	MID-1990 NUMBER MISSIONS	MID-1990 MASS (LB)
GEO	5	3.6K LB	MISSION EQUIPMENT GROWTH ~200 LB — OPTICS — ANTENNAS — ELECTRONIC EQUIPMENT	6	7.6K LB
LEO — MEDIUM INCLINATION			COST AVOIDANCE ~780 LB — HEAVIER STRUCTURE — ENVIRONMENTAL PROTECTION — DESIGN FOR SERVICING		
MEDIUM ENERGY	2	3.5K LB	SURVIVABILITY HARDWARE ~530 LB	2	3.6K LB
HIGH ENERGY	2	4.0K LB	— SHIELDING CIRCUMVENTION — DECOYS	3	6.0K LB
HIGH INCLINATION (LOW ALTITUDE)	2	32.0K LB	MISSION FLEXIBILITY & SURVIVABILITY ~2,300 LB — MANEUVER PROPELLANT	8	36.0K LB
	11		NEW MISSIONS ~60,000 LB — ASAT, DSAT — SBR — DS^3 — SBL	19	

FIGURE 1-3. MILITARY PAYLOAD GROWTH

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NASA Planetary Missions

The NASA Planetary Mission Area spacecraft definitions were established from the current NASA planning for near term solar system exploration and the NASA/JSC Wolfer model to fill out the long term mission requirements. Specific solar system exploration selected as most probable to be executed and therefore included in the model were the following:

- Galileo
- International Solar Polar Mission
- Venus Orbiting Imaging Radar
- Origin of Plasma
- Plasma Turb. Explorer
- Saturn Orbiter (Dual)
- UNP Program - Uran Nep Pluto
- Lunar Polar Orbiter
- Astroid Multi Rendezvous
- Mars Advanced Technology
- Extraterrestrial Material Processing
- Luner Sample Return
- Close Solar Orbiter
- Venus Lander
- Auto Mobile Lunar Survey

Missions UNP Program through Auto MOBILE Lunar Survey are launched during the SOC era under consideration (1990-2000). The upper stage used for these missions is the cryogenic OTV defined for the SOC era. The addition of drop tanks to provide additional OTV propellant are required for the UNP Program-Uran Nep Pluto Mission.

Space Processing Mission Model

The space processing development logic used for mission and traffic modeling involves an evolutionary process leading from small experiments to a free-flying space factory spanning a development period of eight years (Figure 1-4).

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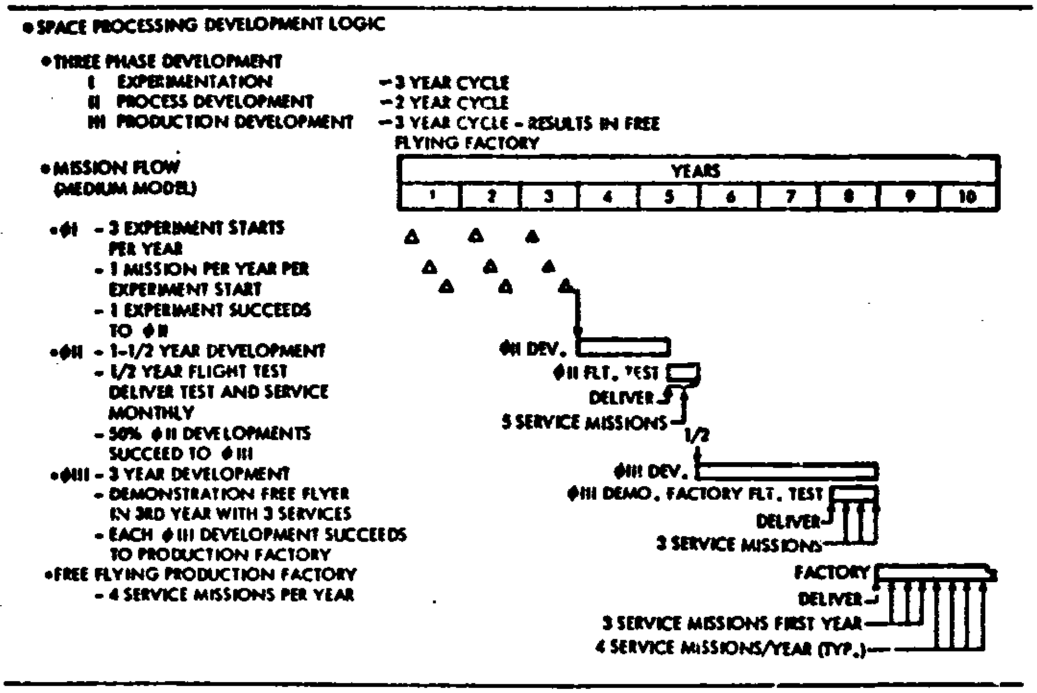

FIGURE 1-4. SPACE PROCESSING DEVELOPMENT LOGIC

A three-phase space processing development has been postulated, i.e., experimentation, process development, and production development. These phases have 3-, 2-, and 3-year cycles, respectively, and result in a free-flying factory at the end of eight years; the space processing payload model is given in Table 1-6. Three experiment starts have been assumed per year with 33% of experiment starts succeeding to Phase 2 at the end of the three-year cycle. Fifty percent of process developments are assumed to succeed and become production developments at the end of the two-year process development cycle.

Each production development is assumed to result in a production free-flying factory. Process development flight test spans a six-month period, with service monthly. Production development payloads and free-flying factories are serviced quarterly after delivery. Resulting total mission payloads are as shown in Table 1-5.

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TABLE 1-6. PAYLOAD MODEL
MISSION AREA SPACE PROCESSING

	YEAR																			
	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000	TOTAL
1. PHASE I EXPERIMENT STARTS	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	57
2. PHASE I MISSIONS PER YEAR	3	6	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	162
3. PHASE 2 PROCESS DEVELOPMENT STARTS						1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
4. PHASE 2 SERVICE MISSIONS						5	5	5	5	5	5	5	5	5	5	5	5	5	5	70
5. PHASE 3 PRODUCTION DEVELOPMENT DEMONSTRATION (FREE FLYER)										1		1		1		1		1		5
6. PHASE 3 SERVICE MISSIONS										3		3		3		3		3		15
7. FACTORY NO. 1 (FREE FLY)											1									1
8. FACTORY NO. 1 SERVICE MISSIONS											3	4	4	4	4	4	4	4	4	35
9. FACTORY NO. 2													1							1
10. FACTORY NO. 2 SERVICE MISSIONS													3	4	4	4	4	4	4	27
11. FACTORY NO. 3															1					1
12. FACTORY NO. 3 SERVICE MISSIONS															3	4	4	4	4	19
13. FACTORY NO. 4																	1			1
14. FACTORY NO. 4 SERVICE MISSIONS																	3	4	4	11
15. FACTORY NO. 5																			1	1
16. FACTOR NO. 5 SERVICE MISSIONS																			3	3
TOTAL MISSION PAYLOADS (SUM LINES 2 THROUGH 16)	3	6	9	9	9	15	15	15	15	19	19	23	22	27	27	31	31	35	35	366

NASA Technology Development & Life Sciences Missions

Mission needs and spacecraft definition for the NASA Technology Development and Life Sciences Mission Area were established from the current NASA definition of 28.5° spacelab missions, science and applications missions for the proposed NASA 25KW power system follow-on, and NASA research and development mission spacecraft contained in the mission model assembled by Mr. Barry Wolfer at NASA/JSC. Included also, in this mission area were NASA Growth Missions to GEO. The logic for the inclusion of these missions is that the advent of SOC will provide the impetus and opportunity for conducting technology development and life science missions at GEO such as the development of large servicable communications platforms. Therefore, a large low density (12,000 lb - 44 foot cargo bay package) growth mission payload was postulated for annual launch subsequent to the SOC achieving full operational capability as part of the mission model. Typical of the NASA research and development spacecraft selected for inclusion are space telescope, LDEF, large solar observatory, and the large optical ultraviolet telescope. Each of the missions included for this mission area are considered to consist of servicable spacecraft during the SOC operational era under analysis (1990-2000). However, this mission area includes spacecraft and platform launches only, while the servicing missions are included in the satellite servicing mission area.

Earth Observation & Science & Application Missions

Earth observation and science and applications programs have been reviewed to give initial insights into earth surveillance missions. This study resulted in definition of a concept integrating all of the benefits obtained during the past 20 years. A spectrum of weather, resource, and climate satellites have been examined, representing a reasonable range of feasible approaches.

Satellite Servicing Missions

The satellite servicing mission area consists entirely of LEO servicing missions for the spacecraft, and science and applications platform payloads that were included for launch in the NASA technology development and life sciences mission area discussed above. Servicing missions are considered to be an integral part of the materials processing in space mission area as well. However these servicing missions are included as part of the space processing mission model. The spacecraft and platforms selected for servicing missions, being a subset of the NASA technology development and life sciences mission model, are described for that mission area. The spacecraft selected for servicing missions are the following:

- Space Telescope
- LDEF
- 25KW Power System Science and Applications Platform
- AXAF - Advanced X-Ray Astro
- Large Solar Observatory
- Ambient Deployable Infrared Telescope
- Large Optical Ultraviolet Telescope

Each of these spacecraft and the 25KW power system science and applications platform were considered to require servicing on a ratio of 15% of their orbiting weights. The spacecraft were scheduled for a four year servicing cycle and the platform was scheduled for annual servicing in order to develop the mission model. For the purpose of this medium model no servicing at GEO, either manned or unmanned, was considered to occur before the year 2000.

Space Construction Missions

Only two operational missions are included in the model for the space construction mission area. These missions are, the pinhold x-ray telescope launched in 1995 and the deep space relay station launched n 1997. These missions were selected from the candidate list of space construction missions contained in the NASA/JSC Wolfer model. Each of these missions are operational GEO spacecraft that are constructed and checked out in LEO and then transferred to GEO using the cryogenic OTV. Earlier technology development missions associated with space construction are included in the NASA technology development and life sciences mission area and only the operational missions that were considered most likely to occur were included in the space construction mission area.

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1.2 TRAFFIC MODELS ANALYSIS

Traffic models are developed that accommodate the mission model needs. The models developed consider both a SOC element available case and a no - SOC case.

Alternate Accommodation Modes Options Defintions

Three accommodation modes were selected for the cost effectiveness trends and analyses (Figure 1-5 and 1-6). The different accommodation modes were selected to provide a data base for an evaluation of the most reasonable spectrum of viable options to establish the key issues that must be addressed and evaluated. They also serve as the definition of the factors that provide the cost comparisons between options. Analysis of the crew hours required to accomplish the total mission area payload requirements was established and evaluated to compare the compatility and total costs of the Shuttle-only options and the SOC options.

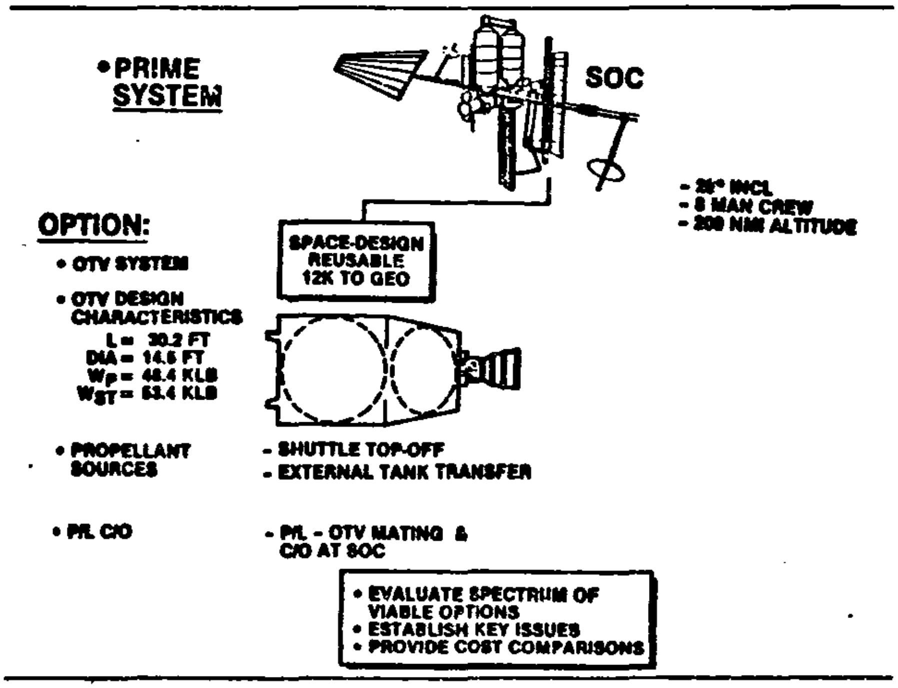

FIGURE 1-5. ALTERNATE ACCOMMODATION MODE "A"

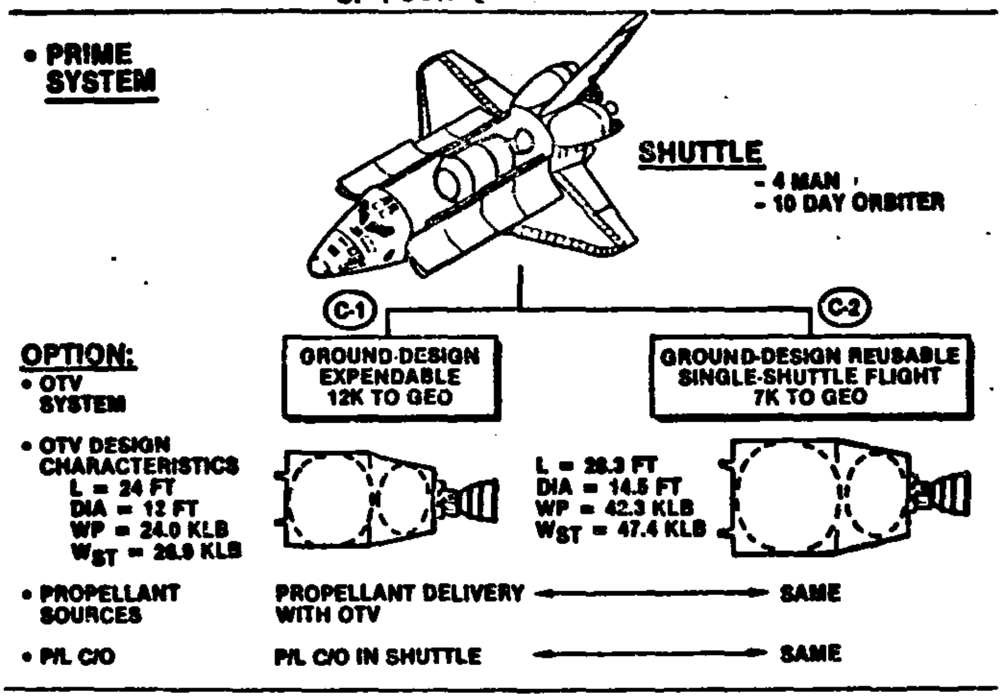

FIGURE 1-6. ALTERNATE ACCOMMODATION MODE "C"

Summarized in Figure 1-7 and Figure 1-8 are all the significant features of each of the three options. The three accommodation modes were evaluated by creating mission manifests for the 11-year period from 1990 to 2000. Option A-1, that includes the SOC in the accommodation mode is shown to be the most cost effective, $22.8 billion for Option A-1 vs $37.2 billion for Option C-2. The major reason is the significantly increased load factor for the STS and a reduction in user risk because of payload deployment and checkout at the SOC.

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	OPTIONS		
	A-1	C-1	C-2
NO. OF SUPPORT SYSTEM ITEMS			
SOC	1	—	—
PAM-A	8	8	8
PAM-D	8	8	8
OTV	12	172	22
DELTA ORBITER (>4 FLEET)	7	10	12
NO. OF MISSIONS	536	530	[illegible]
NO. OF OTV FLIGHTS	172	172	331
NO. OF STS FLIGHTS			
GEO NODE	247	306	469
TOTAL (INCLUDES VAFB)	436	548	651
GEO NODE FLIGHTS			
MASS LOAD FACTOR	0.96	0.37	0.75
SUPPORT SYSTEM AND TRANSPORTATION COSTS	$22.8B	$30.8B	$37.2B

FIGURE 1-7. COMPARISONS OF OPTIONS - 1990-2000

• 1990-2000 MISSION SUPPORT CREW HOUR REQUIREMENTS (11 YEARS OF OPERATIONS)	OPTIONS		
	A SOC + SPACE-BASED REUSABLE OTV	C-1 NO SOC EXPENDABLE OTV	C-2 NO SOC GROUND-BASED REUSABLE OTV *
• MISSION AREA			
• U.S. COMMERCIAL COMM	18,630	31,166	69,366
• FOREIGN COMMERCIAL COMM	8,050	16,435	34,445
• DoD PAYLOADS (GEO)	16,200	22,200	22,200
• NASA PLANETARY	3,500	3,000	3,000
• SPACE PROCESSING	32,840	40,900	40,000
• NASA R&D, LIFE SCIENCE	16,050	10,000	10,000
• SATELLITE SERVICING	2,000	3,000	3,000
• SPACE CONSTRUCTION	600	660	1,200
• TOTAL CREW HOURS REQUIRED	93,020	127,070	184,800
• CREW HOURS AVAILABLE	166,000	127,070	184,800
• UTILIZATION FACTOR*	56%	100%	100%

$$\text{*UTILIZATION FACTOR} = \frac{\text{HOURS REQUIRED}}{\text{HOURS AVAILABLE}}(100)$$

FIGURE 1-8. MISSION CREW HOURS SUMMARY

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Scavenging Analysis Summary

All analysis to date have indicated that suborbital recovery of unused ET propellants is a viable concept with significant benefits to the SOC operational scenario.

The amount of propellant remaining in the ET at the end of boost is dependent upon how much payload was carried to orbit. Aside from the flight performance reserves and residuals trapped in the system the ET will contain an additional 0.95 pounds of propellants for every pound of unused payload capacity that might exist on a given flight manifest.

The relationship between LO_2, LH_2 and total propellants remaining and the Shuttle unused payload capacity is shown in Figure 1-9. Values of propellant remaining can be up to 80,000 pounds or even higher depending upon future Shuttle improvements and/or growth options.

The benefits of recovering these propellants and delivering them to a storage facility on the SOC for later use on OTV missions provides significant savings in annual Shuttle flights through reduced OTV propellant deliveries.

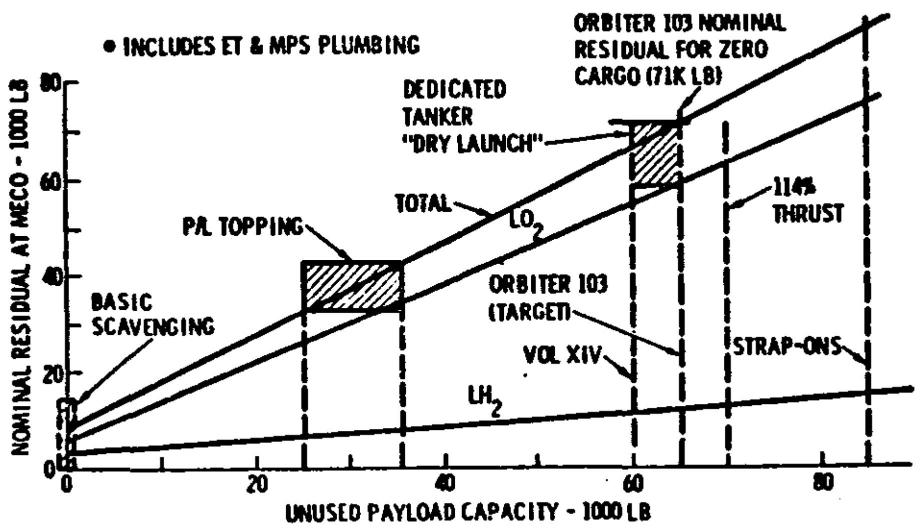

FIGURE 1-9. NOMINAL UNUSED PROPELLANT AT MECO

Orbit Transfer Vehicle Options

Achieving the most effective and efficient orbit transfer capability is a multifaceted problem. The answer involves interactions with the design of the payloads to be transported, interactions with the design approaches to be applied to the OTV itself, interactions with the Shuttle as the primary ground-to-LEO logistics vehicle, and interactions related to whether or not a space base is to be employed.

Payloads must be designed to take maximum advantage of whichever orbit transfer concept is employed. They must be compatibly sized and designed for the orbital deployment and checkout operations most appropriate to the basic transfer concept.

The OTV design approach, either space based or ground based, affects its size and delivery performance as well as the program support elements (deployment and mating aids, etc.) required to make each design approach work.

The Shuttle as the main LEO logistics vehicle in the Space Transportation System interacts with both the payload design and the OTV approach. It interacts with the payloads by virtue of their size, packaging density in the orbiter bay and deployment/checkout/OTV mating requirements and aids. The main OTV-payload interactions are the mass/size to be transported and the OTV thrust environment during the powered delta-V maneuvers. OTV size further affects the operational tactics required, multi-Shuttle time on orbit needed to perform the required delivery and on-orbit operations. This interacts with the orbiter fleet size and related launch and turnaround facility needs. OTV/payload/shuttle interaction concepts for the ground based no SOC option in the single launch and dual launch operations mode are depicted in Figure 1-10 and Figure 1-11.

The use of a space base affects all three of the above interactive areas: payloads, OTV's, and the Shuttle. With a space base, payloads would have a facility for easy deployment and checkout with manned trouble-shooting support. Space-based OTV's can have high stage weight efficiencies, can be designed for reusability, and can have broadened sizing option not constrained by what can be delivered full of propellant in a single Shuttle flight. In addition, space basing with propellant storage allows full exploitation of external tank propellant scavenging and the use of propellant piggybacking to greatly reduce space transportation costs. SOC based OTV operations concepts are indicated in Figure 1-12.

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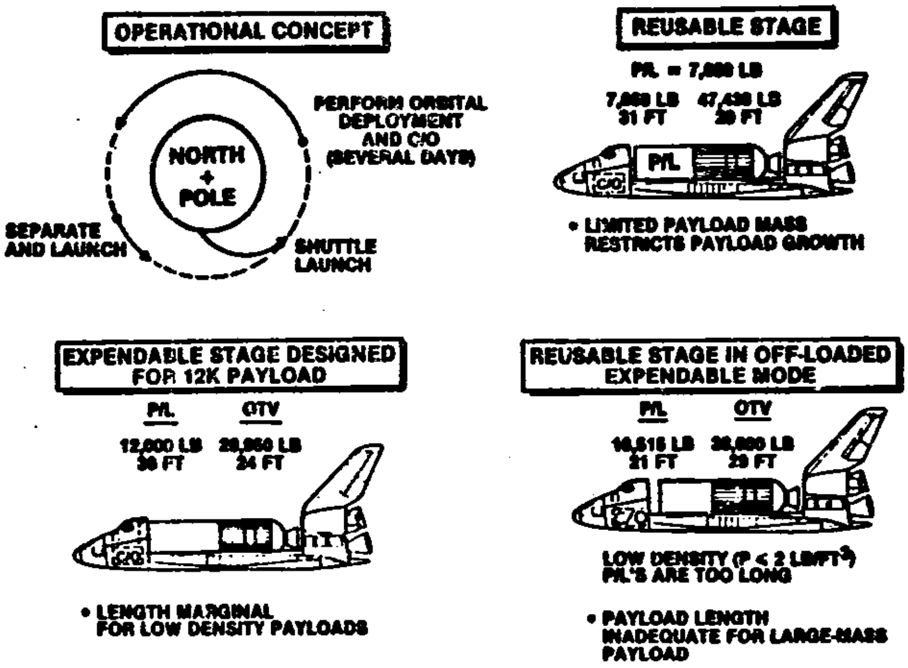

FIGURE 1-10. GROUND DESIGN CONCEPTS - ONE SHUTTLE LAUNCH

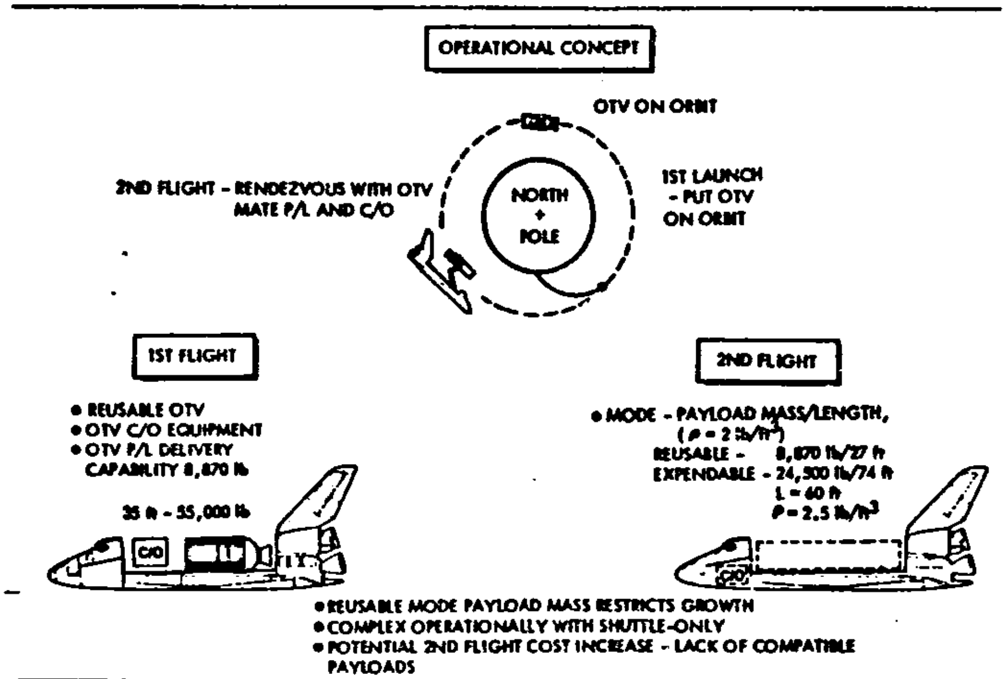

FIGURE 1-11. GROUND BASED CONCEPTS -- TWO SHUTTLE LAUNCHES

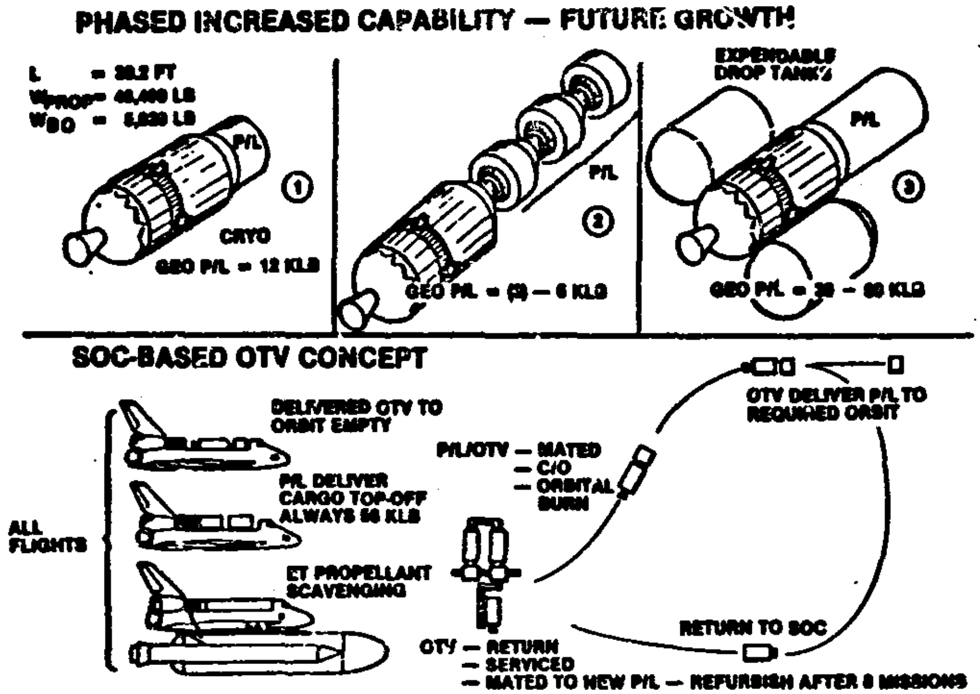

FIGURE 1-12. SOC BASED OTV CONCEPT

On Orbit-Checkout and Servicing

A preliminary estimate of total checkout and servicing manpower requirements for the three traffic model alternatives, covering the years 1990-2000, was prepared, Figure 1-8. These results dealing with small, free-flying satellites and assembling larger payloads in space, generally indicated the Space Base option is less costly to the user, requiring fewer man-hours and less costly transportation of airborne support equipment.

The analysis performed to determine the significant differences and similarities between servicing and checkout operations involving an STS orbiter alone (Alternatives C-1 and C-2) and analogous operations utilizing a space operations center (SOC)--Alternative A is reported in Section 4, the flight support facility.

STS Traffic Model

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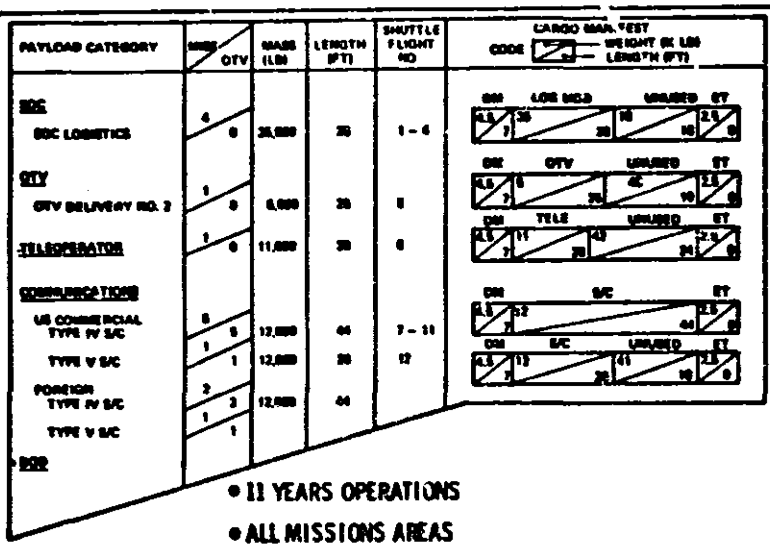
Having established the mission model and alternative accommodation options, and identifing the mission payloads that are available for SOC interaction, STS Traffic Models for each of the accommodation options are developed.

STS manifests that incorporate the payload packets identified by mission area and packaging density, are determined for each accommodation option. Table 1-7 represents a typical example of the manifests generated. The manifests cover eleven years of SOC operation (1990-2000), include all mission areas, and display the mission payload physical characteristics and manifesting ground rules used. The example shown is for the SOC option for which the payload bay volume was used to load the OTV propellant required for the GEO missions. This capability to "top off" the orbiter payload bay when conducting missions to SOC lead to the conclusions that no dedicated "tanker" flights are required when SOC is utilized, and that the orbiter is operated at a higher average load factor and therefore more efficiently for SOC operations. The manifests were than compiled into STS traffic models for each accommodation option. These resulting traffic models are shown as Tables 1-8 through 1-10.

For convenience a subset of each model was generated to identify the SOC related GEO node traffic for the years 1990-2000. These GEO node traffic models are shown as Tables 1-11 through 1-13.

TABLE 1-7. OPTION A MISSION MANIFEST (TYPICAL)



- 11 YEARS OPERATIONS
- ALL MISSIONS AREAS
- PAYLOAD PHYSICAL CHARACTERISTICS AND MANIFESTING GROUNDRULES USED TO ESTABLISH 3 TRAFFIC MODELS
- UNALLOCATED LOAD FACTOR (LF) AND PAYLOAD VOLUME USED IN PROPELLANT TRANSPORT ANALYSIS (A)

TABLE 1-8. TOTAL TRAFFIC MODEL - ALTERNATE A

	YEAR																				
	82	83	84	85	86	87	88	89	SUM	90	91	92	93	94	95	96	97	98	99	00	SUM
KSC																					
FIRST SOC																					
SOC DELIVERY AND CHECK OUT								6	6												6
PROP STORAGE TANK DEL								2	2												2
SOC LOGISTICS								2	2	4	4	4	4	4	4	4	4	4	4	4	46
OTV TEST								1	1												1
OTV DELIVERY										2	2	2	2	2	2	1	2	2	2	2	21
25 KW MODULE						1		1	2												2
TELEOPERATOR										1											1
SUBTOTAL						1		11	12	7	6	6	6	6	6	6	6	7	6	6	79
COMMUNICATIONS																					
US COMMERCIAL	1	1	1	6	5	6	5	3	27	6	6	6	6	5	5	2	2	8	10	6	89
FOREIGN GOVT		1		3	3	3	2	2	14	3	3	3	3	2	3	1	1	5	6	2	46
SUBTOTAL	1	2	1	9	8	9	7	5	41	9	9	9	9	7	8	3	3	13	16	8	135
DoD PAYLOADS				6	2	2	3	5	18	2	7	5	5	5	3	3	6	3	4	4	65
NASA PLANETARY				1	3	1		1	6				3	3	2		3		1		18
SPACE PROCESSING		1	1	1	1	2	2	2	10	1	1	2	2	3	3	4	4	5	6	6	47
NASA R&D, LIFE SCIENCE				1	1	1	1	1	5	2	1	2	2	2	3	3	2	2	3	4	31
SATELLITE SERVICING				1	1	1	1	2	6	1			1			1			1	2	12
SPACE CONSTRUCTION															1		2				3
SUBTOTAL		1	1	8	8	6	7	11	43	7	8	9	13	13	11	11	17	10	16	16	172
TOTAL KSC FLIGHTS TO GEO MODE	1	3	2	17	16	16	14	20	88	23	21	22	27	26	26	19	27	31	35	28	389
SHUTTLE ONLY FLIGHTS																					
NASA	1	1	4	4	2	3	2	3	20	3	4	3	4	3	4	2	4	3	4	3	60
DoD				6	5	5	5	4	26	3	5	4	7	1	2	1	2	1	1	1	48
SUBTOTAL	1	1	4	10	7	8	7	7	46	6	8	7	8	4	6	4	6	4	5	4	100
TOTAL KSC FLIGHTS	2	4	6	27	23	24	21	26	141	29	32	29	33	30	31	23	33	35	40	32	389
VAFB																					
CIVIL				1	1	1	1	1	5	1	1	1	1	2	2	2	2	2	2	2	20
NASA				1	1	1	1	1	5	1	1	1	1	1	1	2	2	2	2	2	21
DoD				4	4	4	4	5	21	7	8	8	8	8	7	8	8	8	8	8	108
TOTAL VAFB FLIGHTS				6	6	6	6	7	31	9	9	10	11	11	10	12	12	12	12	13	162
TOTAL ALL FLIGHTS (KSC AND VAFB)	2	4	6	33	29	30	27	41	172	38	41	39	44	41	41	35	45	48	52	45	601

TABLE 1-9. TOTAL TRAFFIC MODEL - ALTERNATE C-1

	YEAR																				
	82	83	84	85	86	87	88	89	SUM	90	91	92	93	94	95	96	97	98	99	00	SUM
KSC																					
OTV TEST								1	1												1
SUBTOTAL								1	1												1
COMMUNICATIONS																					
US COMMERCIAL	1	1	1	6	6	6	6	3	27	11	11	8	8	8	7	2	3	14	16	8	120
FOREIGN GOVT		1		3	3	3	2	2	14	6	5	4	6	4	4	1	1	6	7	4	62
SUBTOTAL	1	2	1	9	9	9	7	5	41	17	16	12	14	12	11	3	4	20	23	12	182
DoD PAYLOADS				6	2	1	3	6	18	6	10	8	8	6	6	6	6	6	5	7	89
NASA PLANETARY				1	3	1		1	6				2	3	2		3		1		18
SPACE PROCESSING		1	1	1	1	2	2	2	10	3	3	4	5	5	6	7	8	9	10	10	80
NASA R&D, LIFE SCIENCE				1	1	1	1	1	5	2	1	3	2	3	3	6	4	4	5	5	42
SATELLITE SERVICES				1	1	1	1	2	6	2	2	2	2	2	2	2	2	2	2	2	28
SPACE CONSTRUCTION															2		3				5
SUBTOTAL		1	1	9	8	6	7	11	43	10	16	17	19	21	21	20	20	18	23	24	251
TOTAL KSC FLIGHTS TO GEO MODE	1	3	2	17	14	15	14	17	85	27	32	29	33	34	32	23	24	38	46	37	484
SHUTTLE ONLY FLIGHTS																					
NASA	1	1	4	4	2	3	2	3	20	3	4	3	4	3	4	3	4	3	4	3	60
DoD				6	5	5	5	4	25	3	5	4	2	1	2	1	2	1	1	1	48
SUBTOTAL	1	1	4	10	7	8	7	7	45	6	9	7	6	4	6	4	6	4	5	4	106
TOTAL KSC FLIGHTS	2	4	6	27	22	23	21	24	130	33	41	37	39	38	38	27	30	42	51	41	597
VAFB																					
CIVIL				1	1	1	1	1	5	1	1	1	1	2	2	2	2	2	2	2	20
NASA				1	1	1	1	1	5	1	1	1	1	1	1	2	2	2	2	2	21
DoD				4	4	4	4	5	21	7	8	8	8	8	7	8	8	8	8	8	108
TOTAL VAFB FLIGHTS				6	6	6	6	7	31	9	9	10	11	11	10	12	12	13	12	13	162
TOTAL ALL FLIGHTS (KSC AND VAFB)	2	4	6	33	28	29	27	31	161	42	48	47	48	48	48	39	51	58	62	54	705

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TABLE 1-10. TOTAL TRAFFIC MODEL - ALTERNATE C-2

	YEAR																				
	82	83	84	85	86	87	88	89	SUM	90	91	92	93	94	95	96	97	98	99	00	SUM
SOC																					
OTV TEST								1	1												1
SUBTOTAL								1	1												1
COMMUNICATIONS																					
US COMMERCIAL	1	1	1	8	5	9	5	3	27	[illegible]	17	[illegible]	14	12	8	10	8	21	[illegible]	[illegible]	[illegible]
FOREIGN GOVT		1		3	3	2	2	2	14	5	8	8	7	6	4	6	6	12	15	9	[illegible]
SUBTOTAL	1	2	1	8	8	[illegible]	7	5	41	15	21	22	21	18	12	16	14	31	46	27	[illegible]
DoD GEO NODE				8	2	1	3	5	19	4	10	6	8	8	8	6	9	6	6	7	[illegible]
NASA PLANETARY				1	3	1		1	6				3	3	2		3		1		[illegible]
SPACE PROCESSING		1	1	1	1	2	2	2	10	2	3	4	5	6	8	7	8	9	10	10	70
NASA R&D, LIFE SCIENCE				3	1	1	1	1	6	2	1	3	2	3	3	6	4	4	5	5	42
SATELLITE SERVICING				1	1	1	1	2	6	2	2	2	2	2	2	2	2	2	2	2	28
SPACE CONSTRUCTION															3		3				6
SUBTOTAL		1	1	8	6	6	7	11	40	16	16	17	18	21	22	26	20	19	23	24	[illegible]
TOTAL SOC FLIGHTS TO GEO NODE	1	2	2	17	16	16	14	17	[illegible]	35	41	44	39	39	34	38	43	50	69	51	[illegible]
SHUTTLE ONLY FLIGHTS																					
NASA	1	1	4	6	2	3	2	3	[illegible]	3	6	2	6	1	6	3	6	3	6	3	[illegible]
DoD				6	5	6	6	4	[illegible]	3	6	4	2	1	2	1	3	1	1	1	[illegible]
SUBTOTAL	1	1	4	10	7	9	7	7	[illegible]	6	9	7	8	4	6	4	8	4	6	4	[illegible]
TOTAL KSC FLIGHTS	2	4	6	27	23	23	21	24	130	71	[illegible]	61	45	43	40	39	49	50	73	[illegible]	[illegible]
VAFB																					
CIVIL				1	1	1	1	1	[illegible]	1	1	1	1	2	2	2	2	2	2	2	[illegible]
NASA				1	1	1	1	1	5	1	1	1	1	1	1	2	2	2	2	2	27
DoD				4	4	4	4	5	21	7	6	6	8	6	7	8	8	8	8	9	[illegible]
TOTAL VAFB FLIGHTS				6	6	[illegible]	6	7	[illegible]	8	8	10	11	11	10	12	12	13	12	13	[illegible]
TOTAL ALL FLIGHTS (KSC AND VAFB)	2	4	6	33	29	[illegible]	27	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 1-11. SOC-GEO NODE TRAFFIC MODEL - ALTERNATE A

	YEAR																				
	82	83	84	85	86	87	88	89	SUM	90	91	92	93	94	95	96	97	98	99	00	SUM
SOC																					
FIRST SOC																					
SOC DELIVERY AND CHECK OUT																					
PROP STORAGE TANK DEL																					
SOC LOGISTICS										1				1				1			3
OTV TEST																					
OTV DELIVERY										2	2	2	2	2	2	1	2	2	2	2	22
25 KW DOUBLE																					
TELEOPERATOR										1											1
SUBTOTAL										4	2	2	2	3	2	1	2	4	2	2	[illegible]
COMMUNICATIONS																					
US COMMERCIAL										8	8	9	5	6	6	7	5	9	10	8	81
FOREIGN GOVT										3	3	2	3	2	3	1	1	6	5	2	[illegible]
SUBTOTAL										[illegible]	[illegible]	7	[illegible]	7	[illegible]	3	4	14	15	7	91
DoD PAYLOADS										3	7	9	5	5	3	3	6	3	4	4	[illegible]
NASA PLANETARY													3	3	2		3		1		12
SPACE PROCESSING										1	1	2	2	3	3	4	4	6	6	6	[illegible]
NASA R&D, LIFE SCIENCE										2	1	2	2	2	2	3	3	2	3	4	[illegible]
SATELLITE SERVICING										1			1			1			1	2	6
SPACE CONSTRUCTION															1		2				3
SUBTOTAL										7	5	9	13	13	11	11	17	10	14	16	[illegible]
TOTAL KSC FLIGHTS TO GEO NODE										28	20	18	23	23	21	15	23	28	31	20	247

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TABLE 1-12. GEO NODE TRAFFIC MODEL - ALTERNATE C-1

	YEAR																				
	82	83	84	85	86	87	88	89	SUM	90	91	92	93	94	95	96	97	98	99	00	SUM
OSC																					
COMMUNICATIONS																					
US COMMERCIAL										11	11	9	8	8	7	8	5	16	15	6	109
FOREIGN (SPN)										6	5	4	6	4	4	1	1	6	7	4	58
SUBTOTAL										17	16	13	14	12	11	9	6	22	22	10	160
DoD PAYLOADS										4	10	8	4	8	6	6	6	6	6	7	70
NASA PLANETARY													3	3	2		3		1		12
SPACE PROCESSING										2	2	4	6	6	6	7	8	7	10	10	69
NASA R&D, LIFE SCIENCE										2	1	2	2	3	2	6	4	4	6	6	37
SATELLITE SERVICING										2	2	2	2	2	2	2	2	2	2	2	22
SPACE CONSTRUCTION															2		3				5
SUBTOTAL										10	16	17	18	21	21	20	20	19	26	26	210
TOTAL OSC FLIGHTS TO GEO NODE										27	30	30	32	34	32	29	26	41	48	36	370

TABLE 1-13. GEO NODE TRAFFIC MODEL - ALTERNATE C-2

	YEAR																				
	82	83	84	85	86	87	88	89	SUM	90	91	92	93	94	95	96	97	98	99	00	SUM
OSC																					
COMMUNICATIONS																					
US COMMERCIAL										10	17	18	14	12	8	10	9	21	20	16	167
FOREIGN (SPN)										5	6	9	7	6	4	6	5	10	16	9	88
SUBTOTAL										16	25	27	21	18	12	16	14	31	40	27	256
DoD GEO NODE										4	10	8	8	8	8	8	8	6	6	7	74
NASA PLANETARY													2	3	2		3		1		12
SPACE PROCESSING										2	3	4	6	5	6	7	8	8	10	10	69
NASA R&D, LIFE SCIENCE										2	1	2	2	3	2	6	4	4	6	6	37
SATELLITE SERVICING										2	2	2	2	2	2	2	2	2	2	2	22
SPACE CONSTRUCTION															3		3				6
SUBTOTAL										10	16	17	18	21	22	20	20	18	25	34	210
TOTAL OSC FLIGHTS TO GEO NODE										26	41	44	39	39	34	36	43	49	66	61	466

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The final task in organization of the basic data required for the fleet utilization analysis was to identify the LEO to GEO OTV Traffic Model for the SOC related years from the mission and STS traffic models. A summary of the OTV usage for the three options using the medium mission model is shown in Table 1-14.

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TRAFFIC MODEL LINE ITEMS REQUIRING OTV'S	ACCOMMODATION OPTIONS					
	A		C-1		C-2	
	OTV TYPE	NO. OF OTV'S REQUIRED	OTV TYPE	NO. OF OTV'S REQUIRED	OTV TYPE	NO. OF OTV'S REQUIRED
• US & FOREIGN COMMUNICATION	SPACE-BASED REUSEABLE-12K	5	GROUND-BASED EXPENDABLE-12K	52	GROUND-BASED REUSEABLE-8K	16
• NASA GROWTH	SPACE-BASED REUSEABLE-12K	1	GROUND-BASED EXPENDABLE-12K	8	GROUND-BASED REUSEABLE-8K	2
• DOD GROWTH	SPACE-BASED REUSEABLE-12K	2	GROUND-BASED EXPENDABLE-12K	30	GROUND-BASED REUSEABLE-8K	2
• NASA PLANETARY	SPACE-BASED REUSEABLE-12K	1	SPACE-BASED EXPENDABLE-12K	16	SPACE-BASED REUSEABLE-8K	2
• DOD GEO NODE	IUS SPACE-BASED REUSEABLE-12K	8 2	IUS GROUND-BASED EXPENDABLE-12K	8 30	IUS GROUND-BASED REUSEABLE-8K	8 3
• SPACE CONSTRUCTION	SPACE-BASED REUSEABLE-12K	3	GROUND-BASED EXPENDABLE-12K	40	GROUND-BASED REUSEABLE-8K	2
TOTAL	IUS SPACE-BASED REUSEABLE-12K	8 14	IUS GROUND-BASED EXPENDABLE-12K	8 [illegible]	IUS GROUND-BASED REUSEABLE-8K	8 27

TABLE 1-14. MISSION SCENARIO 2 OTV USAGE SUMMARY
(SOC ERA 1990-2000)

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1.3 TRAFFIC SENSITIVITY ANALYSIS

In addition to the basic traffic analysis , focused on SOC vs. no-SOC options, an investigation was performed of the important traffic sensitivities. For the SOC related missions an analysis was conducted to determine the interrelated effects of payload density and key space system-variables on the number of shuttle flights required to satisfy the mission model. The key space system variables considered are: OTV performance, shuttle payload capability, the application of aero braking technology to OTV performance, the effect of eliminating ET propellant scavenging, and the effects of changing the variable altitude strategy for SOC to a constant altitude strategy. A discussion of each of these issues follows.

Average Cargo Characteristics

As a starting base for the traffic sensitivity analysis average cargo characteristics were determinod for the complete traffic summary over the 11 year (1990 through 2000) period used in the study. These data are summarized in Table 1-15.

TABLE 1-15. AVERAGE CARGO CHARACTERISTICS
(11 YEAR TRAFFIC SUMMARY)

SOC		NON-SOC	
ΣN	= 247 STS FLIGHTS	ΣN	= 366 STS FLIGHTS
ΣW_{CARGO}	= 6,733,000 lb	ΣW_{CARGO}	= 3,974,000 lb
$\Sigma W_{PROPELLANT}$	= 7,485,000 lb	$\Sigma W_{PROPELLANT}$	= 4,123,000 lb
W_p REQUIRED	= 7,356,000 lb	W_p REQUIRED	= 4,128,000 lb
$\frac{W_p}{W_{CARGO}}$	= 1.093 lb/lb	$\frac{W_p}{W_{CARGO}}$	= 1.039 lb/lb
$\Sigma W_{P/L}$	= 4,557,000 lb	$\Sigma W_{P/L}$	= 3,017,000 lb
$(W_{P/L})_{AVG}$	= 18,450 lb	$(W_{P/L})_{AVG}$	= 8,240 lb
$(W_{CARGO})_{AVG}$	= 27,260 lb	$(W_{CARGO})_{AVG}$	= 10,860 lb
$(W_{CARGO}+W_P)_{AVG}$	= 57,560 lb	$(W_{CARGO}+W_P)_{AVG}$	= 22,140 lb
$(\rho_{P/L})_{AVG}$	= 2.5 lb/ft^3	$(\rho_{P/L})_{AVG}$	= 1.0 lb/ft^3
LOAD FACTOR: 60K REF $(L.F.)_{AVG}$	= 0.96	LOAD FACTOR: $(L.F.)_{AVG}$	= 0.37
56K REF $(L.F.)_{AVG}$	= 1.03		

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Load factors based on the combined cargo and propellant weight delivered per flight are shown for two reference conditions. The 60K reference condition refers to the current JSC 07700, Vol. 14, shuttle payload capability to 150 n.mi orbit (60000 lb). This allows direct comparison with load factors for non-SOC missions where payloads may not require delivery to the 200 n.mi SOC orbit altitude. The 56K reference condition incorporates the reduction in shuttle payload capability to the 200 n.mi. SOC orbit (56000 lb). The 1.03 load factor for this condition reflects the benefits of propellant scavenging. The shuttle arrives at the SOC with more than the 56000 lb lift capability because of the propellants recovered from the ET. The relatively poor load factor for the non-SOC option is the result of many GEO satellite delivery missions requiring two shuttle launches each, one for the satellite and one for the OTV.

Propellant to Cargo Weight Relationship

In order to properly assess the effects of many of the traffic sensitivities it is necessary to determine the relationships between cargo weight and propellant weight which are possible when operating in the SOC scenario and with maximum propellant scavenging. Plots of this weight ratio (W_P/W_{CARGO}) are shown in Figure 1-13 for several orbiter payload capabilities. The 80K orbiter refers to a growth shuttle with 80000 lb delivery capability to LEO. The other two cases ref ct the standard orbiter capability to (a) 200 n.mi. and (b) 236 n.mi. This is 56 0 lb and 47000 lb for the two cases respectively. These curves are needed to determine the effects of OTV performance, shuttle performance and SOC altitude strategy on the number of shuttle flights required to satisfy the mission model. Specifically, the effects of changes in propellant requirements (OTV perf.) and/or shuttle payload capability on the cargo weight while maintaining the maximum attainable load factor can be determined.

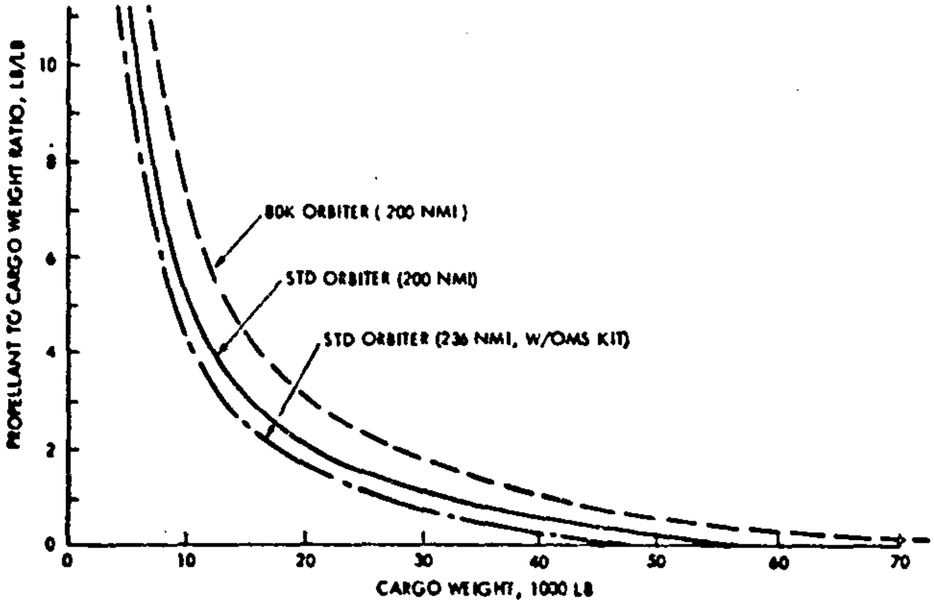


FIGURE 1-13. CARGO TO PROPELLANT WEIGHT RATIO FOR MAXIMUM SCAVENGING

OTV Performance Effects

The basic OTV performance factors considered were structural mass fraction, λ, and specific impulse, I_{sp}. Figures 1-14 and 1-15 show the effects of these variables on the propellant requirements to deliver a pound of payload to GEO from the SOC. The reference configuration used for these data was the space-based reusable OTV described earlier (λ = 0.906. I_{sp} = 470 sec.). As shown on the curve (Figure 1-14) a reduction in stage mass fraction, $\Delta\lambda$, of 0.01 results in a 21.8% increase in propellant required. Applying this factor to the 1.093 value of W_p/W_c from the traffic summary data a new value of 1.331 is required. From the standard orbiter curve of Figure 1-13, the cargo weights for these two propellant to cargo weight ratios are 30300 lb and 27400 lb respectively. The number of shuttle flights must increase by the ratio of these two weights in order to deliver the new mix of propellant to cargo along with the same total cargo as required for the reference OTV case. Thus, the number of shuttle flights is: N = 30300/27400 x 247 = 273, ΔN = +26 flights. Average payload density for this case must increase to 5.3 lb/ft^3.

In the event that cargo density cannot be increased to the above value, the extra propellant required to make up for the 0.01 reduction in OTV mass fraction could be carried up in dedicated tanker flights. Thus, where cargo density is held constant the number of extra shuttle flights required, ΔN = +35. Thus, shuttle flight requirements are extremely sensitive to OTV mass fraction.

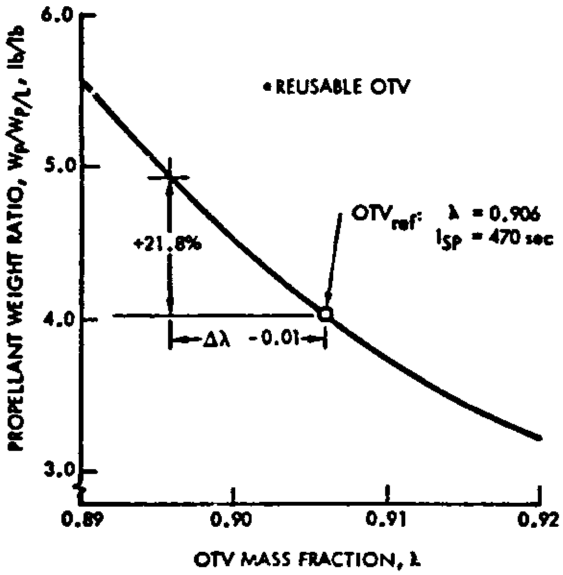


FIGURE 1-14 PROPELLANT SENSITIVITY TO MASS FRACTION FOR GEO DELIVERY FROM SOC

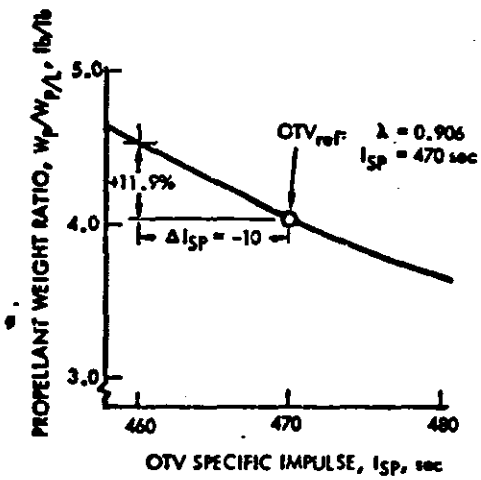


FIGURE 1-15 PROPELLANT SENSITIVITY TO SPECIFIC IMPULSE FOR GEO DELIVERY FROM SOC

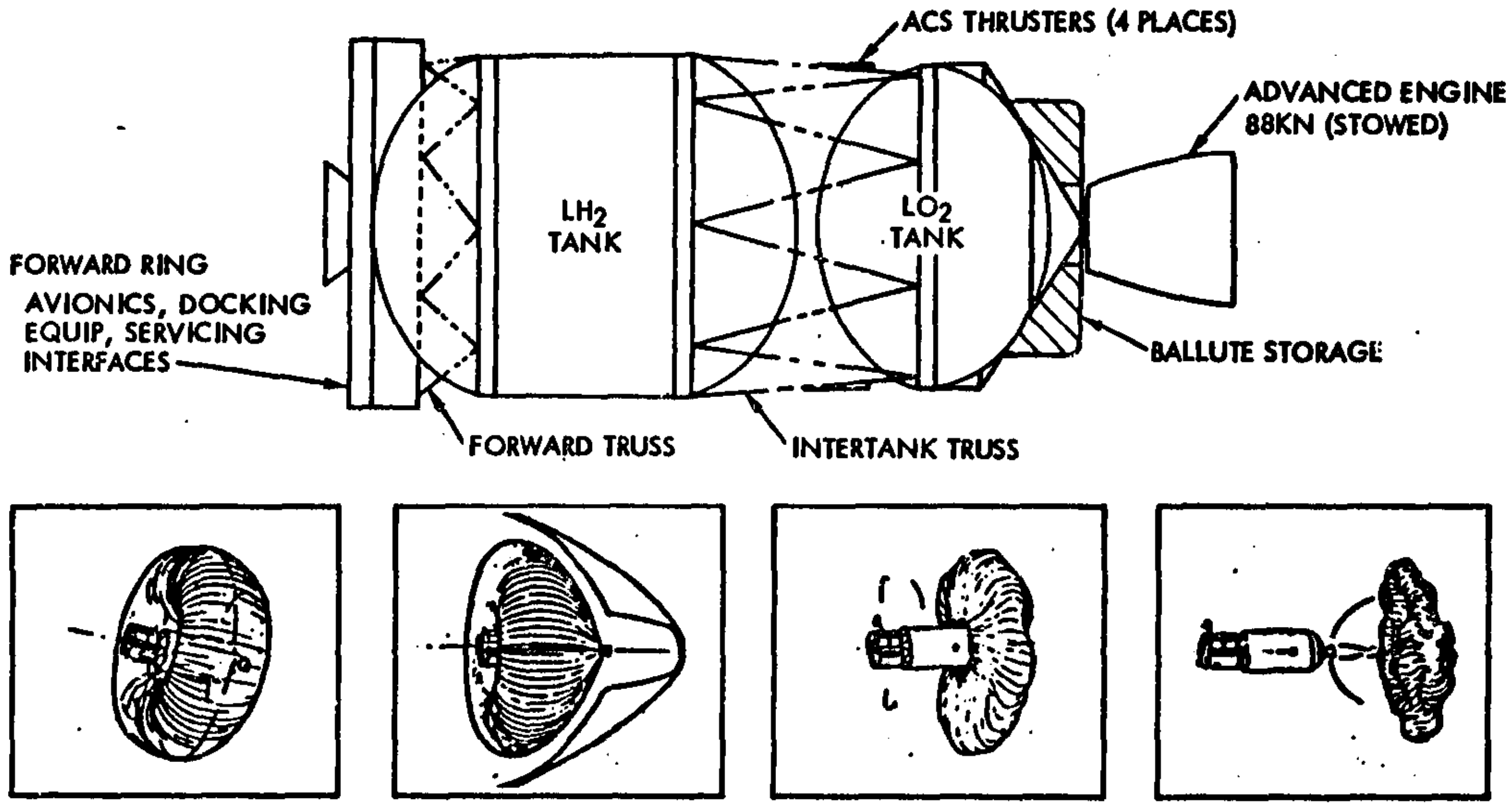
Figure 1-15 shows the equivalent effects of I_{sp} on OTV propellant requirements. Converting these data to shuttle flight numbers in the same manner as described above for the mass fraction effect, ΔN = +14 flights for a reduction in I_{sp} of 10 seconds. This case requires a cargo density increase to 5.4 lb/ft^3. If cargo density cannot be increased the number of extra shuttle flights grows to +19, again assuming all the extra propellants are delivered by dedicated tanker launches.

Sensitivity to Shuttle Payload Capability

Various growth options for improving the shuttle payload capability have been studied. To analyze the effects of these increased capabilities on shuttle flight requirements a representative growth value of 80000 lb to LEO was selected. Returning to Figure 1-13, the cargo weight for the 80K orbiter, is 39500 lb. Rationing this to the standard orbiter value of 30300 lb provides a savings of 57 flights. However, cargo density must increase to the very high value of 7.1 lb/ft^3. No reduction in shuttle flights is possible if cargo density cannot be increased, because all the propellants required can be delivered with the standard 60K orbiter.

Effect of Applying Aerobraking Technology

Several studies have appeared in the recent literature showing the potential performance advantages of employing aerobraking technology to OTV designs. Figure 1-16 shows a representative configuration which was used to determine the effect of aerobraking technology on the number of shuttle flights required for the specified mission model.



ASSUMED GENERIC CHARACTERISTICS:

$I_{SP} = 470$ SEC

$\lambda = 0.875$

REDUCTION IN $\Delta V_{RETURN} = 6000$ FPS

FIGURE 1-16. REFERENCE AEROBRAKER CONCEPT

Using these generic characteristics it was determined that a propellant savings of 18.7 percent over the reference OTV configuration could be achieved using aerobraking technology. This applies to GEO deliveries with the OTV returning to the SOC empty, and results in the reduction of shuttle flights by N=-27. Again because of payload compaction and orbiter c.g. constraints the cargo density must be increased to 6.3 lb/ft^3 to take full advantage of the increased OTV performance offered by aerobraking.

Propellant Scavenging Effects on the Number of Shuttle Flights Required

There are two cases which tend to bound the potential effects of propellant scavenging on the number of shuttle flights required to meet the mission model. They are: (a) assume all propellant which can be carried to the SOC with the required W_p/W_c ratio is used by the OTV (no excess), then approximately 9000 lb per flight would be scavenged (the maximum possible with a full cargo), (b) assume a load factor of 1.0 (referenced to the 56000 lb orbiter capability to the SOC altitude) can be achieved with payload topoff techniques alone and without scavenging. Then only the 3 percent associated with the 1.03 load factor in the average cargo characteristics, Table 1-15, would be provided by scavenging.

The effect on shuttle flights for case (a) is to increase the number of shuttle flights by 61 and for case (b) by 12 flights. Thus, without propellant scavenging somewhere between 12 and 61 additional shuttle flights would be required to meet the mission model needs.

Effects of Constant Altitude Strategy

Another important factor in optimizing the logistics efficiency for the SOC is the application of a variable altitude strategy. In part one of the study (Rockwell Report No. SSD 81-0076, Vol 1, dated 17 April 1981) it was determined that SOC orbit altitude for a constant altitude strategy would be 236 n.mi. to meet the 90-day orbit decay criteria with a $+3\sigma$ maximum atmosphere. The effects of flying continuously at this altitude are presented here.

Holding the W_p/W_c ratio at the nominal value of 1.093 lb/lb in Figure 1-13, the cargo weight is shown to drop to 25000 lb going from the standard orbiter curve at 200 n.mi to the curve for the orbiter at 236 n.mi. The number of shuttle flights therefore grows to $\Delta N = +52$ flights. The minimum payload density becomes 3.5 lb/ft^3. The density effect of the reduction in average cargo mass from 30300 lb to 25000 lb is partially offset by the bay volume reduction for the OMS kit needed to reach 236 n.mi. When the atmospheric density follows the expected trends over the 11 year solar cycle (which is most of the time) the SOC can be safely operated at altitudes of 200 n.mi. and lower. Thus, the constant altitude strategy could cost up to an additional 52 flights.

The traffic sensitivity effects for all of the foregoing factors are summarized in Table 1-16. Degraded OTV performance, eliminating propellant scavenging and applying a constant altitude strategy, can all require dramatic increases in the number of shuttle flights. Increased shuttle payload

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TABLE 1-16. TRAFFIC SENSITIVITIES

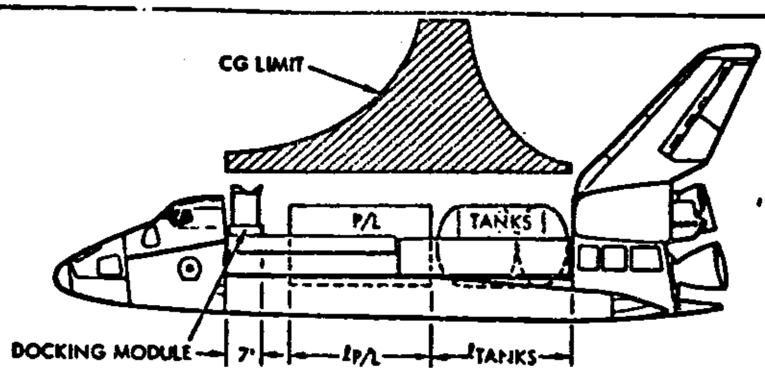
REFERENCE VALUES (11 YR TRAFFIC):
N = 247 FLIGHTS ρ_{AVG} = 2.5 lb/ft^3

FACTOR		ΔN SHUTTLE FLTS	ρ_{AVG} lb/ft^3
OTV PERFORMANCE:	Δλ = -0.01	+35 +29	2.5 4.4
	ΔIsp = -10 sec	+19 +16	2.5 4.8
STS P/L PERF: 80K ORBITER		0 -57	2.5 6.3
AEROBRAKING		0 -23	2.5 5.6
NO SCAVENGING (a) 9000 lb/FLT (b) 3% LOAD FACTOR		+61 +12	-7% -1.3%
CONSTANT ALTITUDE STRATEGY		+37	6.7

performance and the application of aerobraking technology to the OTV can significantly reduce the number of shuttle flights required, but only if very high packaged densities can be attained by the payload designs. These high densities are two to three times higher than current payload definitions (excluding propellant/fluid deliveries) which suggests they will be difficult to attain.

Payload Density Considerations

In the preceding discussions on traffic sensitivies payload density was shown to be significantly affected by many of the sensitivity factors. This is the result of the interrelating constraints of payload volume vs. propellant volume and the orbiter c.g. constraints. As the ratio of propellant to cargo weight is changed to meet different OTV needs or the cargo weight is changed in accordance with variations in shuttle payload capability the relative volumes for propellant and cargo change. The tank length affects the location of the payload c.g. as shown in Figure 1-17, and the tank length is affected by the amount of propellant it must contain. For this analysis we are interested in the maximum propellant which can be carried with a given payload. The relationship between propellant and payload, assuming maximum scavenging is shown in Figure 1-18. Applying these propellant weights to the c.g. constraint geometry depicted in Figure 1-17 results in the payload density versus payload weight curve (dashed line) in Figure 1-19. This curve represents the minimum density attainable while still maintaining maximum shuttle load factors (actually greater than 1.0 because of scavenging). The dashed line is slightly conservative because it presumes a uniform density for the payload and ignores the effect of tank weights in calculating the c.g.'s.



WITH MAX SCAVENGING:

PROPELLANT, $W_p = f$ (UNUSED ORBITER P/L CAPABILITY)

$\ell_{TANK} = k_1 + k_2 W_p$

$$\text{C.G. LIMIT} = \frac{W_{DM} \times 56.5 + W_{P/L}\left(\ell_T + \frac{\ell_{P/L}}{2}\right)}{W_{DM} + W_{P/L}}$$

SOLVE FOR $\frac{\ell_{P/L}}{2}$

PAYLOAD DENSITY $\rho_{P/L} = \dfrac{W_{P/L}}{\ell_{P/L} \times 177}$, LB/FT^3

MINIMUM DENSITY FOR MAX LOAD FACTOR

FIGURE 1-17. C.G. CONSTRAINTS ON PAYLOAD DENSITY

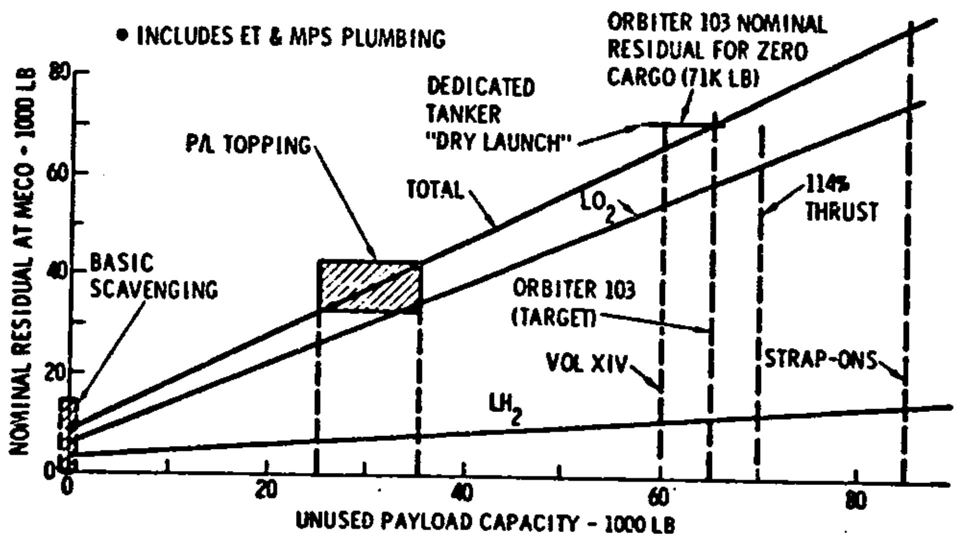


FIGURE 1-18. NOMINAL PROPELLANT RESIDUALS AT MECO

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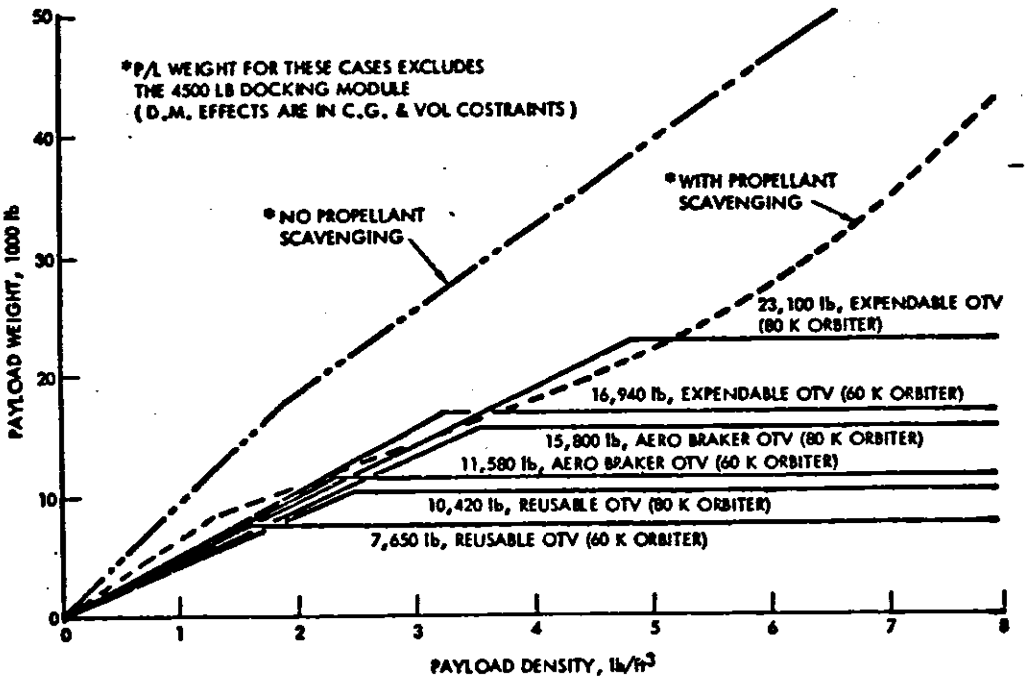


FIGURE 1-19. PACKAGED DENSITY CONSTRAINTS ON SHUTTLE PAYLOADS

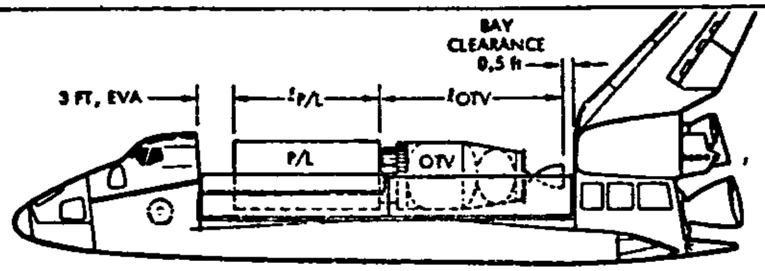
It should also be noted that the allowed c.g.'s were determined for the case with the tanks empty which is the probable condition for landing where the c.g. constraints apply.

A similar analysis was conducted for cases where scavenging was eliminated to determine the effects of the c.g. constraints on pure payload deliveries. This is plotted on the double dashed line of Figure 1-19. As would be expected, eliminating the propellant tanks and allowing the payloads to be placed farther aft in the bay reduces the minimum density requirement significantly.

Although these results are slightly conservative they give a reasonable insight into logistics sensitivity to payload density.

Payload Density Effects for Non-SOC Options

Payload density effects on non-SOC missions were also briefly investigated. The most critical of these mission types are cases involving GEO payloads which are delivered to orbit on the same flight with the OTV which will carry them to GEO. Here the big variables are OTV design and shuttle payload capability. Both of these variables affect how big the OTV must be and hence how much room is left in the shuttle bay for the payload. The main problem variables are depicted in Figure 1-20.



$$\frac{W_{P/L}}{W_{OTV}} = f(I_{sp}, \lambda, \Delta V, \text{EXPENDABLE/REUSABLE, AEROBRAKING})$$

	SPACE DESIGN REUSABLE	GRND DESIGN REUSABLE	GRND DESIGN EXPENDABLE	SPACE DESIGN AEROBRAKING
$\frac{W_{P/L}}{W_{OTV}}$	0.224	0.161	0.445	0.267

$$W_{GROSS} = W_{P/L} + W_{OTV} + 5000_{ASE} = \text{SHUTTLE LIMIT}$$

$$\ell_{OTV} = f(W_{OTV})$$

$$\ell_{P/L} = 60 - 3 - 0.5 - \ell_{OTV}, \text{ FT}$$

$$\boxed{\rho_{P/L} = \frac{W_{P/L}}{\ell_{P/L} \times 177} \quad \text{LB/FT}^3}$$

FIGURE 1-20. OTV SIZING EFFECTS ON PAYLOAD DENSITY

The ratio of payload weight to OTV weight for GEO delivery missions are shown for four OTV options. These reflect the mass fraction and I_{sp} characteristics described in the preceding sections for their respective concepts. The OTV weights are converted to their respective lengths with the relationships in Figure 1-21. Payload lengths are converted to their minimum payload densities (assuming uniform mass distribution) as shown in Figure 1-19. The effects of shuttle payload capability are determined by simply increasing the gross cargo weight allowed and solving for the matching OTV and payload weights.

As shown in the curves, increases in OTV performance and Shuttle payload capability lead to higher plateaus of payload performance. However, to actually achieve these performance increases payload density must also be increased. OTV technology advances cannot be fully exploited without increases in payload packaged density. This is because the advances which allow down sizing the OTV also result in larger payload weights. The increase in space available for payloads approximately matches the growth in payload capability thereby resulting in a clustering of the payload versus density relationships to follow the same growth trend for all options.

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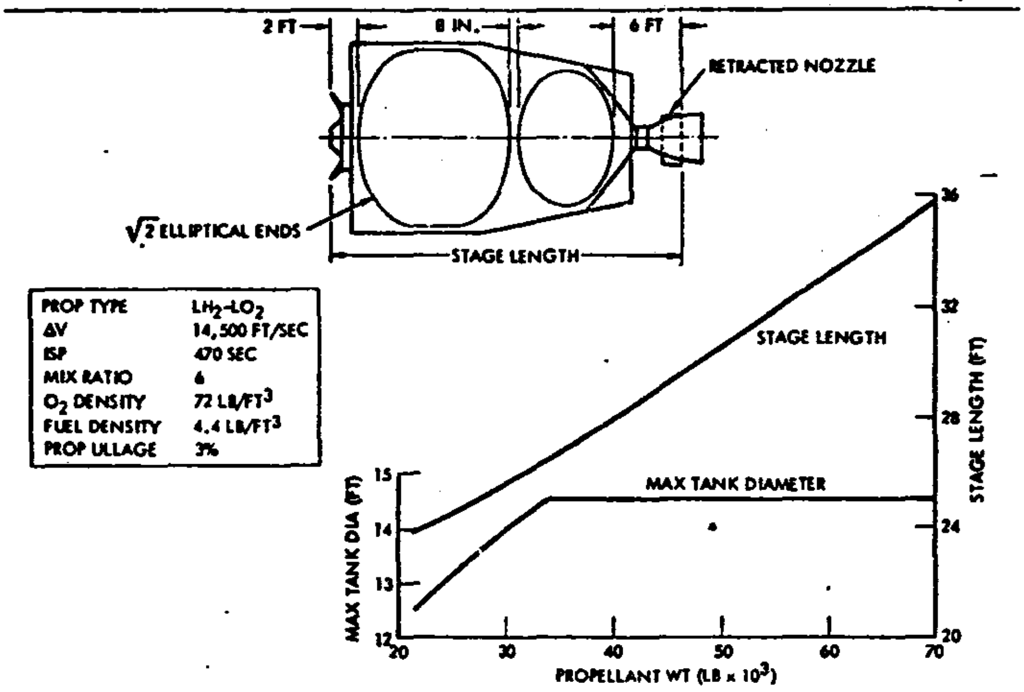

FIGURE 1-21. OTV STAGE LENGTH VS PROPELLANT WEIGHT

1.4 DEDICATED ORBITER CONSIDERATIONS

Four aspects of a dedicated SOC mission versus a non-dedicated (mixed missions) Orbiter configuration were studied to determine the feasibility/desirability of a special Orbiter for the projected SOC missions. The four aspects studied were: reconfiguration tasks, time to accomplish each task, and the manpower requirements for these operations; ETR and WTR traffic levels; the cost of repeated reconfigurations of the Orbiter during an eleven year period; and the increased payload benefits associated with a dedicated SOC mission configured Orbiter. Preliminary conclusions are established from the four-part analysis.

The Orbiter turnaround baseline of 160 hours, which will govern the turnaround of operational vehicles in the eleven year period of interest, is shown in Figure 1-22. The timeline shows that 96 hours are allocated for Orbiter maintenance and checkout operations in the OPF, and of that total period, only 78 hours are nominally available for payload related tasks. One objective of this analysis is to avoid any schedule impact related to payload-type tasks.

Reconfiguration Time and Manpower Requirements

Using the KSC STS Ground Operations Plan, Volume III, STS Flight Kits Plan (April 13, 1979), fifteen items were identified as possible operations to be performed when reconfiguration from a mixed cargo to a SOC mission configuration is performed. Figure 1-23 lists these items and indicates that 957 manhours are required.

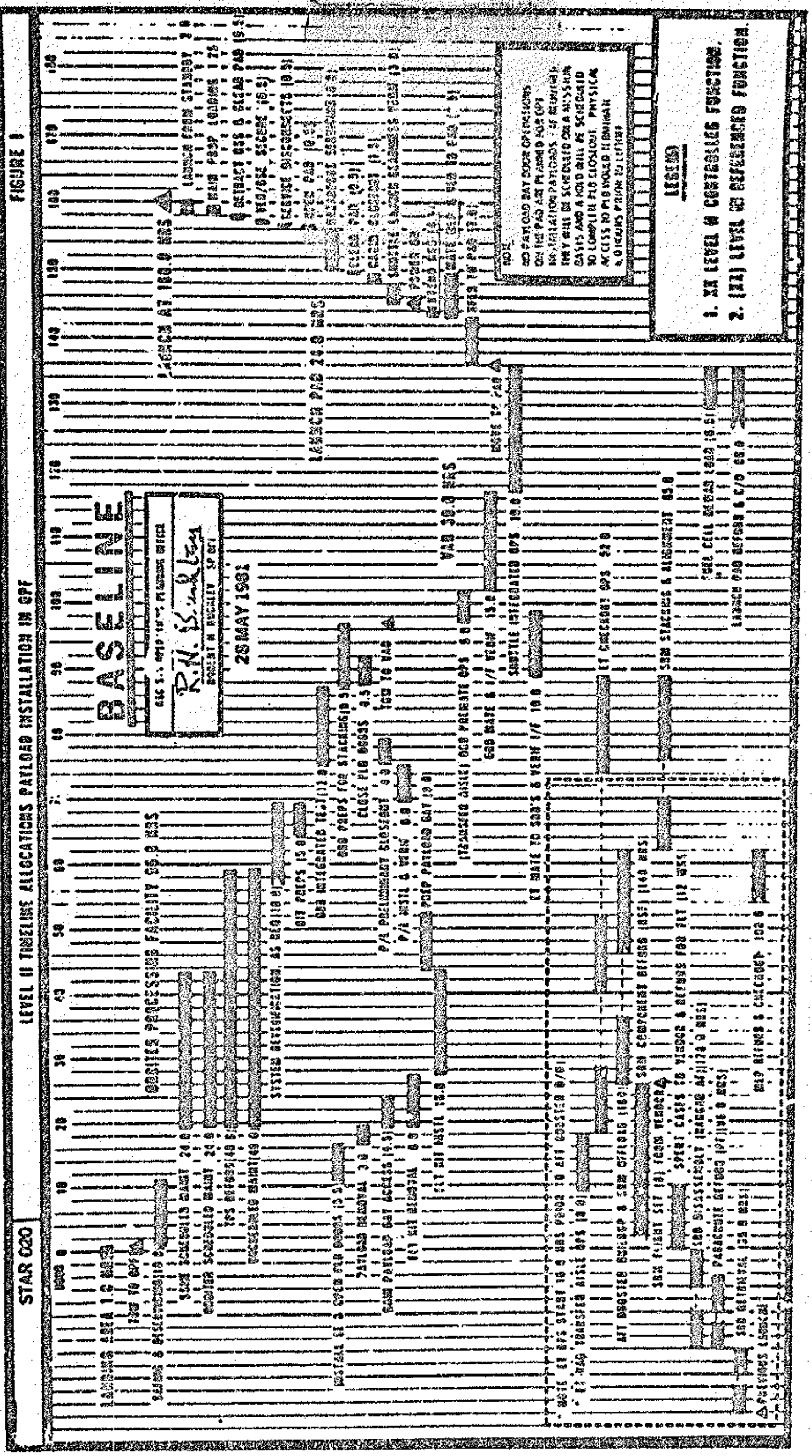

FIGURE 1-22. ORBITER TURNAROUND TIMELINE

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TASK	HRS	MEN	TOTAL MHR
1. RECONFIGURE FROM MIXED CARGO HARNESS KIT TO SOC MISSION HARNESS KIT (B5)*	26.0	4.0	104.0
2. INSTALL LOGISTICS FLUIDS DUMP LINES KIT (B8)	28.0	2.0	56.0
3. REMOVE MIXED CARGO BALLAST KIT (B11)	4.0	2.0	8.0
4. INSTALL SOC MISSION BALLAST KIT (B11)	4.0	2.0	8.0
5. REMOVE MISSION STATION ACCOMMODATION KIT	5.5	2.0	11.0
6. REMOVE PAYLOAD STATION ACCOMMODATION KIT	5.5	2.0	11.0
7. INSTALL SOC ON-ORBIT STATION ACCOMMODATION KIT (B14)	5.5	2.0	11.0
8. REMOVE ONE SET OF FUEL CELL CRYO TANKS (B15)	60.0	4.0	240.0
9. INSTALL MID-DECK CREW SEATS AND ACCOMMODATIONS (B20)	3.0	2.0	6.0
10. INSTALL ET SCAVENGING TANKS (B23)	29.0	4.0	116.0
11. INSTALL PAYLOAD GRAPPLE FIXTURE (B25)	2.0	1.0	2.0
12. REMOVE INSIDE AIRLOCK (B25)	31.0	3.0	93.
13. INSTALL DOCKING MODULE AND MOUNTING KIT (B31)	55.0	3.0	165.0
14. INSTALL PIDA (B32)	15.0	3.0	45.0
15. INSTALL HPA (B32)	27.0	3.0	81.0
	289.5	2.7	957.0

*APPENDIX B, KSC STS GROUND OPERATIONS PLAN, VOLUME III, STS FLIGHT KITS PLAN

FIGURE 1-23. RECONFIGURE FROM MIXED CARGO TO SOC MISSION CONFIGURATON

Preliminary scheduling of the reconfiguration tasks is shown to take 86 hours, caused by the requirement to remove the internal airlock and install the docking module and associated mounting kit in sequential operations. The 86 hours required is just sufficient to meet the milestone (at 87.5 hours) of closing the payload bay doors. Although additional study of these tasks would be necessary to add more margin (86 hours versus the allocated 78 hours modification period), no actual schedule impact is anticipated for this reconfiguration operation from a general cargo to a SOC mission configuration.

To reverse the Orbiter configuration (from a SOC mission to a mixed cargo mission) the same fifteen tasks are shown in Figure 1-24 to require 2311 manhours. Task no. 8 (install one set of fuel cell cryo tanks) is the principal contributor to the excessive amount of manhours required to perform this turn around operation. Retention of the cryo tank installation for the SOC orbiter is recommended. By deleting this Task no. 8, the manpower totals decreas to 651.

No schedule impact, therefore, is anticipated for these reconfiguration operations, changing the Orbiter from a SOC mission to a general cargo mission configuration.

ETR and WTR Traffic Models

The ETR traffic model, Figure 1-25, indicates that all SOC-related missions average 22.5 flights per year for the eleven year period of interest.

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	TASK	HRS	MEN	TOTAL M-HRS
1.	RECONFIGURE FROM SOC MISSION HARNESS TO MIXED CARGO HARNESS (B5)	26.0	4.0	104.0
2.	REMOVE LOGISTICS FLUIDS DUMP LINES KIT (B8)*	16.0	2.0	32.0
3.	REMOVE SOC MISSION BALLAST KIT (B11)	4.0	2.0	8.0
4.	INSTALL MIXED CARGO BALLAST KIT (B11)	4.0	2.0	8.0
5.	REMOVE SOC ON-ORBIT STATION ACCOMMODATION KIT (B14)	4.0	2.0	8.0
6.	INSTALL MISSION STATION ACCOMMODATION KIT (B12)	7.5	2.0	15.0
7.	INSTALL PAYLOAD STATION ACCOMMODATION KIT (B13)	7.0	2.0	14.0
8.	INSTALL ONE SET OF FUEL CELL CRYO TANKS (B15)	415.0	4.0	1660.0
9.	REMOVE MID-DECK CREW SEATS AND ACCOMMODATIONS (B20)	2.0	2.0	4.0
10.	REMOVE ET SCAVENGING TANKS (B23)	22.0	4.0	88.0
11.	REMOVE PAYLOAD GRAPPLE FIXTURE (B24)	1.0	1.0	1.0
12.	REMOVE DOCKING MODULE AND MOUNTING KIT (B31)	16.0	3.0	48.0
13.	INSTALL INSIDE AIRLOCK (B25)	55.0	3.0	165.0
14.	REMOVE PIDA (B32)	18.0	3.0	54.0
15.	REMOVE HPA (B32)	34.0	2.6	102.0
	* APPENDIX B, KSC STS GROUND OPERATION PLAN, VOLUME III, STS FLIGHT KITS PLAN	631.0	2.6	2311.0

FIGURE 1-24. RECONFIGURE FROM SOC MISSIN TO MIXED CARGO MISSION

YEAR	SOC PAYLOADS (NON-OTV)	OTV PAYLOADS	SOC LOGISTIC	OTV DELIVERIES	TOTAL SOC FLIGHTS	NO. OF FLIGHTS POSSIBLE WITH ONE ORBITER (14 + 3) DAYS	EXCESS SOC FLIGHTS
1990	5	12	1	2	20	21	-
1991	3	15	-	2	20	21	-
1992	1	15	1	2	19	21	-
1993	4	17	-	2	23	21	2
1994	4	16	-	2	22	21	1
1995	1	18	-	2	21	21	-
1996	5	9	1	1	16	21	-
1997	5	16	-	2	23	21	2
1998	5	19	-	3	27	21	6
1999	7	22	-	2	31	21	10
2000	11	12	-	2	25	21	4

• A DEDICATED ORBITER FOR ETR SOC-TYPE MISSIONS IS JUSTIFIED BY THE HIGH DENSITY TRAFFIC MODEL

100% AVERAGE USAGE FACTOR

FIGURE 1-25. ETR TRAFFIC MODEL SOC OPERATIONS

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An orbiter, configured especially for the SOC mission, would be utilized 100%. Individual years, however, shows some under-usage (1990-1992) and some excess SOC flights (1993, 1994, 1997-2000) which can be resolved by sharing the Orbiter stationed at WTR, (Figure 1-26), (or a third Orbiter based at ETR).

A third operational Orbiter may be a necessity at an early date because of various contingencies which may arise during STS operations:

- Delayed launches and/or recovery of the SRBs due to inclement weather at the launch site and/or heavy sea states at the SRB impact area.
- Unscheduled Orbiter maintenance may require more than the allocated time (40 hours) in the OPF.
- AF (WTR) launch-on-demand requirements may prevent mission sharing with the ETR launch site.
- On-orbit recovery operations may dictate that the WTR-based Orbiter land at WTR rather than ETR for mission sharing. Ferry requirements would add 7 to 9 days to the Orbiter turnaround operations. The reverse situation may also exist.

The above factors will reduce the usage of ETR-based Orbiters by about 15% and WTR-based Orbiters by about 10%.

YEAR	TOTAL WTR PAYLOADS	EXCESS SOC FLIGHTS	TOTAL WTR + ETR EXCESS FLIGHTS	NO. OF FLIGHTS POSSIBLE ONE ORBITER (14 + 3) DAYS	EXCESS FLIGHTS
1990	9	-	9	21	-
1991	8	-	8	21	-
1992	10	-	10	21	-
1993	11	2	13	21	-
1994	11	1	12	21	-
1995	10	-	10	21	-
1996	12	-	12	21	-
1997	12	2	14	21	-
1998	13	6	19	21	-
2000	13	4	17	21	-

- MISSION SHARING (BETWEEN WTR/ETR) IS RECOMMENDED FOR COST-EFFECTIVE USE OF WTR ORBITER
  - RECOMMENDED ORBITER BE RECONFIGURED FOR EACH SOC MISSION (EXCEPT CRYO TANKS)
  - AFTER 1998, A THIRD OPERATIONAL ORBITER WILL BE REQUIRED TO SUPPORT THE TRAFFIC MODEL

63% AVERAGE USAGE FACTOR

FIGURE 1-26. WTR TRAFFIC MODEL

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Cost of Reconfiguration Operations

Figure 1-27 is a summary of the ETR excess SOC flights which could be accommodated by the WTR-based Orbiter. During the eleven year period of interest, the WTR based orbiter reconfiguration operations will cost approximately 1.4 million dollars (about $125,000 per year). Our tentative conclusion is that $125,000 per year (average cost) is acceptable in order to utilize the WTR-based Orbiter as much as possible.

The cost benefits of employing a SOC dedicated orbiter, that requires no reconfiguration effort, is approximately $13,600,000 during the eleven year period of interest.

Payload Weight Change Benefits

Figure 1-28 summarizes the effect on payload weight of a dedicated Orbiter configured for SOC missions. The weight shown is in contrast to a standard Orbite. configured for a SOC mission. The net payload improvement is approximately 2217 pounds more than a standard Orbiter. In the SOC scenario this extra payload can be fully exploited using the payload top off and propellant scavenging techniques.

YEAR	NO. OF EVENTS	MAN HOURS FOR EACH EVENT*	TOTAL MAN HOURS	
1990	—		—	
1991	—		—	
1992	—		—	
1993	2	1368*		
1994	1		1,368	
1995	—		—	
1996	—		—	
1997	2		2,736	
1998	6		8,208	
1999	10		13,680	
2000	4		5,472	

* 717+651 = 1368 MANHOURS

34,200 x $40/HR = $1,370,000

FIGURE 1-27. COST OF RECONFIGURING WTR ORBITER

		WT. CHANGE
1.	RECONFIGURE FROM MIXED CARGO HARNESS KIT TO SOC MISSION HARNESS KIT	–
2.	ADD LOGISTICS FLUIDS DUMP LINES KIT (NO DELTA WEIGHT)	–
3.	REMOVE MIXED CARGO BALLAST KIT (DELTA WEIGHT UNKNOWN)	–
4.	INSTALL SOC MISSION BALLAST KIT (DELTA WEIGHT UNKNOWN)	–
5.	REMOVE MISSION STATION ACCOMMODATION KIT (DELTA WEIGHT UNKNOWN)	–
6.	REMOVE PAYLOAD STATION ACCOMMODATION KIT (DELTA WEIGHT UNKNOWN)	–
7.	INSTALL SOC ON-ORBIT STATION ACCOMMODATION KIT (DELTA WEIGHT UNKNOWN)	–
8.	REMOVE ONE SET OF FUEL CELL CRYO TANKS	+1317
9.	INSTALL MID-DECK CREW SEATS & ACCOMMODATIONS (COUNTED AS PAYLOAD WEIGHT)	–
10.	INSTALL ET SCAVENGING TANK (COUNTED AS PAYLOAD WEIGHT)	–
11.	INSTALL PAYLOAD GRAPPLE FIXTURE	–
12.	REMOVE INSIDE AIRLOCK	+900
13.	INSTALL DOCKING MODULE & MOUNTING KIT (NO DELTA WEIGHT)	–
14.	INSTALL PIDA (NO DELTA WEIGHT)	–
15.	INSTALL HPA (NO DELTA WEIGHT)	–
		+2217

FIGURE 1-28. PAYLOAD WEIGHT CHANGE WITH DEDICATED SOC CONFIGURATION

The cost of removing and re-installing the cryo tanks, over the eleven year period of interest, would cost 468,000 manhours (1900 manhours for remove and replace operations, times 247 missions), or $18,750,000.

Conclusions

Table 1-17 summarizes the preliminary conclusions, indicating that a dedicated Orbiter, configured for SOC missions, is recomended. Also, the WTR-based Orbiter (or a third Orbiter based at ETR) should be time-shared to accommodate excess SOC missions originating at ETR. A third Orbiter may be required earlier than the 1999 date, indicated by the traffic model studied, based on operational contingencies. Approximately 2000 lbs of additional payload capability is also available with the dedicated orbiter configuration.

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TABLE 1-17. PRELIMINARY CONCLUSIONS

SUBJECT	CONCLUSIONS
RECONFIGURATION TASKS/TIME AND MANPOWER	• NO SCHEDULE IMPACT IS ANTICIPATED FOR REPEATED RECONFIGURATION OPERATIONS IF TASK NO. 8 IS DELETED • ONE SET OF FUEL CELL CRYO TANKS SHOULD BE REMOVED FOR A DEDICATED SOC MISSION CONFIGURED ORBITER
ETR/WTR TRAFFIC MODELS	• A DEDICATED ORBITER FOR SOC MISSIONS WOULD BE UTILIZED 100% (AVERAGE) DURING THE ELEVEN YEAR PERIOD OF INTEREST • WTR ORBITER SHOULD BE MISSION-SHARED WITH ETR • WTR ORBITER SHOULD BE RECONFIGURED FOR EACH SOC MISSION • AFTER 1998, A THIRD OPERATIONAL ORBITER IS REQUIRED
COST OF RECONFIGURATION OPERATIONS	• $125,000 AVERAGE YEARLY COST IS ACCEPTABLE IN ORDER TO UTILIZE THE WTR ORBITER AS MUCH AS POSSIBLE (APPROACH 100%)
PAYLOAD WEIGHT CHANGE	• 2217 PAYLOAD INCREASE CAN BE EXPECTED FOR A DEDICATED ORBITER CONFIGURED FOR SOC MISSIONS • PAYLOAD WEIGHT IS WORTH ABOUT $1000 PER POUND • ALL INCREASED PAYLOAD WEIGHT OPTIONS SHOULD BE FULLY EXPLORED

1.5 Fleet Size Analysis

Fleet utilization analyses have shown that for the peak annual flight rate projected for the SOC mission scenario (48 flights per year) a fleet of three orbiters will meet the traffic needs, Figure 1-29. This offers fleet capacity margin to handle uncertanties in contingencies and relative mission priorities (DOD vs civil, etc.). Fleet size is greatly affected by flight rate and ground turnaround time. An increase in flight rate of about 12 flights per year or an 8-day increase in turnaround time would each require one additional orbiter in the fleet. Also, the higher flight rates required without a SOC will generally require one more orbiter in the fleet, regardless of the contingency and mission priority criteria that are established, as long as they are the same for both SOC and non-SOC cases.

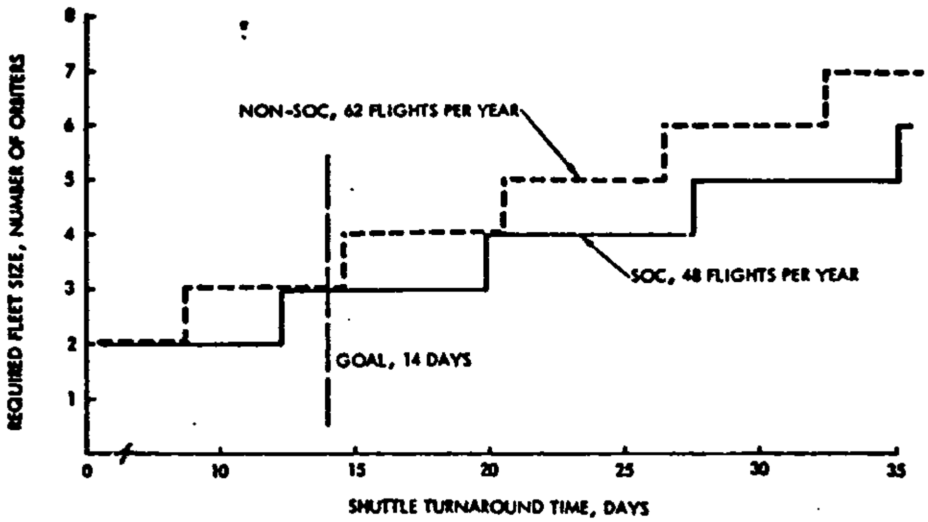

FIGURE 1-29. TURNAROUND TIME EFFECTS ON SHUTTLE FLEET SIZE

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2.0 SOC ASSEMBLY OPERATIONS

Procedures required to assemble the SOC modules are investigated, in this task, in greater detail than was previously accomplished (Ref 1). With the aid of a Rockwell International developed computer graphic program, the capabilities and constraints of the Shuttle RMS to perform the assembly operations can be assessed. The principal objective of the task is to determine the feasibility of the Shuttle RMS to perform the SOC assembly task, and to determine the requirements for associated equipment to aid in the assembly process such as the handling and positioning aid (HPA). The location of the RMS grapple fixture on each of the modules is also determined.

2.1 SOC ASSEMBLY SCENARIO

Two principal modes of the SOC assembly sequence were investigated, (1) a sequence that assembles the SOC in its full-up configuration before being manned, and (2) an incremental sequence that provides an initial four man autonomous capability building to a full-up capability in a future period. Figure 2.1 illustrates the configuration of a SOC utilized for the full-up assessment and Figure 2.2 illustrates the configuration of a SOC utilizing an incremental build-up sequence.

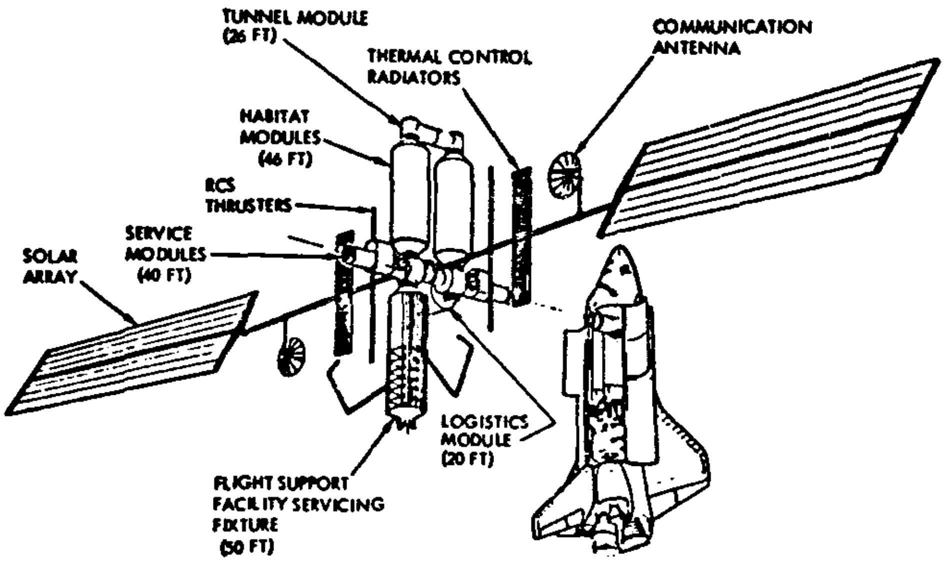

FIGURE 2.1 SPACE OPERATIONS CENTER FULL-UP CONFIGURATION

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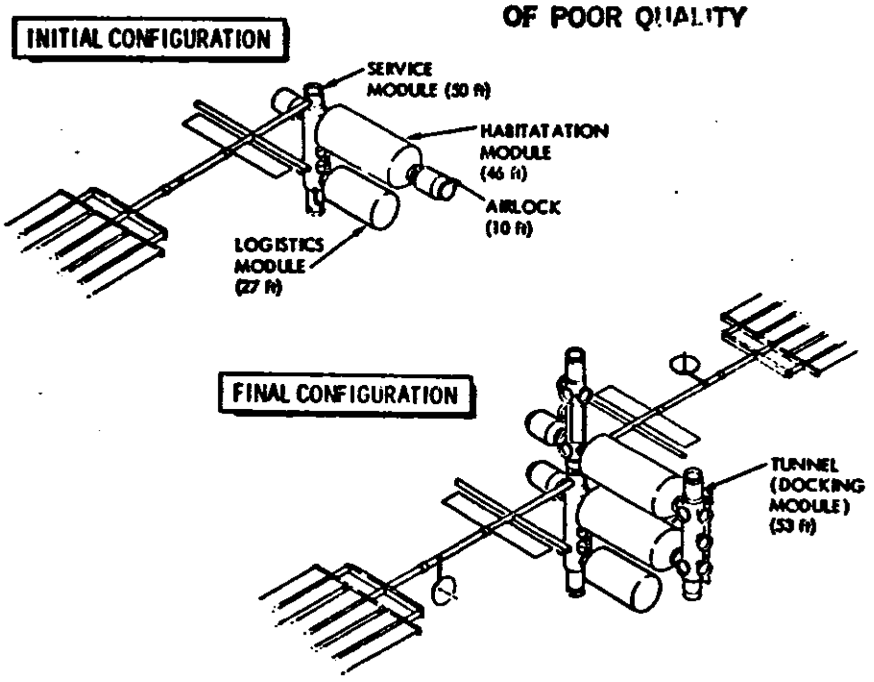

FIGURE 2.2 SOC INCREMENTAL BUILD-UP CONFIGURATION

A summary of the resultant RMS joint angle readings associated with the assembly sequence, Figure 2.3, of the full-up concept is shown in Table 2.1. The table indicates that all of the RMS maneuvers can be accomplished within the RMS limits, but do exceed the desired range in a few places. Thesedeviations are not critical to the assembly operation, and could probably be eliminated with additional iterations. Figure 2.4 indicates the grapple fixture locations on each of the modules resulting from the assembly sequence computer simulations. The grapple fixture position on the tunnel module is unique and is indicated in more detail in Figure 2.5.

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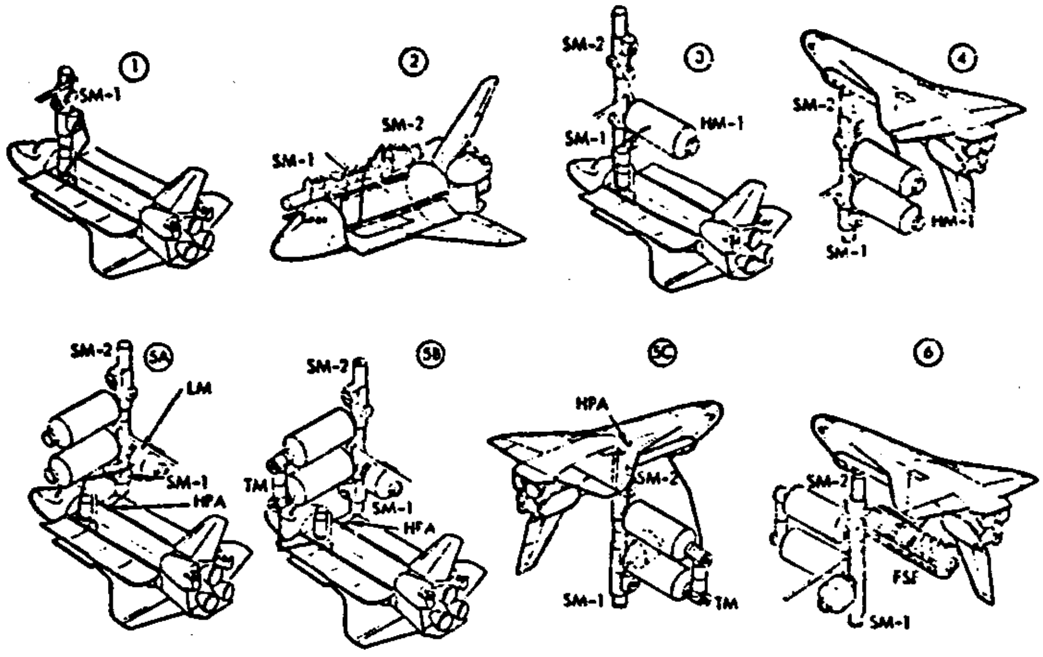

FIGURE 2.3 SOC ASSEMBLY - FULL UP CAPABILITY

TABLE 2.1 RMS JOINT ANGLES - FULL-UP SOC ASSEMBLY SEQUENCE

MODULE	SY (-177.4 TO 177.4)	SP (0.6 TO 142.4)	EP (-0.4 TO -157.6)	WP (-116.4 TO 116.4)	WY (-116.6 TO 116.6)	WR (-442 TO 442)
SM-1 STOWED	-31.51	49.50	-69.39	-46.78	-32.86	-51.53
SM-1 DEPLOYED	-119.14	129.60	-109.42	-42.22	27.33	100.53
SM-2 STOWED	-31.51	49.50	-69.39	-46.78	-37.86 *	-51.53
SM-2 DEPLOYED	-8.73	85.31	-110.91	-41.17	-68.72	114.74
HM-1 STOWED	-34.96	68.48	-92.42	-40.76	-31.44 *	132.19
HM-1 DEPLOYED	-21.49	78.27	-42.47	-79.80	-61.31	139.73
HM-2 STOWED	-34.96	68.48	-92.42	-40.76	-31.44 *	132.19
HM-2 DEPLOYED	-21.49	78.27	-42.47	-79.80	-61.31	139.73
LM STOWED	-49.59	87.77	-118.34	-29.30	-24.36	147.00
LM DEPLOYED	-61.31	75.58	-48.93	-28.61	-26.91	169.66
TM STOWED	-20.27	59.44	-114.29	-21.67	24.36	-75.00
TM DEPLOYED	56.74	94.02	-54.29	112.14	46.31	130.00
FSF STOWED	-33.56	65.64	-88.43 *	-42.70	-32.02 *	131.00
FSF DEPLOYED	-20.72	73.61	-36.52	-82.09	-61.66	138.50

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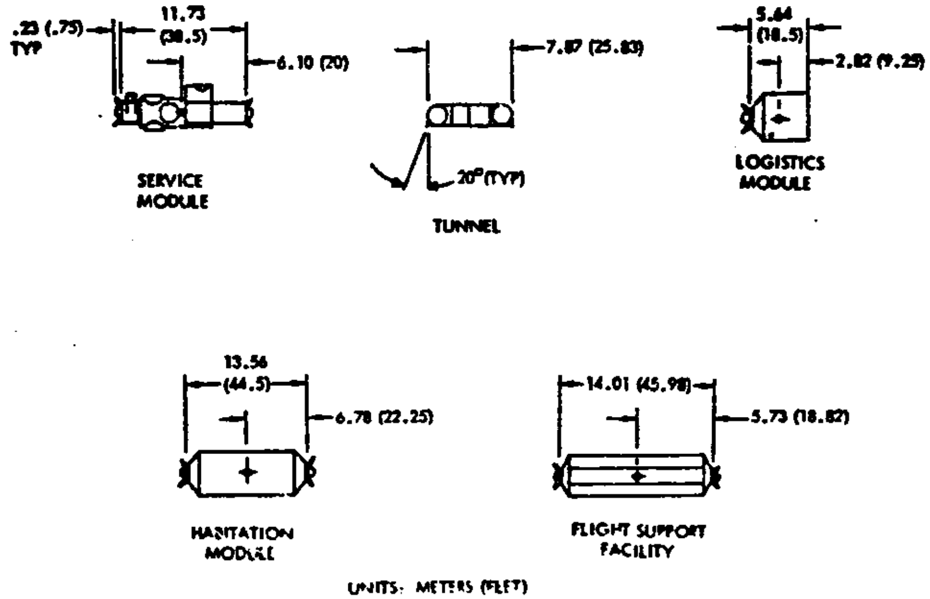

FIGURE 2.4 GRAPPLE FIXTURE LOCATIONS

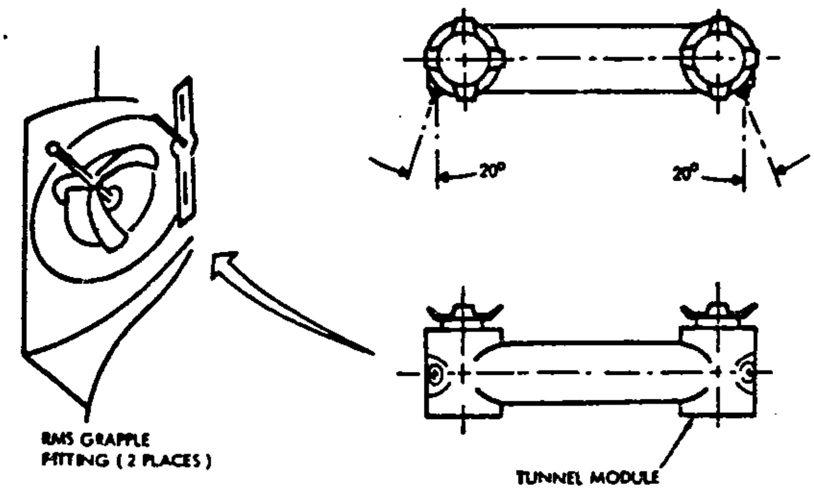

FIGURE 2.5 TUNNEL MODULE GRAPPLE LOCATION

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Table 2.2 summarizes the resultant joint angle readings for the incremental assembly sequence, Figures 2.6 through 2.11, and Figure 2.12 indicates the grapple fixture positions on each of the modules.

A comparison was made of the assembly issues/operations between these two concepts. Figure 2.13 indicates the results of this comparison analysis. The significant result of this analysis is that the SOC can be assembled utilizing only the Shuttle RMS in either arrangement. However, a significant increase in the number of operations required to assemble the longer modules is indicated. The complexities and, consequently, the risks are evident for the longer module assembly concept. The HPA is required more frequently and needs greater capabilities.

TABLE 2.2 RMS JOINT ANGLES SOC INCREMENTAL ASSEMBLY

RMS JOINT (MAXIMUM LIMITS) / MODULE	SY (-177 & TO 177.4)		SP (0 & TO 145.4)		EP (-0 & TO -155.6)		WP (-116 & TO 116.4)		WY (-116 & TO 116.4)		WR (-447 TO 447)	
	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
2A/B (SOC)	-166.17	-137.71	105.46	56.56	-129.75	-93.04	-32.64	0.56	64.27	64.22	0	0
2C/D (HM-1)	-50.55	-57.45	56.10	86.01	-123.75	-103.64	-27.21	-0.77	-19.39	-37.93	0	0
2E/F (SOC)	-166.17	-137.71	106.46	56.56	-129.75	-93.04	-32.66	0.56	64.27	64.22	0	0
3A/B (A/L-1)	-48.29	-88.61	92.06	71.40	-146.50	-47.83	-50.27	63.28	13.02	-46.45	0	0
3C (LM)	-30.22	45.01	59.66	132.53	-78.61	-116.75	-48.05	55.56	-33.58	76.01*	0	0
3D (A/L-2)	-36.00	50.11	71.50	57.71	-120.64	-76.67	-49.60	107.26	17.64	0.06	0	0
3F (SOC)	-113.36	-50.07	116.06	64.27	-85.26	-55.62	-51.09	-28.16	21.95	0.07	0	0
4A/B (SOC	-113.36	-130.56	116.06	70.39	-85.26	-81.64	-51.09	-16.88	21.95	60.97	0	0
4B/C (HM-2)	-35.15	-40.00	64.01	47.42	-100.40	-81.93	-20.21	100.46	-31.36	-12.43	0	0
5A/B (SOC)	-113.36	-113.37	116.06	58.09	-85.26	-91.35	-51.09	12.33	21.95	27.02	0	0
5C (A/L-2)	124.31	-110.01	85.53	43.63	-40.72	-50.64	19.16	3.91	-31.01	72.83*	0	0
5D (HM-2)	-32.10	-132.10	64.21	94.65	-85.45	-130.22	-46.09	111.03	-33.67	12.58	0	0
6A/B (SOC)	-113.36	-113.13	116.06	70.54	-85.26	-59.05	-51.09	-31.73	21.95	27.73	0	0
6C (TM)	-86.16	145.45	73.09	105.06	-127.36	-49.72	-74.96	-3.39	1.19	-50.53	0	0

JOINT ANGLES EXCEEDING DESIRED RANGE (EP > 40°; WY < ±60°)

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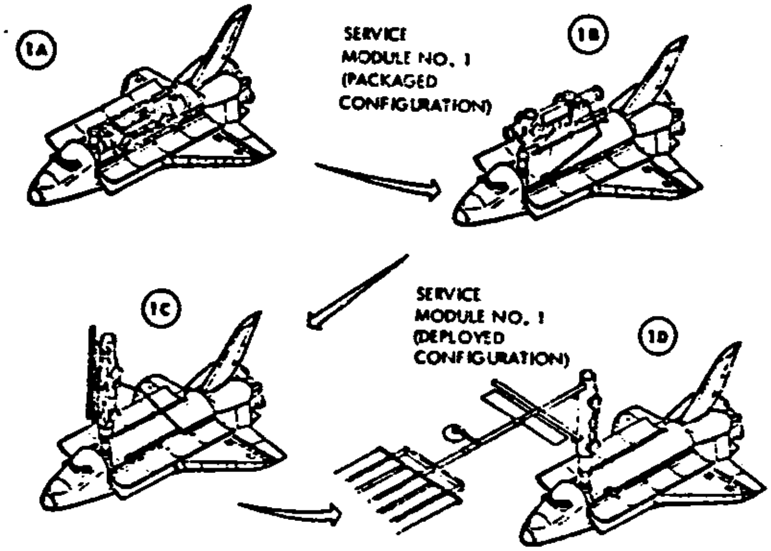

FIGURE 2.6 SOC ASSEMBLY - INCREMENTAL CONCEPT FLIGHT 1

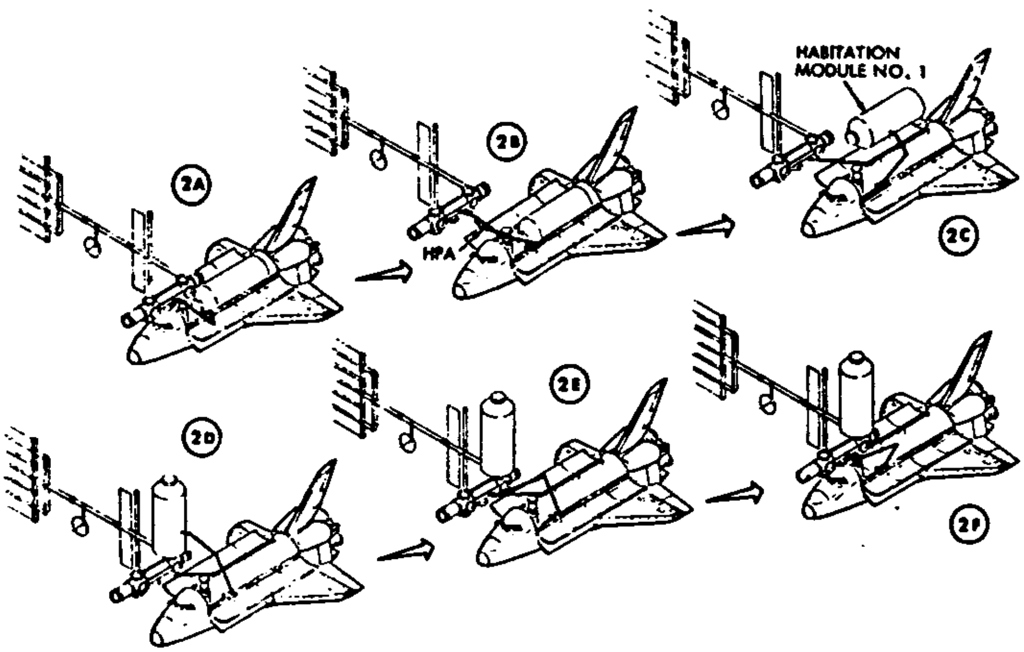

FIGURE 2.7 SOC ASSEMBLY - INCREMENTAL CONCEPT FLIGHT 2

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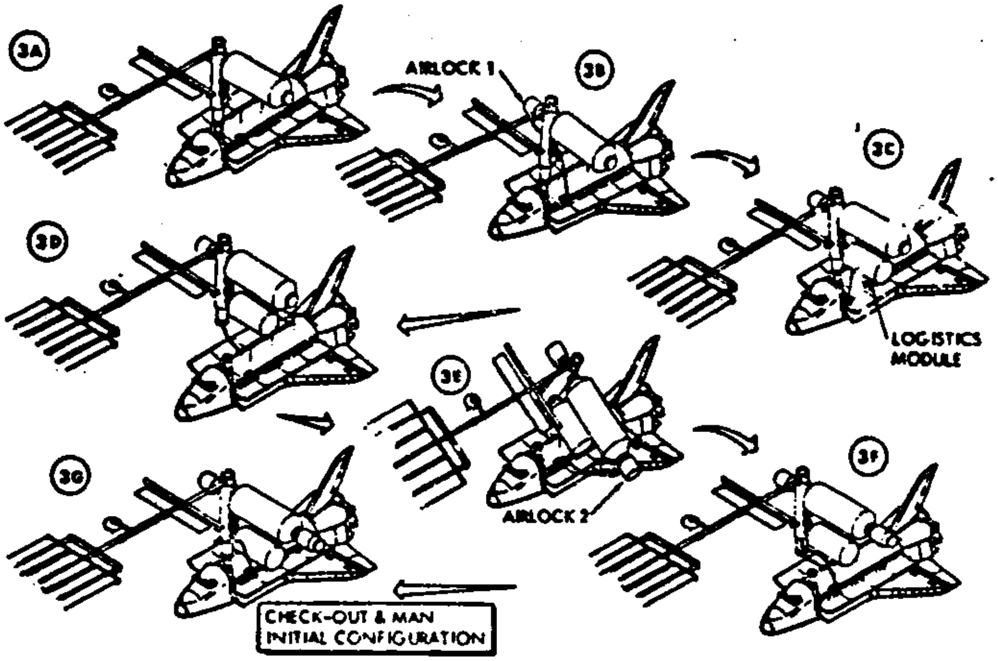

FIGURE 2.8 SOC ASSEMBLY - INCREMENTAL CONCEPT FLIGHT 3

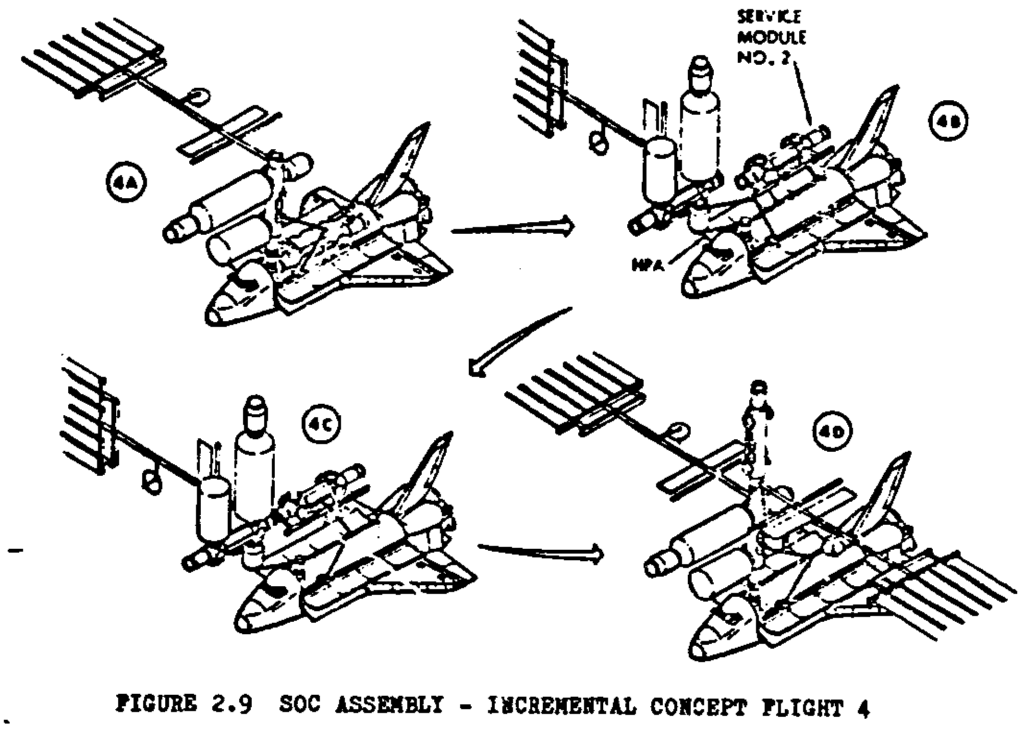

FIGURE 2.9 SOC ASSEMBLY - INCREMENTAL CONCEPT FLIGHT 4

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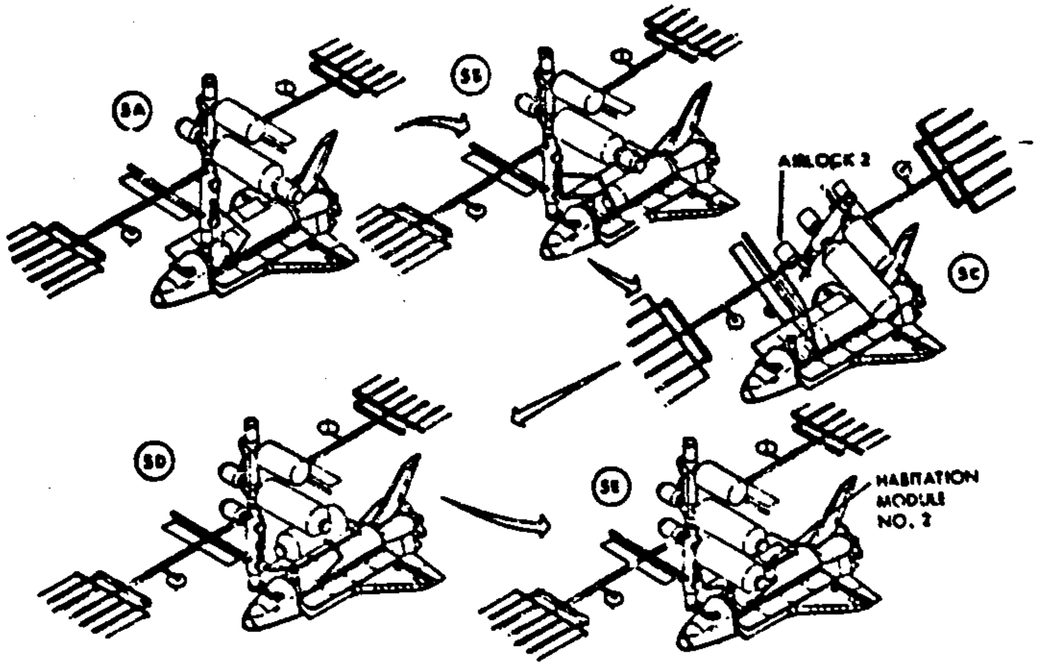

FIGURE 2.10 SOC ASSEMBLY - INCREMENTAL CONCEPT FLIGHT 5

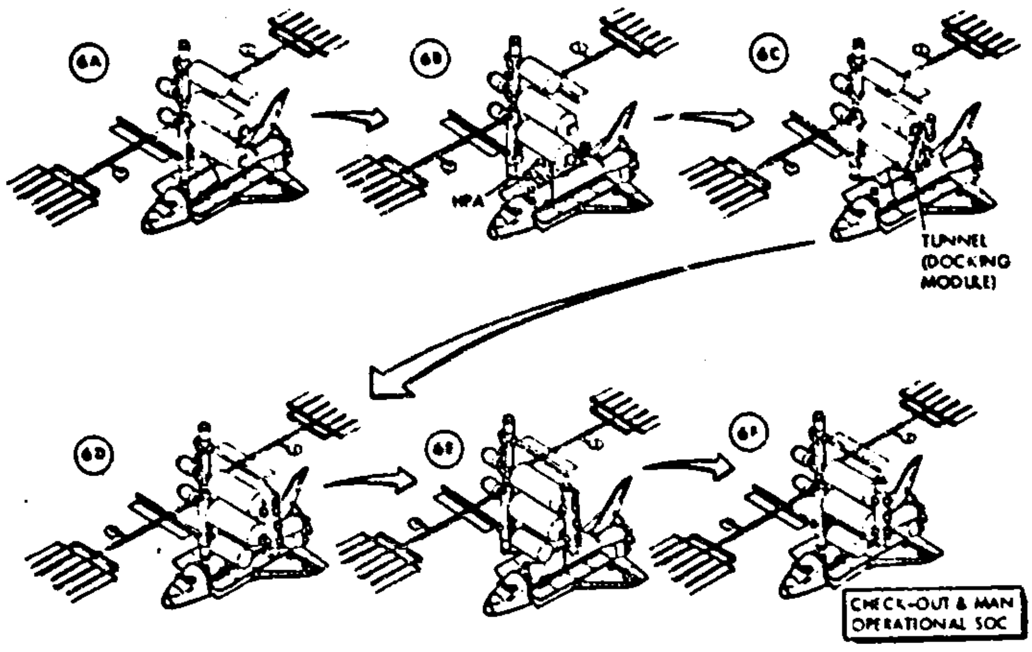

FIGURE 2.11 SOC ASSEMBLY - INCREMENTAL CONCEPT FLIGHT 6

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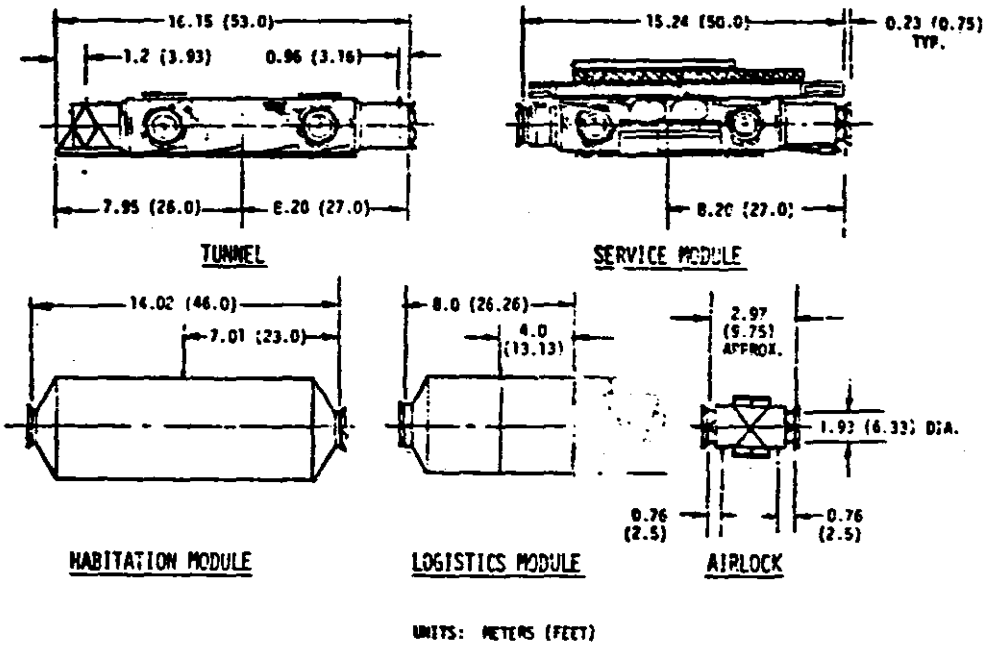

FIGURE 2.12 GRAPPLE FIXTURE LOCATIONS

		A	B
NO. OF FLIGHTS REQUIRED FOR ASSEMBLY		6	6
NO. OF MODULES		7	8
LENGTH OF MODULES, M (ft)	SERVICE MODULE	12.19 (40)	15.24 (50)
	HABITATION MODULE	14.02 (46)	14.02 (46)
	TUNNEL (DOCKING) MOD.	7.87 (26)	16.15 (53)
FLIGHTS REQUIRING HPA		1	5
SOC PORTS INTERFACING WITH	ORBITER DM	3	3
	HPA	2	4
DOCKING OPERATIONS		6	6
GRAPPLING, TRANSFER & BERTHING OPERATIONS		10	20
DISASSEMBLY OPERATIONS		0	1
SOC PORTS REQUIRING DOCKING INCREMENTS OF	90°	0	2
	180°	2	0
DEVIATIONS FROM RMS JOINT ANGLES	DESIRED LIMITS	5	2
	MAX LIMITS	0	0

FIGURE 2.13 COMPARISON OF SOC ASSEMBLY CONCEPTS

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REFERENCES

1. Space Operations Center - Shuttle Interaction Study, Final Report, Rockwell International Corporation, Report No. SSD 81-0076, February 1981; Contract NAS 9-16153, NASA/JSC.
2. Space Operations Center System Analysis, Final Report, The Boeing Company, Report No. D180-26495, July 1981, Contract No. NAS 9-16151, NASA/JSC.

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3.0 SHUTTLE SYSTEM PROPELLANT SCAVENGING

In order to determine the SOC impact due to propellant storage and transfer activities a study, under Rockwell International discretionary funds, was performed to determine the feasibility of recovering the unused propellant from the external tank (ET) of the shuttle and transferring this propellant to the SOC.

3.1 SUBORBITAL RECOVERY OF EXTERNAL TANK PROPELLANTS

This study indicated the practical feasibility of recovering unused propellants remaining in the external tank (ET) after boost. As indicated in Figure 3.1, a nominal 9378 pounds of propellants are left in the ET and the main engine system of the orbiter at the completion of main engine cutoff (MECO). These propellants are currently jettisoned with the ET or vented to space following ET separation. This task shows the overall feasibility of transferring these propellants to an Orbiter-mounted receiver tank, during mated coast after MECO for subsequent delivery to SOC or a space base, and identifies practical hardware elements for implementation of the concept.

The benefits of applying this concept to a space base are very substantial. The nearly 10,000 pounds of recovered propellant represent nearly one fifth of a Shuttle load. Thus, ET propellant recovery can reduce the number of logistic flights in support of a space base by nearly 20 percent. In the usual case of an underloaded Orbiter, much greater benefits can be realized.

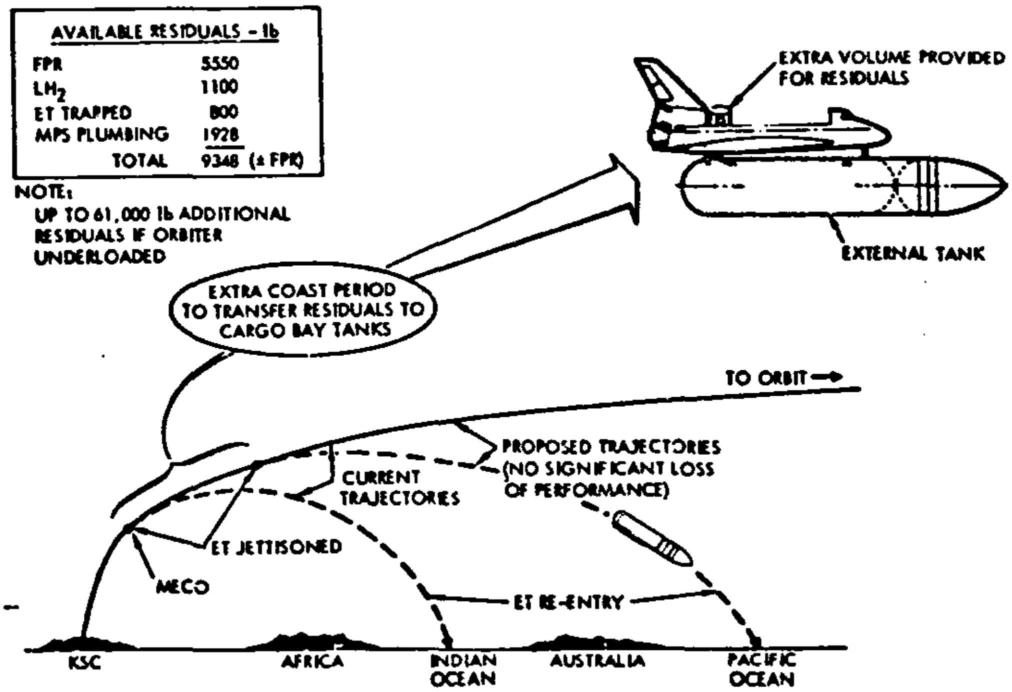

FIGURE 3.1 ET RESIDUALS RECOVERY CONCEPT

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Scavenging Scenarios

Figure 3.2 identifies 3 main scenarios in which ET scavenging can be used to reduce the number of Shuttle launches required to service and resupply SOC. The basic scenario assumes a "full-up" 65K pound payload (not volume limited) in which there is room left for a small size "catch tank" or scavenging tank large enough to capture the maximum expected (+3 sigma) residuals. The second scenario assumes that the payload is less than 65Klb and not volume limited, and that room is left to add a loaded propellant resupply tank in addition to the basic scavenging tank. The third scavenging scenario assumes a dedicated tanker flight fully loaded with an orbiter-mounted resupply tank.

Key Issues

The following key issues were identified and investigated in this study.

1. Boost trajectory interactions with ET impact constraints, ullage thrust options, and transfer time availability.

2. Factors affecting cryogenic fluid flow phenomena.

3. Main engine shutdown and ullage thrust transient effects on fluid dynamics at MECO.

4. Receiver tank and plumbing hardware concepts.

5. Preliminary crew considerations.

6. Important safety-related issues.

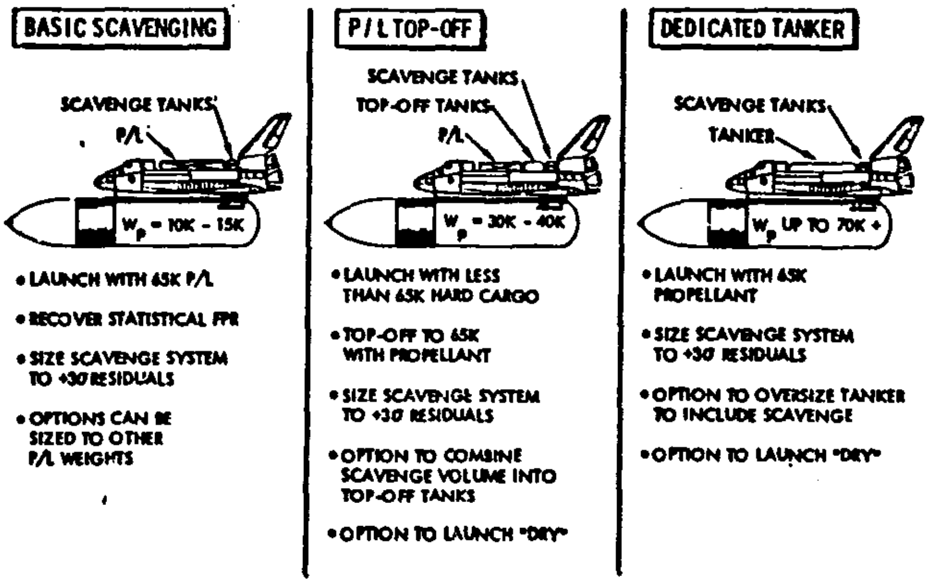

FIGURE 3.2 POSSIBLE SCAVENGING SCENARIOS

3.1.1 Trajectory Analysis

The following guidelines were used to define the necessary changes to the present Shuttle mission flight plan in order to allow for a five to twenty minute post-meco mated coast phase: 1) Safe ET impact in either the Indian or Pacific Oceans, 2) Continuous positive accelerations of $1X10^{-4}$ g's or greater, 3) Minimal changes to the Shuttle abort and nominal meco requirements, and 4) Minor modifications to Shuttle subsystems.

RCS Thrust Options

The three RCS thrust options shown in Figure 3.3 were selected as the most likely candidates requiring minimal amounts of subsystem modification, cost and checkout before implementation. Two thrust options utilized present aft-facing RCS primary thrusters, whereas the third option assumed that an idealized thrust level of "Drag + 50 lbs" was provided by added RCS vernier engines.

ET Entry and Impact Area Assumptions

The Shuttle ascent trajectory is constrained primarily by the requirement to aim the empty ET for impact in a safe target area and at the same time satisfy abort safety requirements.

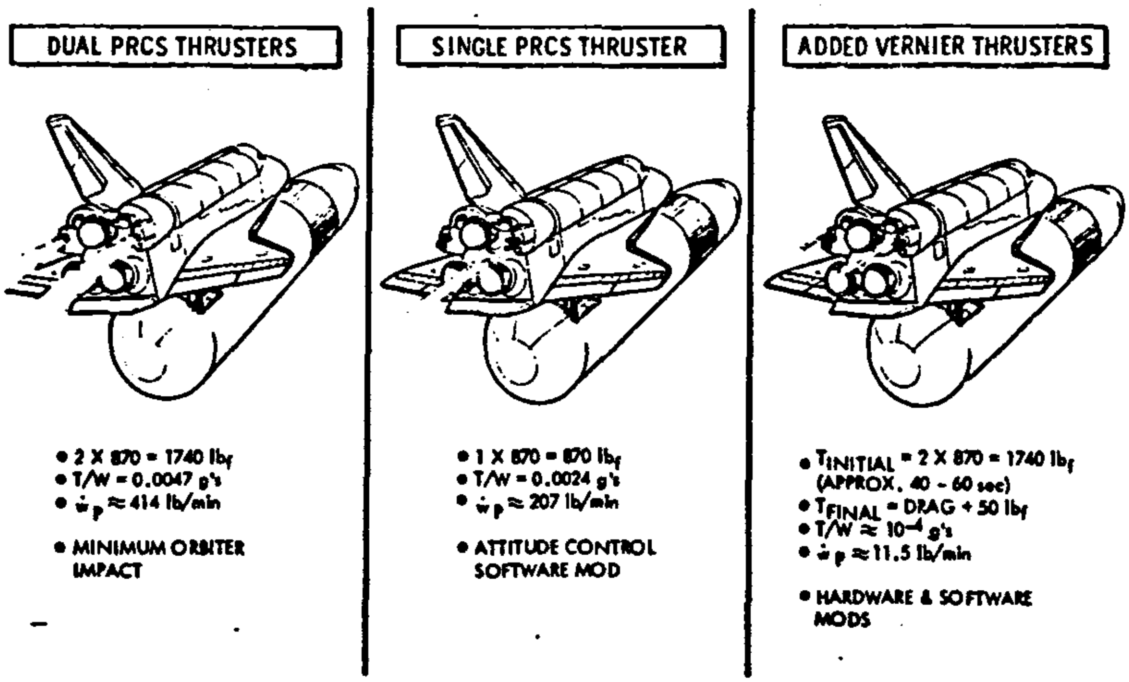

FIGURE 3.3 ULLAGE THRUST OPTIONS

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Two impact zones were identified primarily on the basis of land mass avoidance. The area west of Australia in the Indian Ocean was designated Zone 1, whereas, the impact area north east of the Gilbert Islands in the Pacific Ocean was designated Zone 2. Figure 3.4 presents the ground trace of a due east launch from ETR and the ET impact zones assumed in this study.

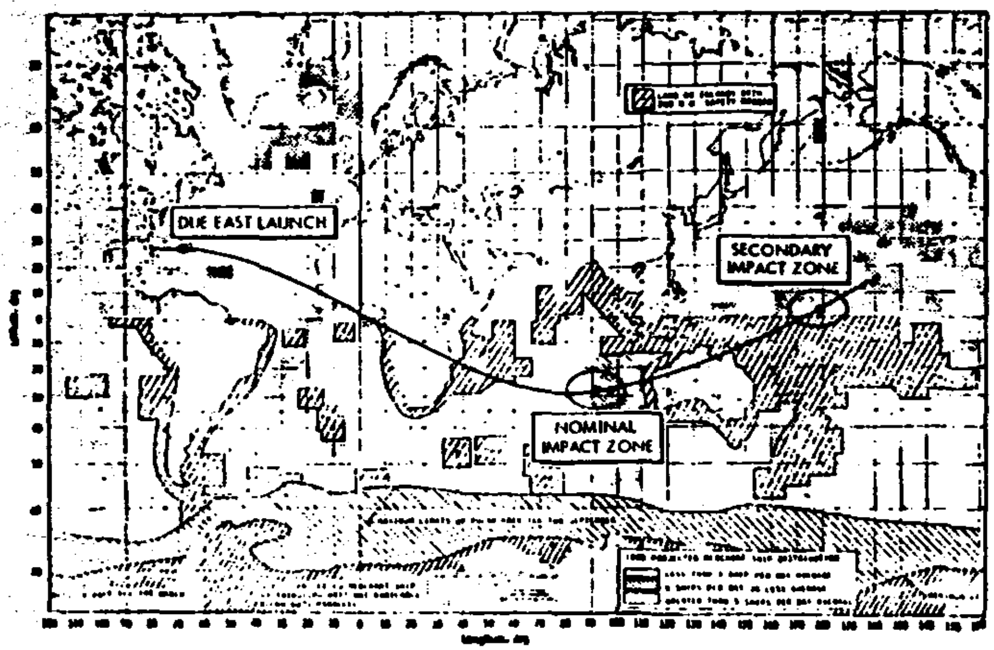

FIGURE 3.4 ET IMPACT CONSTRAINTS

Table 3-2 summarizes the selected RCS thrust options and the resulting payload implications. The net payload effect shown is referenced to the nominal 65 Klb cargo capability for the Basic Reference Mission (BRM) and, as such, takes credit for the predicted 1604 lb of loaded RCS propellant left over after ascent/descent and mission operations. It is seen that ET propellant recovery times up to 21 minutes are possible for either impact zone, with a relatively small payload penalty.

Figure 3.5 summarizes the combinations of RCS thrust option, burn time and Δ MECO velocity which result in an ET disposal in either Zone 1 or Zone 2.

3.1.2 ET Fluid Dynamics and RCS Operation

During conventional normal post MECO flight operations, there is an 18 second mated coast period prior to ET separation during which aerodynamic drag, sloshing disturbances and surface tension forces allow the residual propellants in the ET to creep forward or be thrown into contact with the upper walls of the ET tank.

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TABLE 3.2 PAYLOAD IMPACTS

OPTION	ET IMPACT ZONE	NO. OF RCS THRUSTERS	THRUST (LB)	ULLAGE TIME (MINUTES)	ΔV MECO (FPS)	ΔV P/L (1) PER ΔMECO (LB)	ΔOMS PROPELLANT (LB)	RCS PROPELLANT FOR ULLAGE THRUST (LB)		ΔP/L NET (LB)
								TOTAL	CROSSFEED	
1	I	2	1740	5	-50	+1284	+474	2070	466	+ 344
2	I	1	870	5	-25	+ 642	+ 469	1035	- 569 (2)	+742
3	I	0	50+DRAG	20	-5	+128	+ 260	224	- 1380 (2)	+1248
4	II	1	870	20.3	0	0	- 2597	4306	2702	- 105
5	II	2	1740	11	0	0	-2564	4554	2950	- 386
6	II	2	1740	8	+30	-771	-2589	3312	1708	+110

(1) AN EARLY MECO CUTOFF PROVIDES AN INCREASE IN PAYLOAD AT THE RATE OF 25.7 LB PER FPS

(2) NEGATIVE NUMBER INDICATES LESS THAN FULL RCS PROPELLANT IS REQUIRED AND OFFLOADED PROPELLANT COULD BE CREDITED TO ADDITIONAL PAYLOAD.

NEGLIGIBLE PAYLOAD IMPACT

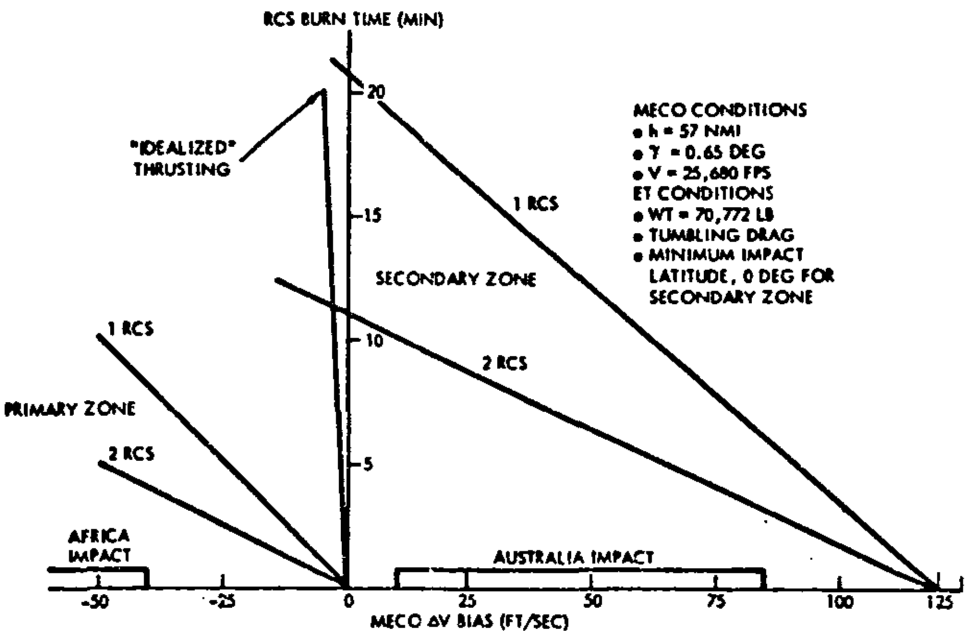

FIGURE 3.5 DELTA MECO FOR ET IMPACT CONTROL

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In order to transfer residual propellants from the ET, it is necessary to extend the mated coast period and provide a minimum positive acceleration of 10^{-4}g to keep the propellants settled against the aft bulkheads. This avoids vaporization of liquid on the tank forward structure and permits efficient draining from the tank outlet ports. For all ullage thrust options, Figure 3.3, it is anticipated that at least two primary thrusters would be used for approximately 60 seconds after MECO to limit sloshing excursions until they can be dissipated by natural damping forces.

Figure 3.6 depicts the possible problem of ET aft bulkhead rebound or "twang" resulting from a sudden decrease of MPS thrust at MECO. This could possibly propel the residual propellants forward against the warm tank structure. As shown, the bulkhead structural response is sufficiently rapid (~26 HZ) and the MPS thrust tailoff sufficiently slow, that no appreciable forward velocity of the bulkhead can occur.

Figure 3.7 and 3.8 show that the RCS X thrust vector (10° pitch) is nearly aligned with the ET LOX and LH_2 tank outlet centerlines (8° pitch). Also the outlet bell or sump flares can accommodate RCS thrust vectors over a range from -1° to +17° pitch without geometry trapping of propellants. This range includes any RCS vectors resulting from combined operation of X and Z thrusters during steering.

Inertial trapping is not a concern in the LOX tank because, after ullage vapor breaks through the sump screen, liquid remaining in the tank can still

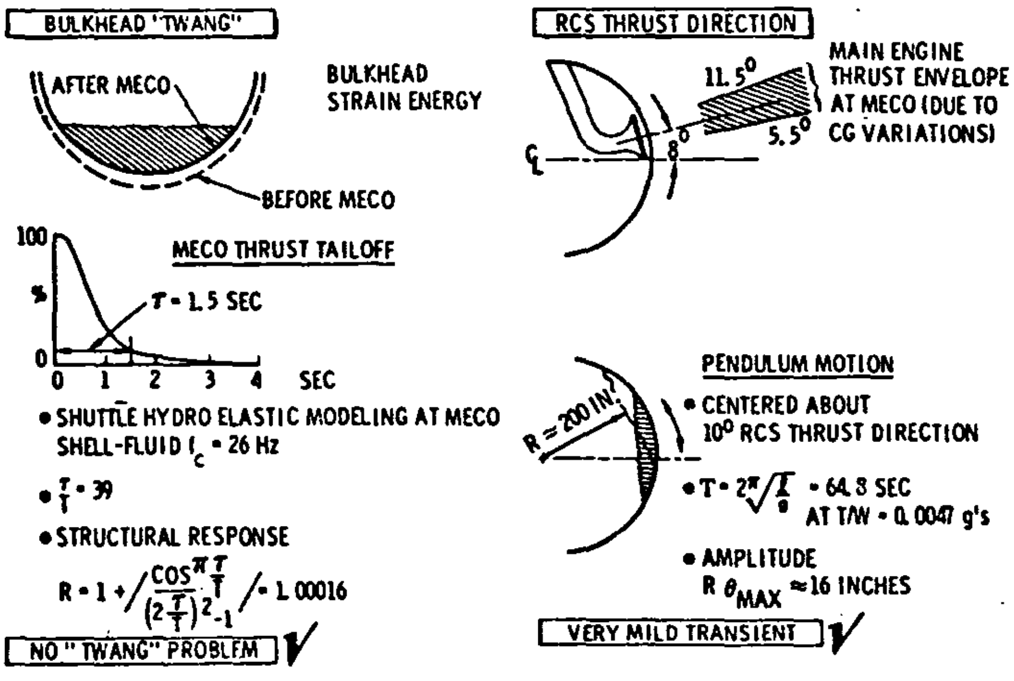

FIGURE 3.6 MECO THRUST TRANSIENT EFFECTS

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drain over the lip of the sump and catch up with the liquid surface in the drain line below. The only significant liquid trapping in the LOX tank is by surface tension, which can be as low as 300 lb at 10^{-3}g.

During mated coast, sloshing or lateral motion of propellant along the ET aft bulkhead can result from several factors. Figure 3.6 shows that the MPS thrust vector just prior to MECO can vary as much as 4.5° from the 10° RCS thrust vector applied shortly thereafter. This would induce a pendulum type oscillation of the propellant mass about the RCS thrust vector, with a maximum amplitude along the bulkhead of 16 inches.

A second source of slosh disturbance can arise from MPS thrust structure rebound during main engine shutdown which induces a vehicle pitch rate of approximately 0.3 deg/sec. Also, tailoff mismatch between the three main engines can induce slosh disturbances.

Another source of slosh disturbance is the pre-MECO sloshing velocity due to normal hunting in the Orbiter flight control system, caused mostly by stiction in the SSME engine hydraulic actuators.

The conclusion is that normal sloshing disturbances will not interfere with ET tank draining or otherwise be a problem for propellant transfer. An engine-out condition, however, during the last 20 seconds of ascent could interfere with complete scavenging since there would not be time for the resulting large slosh transients to decay prior to MECO. But the chance of an

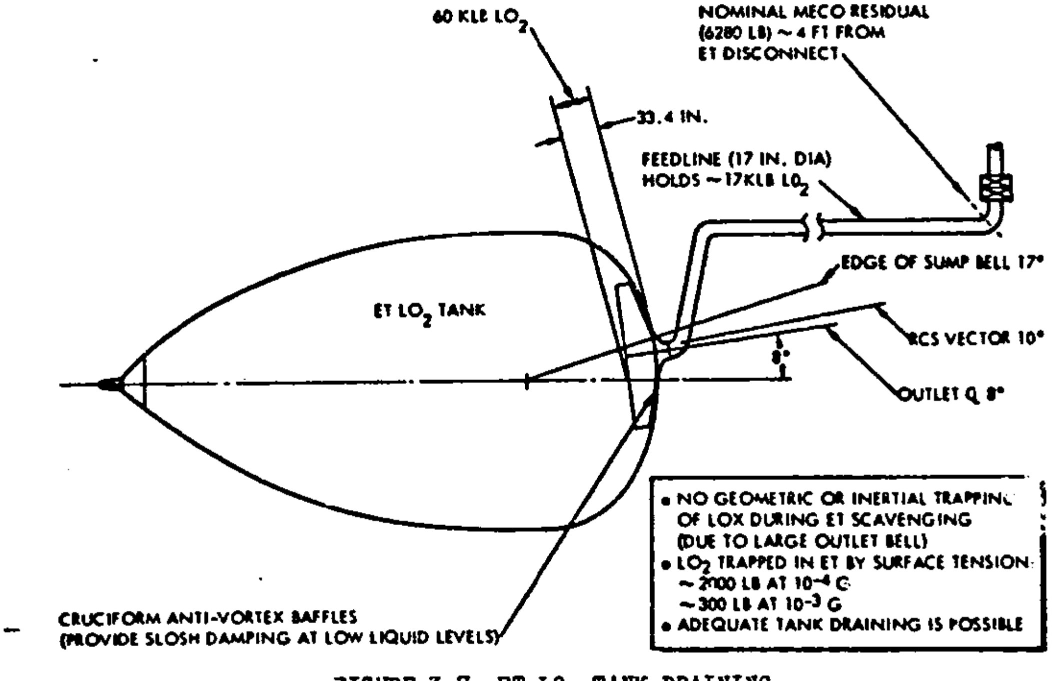

FIGURE 3.7 ET LO_2 TANK DRAINING

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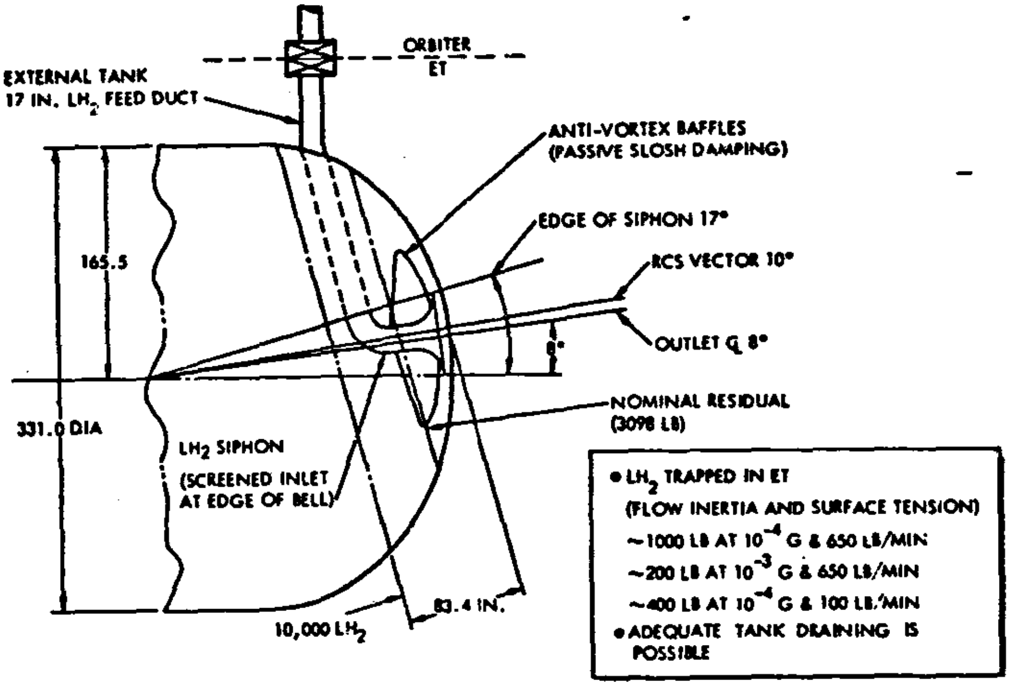

FIGURE 3.8 LH_2 TANK DRAINING

engine-out during the last 20 seconds of boost is very remote (less than 1 per 1000 flights) and would not materially affect the logistic advantages of propellant scavenging.

3.1.3 Available Propellant Residuals

The Shuttle mission assumed for this study was a BRM (Baseline Reference Mission) with a due east launch from ETR and a full 65 Klb payload (Orbiter (103 configuration). The current values of residual mass at MECO (main engine cutoff) are shown graphically in Figure 3.9. "Trapped residuals" are defined as those existing above the main engine valves at low-level cutoff, which is the lowest point to which propellant can be drained and still insure adequate NPSH (net positive suction head) at the SSME engine pump inlets. On the LOX side, that level exists between the engine main LOX valve and the pre-valve in the MPS (main propulsion system) plumbing of the Orbiter. On the LH_2 side, the low-level cutoff level is in the ET at the point where drawdown of the liquid surface permits first entry of ullage gas into the LH_2 outlet or siphon bell. Of the 800 lbs of LH_2 trapped in the ET, 160 lbs is in the siphon and 640 lbs is inertially trapped in the tank bottom.

The fuel bias of 1100 lbs is an extra amount of LH_2 loaded in the ET to cause most of the low-level cutoff cases to be LOX depletion. Therefore, most of the useable residual cases at low-level cutoff are LH_2 which is consumed at 1/6th the mass flowrate of LOX and therefore tends to minimize the average weight of residuals experienced over a number of flights.

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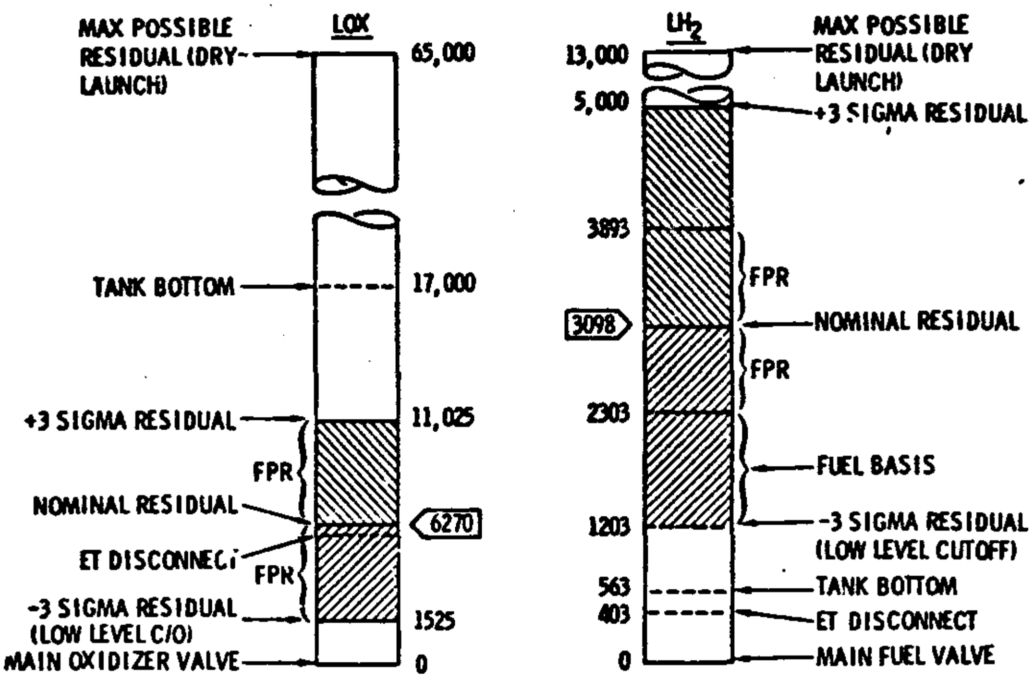

FIGURE 3.9 PROPELLANT RESIDUALS AT MECO (+5 SECONDS)

The FPR (flight performance reserve) of 5550 lbs (at 6:1 mixture ratio) is provided to help cover random variations in vehicle performance factors such as I_{sp}, thrust, loaded propellant mass, atmospheric drag, etc. In combination with the fuel bias of 1100 lbs, it provides a one-sided 3-sigma probability (0.9987) that sufficient vehicle performance will be available to reach desired MECO velocity and altitude (barring engine or vehicle failure).

Figure 3.10 shows the nominal residual mass available, as a function of unused cargo capacity, including advanced Shuttle versions using performance enhancement methods such as increased SSME thrust and strap-on booster engines.

3.1.4 Optimum Receiver Tank Size

For a given Shuttle/SOC traffic model and payload manifesting schedule, there is an optimum family of propellant scavenging and topping tank sizes which minimizes program costs, taking into account factors such as manifesting sequence, total number of Shuttle launches, tank dry weight and cost, tank changeout operations, SOC mixture ratio requirements, and ground turnaround times. Such an optimization depends strongly on the range of payload characteristics (size, density, etc.) and the traffic models assumed.

A nearly optimum tank set could consist of as few as 2 or 3 tanks. Assuming that the LOX/LH_2 mixture ratio desired for SOC is roughly 6:1, the following set of 3 tanks (2 sizes) might be a strong candidate.

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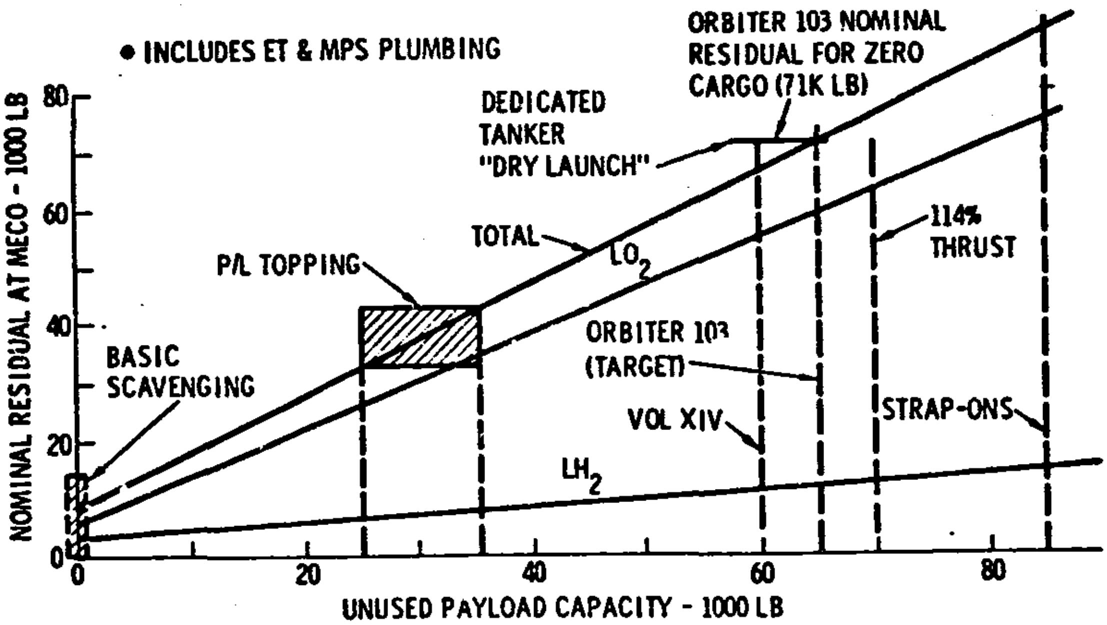

FIGURE 3.10 NOMINAL PPOPELLANT RESIDUALS AT MECO

- 2 each - 30 Klb capacity toroidal tanks, 9 ft long, OMS kit length, per Figure 3.11

- 1 each - 50 Klb capacity tandem tanks, LH_2 cylinder and LOX spheroid, ∿ 18 ft length, using shallow bulkheads, Figure 3.12.

For a dedicated SOC orbiter, one 30 Klb tank might be installed semi-permanently for basic scavenging on all flights.

If a 50 Klb capacity tandem tank is installed in addition to the single 30 Klb basic scavenging tank (total length 27 ft) all MECO residuals at nominal mixture ratios between 5:1 and 10:1 can be accommodated (at 2 sigma probability) for cargo loads down to zero, corresponding to a nominal MECO residual of 71 Klb.

A general strategy for minimizing ground turnaround time would be to have the basic 30 Klb scavenging tank installed against the aft bulkhead of the cargo bay to leave the most unobstructed cargo bay length for payloads. This tank would be installed semi-permanently because of difficulty of making structural and plumbing connections in the cramped quarters there.

Assuming that both LOX and LH_2 receiver tanks would be landed dry (whether or not they are launched dry), examination of the orbiter C.G. envelope (Figure 3.13) verifies that the basic 9 ft, scavenging tank (30 Klb capacity) should be located in most cases at the aft end of the cargo bay, but that any additional receiver tank(s) should generally be mounted at the

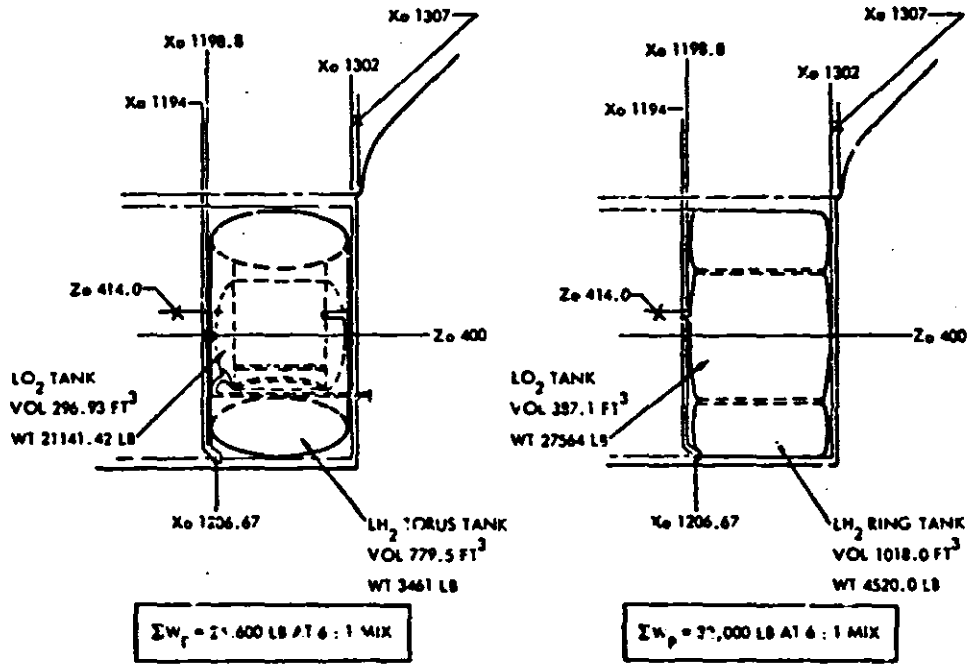

FIGURE 3.11 TORUS & RING TANK CONCEPTS

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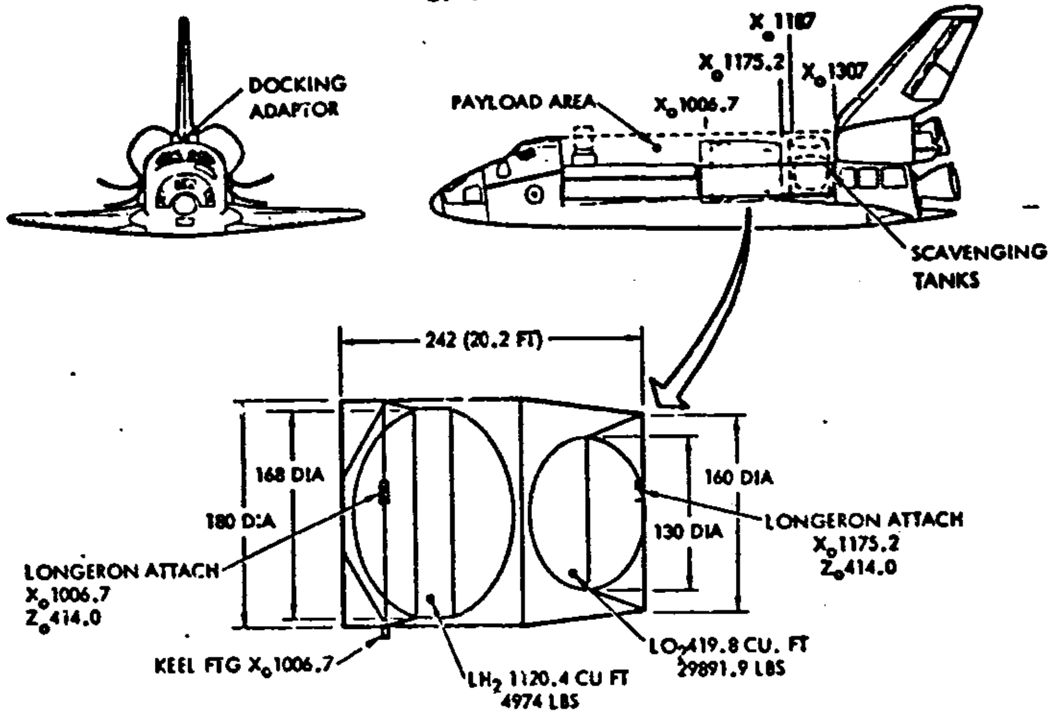

FIGURE 3.12 PAYLOAD TOPPING TANKER CONFIGURATION

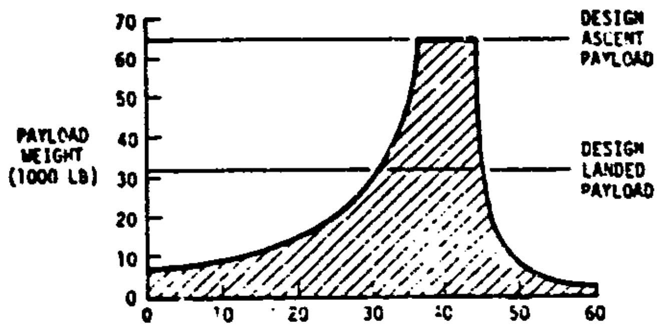

FIGURE 3.13 ORBITER PAYLOAD C.G. REQUIREMENT

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forward end. This still gives an uninterrupted length in the remaining cargo bay and also allows the greatest opportunity for locating the other various payloads inside the C.G. envelope. In general, only for light payloads or very dense payloads would it be feasible to locate a second tank at the aft end, adjoining the basic scavenging tank.

3.1.5 ET Propellant Transfer

A ready made energy source for transferring propellant residuals to the Orbiter is provided by the ullage pressure remaining in the ET after MECO. During ascent boost, ullage gas is supplied to the ET by vaporized propellant tapped off of the main engines. A pressure of approximately 20 psia in the LOX tank and 32 psia in the LH_2 tank is provided to avoid cavitation of the main engine turbopumps during boost.

LOX Transfer Process

Figure 3.14 depicts the basic phenomena involved in the pressurized transfer of LOX from the ET and MPS plumbing into an Orbiter mounted receiver tank after MECO.

Prior to launch, the Orbiter receiver tank is pressurized with ambient temperature GN_2 or helium to approximately 17 psia, and allowed to vent during ascent (maintaining a positive pressure relative to ambient) so that at MECO the tank pressure is less than 1 psia. Childown of the receiver tank and Orbiter-mounted transfer line is initiated after MECO by admitting a low

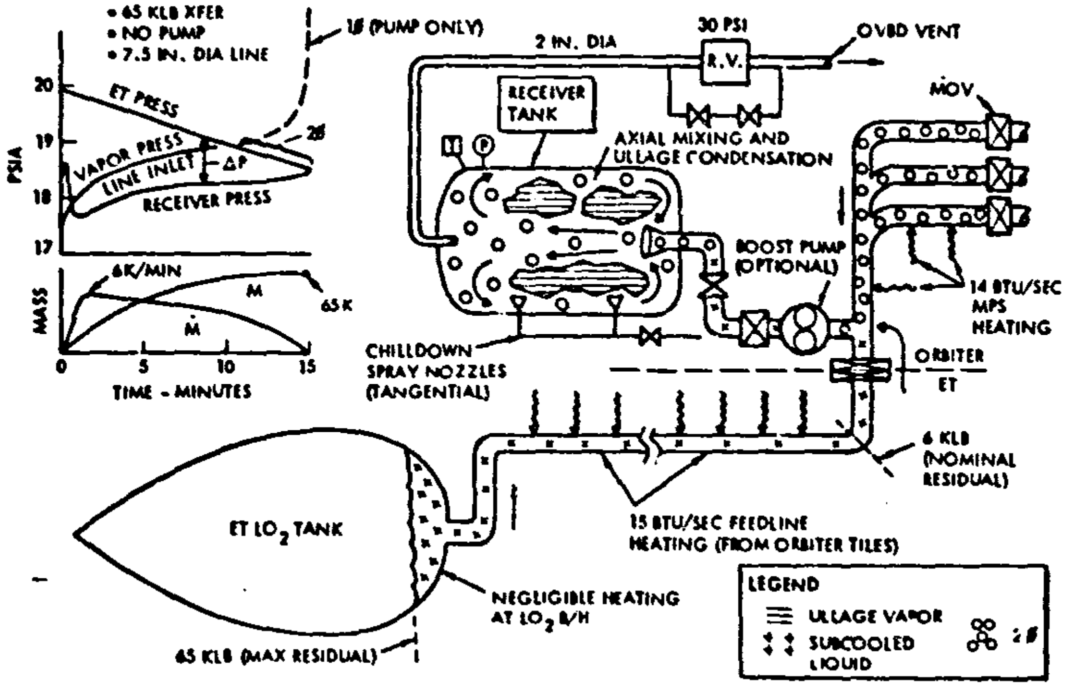

FIGURE 3.14 ET LO_2 TRANSFER PHENOMENA

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flowrate of liquid through the tangential spray nozzles in the receiver tank, which establishes a swirl pattern of 2-phase fluid with the liquid drops driven repeatedly against the warm wall until vaporized. When the transfer line and tank wall are cooled to liquid temperature, main transfer flow of liquid at a high rate is initiated through the main (axial) fill nozzle which sets up a co-axial mixing and recirculation pattern in the tank and allows the relatively cold entering liquid to condense the ullage vapor as the tank fills. Because of the high volumetric heat capacity of LOX, it is not necessary to vent the tank to limit its pressure during chilldown, unless it was initially pressurized with a non-condensible gas such as helium. In that case, venting during the first part of chilldown could be used to purge any remaining non-condensibles (GN_2 condenses in LOX and does not require purging). Figure 3.14 shows the transient pressure spike expected in the receiver tank toward the end of chilldown.

A zero -g gaging system for the receiver tank is desirable but not mandatory, since transfer can be continued until either the ET and MPS plumbing is drained (as indicated by a bubble detector or phase detector in the transfer line) or until the fill limit pressure of 28 psa is reached, which indicates that the filling should be stopped whether transfer is complete or not.

A 98% residual recovery efficiency was assumed for pressurized transfer to allow for early cutoff of flow as the available Δp asymptotically approaches zero. With pump-assisted transfer, the total trapped residual can be as low as 300 lb out of 65 K lb, which is equivalent to a recovery efficiency of 99.5%. Figure 3.15 shows the limiting conditions for 98%

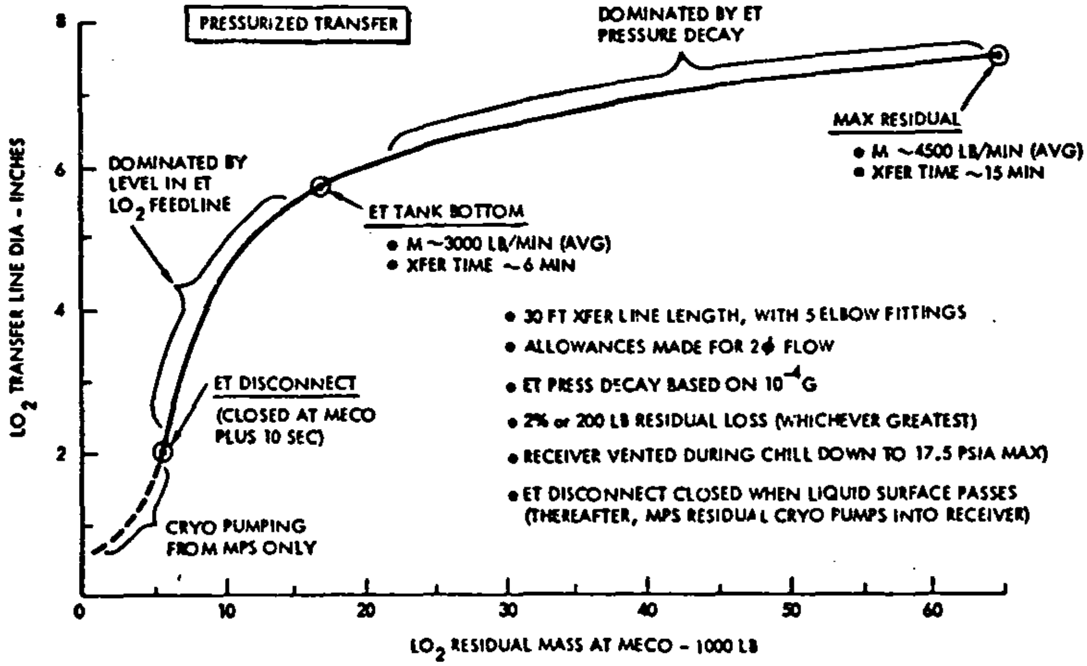

FIGURE 3.15 LO2 TRANSFER LINE SIZE

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efficient pressurized transfer at various LOX MECO residual weights. Based on a 30 ft transfer line length with 5 elbow fitting, the minimum required transfer line size increases rapidly from a 2 inch dia (for only cryopumping from the the MPS plumbing) to 5.5 inch dia as the initial level in the ET feedline (at MECO) increases and the LOX heating also increases.

A study of space constraints and plumbing routing in the MPS engine compartment and at the Orbiter cargo bay aft bulkhead (X = 1307), showed that the line size limit for easy installation was approximately a 4 inch dia. This size line would not permit pressurized transfer of the 3-sigma LOX residuals (~11,000 lbs) expected for basic scavenging with a full 65 K lb Orbiter cargo. It is physically possible but very difficult to install the 7.5 inch dia transfer line required for the worse-case (65 K lb) MECO LOX residual expected with zero cargo. If vernier RCS engines are not added to allow a low (10^{-4} g) settling thrust, ET ullage decay would be substantially increased and require an even larger transfer line size. For this reason, a study was made of boost pumps as a means of reducing line size requirements.

Figure 3.16 shows two families of line sizes (for 7 minute and 20 minute transfer times) superimposed on the pressurized transfer boundary of Figure 3-15. If a standard (10 KW, 3750 RPM) Centaur LOX boost pump is used, it would permit 65 K lb transfer in 20 minutes with only a 2.5 inch dia line. This pump is capable of handling the 2-phase flow expected at its inlet during transfer. For a 7 minute transfer of 65 K lb, the line size requirement is still a reasonable 5 inch dia, but the Centaur pump must be operated at a higher speed (6000 RPM) and some changes may be required in impeller design. The electric power available for scavenging is estimated to be at least 15 KW for mature Orbiter configurations.

LH_2 Transfer Process

As shown in Figure 3.17, the basic fluid transfer phenomena involved in scavenging the ET LH_2 tank is similar to that described for the LOX tank.

The operations for LH_2 transfer are similar to those described for LOX except that prechilling of the LH_2 receiver tank on the ground is recommended. The chief reason is that the lower volumetric heat capacity of LH_2 would require venting of 2 or 3 tank volumes of boil off vapor to achieve chilldown with a tank limit pressure of 30 psia. To vent this much vapor after MECO in a short period of time (2-3 minutes) would require vent line (and vent valve) sizes on the order of 6 inches (dia.), which would impose a considerable weight penalty and be difficult to install.

As shown in Figure 3.17 much more ullage pressure is available in the LH tank for scavenging propellant than in the LOX tanks (32 psia vs 20 psia), and the decay rate after MECO is slower. The maximum expected LH_2 residual of 13 K lb (at zero cargo) can be transferred in 20 minutes without pump assist through a transfer line approximately 4 inches in dia, which is considered a reasonable size for installation.

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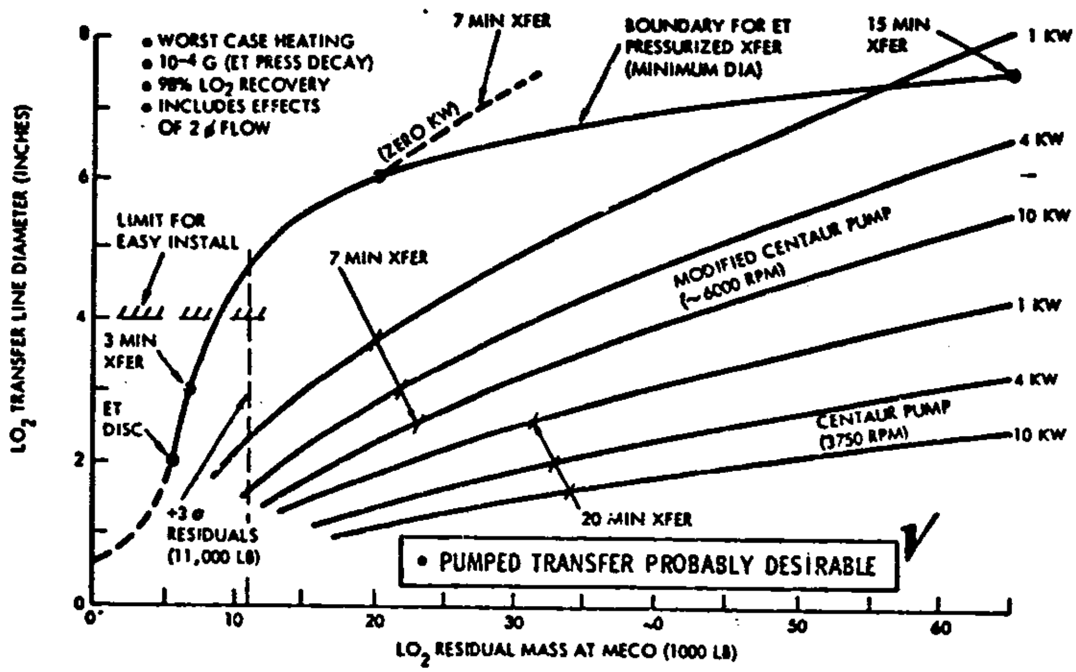

FIGURE 3.16 LO_2 TRANSFER BOOST PUMP TRADE

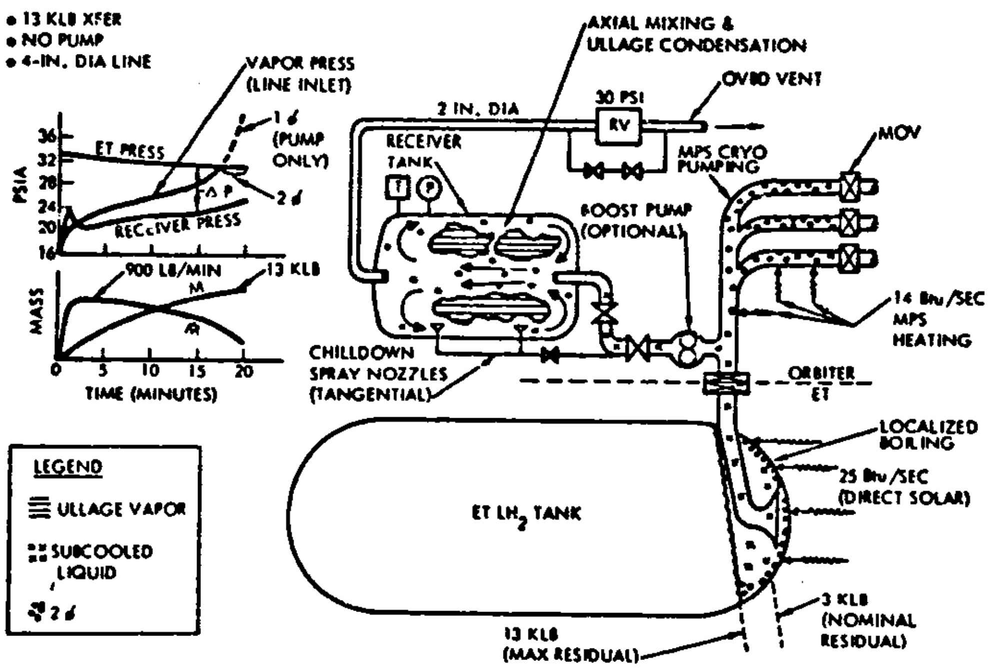

FIGURE 3.17 ET LH_2 TRANSFER PHENOMENA

Figure 3.18 shows the effect of pump assist on required LH_2 transfer line dia. Two families of pump curves are shown, one for 7 minute transfer and one for 20 minute transfer. At the higher flowrates associated with short transfer time and large residual mass, the benefit of pump assist in reducing line size, (even at 10 KW), is very minor. This is because of the high volumetric flowrates and the resulting low pump Δp's, and because of the substantial driving pressure already provided by the ET ullage.

3.1.6 Transfer System Configuration and Installation

The scavenging process and system trades that were performed concluded that pump-assisted transfer is the optimum method of ET LOX transfer, and unassisted pressurised transfer is recommended for LH_2 transfer.

The scavenging system configuration then is basically as shown schematically in Figures 3.14 and 3.17, with redundant valving and instrumentation added where appropriate. Figure 3.19 presents LOX scavenging system weight as a function of transfer flowrate.

Integration of the scavenging system into the overall MPS system is shown schematically in Figure 3.20. The preferred points for tapping off propellants (through the transfer line) to the receiver tanks is the forward side of the 17-inch dia. LOX and LH_2 manifolds, just downstream of the ET disconnects. This provides the coldest propellants early in the transfer and the best efficiency of cryopumping from the MPS plumbing. Figure 3.21 shows a perspective view of the proposed transfer line installation.

3.1.7 Receiver Tank Design

The objective of this task was to identify a representative family of orbiter-mounted receiver tank designs and plumbing concepts for the propellant scavenging and tanker scenarios of Figure 3.2. A secondary objective was to assess the impact of such hardware and plumbing changes on the existing Orbiter propulsion system. This conceptual design effort was done within the guidelines of using basic tank configurations, providing LOX and LH_2 propellant capacities at a ratio of 6:1, and minimizing redesign of the Orbiter MPS plumbing. The receiver tank concepts investigated are illustrated on Fig. 3.22

A conventional tank concept, shows a two tank configuration within its own support cradle, which can be placed into the orbiter bay and attached to both longeron and keel fittings. This tank combination utilizes standard cylindrical tanks sized for LOX and LH_2 at a 6:1 ratio. Connecting supply lines, vent lines and service connections all pass through existing panels in the aft cargo bay bulkhead (Figure 3.21). Tank dimensions, volumes, fuel capacity, wet and dry tank weight plus structural support weights are summarized in Table 3-4 for the scavenging tank configuration considered in this study.

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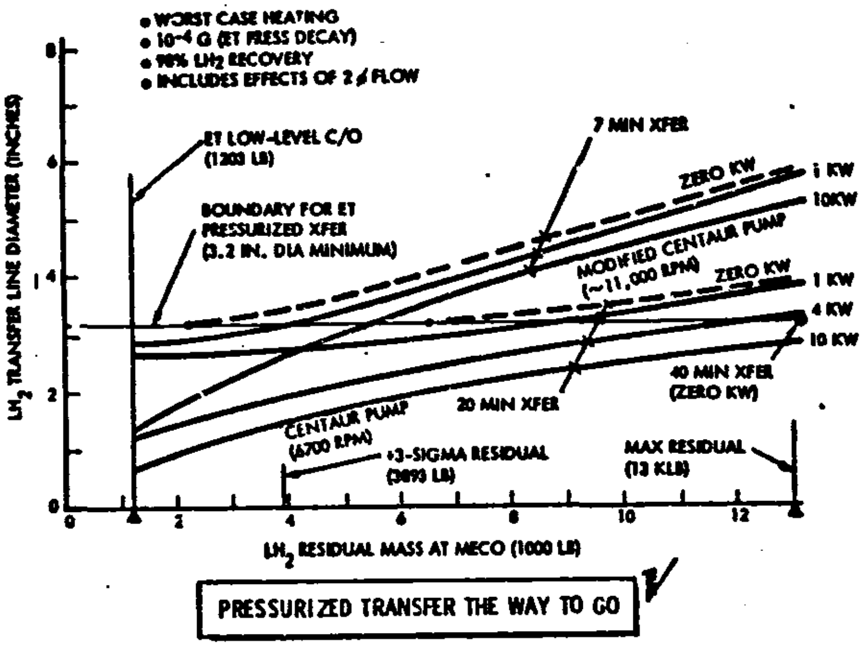

FIGURE 3.18 LH_2 TRANSFER BOOST PUMP TRADE

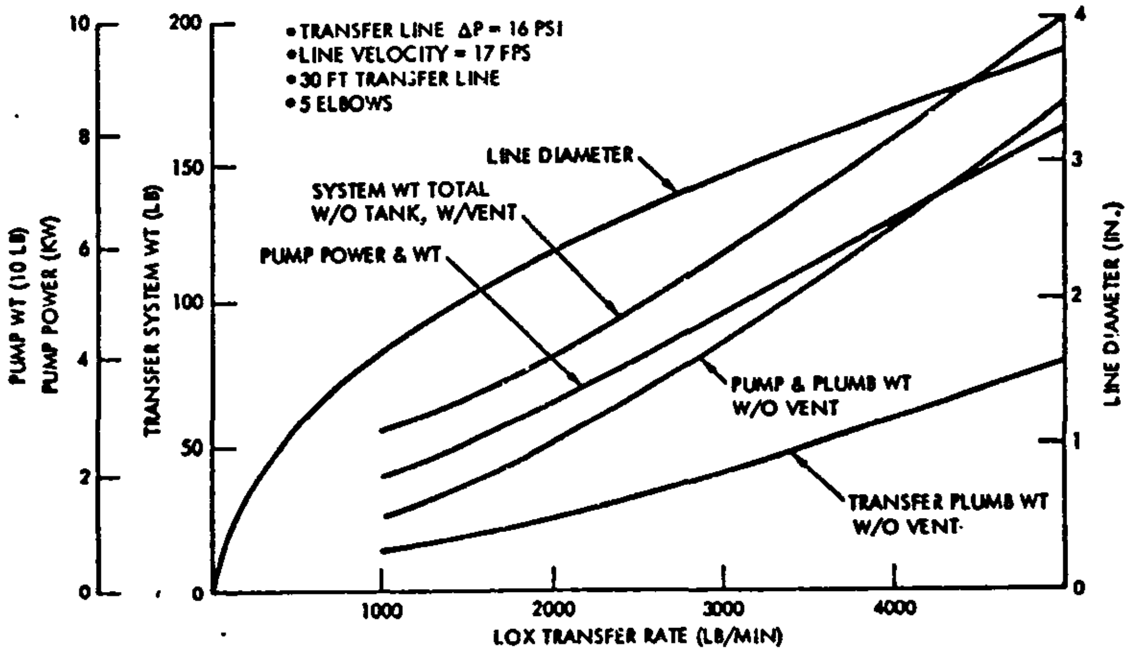

FIGURE 3.19 LOX TRANSFER SYSTEM WEIGHT AND POWER

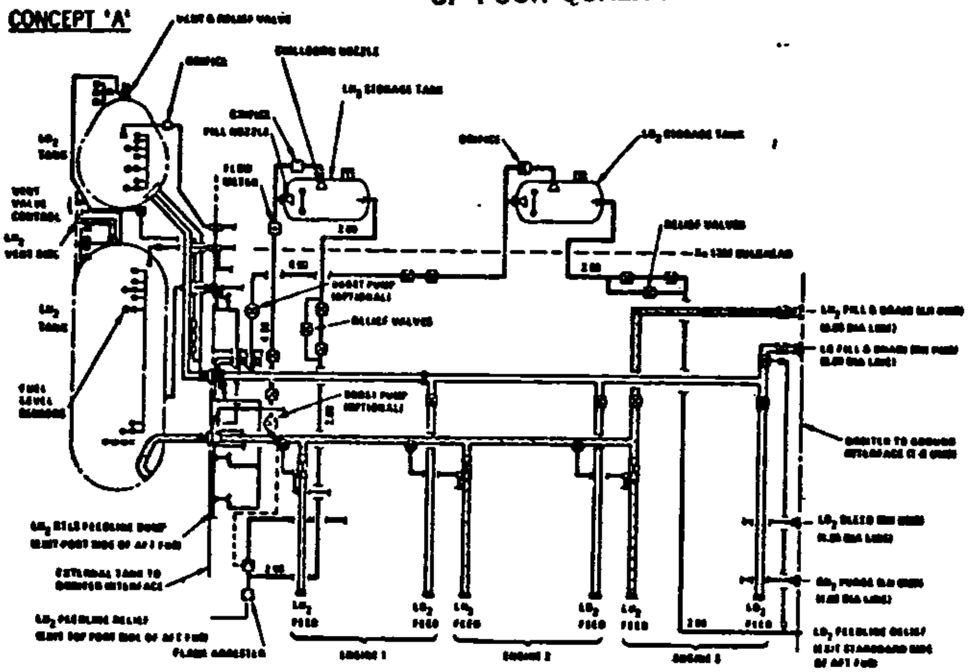

FIGURE 3.20 PROPULSION/SCAVENGING SYSTEM SCHEMATIC

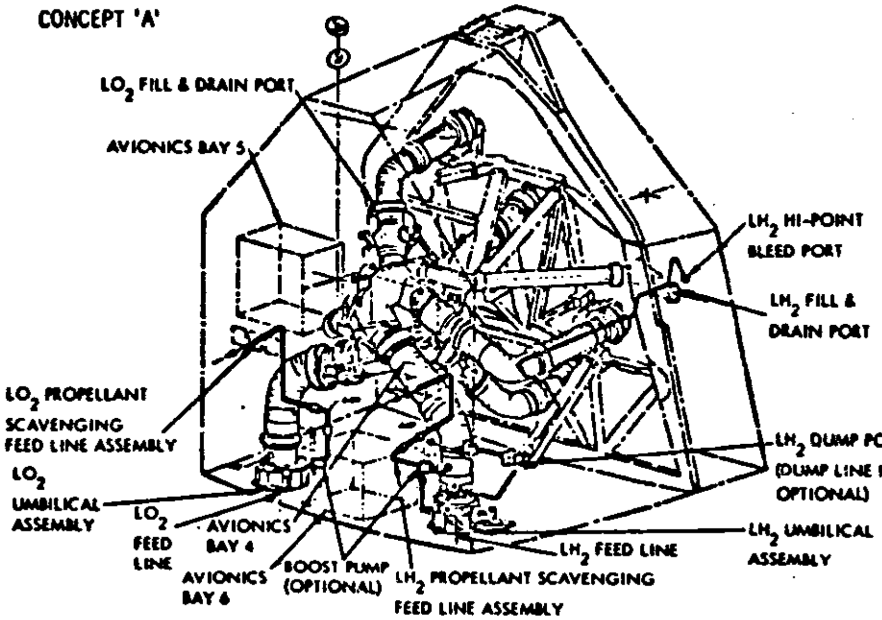

FIGURE 3.21 ORBITER - MAIN PROPULSION SYSTEM

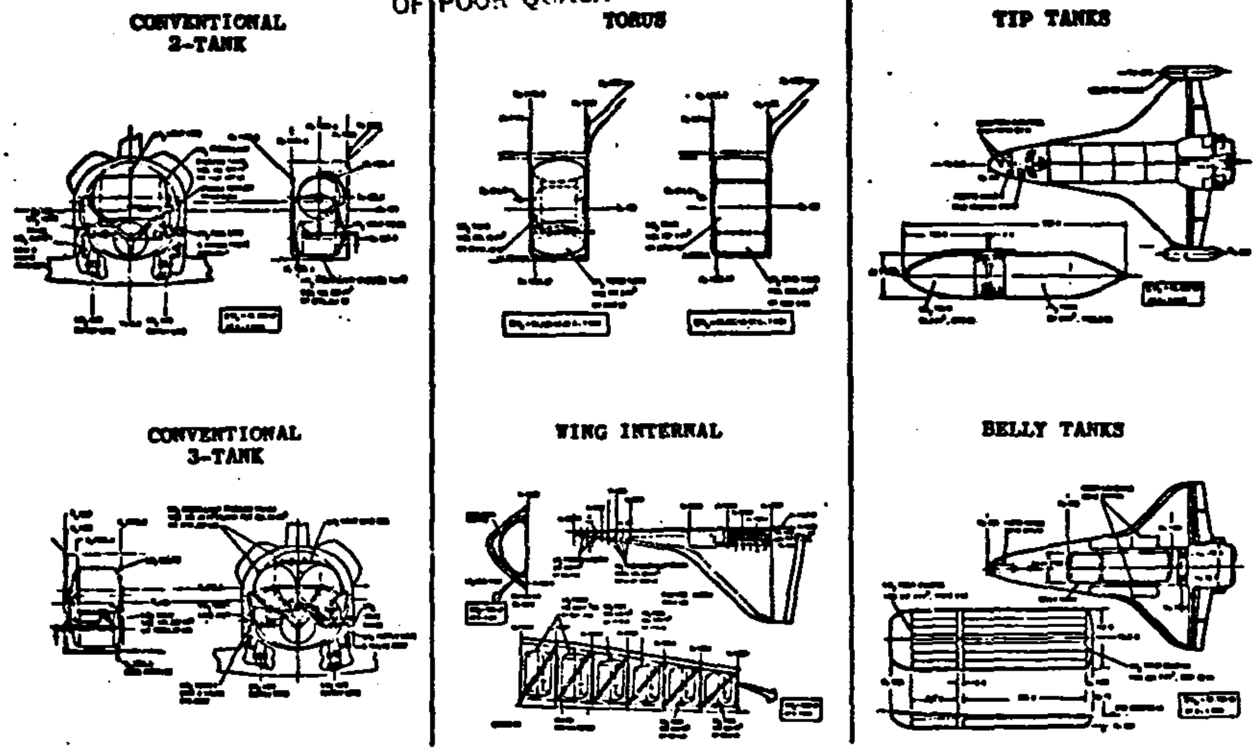

FIGURE 3.22

The three-tank propellant scavenging configuration is similar to the two-tank concept except that the LH_2 is received in two identical tanks, with the remaining tank being used for LOX. This configuration has more fuel storage capacity but also more scar weight from increased structure, lines, valves and associated connections. Propellant transfer from the ET to the receiver tanks on the orbiter would be similar for either the two or three-tank concepts. An OMS payload bay tank kit as presently configured was considered as a possible candidate. This arrangement would have six tanks allocated for LH_2 and three for LOX. Total volume capacity is very low for this concept and was therefore discarded.

The torus and ring tank concepts represent the most promising candidates for providing a high tank volume within a short length of the Orbiter payload bay. The torus tank configuration is a 170-inch O.D. torus with an elliptical cross-section. The inner cylindrical tank located within the torus was sized to store the LOX propellant at a 6:1 mass ratio. THe LH_2 capacity for this configuration is approximately 3461 lbs, and the LOX capacity 21141 lbs. The ring tank configuration is similar to the torus concept except that both the LOX and LH_2 tanks were configured with relatively flat bulkheads for maximum utilization of cargo bay space. Since each tank would be used as a pressure vessel, ring stiffeners would be added at the cylindrical ends to eliminate tank deformation when loaded. Total propellant capacity for this arrangement would be approximately 32000 lbs at a 6:1 mass ratio. The plumbing connections would be nearly identical to those mentioned before except that all supply and vent lines would be routed around the tanks below the cargo bay liner. All tank configurations mentioned above would be insulated with 1 to 3 inches of foam and/or ML1 blankets to minimize boiloff prior to transfer of its contents to SOC.

Tip tanks attached to the Orbiter wings were considered as possible containers for the LH_2 and LOX propellant scavenged from the ET. The tip tanks have a combined volumetric capacity of 524 ft^3 (2325 lbs) for LH_2 and 186.4 cubic ft (13980 lbs) for LOX. Overall tip tank dimensions are 320.0 in. long and 60.5 in. diameter. Supply lines would be routed through the wing structure to disconnect valves located at the wing/tank interface, with tank vent lines located near the trailing tip of each wing tank pod. This configuration has the option of being retained or jettisoned during re-entry. Tank pod insulation for this concept would be determined by dynamic and thermal requirements during launch and return flight.

A belly tank concept was configured with an overall length of 585.0 inches, a width of 168 inches and a depth of 24 inches. LH_2 capacity for this tank cluster is 659.7 ft^3 (2929.3 lbs) and LO_2 capacity is 247.4 ft^3 (17615.5 lbs). All supply lines would be routed below the cargo bay to appropriate connections at the orbiter/tank pod interface. Because of insulation problems that would exist during boost and re-entry, this concept does not appear to be a viable option.

Propellant cells supported within the structure of the Orbiter wing panels and small tanks in the forward section of the wing glove were considered as receiver tanks. The structure of the wing as designed does not permit cells of large volume either in the wing area chosen, or in the glove section. Since the tank and plumbing weights are very high for the propellant capacity afforded, this configuration was not investigated further. Redesign of the orbiter wing as a wet configuration may be an option worth evaluating in further studies.

Figure 3.23 shows an Orbiter equipped with both a scavenging tank and an intermediate size payload-topping tank. The latter consists of conventional LOX and LH_2 tanks suspended within a shell structure, as commonly used for OTV designs. Maximum capacity for this configuration, excluding the scavenging tanks shown in the aft end of the cargo bay, is 34,866 pounds at a 6:1 mass ratio.

Figure 3.24 shows an Orbiter equipped as a dedicated refueling tanker, using the same arrangement as in Figure 3.23, but with a larger (48,338 lb capacity) resupply or payload tank of conventional OTV design. Along with the scavenging tank, this configuration occupies 39 ft of cargo bay and can provide a total capacity of approximately 80,000 lb.

TABLE 3.4 WEIGHT STATEMENT-RECOVERY TANK CONCEPTS

CONFIG	FUEL	NO. TANKS	TANKS–DRY	STRUCT/ FITTINGS	VOL FT^3	FUEL–LBS
2-TANK	LO^2 LH^2	1 1	211 * 432	1906	123.28 326.06	8776.34 1447.6
3-TANK	LO^2 LH^2	1 2	216.5 * 427.3	2148	145.2 386.84	10,338.8 1717.6
OMS KIT	LO^2 LH^2	3 6	172.8 * 670.8	1936	58.2 527.7	4143.8 2342.9
TORUS TANK	LO^2 LH^2	1 1	321.6 * 965.0	1875	296.93 779.5	21,141.4 3461.0
RING TANK	LO^2 LH^2	1 1	343.8 * 1135	1837	387.1 1013.0	27,564.0 4520.0
TIP TANKS	LO^2 LH^2	2 2	662.8 * 850.2	1156	196.36 523.16	13,980.83 2324.7
BELLY TANK	LO^2 LH^2	7 7	890 * 1124.4	2775	247.41 659.7	17,615.52 2829.3
WING TANKS	LO^2 LH^2	12 24	236.8 * 551.6	1966	41.88 111.12	2981.86 493.4
GLOVE TANKS	LO^2 LH^2	4 8	82.5 * 179.7	1232	22.57 61.59	1607.5 272.5
TOP-OFF TANK	LO^2 LH^2	1 1	208 310	1590	41.98 1120.4	29,891.9 4974
DEDICATED TANKS	LO^2 LH^2	1 1	319 375.8	2385	707 1904	48,338 8056

*VALUES BASED ON TANK WALLS OF .125 THICK AL MAT'L
· VALUES BASED ON TANK WALLS OF .030 THICK AL MAT'L

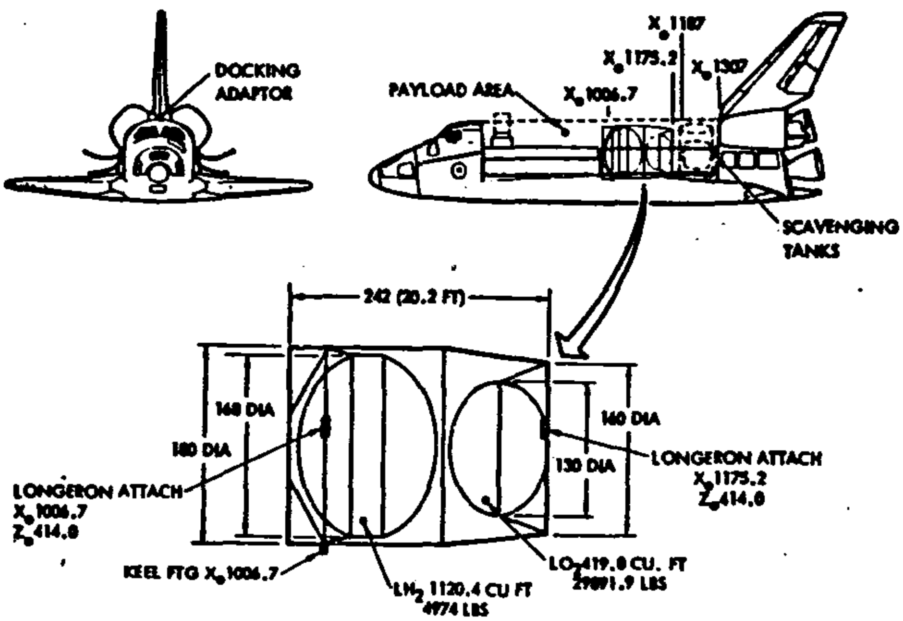

FIGURE 3.23 PAYLOAD TOPPING TANKER CONFIGURATION

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The entire assembly of tank structure, fill and vent lines would all be covered with MLI to minimize heat leaks and boil-off.

The OTV type tanks of Figures 3.23 and 3.24 are a baseline reference design but are not necessarily optimum for Shuttle operations. If nearly flat bulkheads are used, a combination payload topping and scavenging tank of 60,000 lb capacity could be made with a length as short as 20 ft.

3.1.8 Operating Procedures and Crew Considerations

As currently envisioned, most of the monitoring and control functions involved in ET scavenging would be automated by special circuitry, with capability provided for monitoring and override/backup control by at least one crew member. Sequence interlocks and audible/visible redline warnings would be provided for temperature, pressures, flow rates and 2-phase characteristics. Sharing of standard Orbiter computer hardware and CRT displays may be feasible. As shown in Figure 3.25, it has been determined that control panel space is available for monitor and control functions. Further, this area (panel R-11) is within the reach envelope of the mission specialist from his seated position at MECO. Thus, crew participation in supervising the transfer process appears possible. Additional study is required to determine the crew response capabilities from boost environment to zero-g. However, fighter pilots frequently perform in this type of dynamic environment, so active crew participation in the scavenging process appears feasible.

Table 3-5 presents a simplified scavenging sequence for the worst case of transferring maximum residuals in a short (8 minute) coast period. As shown, ET transfer is terminated when excessive bubble content is detected (by optical or capacitance type sensors) in the transfer line.

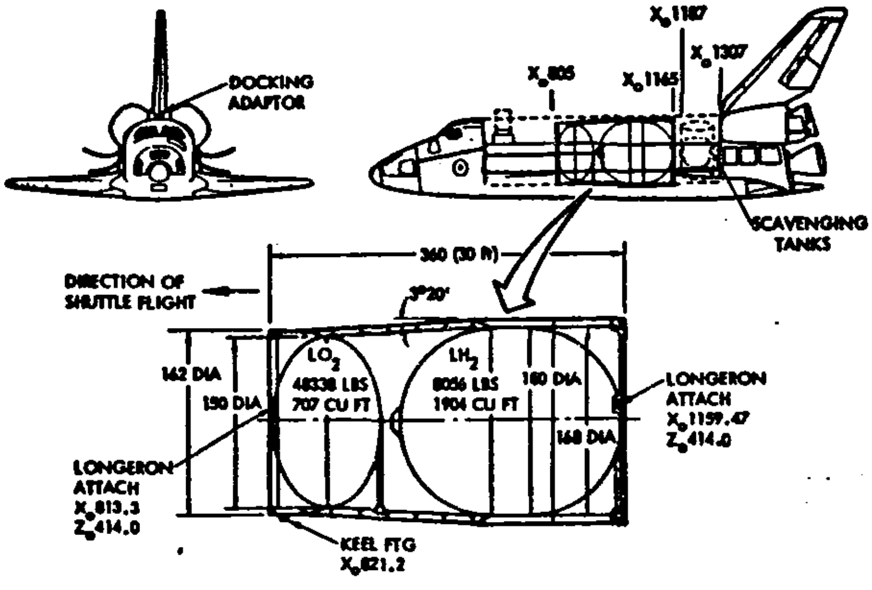

FIGURE 3.24 DEDICATED REFUELING TANKER

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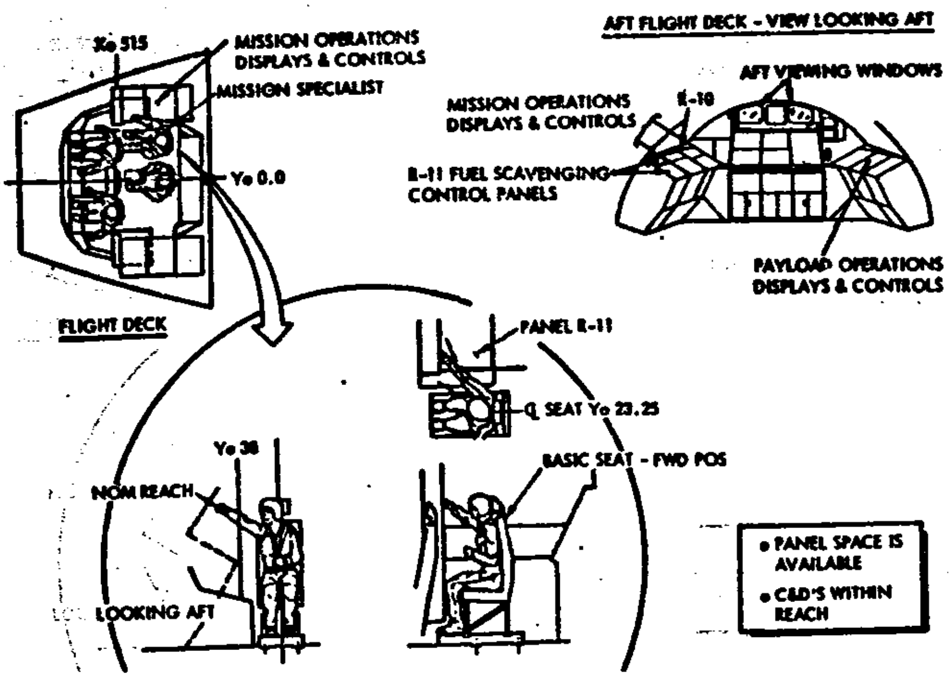

FIGURE 3.25 CREW CONSIDERATIONS

Table 3.5 Representative Scavenging Sequence

ASSUMPTIONS

- MAXIMUM RESIDUALS (66K LOX, 13K LH2)
- 6 MINUTE XFER TIME
- PRESSURIZED LH2 XFER (6 IN. DIA LINE)
- PUMPED LOX XFER (6 KW, 6 IN. DIA LINE)
- SECONDARY ZONE ET IMPACT
- SETTLING THRUST, 5×10^{3} G (2 PRIMARY RCS THRUSTERS)
- LH2 RECEIVER TANK PRECHILLED TO 160°R (LH2)

TIME	EVENT
• L/O + 100 SEC	• START VENTING RECEIVER TANKS
• MECO	• TURN ON RCS SETTLING THRUSTERS
• MECO + 10 SEC	• VERIFY RECEIVER TANKS BELOW ONE PSIA • CLOSE RECEIVER VENT VALVES
• MECO + 15 SEC	• OPEN ISO-VALVES TO START CHILLDOWN OF LOX & LH2 XFER LINES • MONITOR SYSTEM FLOWS/TEMPS/PRESS
• MECO + 60 SEC	• OPEN MAIN FILL VALVES • START LOX PUMP • MONITOR SYSTEM FLOWS/TEMPS/PRESS
• MECO + 400 SEC	• STOP LOX PUMP AND CLOSE ET DISCONNECT WHEN ET LINE DEPLETED (FLOWRATE < 5% AS RECEIVER PRESSURE REACHES 26 PSIA). ALLOW CRYOPUMPING FROM MPS INTO RECEIVER TANK • STOP RCS SETTLING THRUST WHEN LH2 ET DEPLETED (EXCESSIVE BUBBLES IN XFER LINE) AND ALLOW LH2 SIPHON TO DRAIN (AIDED BY AERO-DRAG)
• MECO + 400 SEC	• CLOSE LH_2 ET DISCONNECT WHEN LH_2 SIPHON DEPLETED (FLOWRATE < 5% OR RECEIVER PRESS REACHES 28 PSIA). ALLOW CRYOPUMPING FROM MPS INTO RECEIVER TANK • SEPARATE ET • TERMINATE CRYOPUMPING BY CLOSING XFER LINE ISO-VALVES WHEN RECEIVER TANK PRESSURES REACH 28 PSIA (OR MPS PRESSURES EQUAL RECEIVER PRESSURES.
• MECO + 1200 SEC	• OMS I BURN
• MECO + 1400 SEC	• VENT MPS PLUMBING AND SECURE XFER SYSTEM

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Table 3.6 Safety Considerations

ISSUE	COMMENTS
LINE INTEGRITY	QUALIFY TO MPS PLUMBING REQUIREMENTS
MPS INTEGRITY	MULTIPLE ISOLATION VALVES
VALVE MALFUNCTION	REDUNDANT VALVING
O_2 AND H_2 LEAKAGE	GN_2 PURGE ON THE PAD; MINIMAL HAZARD IN SPACE
SAFEING FOR REENTRY	VENT SYSTEM TO SPACE, PRESSURIZE TO 16 psia WITH INERT GAS
ET IMPACT	ACCEPTABLE IMPACT ZONES ARE ACHIEVABLE
MECO CHANGE	LESS THAN ONE-SECOND CHANGE REQUIRED
RCS MODIFICATIONS	WITHIN THE COMPLEXITY LEVEL OF CURRENT SYSTEM
CREW OPERATIONS	MINIMAL ACTION REQUIRED BEFORE MECO
ORBITER ENGINE OUT	SHUTTLE E/O TOLERANCE INCREASED WITH "DRY LAUNCH" CONCEPT
LO_2 AND LH_2 ABORT DUMPING	NONE REQUIRED WITH "DRY LAUNCH" CONCEPT

3.1.8 Safety Considerations

A study of the safety issues involved in scavenging ET propellants was conducted in cooperation with the Orbiter Safety Group at the Rockwell's Downey facility. The principal safety-related factors are summarized in Table 3.6. In general, no serious safety concerns were identified. The required recovery system hardware is within the complexity levels of current Shuttle hardware and can be designed and qualified to the same standards. ET impacts can be controlled to acceptable impact zones. No safety-related changes are required in the ascent profile (MECO changes are less than one second). The Shuttle engine-out tolerance can even be increased with dry-launch propellant recovery concepts, since keeping all unused propellants in the ET until after MECO makes them available for engine-out situations. If no engine-out occurs, these propellants can then be safely transferred to the receiver tanks in the orbiter. This further eliminates the need for rapid propellant dump capability in the event of an abort during boost, which would otherwise be required for propellants carried in the orbiter bay.

Conceivably, a requirement for early re-entry and dumping of propellants could arise after transfer of propellants to the Orbiter, even though a stable orbit is achieved. In most cases, at least one orbit would be available for dumping through the nominal 2 inch dia-vent lines of the scavenging tanks and/or the fill/drain lines of the MPS. Ignition of oxygen and hydrogen vapors outside the Orbiter could not occur since the low pressure of space would not support combustion. In the event that re-entry is suddenly required due to an emergency such as rapid loss of cabin pressure, rapid dumping of scavenged propellants could be accomplished through the main engines by opening the scavenging transfer line valves, the engine prevalves and engine main valves. Preferably part of the LOX would be dumped first, then all of the LH_2, then the remainder of LOX. This would load the LOX pumps with liquid and help to prevent overspeed when dumping LH_2 through the turbine drives.

Vapor pressure of the scavenged propellants should be adequate for self-pressurized dumping to space; however, enlargement of the MPS helium inerting gas supply may be required to provide additional pressurization and prevent negative tank pressures during re-entry.

4.0 FLIGHT SUPPORT FACILITY

An important element of the Space Operations Center (SOC) is its ability to provide servicing operations in low earth orbit. The servicing operations cover a spectrum of in-space support activities such as refueling, repairing and maintaining free flyers and coorbiting satellites. In addition, the SOC can support major assembly and deployment of large spacecraft with eventual launch to their operational orbits. The cost effectiveness of the SOC-based servicing operations relative to ground and other space-based servicing systems was the principal objective of this task. A comparison of the relative costs of performing flight support services by various methods is presented along with an updated concept of the Flight Support Facility which is an essential provision of the SOC servicing capability.

The objective of this task was to compare the spacecraft servicing operations whether performed from the SOC, or from the orbiter, or on the ground. Three spacecraft representing many of the various anticipated servicing operations were selected. The spacecraft consisted of a space based OTV, a ground based OTV, a large deployable communications satellite, and a space processing facility as shown in Figure 4.1. Each one was analyzed to determine the servicing functions that are to be performed at its particular servicing region, i.e., at the SOC, from the orbiter, or on the ground. This analysis determined the unique equipment required for each servicing operation, the number of man-hours required to perform the servicing, and the number of crew required for each servicing function. Cost estimates of the unique equipment identified for each servicing operation were made. Cost estimates of the man-hours required were also prepared. Figure 4.2 lists these comparison items. The principal evaluator is the cost dollars associated with each operation. Operations at the SOC are considered to be the least costly when considering the expected number of service missions which was based on a medium mission model from 1990 to 2000. The labor and orbiter flight costs are incurred for each servicing mission, whereas the equipment costs reflect the cost of a theoretical first unit (TFU) for each piece of equipment. The number of crew required to perform the comparable servicing functions are approximately the same. Each SOC crew member, however, may be required to be proficient in more skills than each member on the ground. However, the design of these spacecraft to be serviced in space should minimise the skills required to perform the space operations. This may be accomplished by increased automation in checkout procedures and applying, where most advantageous, the removal and replacement of faulty items with detailed repair performed on the ground.

Commonality of subsystems and installation designs minimise the amount of unique equipment required for servicing at the SOC. The realisation of this goal requires the establishment of appropriate design criteria that would be imposed on all spacecraft requesting space servicing at the SOC.

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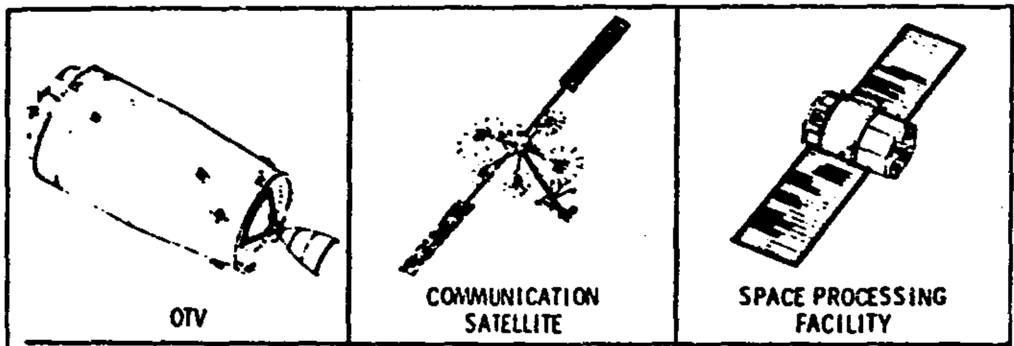

- FEATURES SIGNIFICANT TO SERVICING
  - LOADING OF FLUIDS
    - CRYOGENICS - LO_2, LH_2
    - NON-CRYOGENICS - He, GN_2, HYDRAZINE
  - MODULE & COMPONENT EXCHANGE OPS
  - EXTENSIVE DEPLOYMENT & C/O OPS
  - FREQUENT REVISITS
  - SMALL TO LARGE S/C

S/C	GROUND SERVICING	ORBITER SERVICING	SOC SERVICING
OTV	✓	N/A	✓
COMM SAT	N/A	✓ INITIAL ASSY & LAUNCH TO GEO	✓ INITIAL ASSY & LAUNCH TO GEO
SPACE PROCESSING FACILITY	N/A	✓	✓

FIGURE 4.1 REPRESENTATIVE SPACECRAFTS

	EVALUATION FACTORS								
	NO. OF UNIQUE EQUIPMENT	ELAPSED TIME (HRS)	MAN-HOURS	NO. CREW	** EQUIPT COST ($M)	LABOR COST ($M) PER SERVICING	ORBITER FLIGHT COST ($M)	NO. OF SERVICING MISSIONS	USER 11-YEAR OPERATIONAL COST ($M)
SPACE BASED OTV	3	57.3	193.7	3-5	8.5	4.72	-	172	820
GROUND BASED OTV	5	140	600	3-6	27	2.76	3.56	321	2119
COMM-SAT-SOC	2	61.0	200	2-5	0.3	4.88	-	92	449
COMM-SAT-ORBITER	2	50.8	165	2-4	3.5	7.34	3.56	251	2739
SPF - SOC	3	29.6	103	3-4	14.2	2.51	8.73	110	1251
SPF - ORBITER	4	27.5	106	2-4	9.6	4.72	16.1	110	2300

** LESS DDT & E

FIGURE 4.2 COMPARISON SUMMARY

4.1 SERVICING OPERATIONS

The principle characteristics of the three user spacecraft selected for the servicing analysis follows. The OTV, is a cryogenic stage which may use a monopropellant or a bipropellant for its RCS. It also utilizes helium and GN for pneumatic valve actuation, pressurization and purge systems. This spectrum of fluids must be supplied through the SOC Flight Support Facility and, consequently dictated the required provisions for fluid reloading operations.

The COMMSAT, is a relatively large satellite that requires extensive deployment and checkout operations and final mating to an OTV. The SPF, is a smaller satellite and its servicing requirements consist mainly of materials module exchange operations during frequent revisits to the SOC or to the Orbiter. Both of these satellites utilize hydrazine as the RCS propellant. Modular packaged subsystems concept is utilized for all space serviced spacecraft.

Six turnaround servicing scenarios were identified for the three user spacecraft as shown in Figure 4.1. The analysis of these servicing scenarios generated the data used for the comparison task.

The six servicing scenarios were examined in terms of the major activities that comprise each servicing scenario and the equipment and provisions that are required to perform each servicing activity were identified. An updated preliminary arrangement of the SOC Flight Support Facility, Figure 4.3., was developed. The major activities that constitute each of the six servicing scenarios are depicted in Figures 4.4 through 4.9.

Each of the depicted servicing scenarios presents a complete sequence of activities while, at the same time, taking into consideration the interactions between the scenarios. The OTV ground servicing scenario (Figure 4.4) includes return of the OTV from orbit and its ground turnaround operations to the point of another launch into orbit. It does not include the OTV launch sequence or its in-space operations. However, a ground-based OTV launch sequence was included in Figure 4.6 as part of the COMMSAT orbiter servicing scenario from the orbiter. In Figure 4.17, an initial launch of a space-based OTV was included as part of the COMMSAT SOC servicing scenario. The activities of a typical in-space turnaround servicing of an OTV are delineated in Figure 4.5.

Both SPF servicing scenarios assumed the same initial activities when the SPF is first launched, i.e., appendage deployment and overall checkout will be accomplished on board the orbiter. Typical servicing, commenced on the first revisit operation. The servicing operations of the COMMSAT from the SOC are depicted in Figures 4.10 through 4.12. The servicing operations of the SPF from the orbiter are illustrated in Figure 4.13.

The servicing analysis determined the support equipment that is required to perform the activity and identified the extent of crew involvement, EVA and IVA. The impacts of the particular activity on the SOC, the spacecraft being serviced, and the shuttle if it had a role in that servicing activity was also identified.

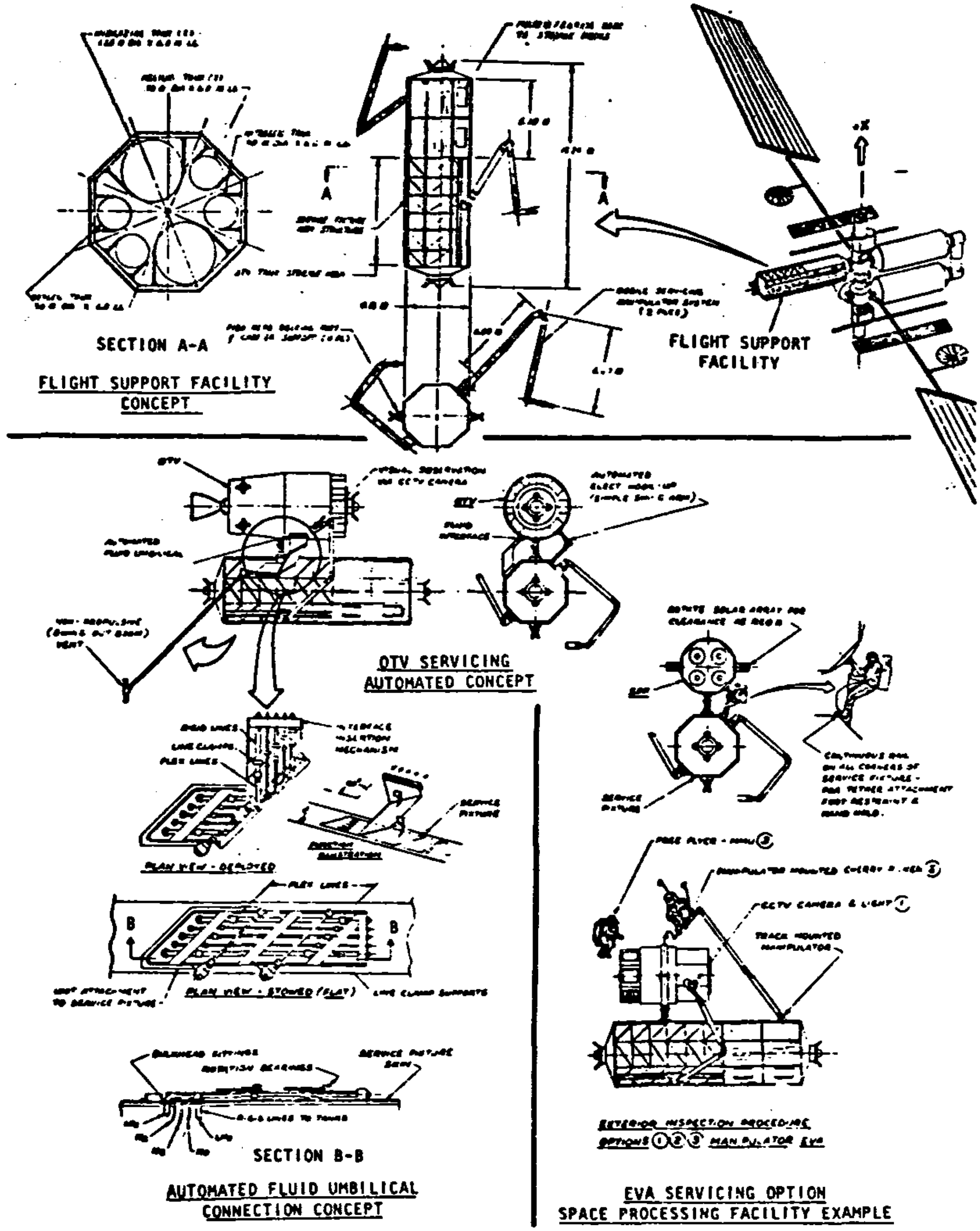

Figure 4.3. SOC Flight Support Facility

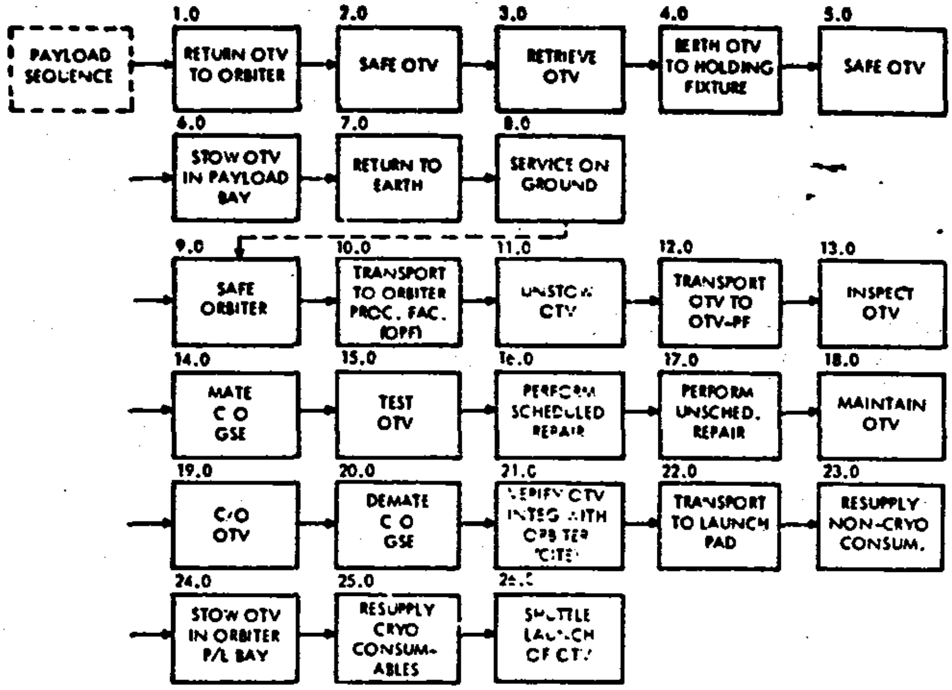

FIGURE 4.4 OTV -- GROUND SERVICING

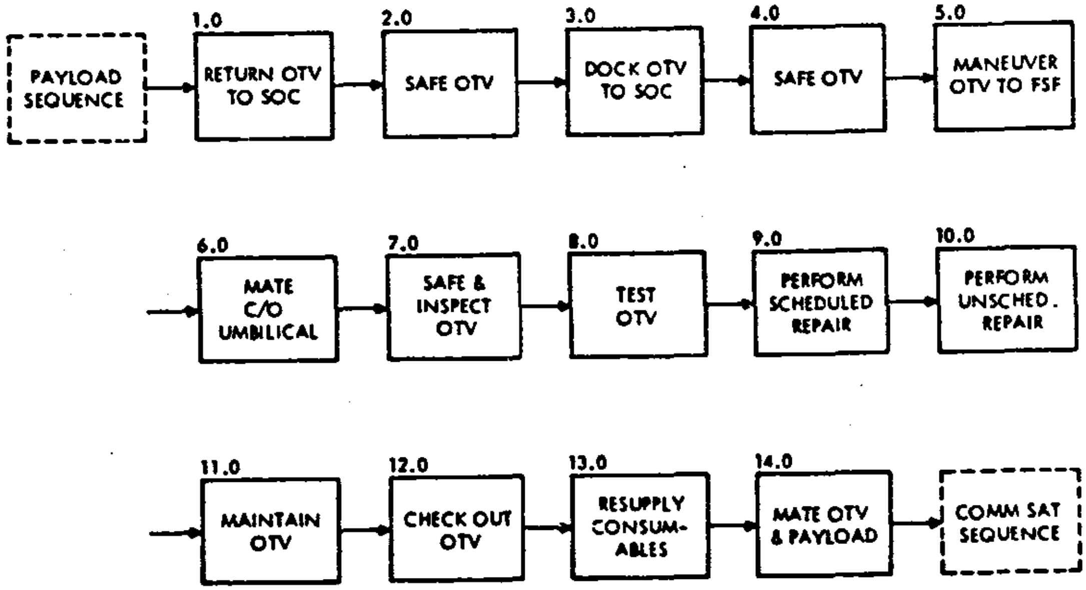

FIGURE 4.5 OTV -- SOC SERVICING

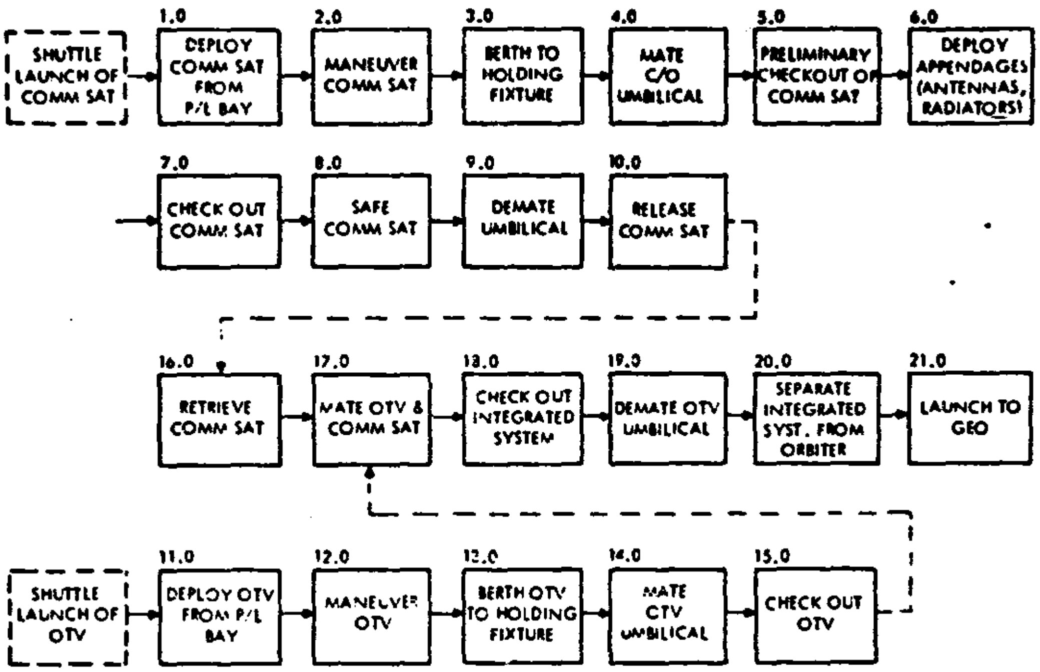

FIGURE 4.6 COMM SAT -- ORBITER SERVICING

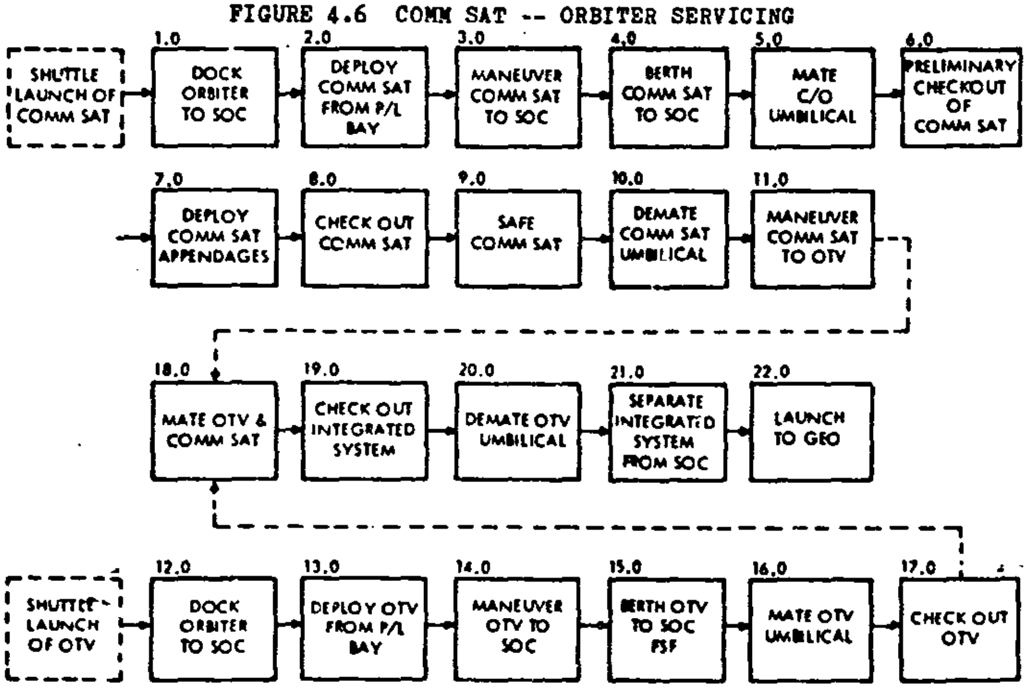

FIGURE 4.7 COMM SAT -- SOC SERVICING

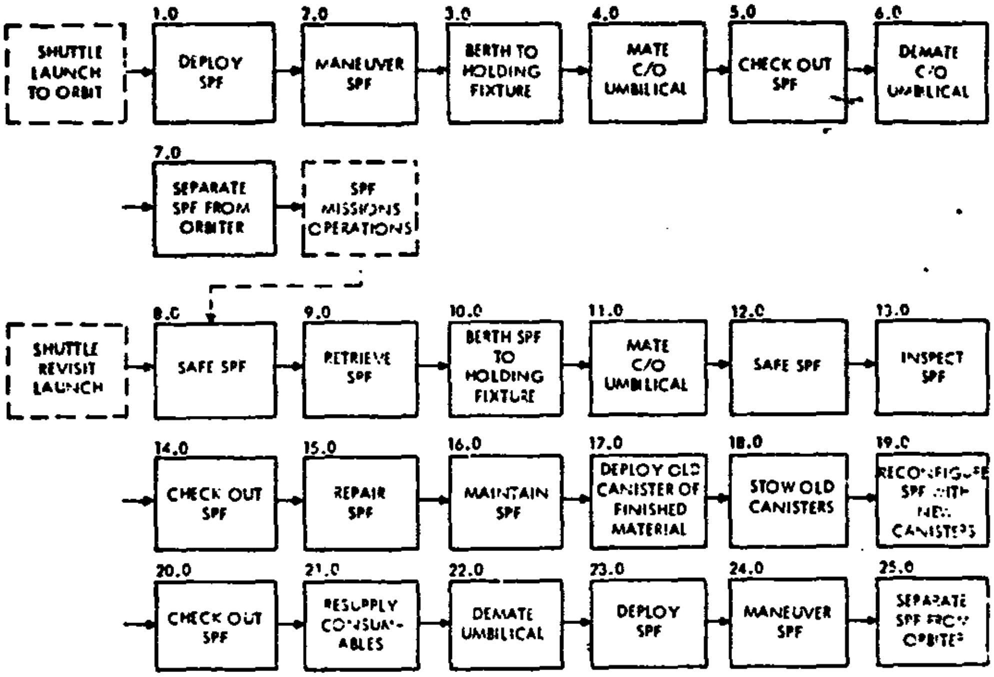

FIGURE 4.8 SPACE PROCESSING FACILITY -- ORBITER SERVICING

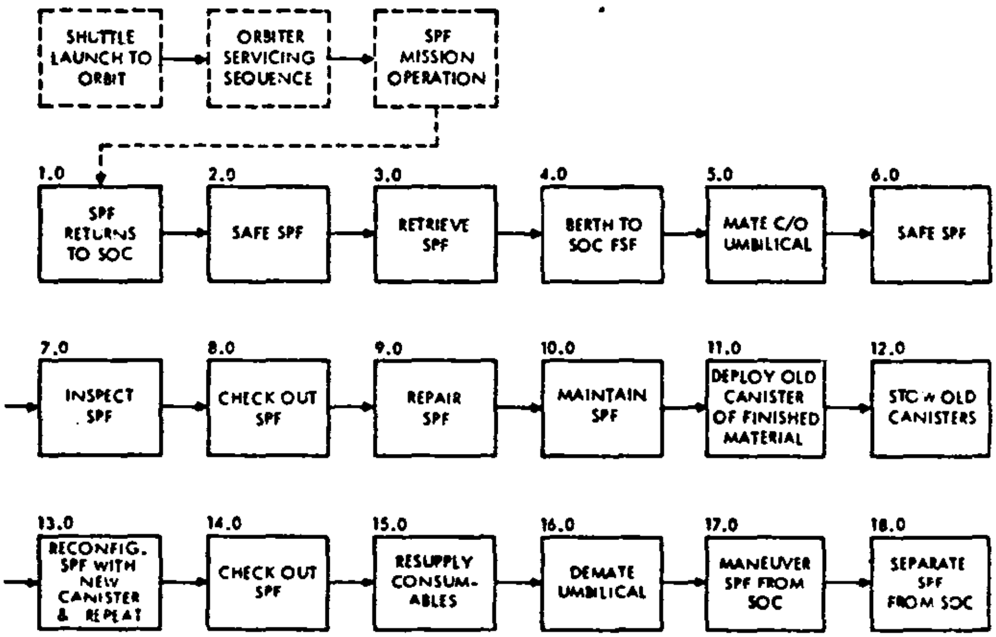

FIGURE 4.9 SPACE PROCESSING FACILITY -- SOC SERVICING

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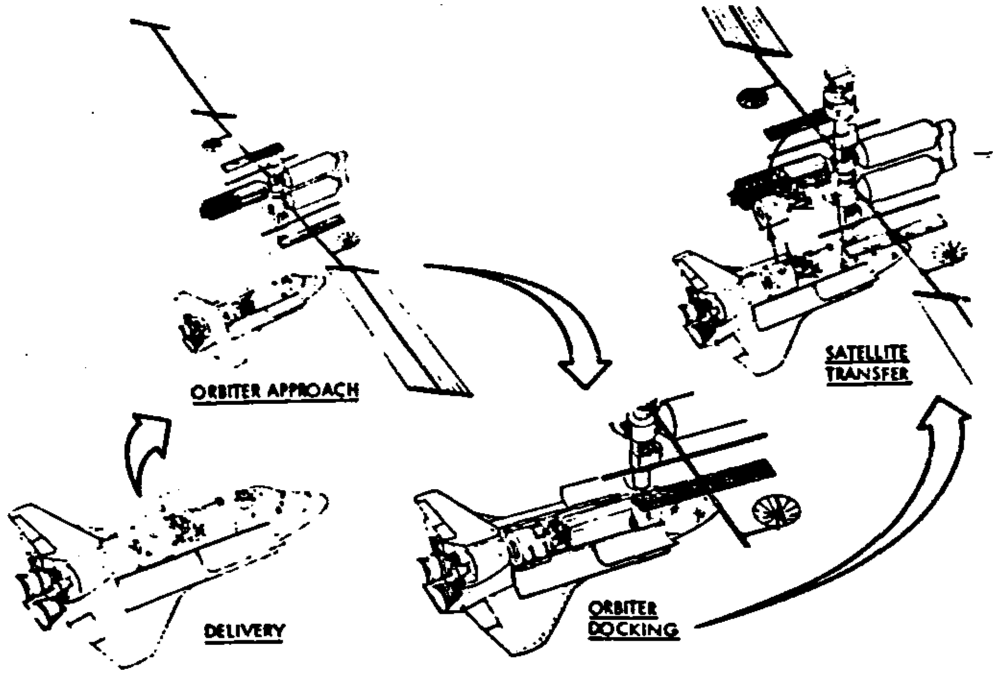

FIGURE 4.10 COMMSAT -- SOC SERVICING SCENARIO

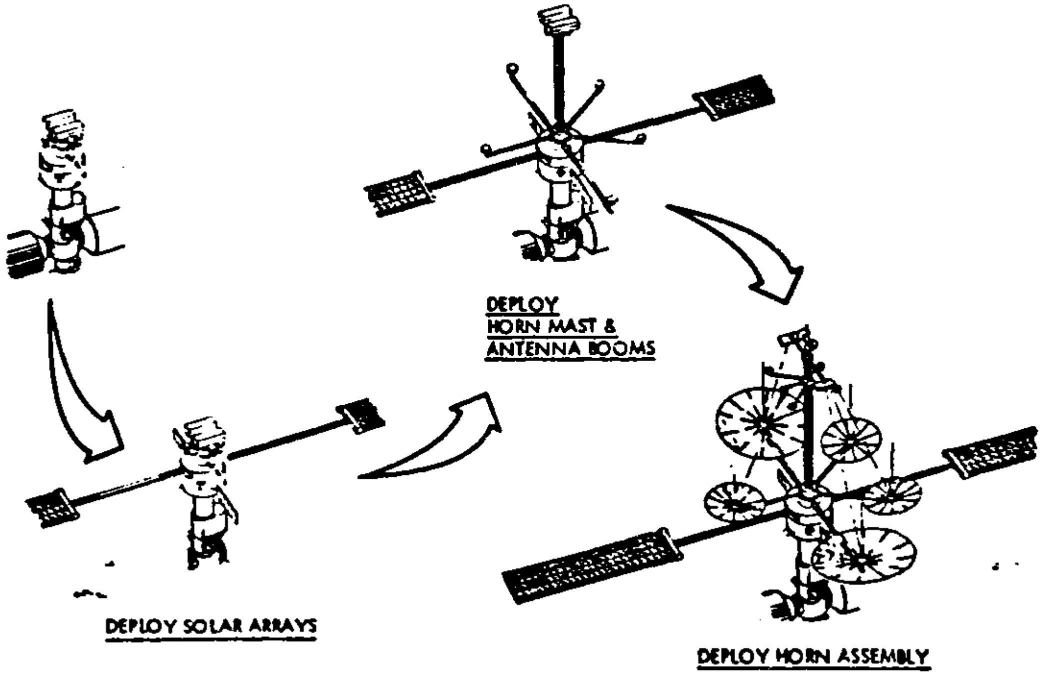

FIGURE 4.11 COMMSAT -- APPENDAGES DEPLOYMENT SCENARIO

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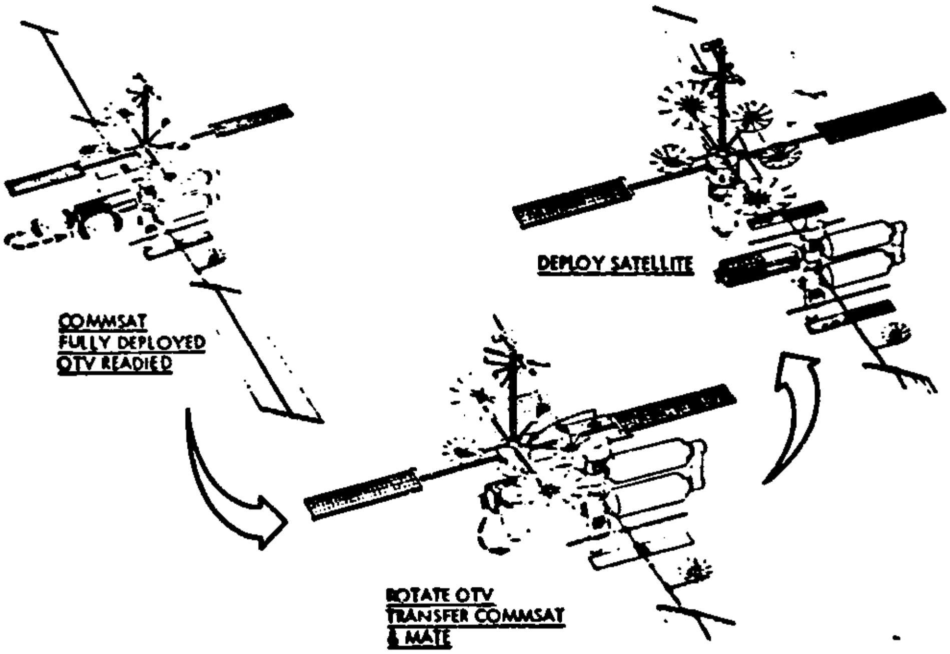

FIGURE 4.12 COMMSAT/OTV MATING & DEPLOYMENT SCENARIO

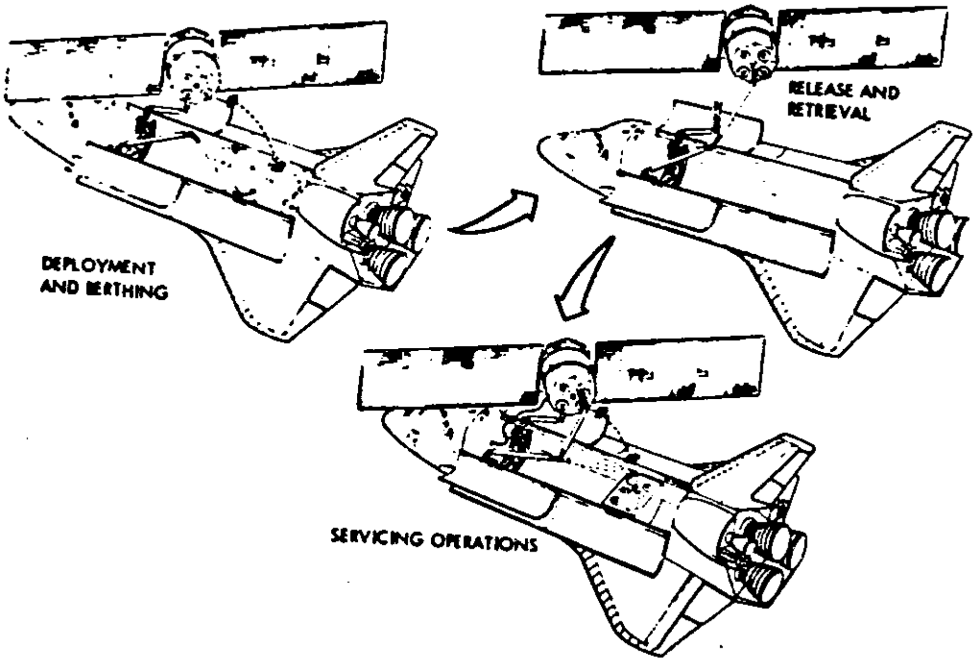

FIGURE 4.13 SPACE PROCESSING FACILITY ORBITER SERVICING SCENARIO

Most of the support equipment and provisions that affect the ground facilities, the orbiter and the SOC are not unique to the particular scenarios but are common usage items. However, there are some unique provisions that are peculiar to a particular scenario and are the only ones that are considered in the costing exercise described later.

In general, timelines were developed by examining and estimating times for each numbered function or step described previously in the block flow diagram scenario Figures 4.4 to 4.9. At the same time, estimates of crew size were prepared for each step to determine man-hours. When inconsistencies or other problems in logic were uncovered as a result of such analyses, some minor changes were made in the sequences. Where appropriate, references to sources of data or similarities to orbiter operations were noted in comments on tables of time and manpower requirements estimations.

This contract study work benefited from previous and concurrent IR&D studies by Rockwell in the areas of space construction human factors and space servicing, and from other contractor studies relating to satellite servicing and manned OTV servicing.

The major assumptions relating to timelines and manpower estimations are listed in Tables 4.1, 4.2, and 4.3, referring respectively to the OTV, communication satellite, and space processing facility checkout. Many of these assumptions are similar for both the SOC and non-SOC options studied, so a two-column check-off format on the right side of the table was employed to show the variations. A conscious attempt was made, during the timelines and man-hours analyses, to divide the servicing operations into functions titled as shown previously by the block flow diagrams.

Estimates were made of the man-hours required to perform the servicing functions for each of the three candidate spacecraft, and are compared within their respective servicing areas; at the SOC, or from the orbiter, or on the ground.

In general, EVA was not an assumed mode of normal operation. However, it is assumed that EVA is an acceptable backup mode whenever the RMS is inoperative or inappropriate because of limited access or special, unforeseen, or low-frequency situations that could be performed safely by EVA operations. At the preliminary level of analysis performed on these specific examples, no such contingencies were identified.

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TABLE 4.1 ASSUMPTIONS FOR TIMELINE/MAN-HOURS ESTIMATION - OTV

	TURNAROUND	
	GROUND	SPACE
• OTV DESIGNED FOR GROUND SERVICING USING STANDARD, MINIMUM WEIGHT & VOLUME CONCEPTS FOR SPACECRAFT SYSTEMS	✓	
• OTV TURNAROUND DOES NOT PACE TOTAL ORBITER TURNAROUND TIME OF TWO WEEKS (DESIGN IS NOT OPTIMIZED TO MINIMIZE GROUND OPERATING TIME)	✓	
• ONLY ACTUAL WORK TIME INCLUDED IN ESTIMATES (SLEEP, MEALS, AND PERSONAL TIME NOT INCLUDED)	✓	✓
• VARIABLE CREW SIZE—CHARGED TO OPERATION AS NEEDED TO ESTIMATE MAN-HOURS	✓	✓
• SOME POTENTIAL LEARNING IS NOT ACCOUNTED FOR: - CITE TEST NOT NECESSARY AFTER EXPERIENCED GAINED ON ONE OR TWO FLIGHTS - REPAIR ACTIVITIES COULD BE FEWER AFTER INITIAL FLIGHTS (BURN-IN) - IMPROVED CREW PROCEDURES AND TOOLS FROM REPETITIVE EXPERIENCE COULD SHORTEN TIME	✓	
• TYPICAL TRANSPORT/HANDLING EQUIP. & TRAVEL DISTANCES ASSUMED	✓	
• OTV DESIGNED FOR EASY ACCESS BY RMS WITH APPROPRIATE TOOL END EFFECTOR		✓
• FAILURE RATES FOR UNSCHEDULED MAINT. BASED ON MATURE DESIGN - 30-40 FAILURES/1000 HR OPERATION (REF. SKYLAB) - MISSION TIME, LEO TO GEO & RETURN—40 HR MAXIMUM		✓
• REPAIRS PRIMARILY BY RMS REMOVAL/REPLACEMENT		✓
• RMS TIMES ESTIMATED BY SIMILARITY TO GROUND SIMULATIONS - SPAR—ELECTRONIC SCENE GENERATIONS - NASA MDF—MECHANICAL ARM SIMULATIONS		✓
• BUILT-IN OTV AUTO TEST FOR SIMPLIFIED FAULT DETECTION AND ISOLATION		✓

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TABLE 4.2 ASSUMPTIONS FOR TIMELINE/MAN-HOURS ESTIMATION COMMUNICATIONS SATELLITE

	CHECKOUT/MATE	
	WITH SOC	WITH ORBITER
• COMM SAT DESIGNED WITH BUILT-IN AUTOMATIC TEST EQUIPMENT		
- APPLICABLE TO SOC CHECKOUT	✓	
- APPLICABLE TO ORBITER CHECKOUT		✓
• COMM SAT INCORPORATES RMS GRAPPLE FIXTURES AND BERTHING PORT INTERFACE		
- COMPATIBLE WITH OTV MATING	✓	✓
- COMPATIBLE WITH SOC OPERATIONS	✓	
- COMPATIBLE WITH ORBITER OPERATIONS		✓
• COMM SAT TO BE DEPLOYED AT SOC BEFORE MATING TO OTV AND ALIGNMENT CHECKED PRIOR TO FLIGHT TO GEO	✓	
• COMM SAT IS DELIVERED TO SOC FULLY FUELED AND SUPPLIED WITH ALL GAS AND CHARGED BATTERIES REQUIRED AT GEO	✓	
• ONLY ACTUAL WORK TIME INCLUDED IN ESTIMATES (SLEEP, MEALS, AND PERSONAL TIME NOT INCLUDED)	✓	✓
• VARIABLE CREW SIZE—CHARGED TO OPERATION AS NEEDED TO ESTIMATE MAN-HOURS	✓	✓
• COMM SAT TO BE DEPLOYED AT LEO AND MATED TO OTV BY ORBITER USING HPA ASSISTANCE; ALIGNMENT TO BE CHECKED PRIOR TO FLIGHT TO GEO		✓
• COMM SAT IS DELIVERED TO LEO AND PARKED UNDER ITS OWN CONTROL UNTIL OTV DELIVERED ON SECOND SHUTTLE FLIGHT		✓
• COMM SAT IS DELIVERED TO LEO FULLY FUELED AND SUPPLIED WITH ALL GAS AND CHARGED BATTERIES REQUIRED AT GEO AND LEO WAIT PERIOD	✓	✓

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TABLE 4.3 ASSUMPTIONS FOR TIMELINES/MAN-HOURS ESTIMATION
SPACE PROCESSING FACILITY

	CHECKOUT/ TURNAROUND	
	AT SOC	AT ORBITER
● SPF SATELLITE DESIGNED WITH BUILT-IN AUTOMATIC TEST EQUIP.		
- APPLICABLE TO SOC CHECKOUT	✓	
- APPLICABLE TO ORBITER CHECKOUT		✓
● SPF PROVIDED WITH GRAPPLE FIXTURE AND ATTACH PORT ON SIDE, COMPATIBLE WITH SOC RMS AND CONSTRUCTION FIXTURE	✓	
● SPF PROVIDED WITH GRAPPLE FIXTURE AND HPA ATTACH PORT ON SIDE, COMPATIBLE WITH ORBITER RMS AND ASE		✓
● SPF IS RESUPPLIED WITH FLUIDS & GASES AT TIME OF CHANGEOUT/ RESUPPLY OF PRODUCT/RAW MATERIALS	✓	✓
● ONLY ACTUAL WORK TIME INCLUDED IN ESTIMATES (SLEEP, MEALS, AND PERSONAL TIME NOT INCLUDED)	✓	✓
● VARIABLE CREW SIZE—CHARGED TO OPERATED AS NEEDED TO ESTIMATE MAN-HOURS	✓	✓
● FAILURE RATES FOR UNSCHED. MAINTENANCE BASED ON MATURE DESIGN	✓	✓
- 30-40 FAILURES/1000 HR OPERATION (REF. SKYLAB)		
● SPF LRU'S DESIGNED FOR EASY ACCESS BY RMS WITH APPROPRIATE TOOL END EFFECTOR	✓	✓
● REPAIR PRIMARILY BY RMS REMOVAL/REPLACEMENT	✓	✓
● RMS TIMES ESTIMATED BY SIMILARITY TO GROUND SIMULATIONS	✓	✓
- SPAR—ELECTRONIC SCENE GENERATIONS		
- NASA MDF—MECHANICAL ARM SIMULATIONS		

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Time estimates were performed by separately considering each functional step in the scenarios outlines. For the most part it was assumed that all functions are performed serially. Notable exceptions were the ground turnaround scheduled and unscheduled maintenance operations for the OTV. These were considered to be conducted partially in parallel.

For each scenario, a tabulation was prepared in the example format shown in Table 4.4. From these summary estimates, timeline bar charts were prepared as indicated in Figure 4.14. (The complete set of timeline analyses charts appears in Appendix C.) The total elapsed time, man-hours and crew sizes for all scenarios are summarized as shown in Table 4.5.

As a part of the comparison of ground and space turnaround of the OTV, Figure 4.15 and Table 4.6 were prepared. The figure illustrates, by dotted shading, those time periods which arise only because of the ground location situation and the direct interaction with the orbiter turnaround activity. That is, such time-consuming activities would not be required at the SOC. Slanted-line shading highlights the aforementioned scheduled and unscheduled repair times which occur in parallel. For initial purposes of this study, it was assumed that the elapsed time for OTV repairs (circa 1990 time period) could be as much as, but no more than, that allocated to the orbiter in the STAR 20 timeline document. [Figure 4.16 shows the OTV timeline elements in shaded bars superimposed on the STAR 20 (baseline) timeline chart.]

Obviously, unscheduled repair activity needs much more detailed study to establish a more accurate time and man-hours data base. In fact, unscheduled maintenance (repair) is apparently a key factor in overall time estimates of servicing and checkout. To a high degree, these time elements are determined by the estimated number of failures and the average time to accomplish repair of each such failure. To date, NASA has had little experience in failure rates, type of failures, or time required to make repairs on a mature vehicle, which was specifically designed to facilitate turnaround in space or on the ground. Except for the STS-2 Orbiter, all space vehicles to date have been in first-flight condition, with a reasonable likelihood of having some undetected manufacturing discrepancies. The most relevant experience at this time is the Skylab vehicle, which had three different visits by astronaut crews, with some activities akin to reactivation and extended operations during each visit. As expected, there were fewer failures (and repairs) per unit time during each visit (Figure 4.17). The last visit experienced approximately 30 failures per 1000 hours (as deduced from a count of "unscheduled" maintenance events). This rate was much less than the rate of 113 failures per 1000 hours during the first visit. At the other extreme are military aircraft, which are designed on the basis of multiple flights and average rates of failure per flight, requiring ready access to modular equipment designs having fairly well known average man-hours per repair. The analyses for this study assumed the Skylab failure rate as a "going-in" estimate for analysis. However, the time allocation for checkout operations was assumed to be closely similar to the aircraft philosophy and experience.

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TABLE 4.4 TIME RATIONALE -- OTV TURNAROUND AT SOC

TASK NO.	TASK DESCRIPTION	ELAPSED TIME (HR)	CREW QTY	MAN HR	RATIONALE
1.0	RETURN OTV TO SOC (PREPARATION BY CREW)	4.0	5	20.0	PLANNING INCLUDES ALL ASSIGNED CREW; ACQUISITION & MONITORING INCLUDED
2.0	SAFE OTV (DEACTIV. MAIN ENGINE) AND PERFORM PROXIMITY MANEUVERS (STATIONKEEPING)	0.5	3	1.5	PRELIMINARY ESTIMATE
3.0	DOCK OTV TO SOC	0.5	4	2.0	SIMILAR TO ORBITER DOCKING; SAFETY-CRITICAL MANEUVER, EXTRA "EYES" REQ'D
4.0	SAFE OTV (DEACTIVATE ATTITUDE CONTROL SYSTEM)	0.3	4	1.2	MULTIPLE CREW AT READINESS
5.0	MANEUVER OTV TO FSF (USING MANIP.)	0.5	5	2.5	RMS OPERATOR, SOC CDR, FSF OPERATOR, OTV DIRECTOR OBSERVER
6.0	MATE CHECKOUT UMBILICALS	0.5	5	2.5	RMS OPERATION, SIMILAR TO SPAR DATA
7.0	(a) SAFE OTV (POWER, FLUIDS) (b) INSPECT OTV (RMS TV CAMERA)	0.5 2.0	4 4	2.0 8.0	ENGR. ESTIMATES
8.0	TEST OTV (ELECTRONICS & MECH ACTUATORS--VERIFY ONBOARD TEST EQUIPMENT DATA)	1.0	4	4.0	INCLUDES GROUND COMMUNICATIONS SPECIAL PROGRAMS
9.0	PERFORM SCHEDULED MAINTENANCE	24.0	3	72.0	TWO MODULES REPLACED @ 2 HR EACH SERIALLY
10.0	PERFORM UNSCHEDULED (CORRECTIVE) MAINT. REPAIR (RMS REPLACEMENT OF LRU'S)	16.0	3	48.0	3 HR PER FAILURE, 2 FAILURES IN 50 HR (EST.), MATURE, RELIABLE DESIGN
11.0	MAINTAIN OTV (NOT USED—SEE 9.0)	-	-	-	DUPLICATION—NOT USED
12.0	CHECKOUT OTV	1.5	4	6	0.75 HR PER FAILURE, 2 FAILURES IN 50 HR (EST.)
13.0	RESUPPLY CONSUMABLES	6.0	4	24	PRELIMINARY ESTIMATE, ASSUMES ADEQUATE LINE SIZE
	TOTAL	57.3	3.75 AVG*	193.7	

*CALCULATED BY $\frac{\text{TOTAL MAN HOURS}}{\text{TOTAL ELAPSED TIME}}$

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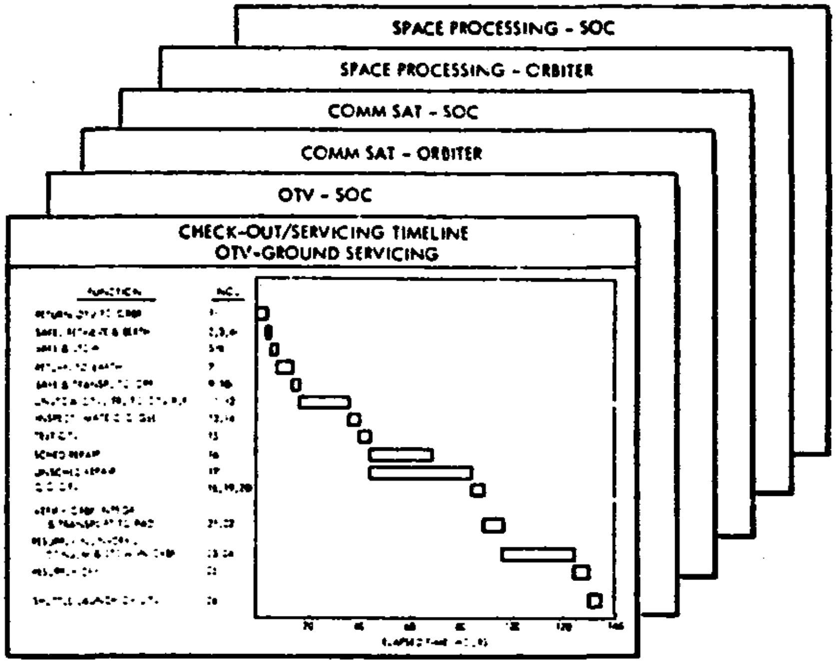

FIGURE 4.14 TIMELINE ANALYSIS CHARTS

TABLE 4.5 CHECKOUT/SERVICING MAN-HOURS SUMMARY

LOCATION	ELAPSED TIME	MAN-HOURS	NO. CREW RANGE	NO. CREW AVG
OTV-GROUND	140.0	600.0	3 - 6	4.3
OTV-SOC	57.3	193.7	3 - 5	3.8
COMM SAT-ORBITER	50.8	164.8	2 - 4	2.4
COMM SAT-SOC	61.0	199.6	2 - 5	2.6
SPACE PROCESSING-ORBITER	27.5	106.0	2 - 4	3.5
SPACE PROCESSING-SOC	29.6	103.4	3 - 4	3.5

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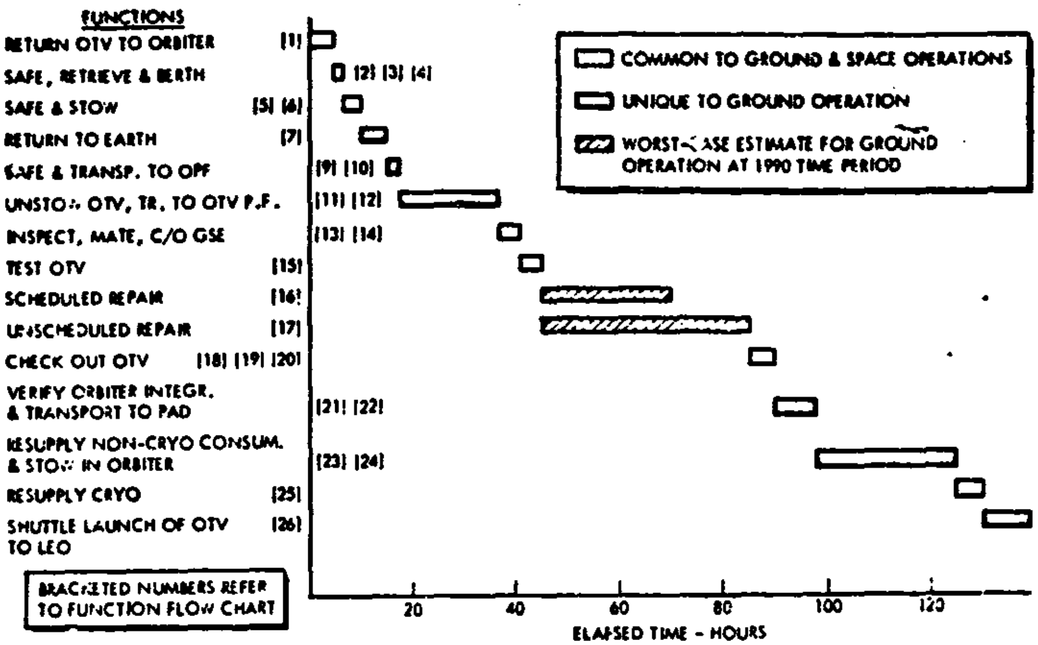

FIGURE 4.15. TIMELINE ANALYSIS OF OTV GROUND TURNAROUND SHOWING UNIQUE DIFFERENCES FROM SPACE OPERATIONS

TABLE 4.6 OTV TURNAROUND OPERATIONS COMPARISONS (GROUND VS. SOC TURNAROUND)

	GROUND	SOC
ELAPSED TIME, HR	140	57.3
MAN-HOURS	600	*93.7

SIGNIFICANT OPERATIONS DIFFERENCES

	GROUND		SOC		DIFFERENCE	
	ELAPSED TIME (HR)	MAN HOURS	ELAPSED TIME (HR)	MAN HOURS	ELAPSED TIME (HR)	MAN HOURS
RETURN TO EARTH [7]	6	24	N/A	N/A	6	24
SAFE & TRANSPORT TO OPF [9] [10]	2	●	N/A	N/A	2	-
UNSTOW OTV, TRANSP. TO P.F. [11] [12]	20	60	N/A	N/A	20	60
SCHEDULED REPAIR [16]	24 } 40 ○	72	24 ◇	72 ◇	8	0
UNSCHEDULED REPAIR [17]	40 } MAX	120	16	40		72
ORBITER OTV CHECKOUT TRANSPORT TO PAD [21] [22]	8	40	N/A	N/A	8	40
RESUPPLY FLUIDS STOW IN ORBITER [23] [24]	27	142	6	24	21	118
TOTAL	103	466	46	144	57	322

REMARKS
● ORBITER FUNCTION - NO CREW INVOLVED WITH OTV
○ CORRECT TWO LRU FAILURES
◇ BATTERIES AND FILTERS

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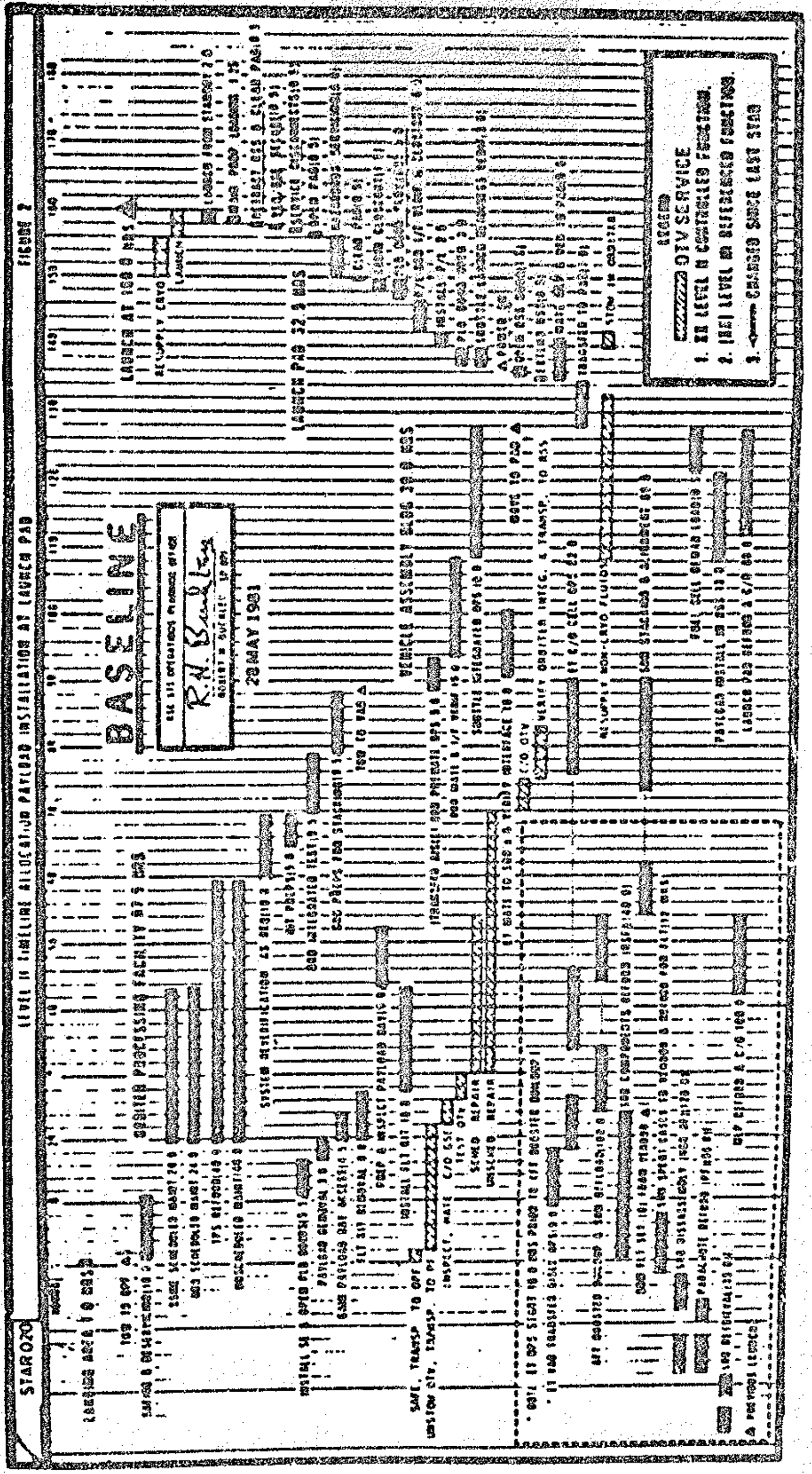
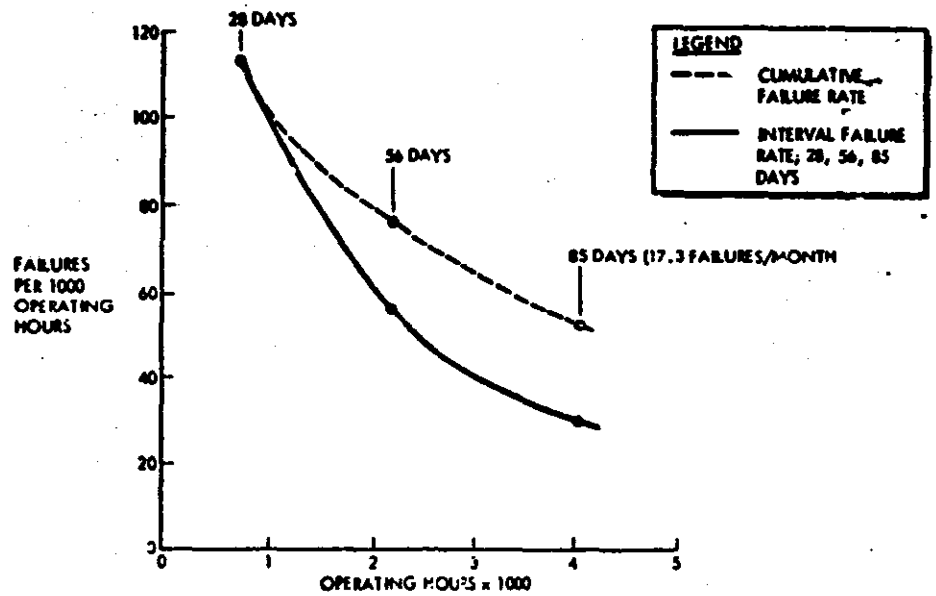


FIGURE 4.16 OTV SERVICING TIMELINE



NOTE: DATA TAKEN FROM AIAA TECHNICAL PAPER 78-325, NEW DIMENSIONS IN MAN-MACHINE DESIGN, BY A. J. LOUVIERE, DATED FEB. 7-9, 1978

FIGURE 4.17 SKYLAB IN-ORBIT FAILURE RATES

At this preliminary stage of analysis, the elapsed time and man-hours comparisons must be considered as very rough approximations, serving primarily for comparisons of relative magnitudes. As noted in Table 4.5 the estimated man-hours for servicing the COMMSAT, which in this case consists of the deployment, checkout, and mating to an OTV, indicates only slight differences between servicing from the orbiter or from the SOC, approximately 35 hours. Similarly, the man-hours difference to service the Space Processing Facility from the orbiter or from the SOC indicates a difference of only 3 hours. However, a large difference between turnaround operations time of the OTV on the ground and in space is indicated. This large difference is partially explained by time requirements assumed as inherent to the locations of different activity sites and the necessity of scheduling certain ground turnaround events in accordance with orbiter-dictated schedules.

In addition, an assumption was made that the OTV involved in space servicing would be specifically designed for ease of maintenance. Many components would be packaged in larger, line-replaceable units (LRU's), more readily handled by remote manipulators. It was also assumed that the level of repairs would be less detailed. The time estimates do not include the secondary, detailed bench check and repair times required for the removed modular units (either at SOC or on the ground). No EVA time was assumed in the estimates, although such a need is recognized as a viable backup option to remotely controlled activities. These fundamental differences between in-space checkout/servicing and ground turnaround checkout/servicing operations are considered likely in the future, regardless of the accuracy of estimation of the individual task element times and man-hours. However, it is recognized that there may well be less difference between the two in future, more detailed and matured estimates. For example, the ground turnaround time may well be lower for the OTV after the third or fourth flight, since it would seem unnecessary to recheck the fit to the orbiter each time, unless something has been changed on the external envelope. On the other hand, it is true that even 15 flights of a single OTV would not approach the maturity of experience that the orbiter turnaround should achieve after 50 to 60 flights.

In the case of communication satellite payloads sent to geosynchronous orbit, each one will be a first-time flight. Much less improvement can be expected in handling equipment, procedures, or reliability of the vehicle due to experience in flight. At present, the greatest uncertainty seems to be how much activity will be required for checking alignment and contours of deployed large antennas and their support structures.

The space processing checkout/servicing timelines have many areas of uncertainty due to the lack of definition of typical systems. However, it may be that these systems will also benefit from learning during repetitive experience in space operations.

In conclusion, it seems that the results developed to date are probably indicative of relative trends to be expected, but lack a high degree of accuracy in absolute values of estimations.

4.2 COST ANALYSIS

Cost estimates were developed for each of the six servicing scenarios for which timelines were estimated and implications were identified. This section presents the cost estimates and compares them in relative terms. The servicing costs that need to be considered by the user of a space operations system fall into many elements as illustrated in Figure 4.18. This task did not consider every element indicated, but only those bounded by the dashed lines in Figure 4.18. Also indicated are the groundrules on which the cost estimates were based.

Figure 4.2 summarizes the cost comparison for each of the servicing scenario options. Shown are the one time hardware investment cost totals and the labor and orbiter flight costs for each servicing mission. Servicing by SOC is shown to be less expensive than orbiter servicing (or ground OTV servicing) for each of the options.

Although the OTV per service labor cost by SOC is more costly, ground servicing of the OTV requires an orbiter return of the OTV. The orbiter is required to retrieve and return the ground-based OTV after every mission. The orbiter was assumed to require two additional days in orbit to perform the OTV retrieval and return operation, the cost of which was estimated at $1.78 million per day. A similar orbiter flight cost is incurred by each COMMSAT mission based on the servicing elapsed time of 50.8 hours (≈ 2 days).

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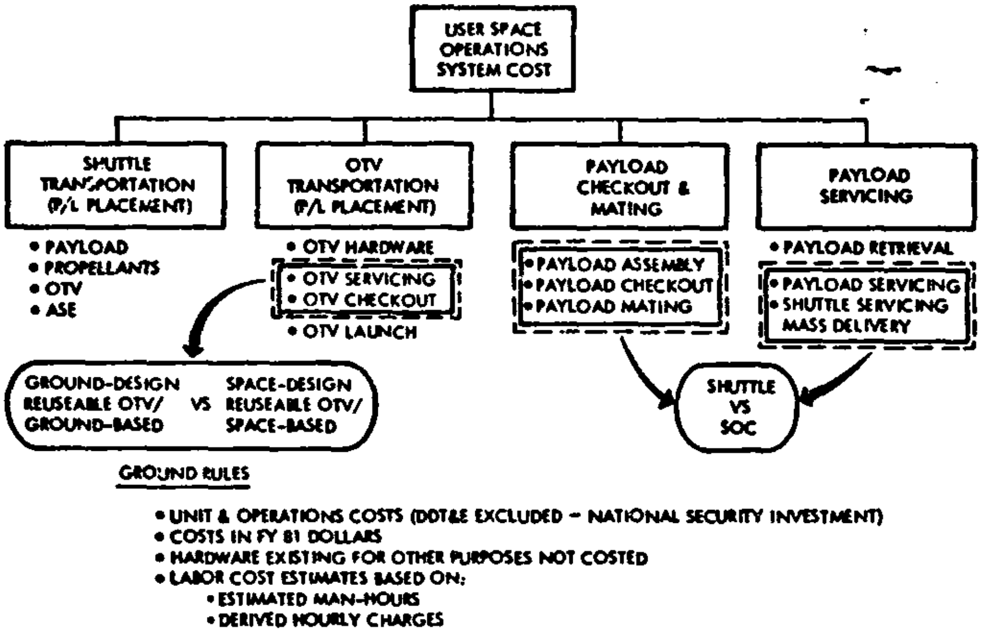

FIGURE 4.18 SERVICING COMPARISONS APPROACH

A requirement of 110 SPF servicing missions during the period of 1990-2000 was the basis for estimating the orbiter flight costs of servicing the SPF. For SPF-SOC servicing, these missions would require 20 orbiter flights to retrieve the completed processing experiments from the SOC. At a cost of $48 million per flight, each servicing mission would cost $8.73 million. If the SPF is to be serviced by the orbiter, 37 additional flights would be required to accomplish the same number of servicing missions. The result is a cost of $16.1 million for each SPF-orbiter servicing mission.

Hardware Cost Estimates

The costing analysis considered the unique hardware items necessary to perform each servicing operation. The hardware cost estimates are shown in Tables 4.7, 4.8 and 4.9 for the OTV, COMMSAT and SPF respectively. DDT&E and production (TFU) estimates are set forth. These estimates were derived by parametric estimating techniques and are based on system descriptions, sketches and associated weight statements. The complete package of the costs analysis sheets are contained in Appendix [illegible] The hardware DDT&E costs were considered as a national security investment and, as such, were excluded from the cost totals. Their inclusion in Tables 4.7, 4.8 and 4.9 is for informational purposes only.

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TABLE 4.7 OTV SERVICING HARDWARE COST IMPACT
(MILLIONS OF FY '81 $)

(MILLIONS OF FY'81 $)

OTV GROUND SERVICING	DDT&E	TFU	OTV-SOC SERVICING	DDT&E	TFU
• SERVICE FIXTURE WITH SERVICE CONNECTION	12.0	12.0	• OTV CONTROL AND MONITOR SOFTWARE	1.0	-
• UMBILICAL ARMS ON OTV SERVICE FIXTURE	4.6	7.9	• EXTENDABLE NON-PROPULSIVE BOOM	0.94	0.56
• OTV FLUIDS INTERFACE ON ORBITER	2.2	2.7	• RETRACTABLE UMBILICALS	4.6	7.9
• ELECTRICAL INTERFACE ON ORBITER	2.1	0.67			
• OTV CONTROL AND MONITOR STATION ON ORBITER	4.7	4.1			
TOTAL	25.6	27.37		6.54	8.46
TOTAL DDT&E AND PRODUCTION UNIT	52.97			15.00	

TABLE 4.8 COMMSAT SERVICING HARDWARE COST IMPACT
(MILLIONS OF FY '81 $)

(MILLIONS OF FY'81 $)

COMMSAT - ORBITER SERVICING	DDT&E	TFU	COMMSAT - SOC SERVICING	DDT&E	TFU
• RETRACTABLE UMBILICAL SYSTEM	2.0	1.4	• RETRACTABLE UMBILICAL SYSTEM	0.6	0.34
• COMMSAT CONTROL AND MONITOR STATION	2.2	2.1	• COMMSAT CONTROL AND MONITOR SOFTWARE	2.0	-
TOTAL	4.2	3.5		2.6	0.34
TOTAL DDT&E AND PRODUCTION UNIT	7.7			2.94	

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TABLE 4.9 SPF SERVICING HARDWARE COST IMPACT

(MILLIONS OF FY '81 $)

SPF - ORBITER SERVICING	DDT&E	TFU	SPF - SOC SERVICING	DDT&E	TFU
● UMBILICAL	2.0	1.3	● SPF CONTROL AND MONITOR SOFTWARE	2.0	-
● SPECIAL PURPOSE END EFFECTOR	1.3	0.58	● SPECIAL PURPOSE END EFFECTOR	1.3	0.58
● MODULE AND CANISTER STORAGE AND RETRIEVAL	6.3	3.3	● MODULE AND CANISTER STORAGE AND RETRIEVAL SYSTEM	10.7	13.6
● SPF CONTROL AND MONITOR STATION	12.1	4.4			
TOTAL	21.7	9.58		14.0	14.18
TOTAL DDT&E AND PRODUCTION UNIT	31.28			28.18	

Labor Cost Estimates

The labor cost per servicing were derived by factoring servicing labor hour estimates (see Table 4.5) by a derived hourly charge factor. The SOC labor charge derivation is illustrated in Figure 4.19. It is based on an 11 year (1990-2000) scenario of operation and includes amortized hardware, spares, logistics flights and a Δ orbiter cost allocation. A $24,384 per hour charge factor is based on the available man-hours over the eleven year period. Again, the SOC DDT&E costs were excluded from the charge factor.

The orbiter service charge estimate is based on adjusted values from the STS Reimbursement Guide as well as an allowance for additive orbiter hardware requirements.

The basic orbiter mission duration is one day. For longer duration missions users are charged for extra days on orbit as prescribed in the STS Reimbursement Guide. In addition, one must consider the overall impact on the potential requirement for buying additional orbiters to accommodate extended duration servicing and other missions. Study of medium level forecasted mission and traffic scenarios reveal that approximately 75 percent of the orbiter missions would be longer duration at an estimated level of 11 days per mission. In order to accommodate the forecast mission and traffic flight rate levels a series of calculations were made to define the dollar impact on the additional servicing hours produced. This is illustrated in Figure 4.20. Shown are the derivation of cost per orbiter servicing hour based on the current charge policy adjusted for current cost targets and the Δ orbiter hardware component of servicing cost. A value of $44,542 per orbiter servicing hour is developed in Figure 4.20.

• SOC	COST ESTIMATE (MILLIONS OF FY '81 $)
BASE	1123*
SPARES (33% FOR 11 YEARS)	374
OPERATIONS (11 YEARS)	440
STS LOGISTICS FLIGHTS	1718
ΔORBITER COST ALLOCATION	362
TOTAL SOC SPACE SEGMENT COST USED AS CHARGE BASIS	4017
NO. OF HOURS AVAILABLE FOR SERVICE	
6 MEN X 48 HOURS/WEEK X 52 WEEKS/YEAR X 11 YEARS	• 164,736
SOC CHARGE COST PER HOUR	• $24,384

*BASED ON ROCKWELL'S MODULAR SPACE STATION STUDY

FIGURE 4.19 BASIS FOR SOC CHARGE ESTIMATES

4.5.3 Costing Results

The hardware cost estimates and the labor cost estimates are combined to provide the servicing cost comparison data as indicated in Figure 4.2. Orbiter flight costs were major contributors to the overall costs of the non-SOC options. Another significant contributor is the increased number of OTV and COMMSAT non-SOC servicing missions that are required to do the same amount of work as the number of SOC servicing missions. The ground-based OTV requires 331 servicing missions as compared to the space-based OTV of 172. Similarly, the orbiter serviced COMMSAT requires 251 servicing missions compared to 92 for the SOC serviced COMMSAT.

GROUND RULES

- REQUIREMENT FOR LAUNCH RATE DURING 90'S = 48 SHUTTLE MISSIONS/YEAR 75 PERCENT OF MISSIONS REQUIRE LONGER DURATION . . . THIS REQUIRES PURCHASE OF ADDITIONAL ORBITERS
- STD ORBITER = 15 MISSIONS/ORB/YR AT 48/YR = 3.2 ORBITERS RQRD
- 11 DAY ORBITER = 10 MISSIONS/ORB/YR AT 48/YR = 4.8 ORBITERS RQRD

REFINEMENT

0.75 X 4.8	(36 LONG DURATION FLTS)	= 3.6 ORBITERS RQRD
0.25 X 3.2	(12 STD FLTS)	= 0.8 ORBITERS RQRD
		4.4
	LESS STD ORB FLTS RQMTS	- 3.2
		1.2 ΔORBITER RQMTS FOR EXTRA HOURS BOUGHT

- Δ HOURS BOUGHT
  1.2 ORBITERS X 100 FLTS/ORB X 400 HRS/FLT = 48000 ΔHRS
- ΔCOST 1.2 X $732M̄/ORB = 878M̄
- HDWR COST PER ADDL HOUR BOUGHT = 878M̄ ÷ 48000 HRS = $18,292/HR
- ORBITER SUPPORT CHARGE FOR ΔDAY = 0.5M̄
  PER HOUR = 0.5M̄ ÷ 40 HRS = $12,500/HR
  ESTIMATED INCREASE = 2.1 *X 12500 = $26250/HR
- COST PER HOUR

Δ HDWR	18292
Δ SUPPORT	26250
TOTAL	$44542/HR

*FORECASTED COST INCREASE

FIGURE 4.20 BASIS FOR ORBITER SERVICE CHARGE

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5.0 CONCLUSION

This conclusion section addresses the total SOC-Shuttle Interaction study. Although the principal objective was to determine the implications to the SOC resulting from the support operations of the shuttle it becomes apparent that programmatic issues needed to be addressed in order to determine the implications. Figure 5.1 indicates the major programmatic issues that were analyzed in order to respond to the individual tasks identified for this study. The principal implication areas identified in support of the study tasks resulting from the programmatic analysis is listed for the SOC, the shuttle, and for OTV concepts. The OTV concept became very prominent in the spacecraft servicing analysis that defined a servicing fixture concept and the servicing implications to an OTV. A significant influence of the OTV was also identified when determining the number of shuttles required to support a space program mission model. A review of each programmatic issue and the associated spacecraft implications identified is discussed.

5.1 PROGRAMMATIC ISSUES

Five significant programmatic issues that pertained to the study tasks have been identified and are listed in Figure 5.1. Each of these programmatic issues are reviewed.

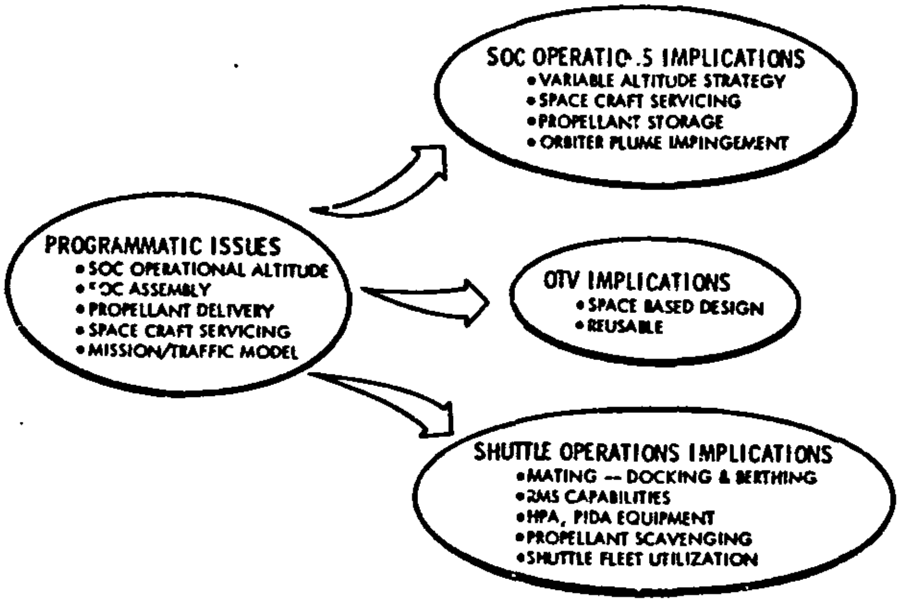

FIGURE 5.1. STUDY PROGRAMMATIC ISSUES

5.1.1 SOC Operational Altitude.

The objective is to seek out the most effective orbit altitude strategy for the SOC which utilizes the maximum potential of the Space Shuttle and at the same time provides adequate safety and an efficient operating base for the SOC.

A Variable Altitude Strategy is Recommended

A variable altitude strategy as depicted in Figure 5.2 combines safety with logistics efficiency. During periods of unusually high solar activity the SOC orbit altitude would be adjusted upward to maintain the 90-day orbit decay life criteria required for orbital safety. However, most of the time, when solar activity levels follow their nominal 11 year cycle trends, the SOC altitude can be greatly reduced to take advantage of the greater shuttle payload delivery capability at low altitudes. This improves the logistics efficiency by reducing the number of shuttle flights required to deliver a given amount of SOC cargo. Further, the actual operating altitude can be optimized for the prevailing atmospheric density and amount of SOC logistics traffic scheduled. This variable altitude approach can save 10 to 15 percent in the number of required shuttle flights to SOC compared to a constant altitude concept which must be based on the worst case decay environment and hence, must always fly at a high altitude. Thus, a variable altitude strategy is recommended.

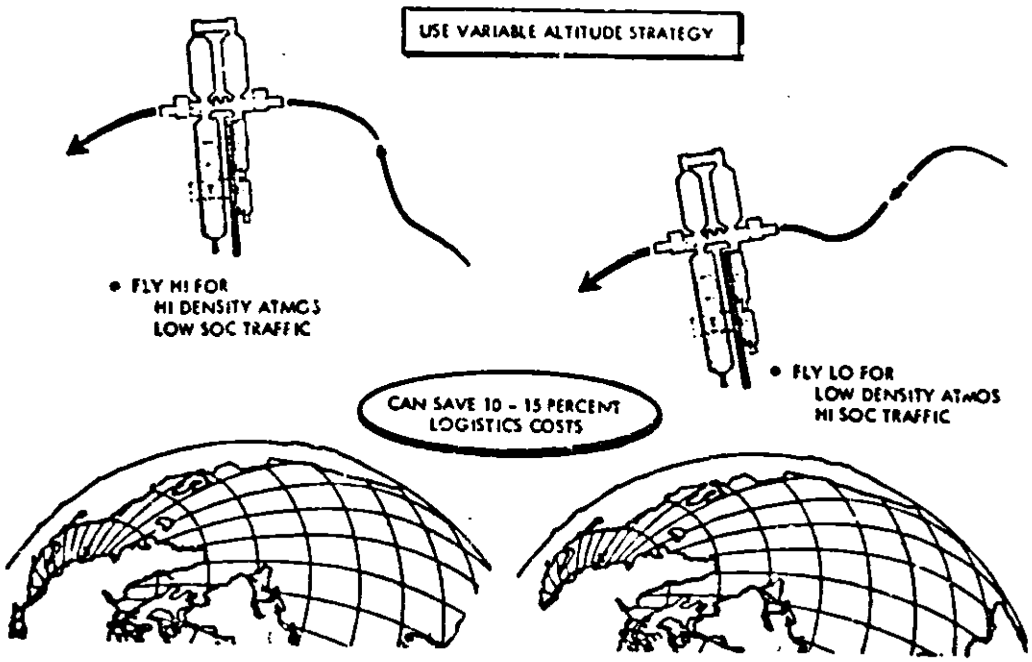

FIGURE 5.2. VARIABLE ALTITUDE STRATEGY

The Standard Orbiter can do the Job

The currently projected modular elements of the SOC configuration, such as the service modules, the habitability modules, etc., can all be delivered to orbit by the standard shuttle. These various modules, logically sized for their respective SOC mission roles, fit within the orbiter cargo bay and are well within the payload delivery capability of the standard shuttle. Normal SOC resupply, OTV propellants and other SOC cargo can also be delivered by the standard shuttle.

The extra payload capability of the thrust augmented Shuttle is not needed for the delivery of the SOC modules. However, if cost effective in terms of dollars per pound to orbit, it may prove to be more efficient for OTV propellant deliveries, but even here the standard shuttle is sufficient. The optimum SOC altitude is about 18 Km (10 nmi) higher with the augmented thrust shuttle, but varies with logistics traffic levels and density in the same manner as the standard shuttle. Therefore, both the standard and augmented shuttles are compatible with the variable altitude strategy, Figure 5.3.

Thus, while gains in logistics efficiency for weight limited payloads such as OTV propellant deliveries may be attainable with the thrust augmented Shuttle, the standard shuttle can do an adequate job. A special new delivery system is not required for the SOC.

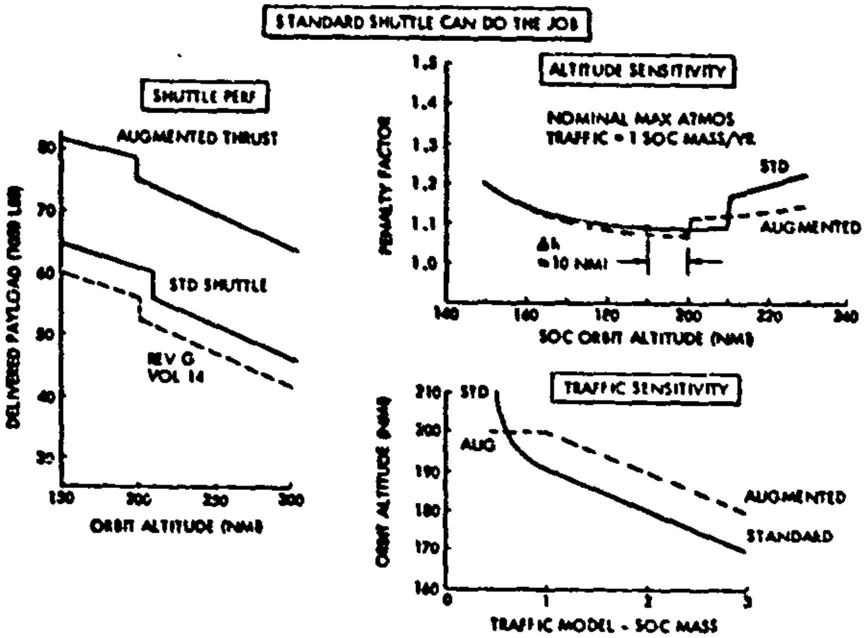

FIGURE 5.3. DELIVERY PERFORMANCE COMPARISON

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5.1.2 SOC Assembly

Many SOC configurations and many more build-up sequences are possible. The build-up sequences can be influenced by the type of planned space program particularly in the early stages. These programs can concentrate on early science objectives, spacecraft assembly, or satellite services. Annual peak funding also severely influences the planned space programs. Because of these many possible variations, Figure 5.4, the capability to assemble modules in various arrangements needs to be confirmed.

The SOC Can Be Assembled by Standard Shuttle

The shuttle is the principle vehicle to perform the modular assembly operation. Its capability utilizing the standard RMS, and other standard equipment anticipated to be operational in the late 1980's time period is desirable in order to minimize cost, crew training, and interfaces.

Utilization of the Rockwell developed computer graphic program provides a rapid means of determining SOC assembly operations. Requirements that may be imposed on the development of shuttle standard equipment such as the HPA and PIDA, Figure 5.5, can also be identified. Verification of the capabilities of the standard RMS can be obtained.

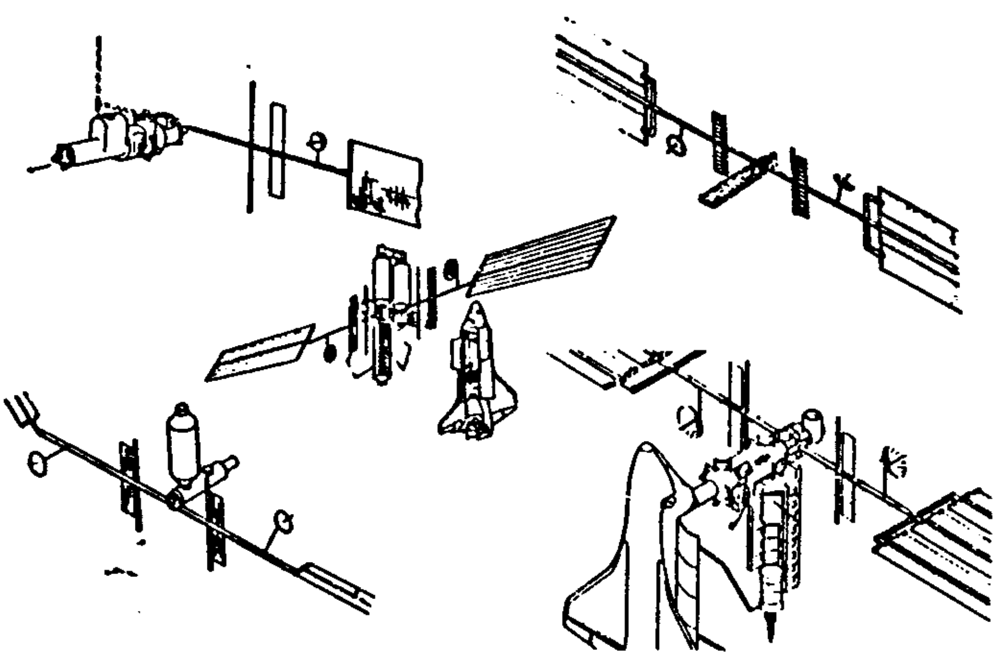

FIGURE 5.4 EARLY OPERATIONAL CONCEPTS

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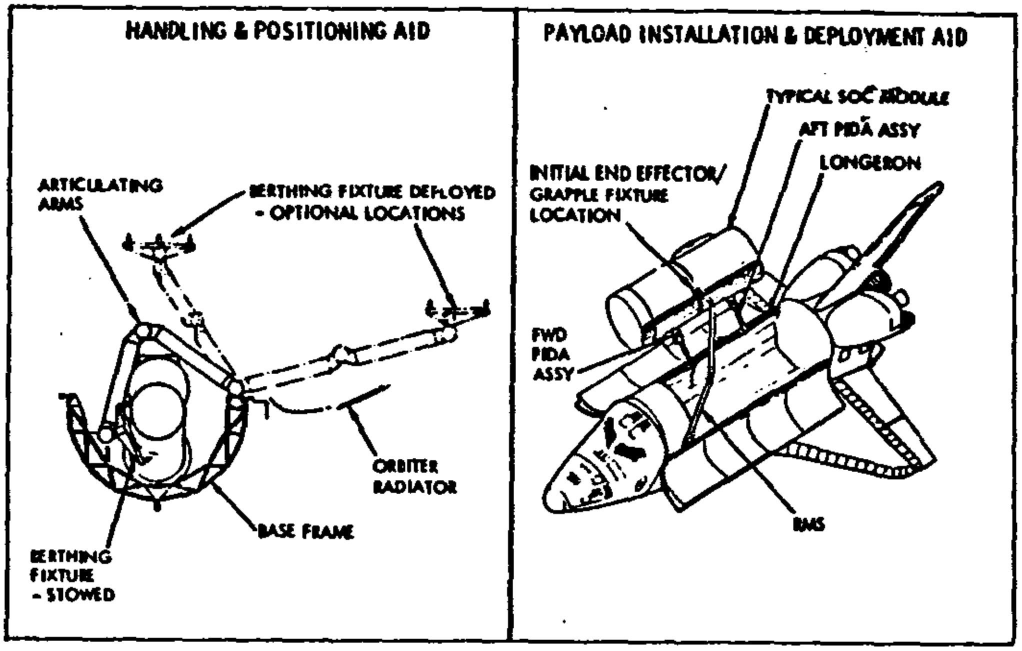

FIGURE 5.5 ASSEMBLY AIDS

A Standard Mating Interface Can Be Provided

Other space programs also require the mating of modules, or of the orbiter to a spacecraft. The standard interface concept developed for the SOC mating operations may also be utilized for these other space program elements, Figure 5.6. The docking module concept for the orbiter provides a standard interface for use with these programs as well, Figure 5.7.

RMS Berthing Requires Software Mods, But Appears Feasible

Two modes of mating the orbiter to spacecraft have been identified, berthing and docking. The berthing operation is distinguished from docking by mating of the orbiter with a spacecraft by use of the RMS. This operation is the prime mode for early shuttle missions. These early mission berthing operations are performed on spacecraft weighing less than 29,465 Kg (65,000 lbs), the design criteria for the RMS. Mating of the orbiter to larger spacecraft, such as the SOC, may be advantageous by minimizing mating impact loads. Simulations of berthing the orbiter to SOC with the RMS have indicated that this mating mode can be achieved with the present RMS, but requires operational changes that necessitate revisions to the present RMS control software, Figure 5.8.

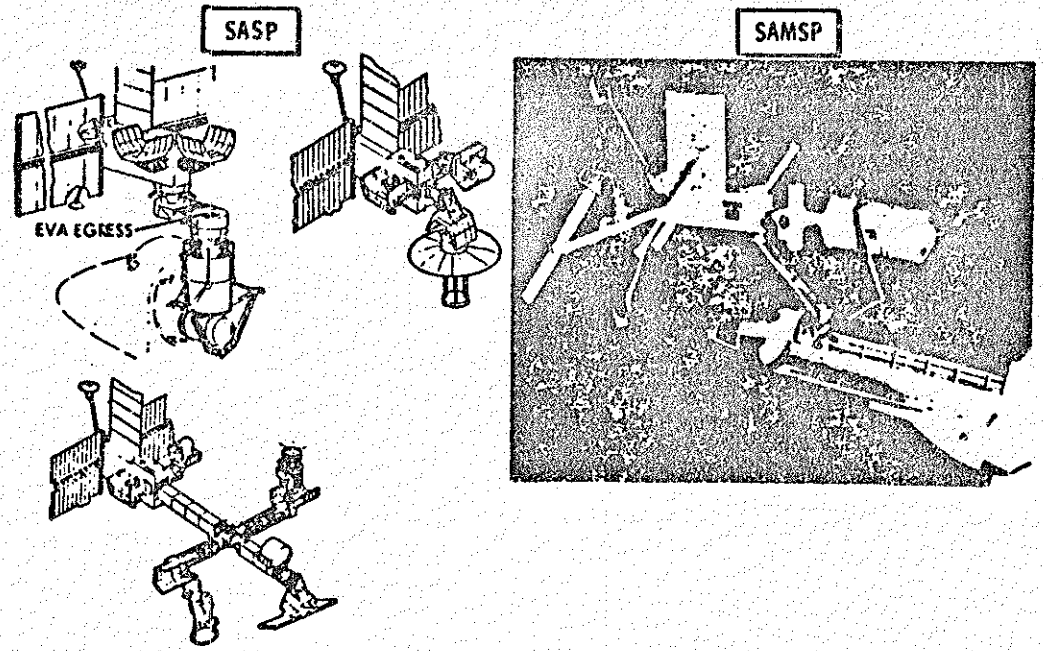

FIGURE 5.6 SPACE PROGRAM ELEMENTS REQUIRING MATING

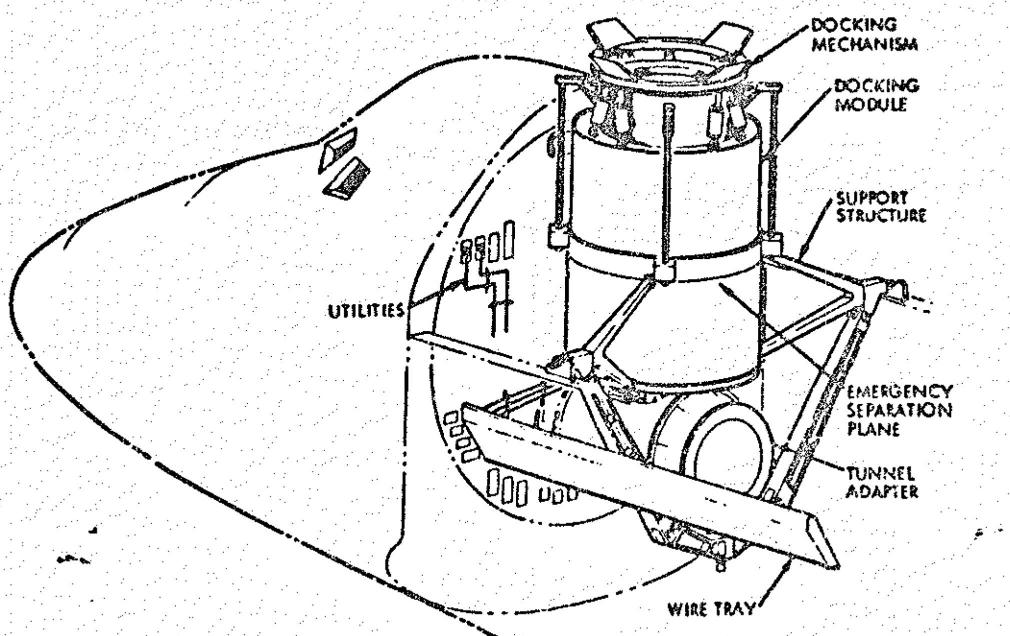

FIGURE 5.7 DOCKING MODULE CONCEPT

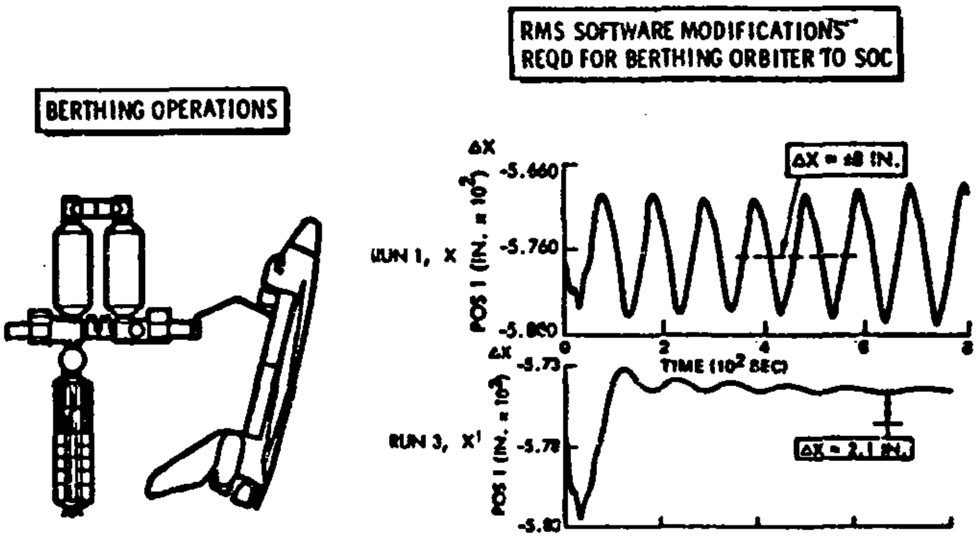

FIGURE 5.8 SHUTTLE BERTHING

The Orbiter Can Dock With The SOC

The docking mode of mating consists of the direct approach/control of the orbiter to achieve a physical attachment. Simulations of orbiter proximity operations relating to docking have verified the orbiters capability to safely perform this docking operation, Figure 5.9. A runaway RCS jet condition, however, is possible and serious consequences could occur if this condition occurs during the docking operation. However, adequate emergency control modes, Hi-Z RCS thrust, are available within the orbiters control system that permit abort maneuvers to provide safe recovery from a run away jet occurrence, Figure 5.10.

The SOC Should be Designed to Accommodate Orbiter RCS Plume Effects

During the SOC's operational life time, many orbiter matings will be accomplished. Each mating, either in a berthing or docking mode, will create orbiter RCS plume pressures, temperatures, and particle deposit effects to the SOC. Run away jet abort operations provide the most severe single occurrence effects, Figure 5.11 and Table 5.1. Space based, reusable OTV's that return to the SOC for refueling and servicing many also contribute plume effects to the SOC.

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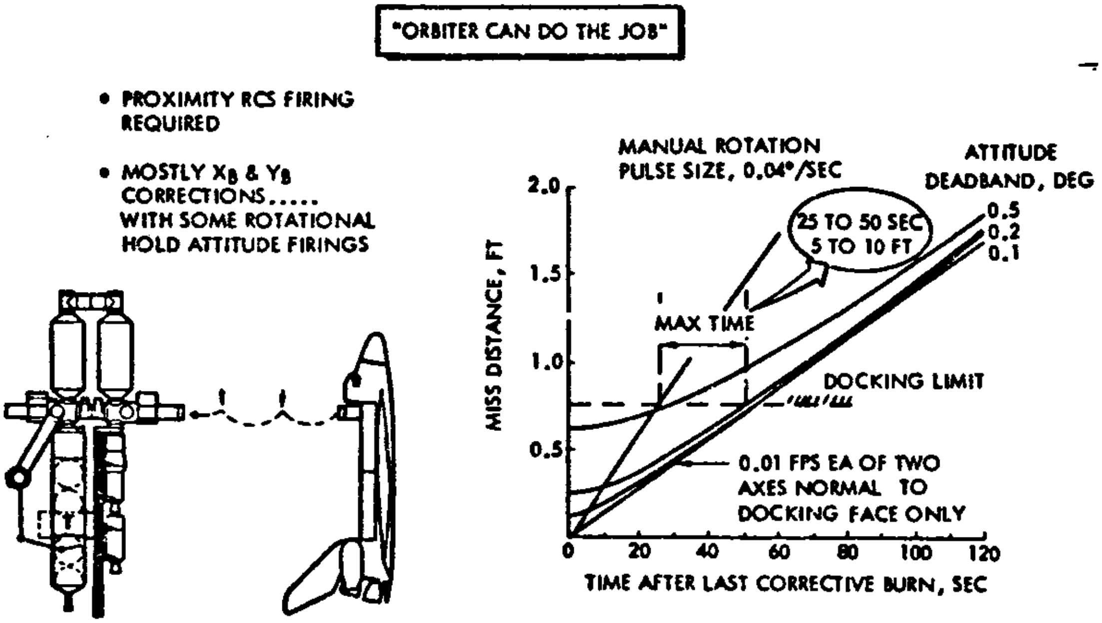

FIGURE 5.9 DOCKING TRAJECTORY ACCURACY

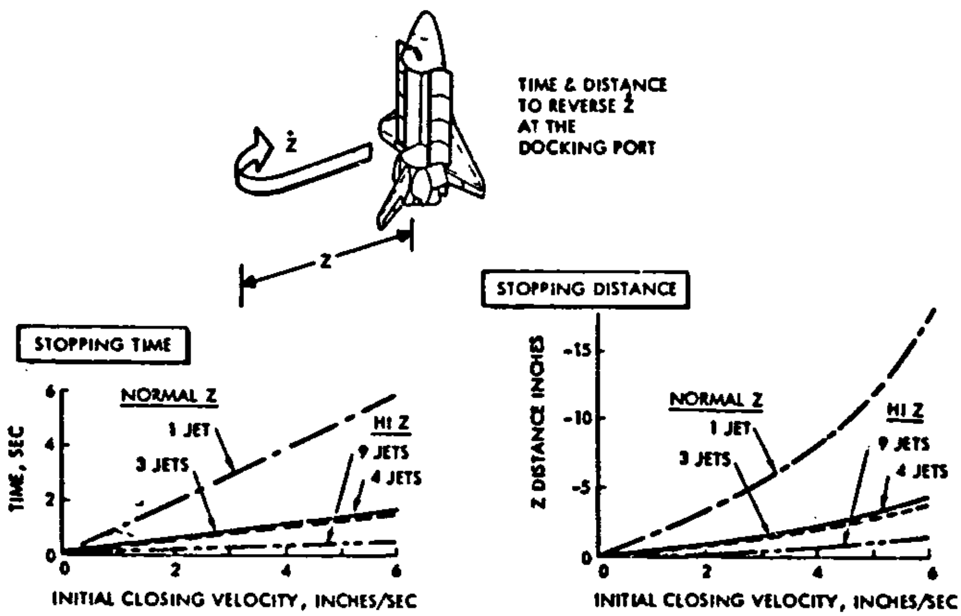

FIGURE 5.10 DOCKING ABORT TURNAROUND

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TABLE 5.1 ORBITER RCS PLUME IMPINGEMENT RESULTS SOC

DESCRIPTION	MASS DEPOSITION RATE (lbm/sec)	SOC IMPINGEMENT FORCES (lb_f)			SOC MOMENTS (lb_f-ft)			CONVECTIVE HEATING RATE (Btu/sec)
		F_x	F_y	F_z	M_x	M_y	M_z	
FWD RCS, 3 ENGINES (+Z DIRECTION)								
HABITABILITY MODULE NO. 1	3.146	581.1	0	41.8	0	24,058.1	0	7730.0
LOGISTICS MODULE	0.272	59.7	-11.7	-60.6	809.6	-508.2	695.0	637.7
SERVICE MODULE NO. 1	0.266	41.2	0	-29.0	0	-289.4	0	609.9
TOTAL	3.684	1082.0	-11.7	-47.8	809.0	23,260.5	695.0	
AFT RCS, 6 ENGINES (+Z DIRECTION)								
PARKED PLANETARY VEHICLE	0.354	90.6	0	50.8	0	-5,185.7	0	773.2
SAM**	2.564	867.2	0	-70.2	0	-67,579.0	0	6540.6
A/CM MODULE	0.280	60.0	23.5	35.2	1758.7	-3,255.6	-747.9	569.8
TOTAL	3.198	1017.8	23.5	19.8	1758.7	-76,020.3	-747.9	
-Y THRUSTER, 1 ENGINE								
SOLAR ARRAY (@ 52° ANGLE)	0.720	116.7	-171.4	-45.1	6018.4	-1957.3	19,554.1	1659.8
4.3 m ANTENNA (-Y DIRECTION)	0.036	3.2	-5.4	-0.4	123.2	55.2	220.6	45.9
RADIATORS (-Y DIRECTION)	0.009	2.3	-1.4	-0.5	35.1	20.3	79.0	20.6
TOTAL	0.765	122.2	-178.2	-46.0	6176.7	-1881.8	19,853.8	

*NOTES: (1) ONE ENGINE PRODUCES 870 lb_f THRUST
(2) MASS FLOW RATE OF ONE ENGINE—3.01 lbm/sec
(3) MASS FLUX CONTAINS APPROX 9% CO_2, 17.5% CO, and 29.2% H_2O

**ASSUMED THAT THE SAM WAS OPAQUE (INTERNAL PARTS STOWAGE)

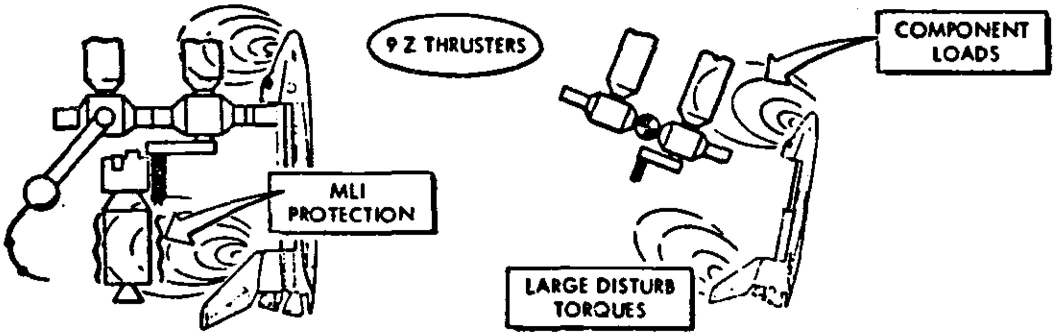

FIGURE 5.11 HI-Z ABORT THRUSTING PLUME EFFECTS

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5.1.3 Propellant Delivery

The space based, reusable, OTV has been identified as the prime vehicle for the transport of spacecraft to GEO. This mode of operation requires propellant to be available at the SOC to refuel the OTV. The delivery of the propellant effects the number of shuttle flights and/or the possible inclusion of a HLLV in the space program inventory. This operation, therefore, becomes a major driver in the establishment of a viable space program.

Recovery of Shuttle External Tank Unused Propellant Appears Feasible

The concept developed that permits the delivery of propellant to the SOC with the least impact to the traffic model is that of recovering unused propellant from the shuttle ET. The concept is depicted in Figure 5.12. This capability permits maximum payload deliveries to the SOC by incorporating payload "top-off" concepts. Figure 5.13 illustrates three possible arrangements that can provide maximum payload efficient flights.

The incorporation of this ET propellant concept can deliver sufficient propellant to the SOC to refuel the OTV flights without requiring a dedicated shuttle propellant delivery flight, or the necessity for a HLLV to deliver propellants.

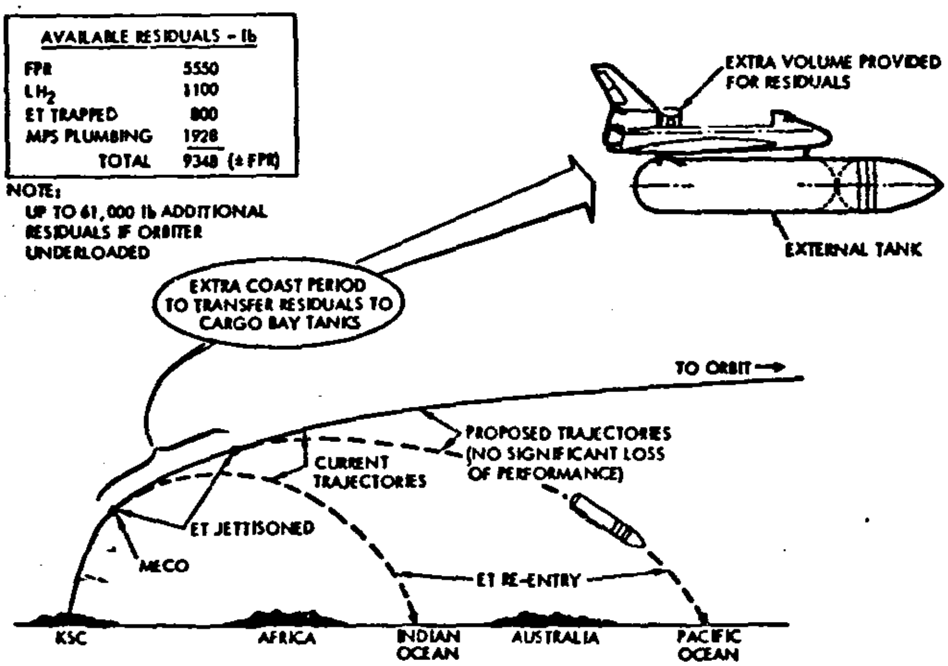

FIGURE 5.12 ET RESIDUALS RECOVERY CONCEPT

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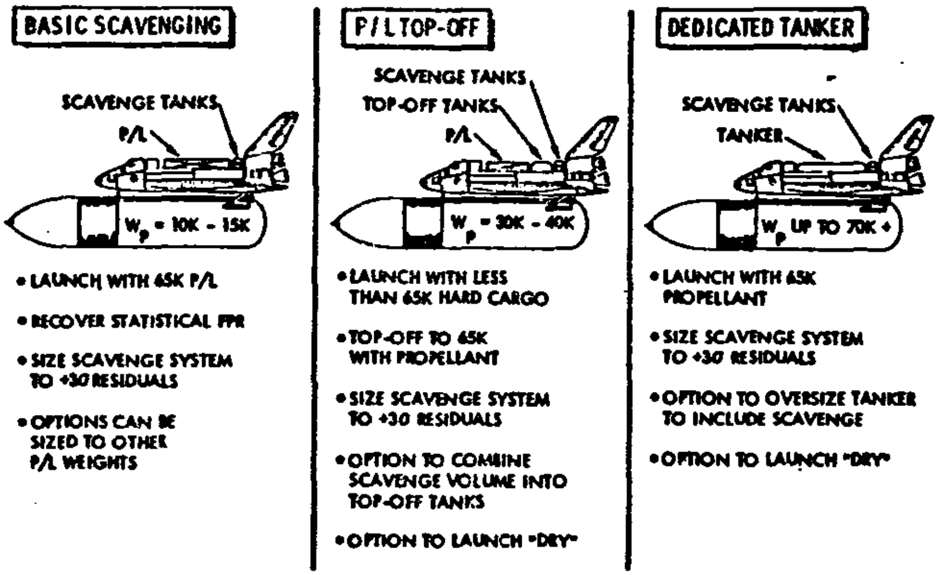

FIGURE 5.13 POSSIBLE SCAVENGING SCENARIOS

Propellant Storage on SOC is Recommended

Propellant storage tanks on the SOC and refueling systems are necessary in order to accommodate the propellant delivery and OTV servicing operations. The SOC will provide this capability utilizing advanced cooling systems to maintain cryo conditions in the most efficient manner. All control of the propellant transfer from the orbiter and to the OTV's will be from the SOC.

5.1.4 Space Craft Servicing

The space program contains various types of spacecraft that can profit from periodic in space servicing. The servicing operation can include servicing and refueling of an OTV, the assembly of a satellite, or the periodic servicing and exchange of raw materials and finished products.

Spacecraft Servicing at SOC Appears Most Cost Effective

Performing these services from the SOC compared to servicing from the orbiter or from the ground appears to be the least expensive. The cost of the man hours required to perform the operations plus the cost of the equipment required to do the tasks are indicated in Table 5.2.

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TABLE 5.2 COMPARISON SUMMARY

	EVALUATION FACTORS								
	NO. OF UNIQUE EQUIPMENT	ELAPSED TIME (HRS)	MAN-HOURS	NO. CREW	** EQUIPT COST($M)	LABOR COST($M) PER SERVICING	ORBITER FLIGHT COST ($M)	NO. OF SERVICING MISSIONS	USER 11-YEAR OPERATIONAL COST ($M)
SPACE BASED OTV	3	57.3	193.7	3-5	8.5	4.72	-	172	820
GROUND BASED OTV	5	140	600	3-6	27	2.76	3.56	331	2119
COMM-SAT-SOC	2	61.0	200	2-5	0.3	4.88	-	92	449
COMM-SAT-ORBITER	2	50.8	165	2-4	3.5	7.34	3.56	251	2739
SPF - SOC	3	29.4	103	3-4	14.2	2.51	8.73	110	1251
SPF - ORBITER	4	27.5	106	2-4	9.6	4.72	16.1	110	2300

** LESS DDT & E

5.1.5 Mission/Traffic Model

Traffic Analysis

Detailed traffic analyses were conducted for SOC and non-SOC options based on a mission model projecting overall space program needs through the year 2000. Specific comparisons were made for the years 1990 through 2000, the years applicable for the SOC - no SOC trades. A number of representative cargo manifests were synthesized covering the various mission categories. These manifests were utilized to determine orbiter unused payload capacity, either volume or weight. For the SOC scenario option these unused capacities were topped off with OTV propellants. Also, ET propellant scavenging was applied to further increase the amount of propellant delivered on each flight. These techniques resulted in orbiter load factors approaching 1.0 for the SOC scenario while values for the non-SOC case were around 0.4. This is reflected in the total traffic levels for the two cases where the total number of flights was 436 and 558 for the SOC and non-SOC scenarios respectively. Thus, the use of a Space Operations Center was shown to save up to 112 shuttle flights over the 11 year period of interest. Peak annual flight rates were down also, from 62 per year for the non-SOC case to 48 yer year for the SOC scenario.

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Traffic Sensitivity Analysis

Traffic sensitivities for five important variables were determined for the SOC related components of the overall traffic model. The key variables are: OTV performance, shuttle performance growth, aerobraking technology for OTV's, elimination of propellant scavenging, and changing from a variable altitude strategy for SOC to a constant altitude strategy. The results are summarized in Table 5.3. Degraded OTV performance, eliminating propellant scavenging and applying a constant altitude strategy, can all require dramatic increases in the number of shuttle flights. Increased shuttle payload performance and the application of aerobraking technology to the OTV can significantly reduce the number of shuttle flights required, but only if very high packaged densities can be attained by the payload designs. These high densities are two to three times higher than current payload definitions (excluding propellant/fluid deliveries) which suggests they will be difficult to attain.

Dedicated Orbiter

Analysis has shown the feasibility and desirability of employing a dedicated orbiter for SOC logistics operations. Flight rates to the SOC are sufficiently high to essentially keep one equivalent orbiter fully utilized. Also, by dedicating an orbiter to SOC missions certain unnecessary equipment can be removed which yields more than 2000 lbs of extra payload per flight.

TABLE 5.3 TRAFFIC SENSITIVITIES

REFERENCE VALUES (11 YR TRAFFIC):
N = 247 FLIGHTS ρ_{AVG} = 2.5 lb/ft^3

FACTOR		ΔN SHUTTLE FLTS	ρ_{AVG} lb/ft^3
OTV PERFORMANCE:	$\Delta\lambda$ = -0.01	+35 +26	2.5 5.3
	ΔIsp = -10 sec	+19 +14	2.5 5.4
STS P/L PERF: 80K ORBITER		0 -57	2.5 7.1
AEROBRAKING		0 -27	2.5 6.3
NO SCAVENGING (a) 9000 lb/FLT (b) 3% LOAD FACTOR		+61 +12	-7 -1.35
CONSTANT ALTITUDE STRATEGY		+52	3.5

In the SOC scenario this extra payload can be fully exploited using the payload topoff and propellant scavenging techniques. With these techniques propellant is added to each payload manifest either on the ground through payload topoff or after MECO with propellant scavenging (or both) to bring the effective load factor to a value of 1.0 or more. Load factors greater than 1.0 are possible with propellant scavenging. Since these propellants are needed by OTV's based on the SOC they represent useful payload. Thus, a dedicated orbiter for SOC logistics makes sense.

Fleet Size Analysis

Fleet utilization analyses have shown that for the peak annual flight rate projected for the SOC mission scenario (48 flights per year) a fleet of three orbiters will meet the traffic needs. This offers fleet capacity margin to handle uncertanties in contingencies and relative mission priorities (DOD vs civil, etc.). Fleet size is greatly affected by flight rate and ground turnaround time. An increase in flight rate of about 12 flights per year or an 8-day increase in turnaround time would each require one additional orbiter in the fleet. Also, the higher flight rates required without a SOC will generally require one more orbiter in the fleet. regardless of the contingency and mission priority criteria that are established, as long as they are the same for both SOC and non-SOC cases.

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