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SPACE PLATFORM EXPENDABLES RESUPPLY

CONCEPT DEFINITION STUDY

STS 85-0174

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This final report of the Space Platform Expendables Resupply Concept Definition study was prepared by the Advanced Engineering organization of the Space Transportation Systems Division of Rockwell International Corporation for the Marshall Space Flight Center (MSFC) of NASA in accordance with Contract NAS8-35618. The study was conducted under the direction of the MSFC Contracting Officer Representative (COR), Mr. Wilbur Thompson, during the period from March, 1984 through December, 1984. The final report is organized into four documents:

Volume I - Executive Summary
Volume II - Study Results
Volume III - WBS and Dictionary
Volume IV - Cost Estimate

Personnel who made major contributions to the study effort are:

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The study was also supported by a subcontract to Science Applications, Inc. personnel, under the leadership of Dr. Brian O'Leary. Useful information was also received from SPAR Incorporated, Seton-Wilson Corporation, and MBB-ERNO.

Executive Summary Contents

Illustrations

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Acronym Dictionary

DRM	Design Reference Mission
ERM	Expendables Resupply Module
ETR	Eastern Test Range
GEO	Geosynchronous Orbit
GSE	Ground Support Equipment
IP	Integral Propoulsion
JSC	Johnson Space Center
LEO	Low Earth Orbit
MMH	Monomethylhydrazine
MSFC	Marshall Space Flight Center
NTO	Nitrogentetroxide
OMS	Orbital Maneuvering System
OMV	Orbital Maneuvering Vehicle
OTV	Orbit Transfer Vehicle
ROM	Rough Order of Magnitude
SDI	Strategic Defense Initiative
SPER	Space Platform Expendables Resupply
USAF SD	United States Air Force Space Division

Vol 1

Volume I is the Executive Summary. ABA Author

1.0 INTRODUCTION

@ABS

NASA has recognized that the capability for remote resupply of space platform expendable fluids will help transition space utilization into a new era of operational efficiency and cost/effectiveness. The emerging Orbital Maneuvering System (OMV) in conjunction with an expendables resupply module will introduce the capability for fluid resupply enabling satellite lifetime extension at locations beyond the range of the Orbiter. This report summarizes a Phase A study of a remote resupply module for the OMV.

1.1 Background

Numerous studies have been performed in recent years concerning the transfer of fluids to satellites within the Orbiter payload bay. These studies have mainly focused on the transfer of hydrazine (N_2H_4). On a recent Shuttle flight, transfer of hydrazine using man-in-the-loop was demonstrated within the Orbiter payload bay. Also the Air Force is considering incorporation of interface requirements allowing on-orbit fluid transfer in future satellites (with notable applications to SDI). It is apparent that the era of fluid transfer on-orbit is emerging and that remote expendables resupply will become a recognized requirement for future satellites and/or propulsion modules.

1.2 Objectives and Scope

The overall objectives of the study are summarized as follows:

Objectives	Task
1. Develop Performance & Operational Requirements associated with critical liquids, gases, and lubricants resupply 2. Develop Design Requirements for the resupply module (ERM) & equipment needed in conjunction with OMV to perform remote fluid resupply functions	Task 1 = 60% of study
3. Develop resupply module Concept Designs (including tankage, transfer systems & supporting mechanisms) & associated spacecraft adaptation (user interface emphasis) 4. Define a Flight Demonstration Program for automated remote fluid resupply	Task 2 = 30% of study
5. Develop Program Planning Data, including cost, schedule & preliminary supporting development program	Task 3 = 10% of study

The study scope was initially limited to the definition of remote fluid resupply concepts for satellites/space platforms; keeping in mind a concurrent servicing system for repair, maintenance, and module change-out. This scope includes fluid transfer to propulsion modules for LEO and higher energy orbit satellites/platforms (expendable or reusable), but not to the space station. This assessment of resupply benefits, with and without other types of servicing was intended to confirm a comprehensive justification for future remote resupply operations.

1.3 Guidelines and Assumptions

The guidelines and assumptions established at the start of and during the study are summarized below:

- o Utilize available data from related study/development activities, including propellant transfer experiments, upper stage design, operations studies, and space station/platform studies.
- o Incorporate results of In-Bay Fluid Transfer Experiment from STS 41-G.
- o Insure coordination with space station/OTV fluid resupply studies.
- o Propellant supply facilities will be assumed to exist as part of the Shuttle, space station, or separate depot facilities.
- o The study scope was initially limited to investigation of fluid resupply; keeping in mind a concurrent servicing system for repair, maintenance, and module change out.
- o Assuming that fluid resupply may be required prior to full-capability spacecraft servicing, the impact of remote spacecraft servicing on nominal fluid resupply modes will be considered.
- o The proposed system must meet all manned safety criteria during initial transport to low earth orbit and if returned to the orbiter or manned station after a resupply mission.

1.4 Study Flow and Methodology

The study tasks and their relationship to each others are shown on figure 2.

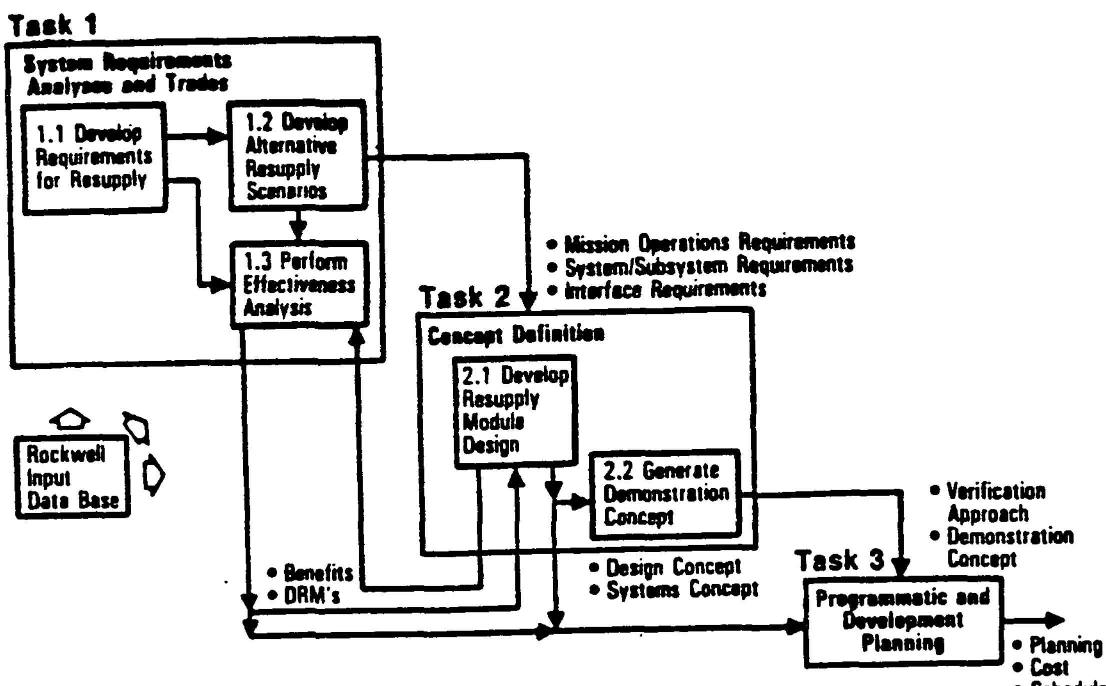

Figure 2. Study Flow

Task 1, System Requirements, Analysis and Trades, was the focus of the mid-term review. In subtask 1.1, resupply requirements were generated in the form of a mission model. Next, fluid parametric requirements were generated for this mission model to determine fluid types, quantities and usage rates for resupply. This data was then examined to allow selection of candidate spacecraft and platforms for resupply. In Subtask 1.2, alternative scenarios were developed and screened for effectiveness. Mission operational and system/subsystem requirements were next generated for these slected scenarios, to provide data in support of the effectiveness analysis (and for the Task 2 design analysis after selection of the Design Reference Missions).

The study effort after the mid-term review concentrated on the development of resupply module concept designs to meet the approved Design Reference Missions (DRM's) resulting from this review (Task 2). Continued effectiveness analysis (subtask 1.3) resulted in the definition of specific requirements for these DRM's in LEO and GEO as well as expanded benefits assessments. In addition the definition of a flight demonstration program and a supporting technology program was accomplished.

Finally Task 3 involved programmatic planning and cost/schedule data development for the technology and flight demonstrations as well as the initial operational segments of the total program.

2.0 SUMMARY OF RESULTS

2.1 Major Conclusions

The remote resupply alone of LEO satellites is found to be of potential economic benefit but resupply combined with servicing is much more advantageous. The latter case can be most effectively accomplished at the orbiter. Hence, remote expendables resupply alone was not recommended for these satellites. Certain DoD satellites in high inclinatioin LEO orbits will require relatively frequent expendables resupply to avoid costly replacement. Since, it will likely be desirable to accomplish these resupply operations without dependence on the orbiter the need for a LEO propellant storage depot with a space-based OMV/ERM is emphasized.

The major commercial industry drivers for GEO resupply relate to satellite revenues. They are a function of the total number of operating transponders and the number of transponders per satellite, transportation costs, satellite production costs, insurance costs, and technological obsolescence.

Lifetime extension of satellites through attitude control subsystem (ACS) resupply is of marginal benefit without concurrent servicing of the satellite electronics. This is due to the relatively rapid rate (assumed 12% annual) of technological obsolescence. Planned lifetime extension where the satellites reliability is increased (and also the initial satellite cost) turns out to be the least attractive scenario because of the increase up front development and production costs. Additionally contingency resupply of satellites which have depleted their fuel from malfunctions is always cost effective, if the problem can be isolated and resolved early in the satellite's life when interruption of the revenue stream can have the greatest impact.

Though adding additional transponders at the expense of ACS fuel increases the total revenue from a satellite, it is not cost effective primarily because of the risk involved in assuring future operation. Less onboard fuel will require more frequent (Optimally 2 in a 10 year period) resupply missions increasing the risk to the satellite revenue stream. Insurance premiums of less than 15% are required to make this resupply case viable.

The resupply system can be configured for reasonably low impact on the receiver spacecraft. The impact is primarily required interface provisions. The ullage exchange propellant transfer process has the inherent versatility to adapt to different receiver propulsion systems; regulated, pressure fed, blowdown, or pump fed without severe weight impacts to the receiver spacecraft.

Servicing large satellites is generally more cost effective than smaller satellites because large satellites house more transponders which may be serviced on only one mission. Multiple manifesting of missions achieves the same benefit when the transponders are spread over several smaller satellites.

If a Comsat undergoes a low rate of revenue loss due to technological obsolesence there is less incentive to resupply and upgrade it. If this rate can be held to 6% or lower it is unlikely that resupply/servicing will be beneficial unless a revenue restoration level greater than 100% can be realized. At a 12% obsolesence rate a revenue restoration of 70% is required to assure a positive impact to the satellite revenue stream.

The DDT&E costs for the resupply module demonstration program could be reduced by exploiting the synergysm with the NASA-JSC Orbiter in-bay earth storable propellant tanker program. Although the JSC program is being configured for different functional requirements and missions, it will potentially result in certain common technology development or modifiable hardware. Such hardware could include interface components, Mission Peculiar Equipment Support Structure (MPESS) (as tankage support for in-bay tanker and resupply module flight demonstration), and propellant pumps.

2.2 Selected Options

Ullage exchange was selected as the best option for the N_2O_4/MMH fluid transfer process. This approach is applicable to all potential receiver propulsion subsystem and acquisition types through appropriate modifications. It minimizes pressurant resupply requirements, involves no adiabatic compression (explosion hazard), requires no waste or hazardous effluent scavenging, and provides constant pressure resupply.

Bi-propellant N_2O_4/MMH fluids were chosen for the resupply module since they are compatible with some GEO propulsion systems, with the OMV propulsion subsystem, and they are scavengable from orbiter OMS tanks.

Figure 3 presents ten scenarios of bi-propellant use (some without helium) which were selected as the design reference missions. Scenarios 1 and 2 are respectively contingency and planned resupply in GEO. Scenarios 6 and 7 are similar operations to 1 and 2 but in LEO. Scenario three is top-off a satellite integral propulsion subsystem. Five is refueling of a perigee stage from the OMV/ERM; eight is similar to five but also includes an apogee burn Resupply Module staging, and OMV aerobraking maneuver on return. In scenario nine only the OMV is being resupplied. Four is a coupling of resupply modules in LEO which function as a depot. Finally, in ten propellant is being transferred from the orbiter to the depot through the OMV.

A propellant depot becomes most attractive if one uses the basic resupply module as the "core" element of the depot. Several of these modules could be used to achieve the desired storable propellant capacity. This could reduce development costs for the depot.

Propellant top-off capability in LEO via remote resupply would allow launch in the STS of up to four satellites with one or more in an off-loaded condition. this could significantly exceed the current payload capability of the orbiter. Near term use of propellant top-off capability may also be applicable to currently projected larger DOD satellites which if launched fully loaded, would exceed STS lift capacity.

An additional application of the ERM would be to fuel a high performance reusable perigee stage being studied at McDonnell Douglas. This stage would be capable of launching a 12K lb payload into GEO after fuelling by a resupply module.

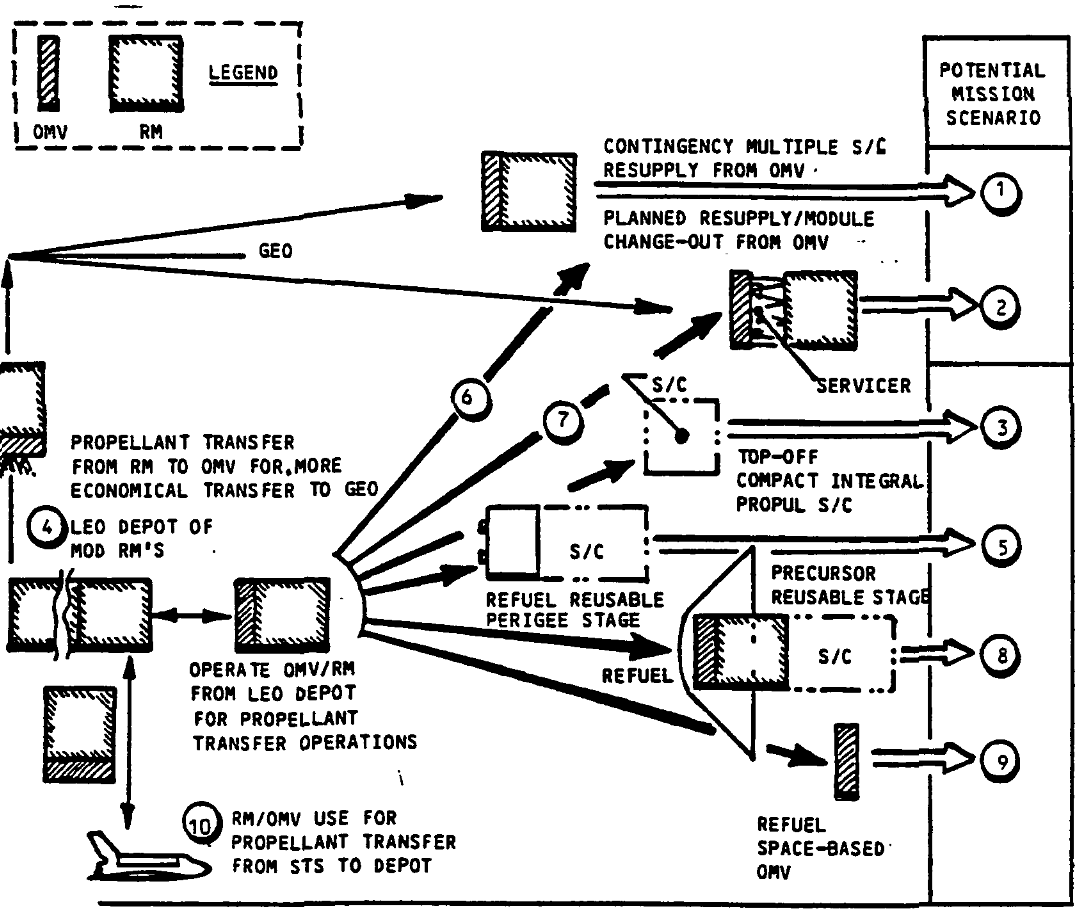

Figure 3. Selected Mission Scenarios

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2.3 Recommended Approach

The selected resupply module configuration is shown in Figures 4 and 5 and is presented in two configurations; without and with the satellite servicer. This concept was selected from among several competing approaches primarily on the basis of overall structural efficiency and for it's use of existing hardware providng low development cost. The resupply module is supported at its forward end by an existing IUS upper stage forward cradle. This cradle includes load equalization capability which reduces the structural redundancy between the resupply module and the orbiter. It also allows a minimum of weight impact on the resupply module for attachment to the orbiter payload bay longerons and keel at its forward end. The resupply module uses six stretched OMS tanks with a modified ullage positioning propellant management device (PMD) for ullage bubble position control.

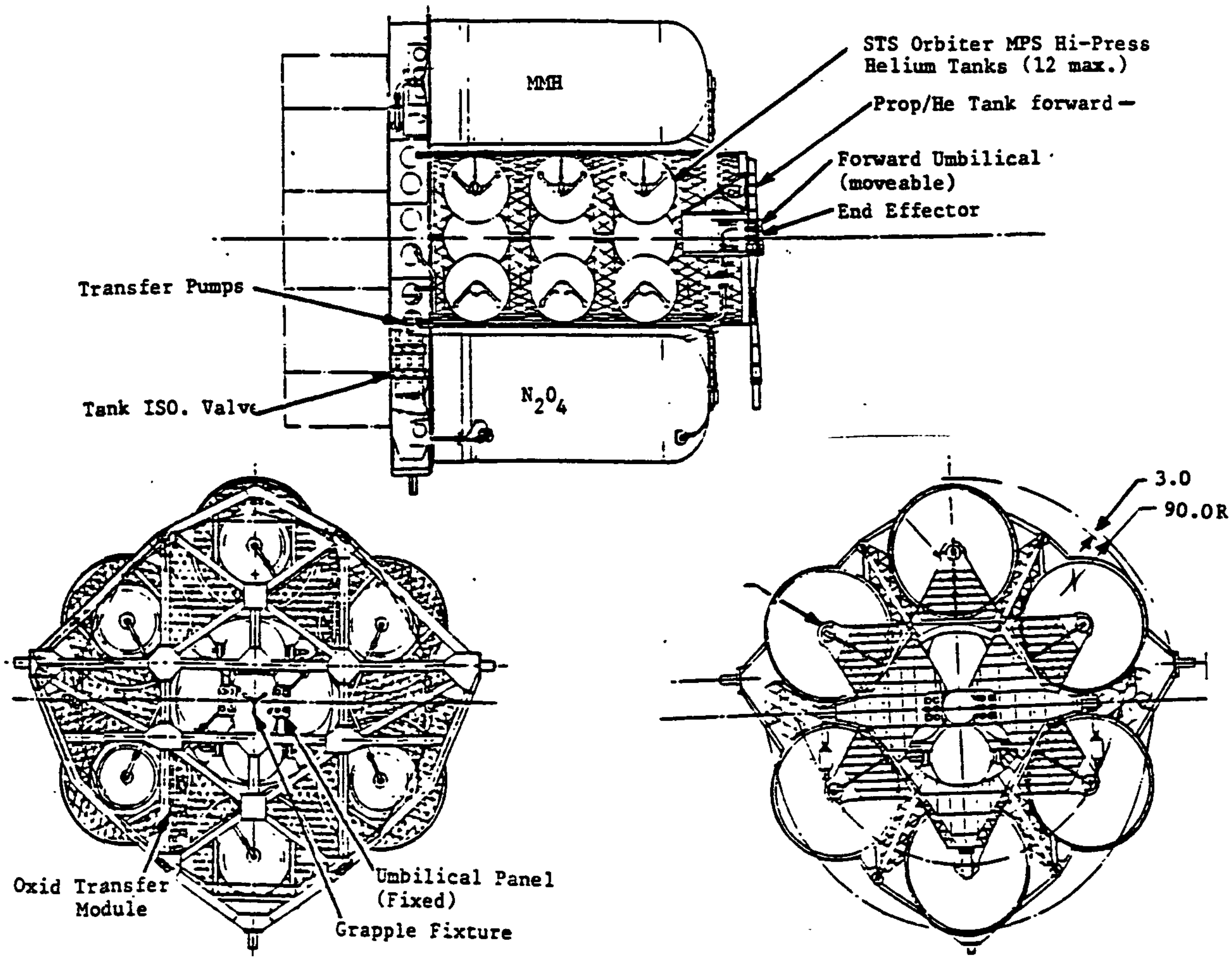


Figure 4. Resupply Module General Configuration (Without Servicer)

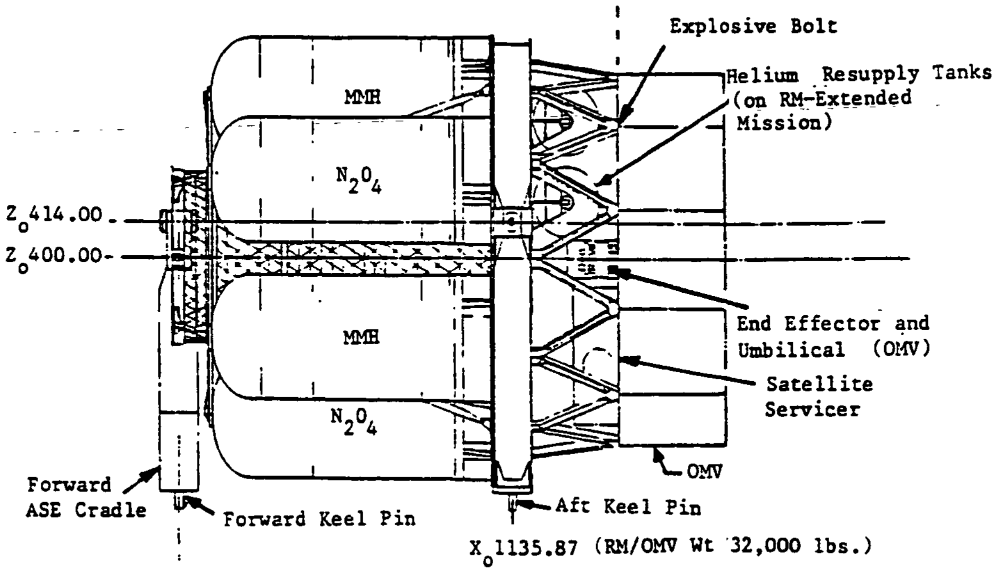


Figure 5. Resupply Module General Configuration (With Servicer)

The selected flight demonstraton approach uses hardware developed through a low-cost Technology Validation Program and many off-the-shelf components in conjunction with a low-cost structural framework. Two modules, both of nearly identical configuration, would be docked together in the payload bay using the RMS. Subsequently, storable bipropellants plus helium transfer would be demonstrated without man-in-the-loop. One module would represent the receiver spacecraft and the other the resupply module. Most of the components, except the main tankage (because of its small size) would later be used for operational resupply units to allow significant program cost savings. The selected flight demonstration concept is depicted in Figure 6.

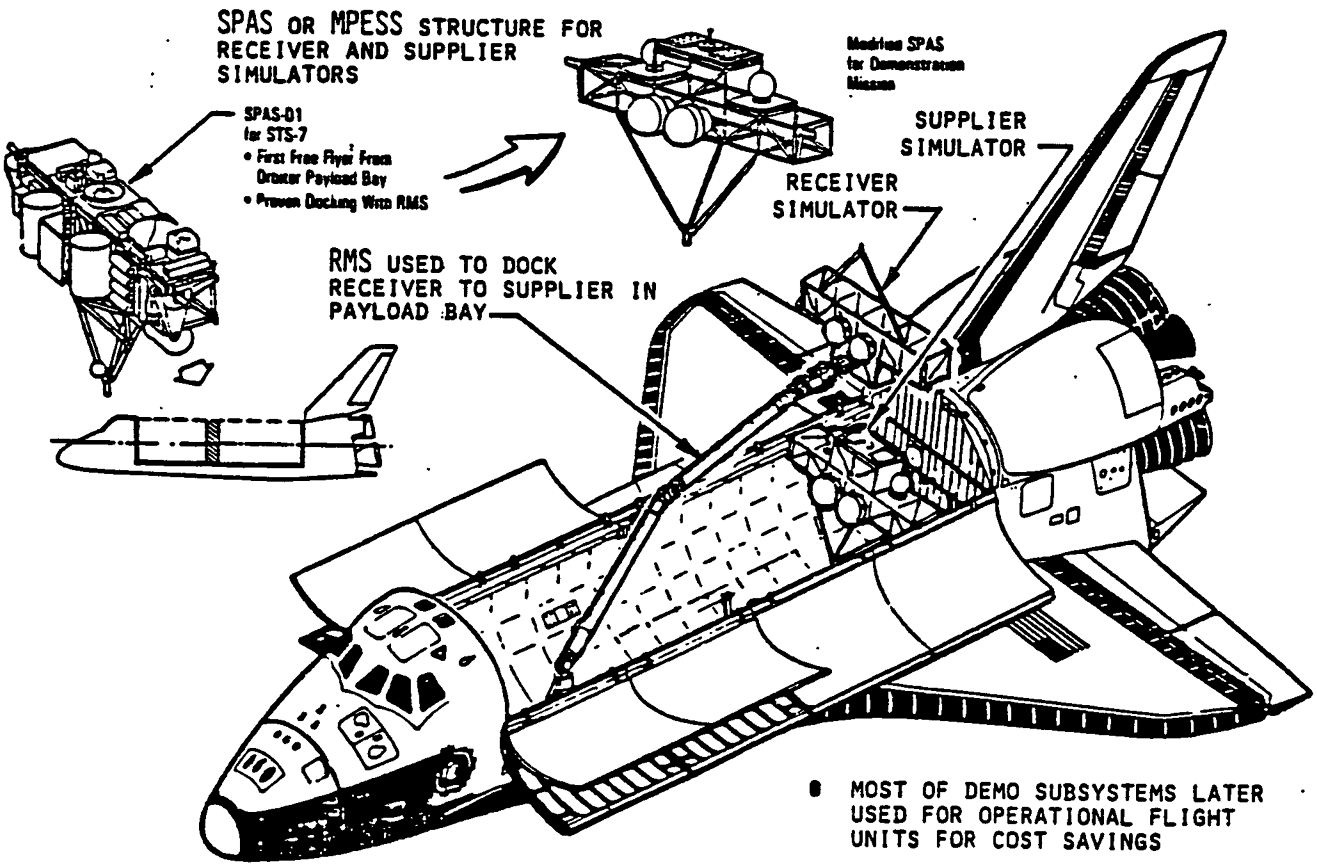


Figure 6. Bi-Propellant/Helium Transfer Flight Demonstration Concept

3.0 STUDY RESULTS

This section presents the analyses associated with the Space Platform Expendables Resupply Concept Definition Study.

3.1 System Requirements Analysis and Trades (Task 1)

The overall activities of the system requirements analysis and trade studies are shown in Figure 7, followed by a description of the main study accomplishments.

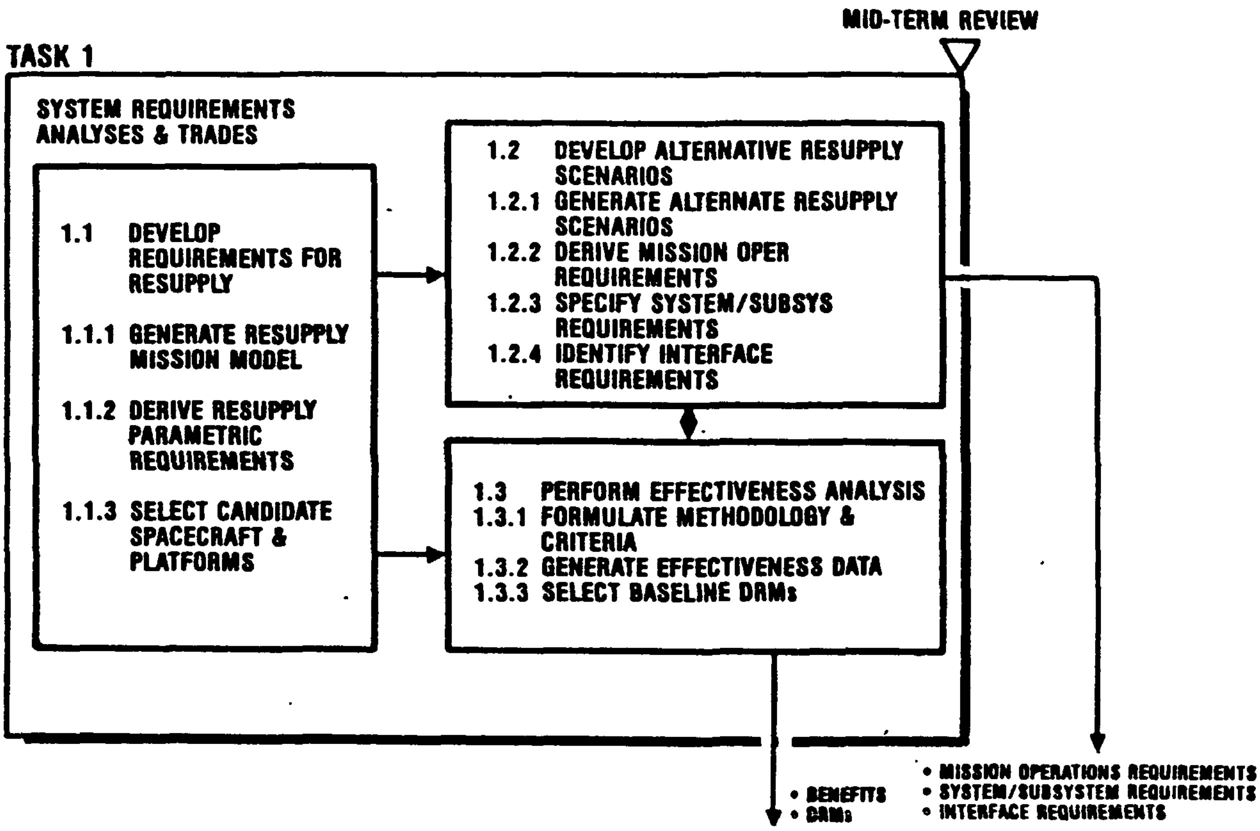


Figure 7. Task 1 Activities

Mission Model

A detailed mission model of fluids resupply was developed in Activity 1.1.1. The model, shown in Table 1, was developed from earlier projections of OMV servicing tasks and estimates of future STS launch rates. All spacecraft that could take advantage of fluid resupply were included. The actual selection of Design Reference Missions was accomplished later in the study.

MISSION	LOCATION NMI	LOCATION DEG	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	COMMENT
GRO	227	28.5	D		1		1		1							3 AT ORBITER
AXAF	320	28.5			D			1			1			1		3
EUVE	324	28.5	D	1												1 AT ORBITER
CREP	216?	28.5			D		1									1
PROTEUS (1)	216	28.5		D	D	1	1	1	1	1	1	1	1	1	1	10, PLATFORMS
LDR	486	28.5							D			1			1	2
SIRTF	486	98					D		1		1		1		1	4
GRAV PROBE-B	520	90						D	1							1
EOS	380	99.8					D			2			2			4, PLATFORMS
MPS (2)	320	28.5		1	3	5	6	6	5	3	1					30, PLATFORMS
GEO PLATFORM	19323	0							1							EXPT SERVICING
CONTINGENCY	TBD	TBD			1(2)			1			1			1		20% OF OMV CONTINGENCIES NEED FLUIDS
CIVILIAN TOTAL				2	5	6	9	9	10	6	5	2	4	3	3	64
DOD				2	3	2	4	5	7	1	7	2	4	7	3	47
NOMINAL TOTAL				4	8	8	13	14	17	7	12	4	8	10	6	111
CUMULATIVE				4	12	20	33	47	64	71	83	87	95	105	111	
POTENTIAL LINE									3	10	7	8	12	8	12	60
POTENTIAL TOTAL				4	8	8	13	14	20	17	19	12	20	18	18	
CUMULATIVE				4	12	20	33	47	67	84	103	115	135	153	171	171

(1) — FIRST MISSION MAN-TENDED AT ORBITER
(2) — DONE AT ORBITER MAN-TENDED
D — DEPLOYMENT

- 111 FLUID RESUPPLY ENGAGEMENTS FOR DOD, NASA AND COMMERCIAL USERS FROM 1989-2001 (NOT INCLUDING SPACE BASED OTV, OMV AND STATION)

Table 1. Fluid Resupply Mission Model

Estimates of the number of resupply engagements for each spacecraft/platform were based on discussions with individual program offices. Such discussions covered estimates of spacecraft technological obsolescence and the value of extended time on-orbit. Classified data on the make up of DoD missions is not available under this contract.

Due to the conceptual nature of many of the candidate missions, particularly those in the late 1990's, a number of assumptions were made in developing representative requirements. Those assumptions are:

- o Hydrazine propulsion using a single blowdown system was assumed for those missions requiring propulsion, but which had no spacecraft design baseline. Though none of the current candidate satellites utilize bi-propellants or require resupply of pressurants, future spacecraft designs could include these as an option for trade analyses.

- o Once rendezvous with candidate spacecraft has been accomplished, one hour is required for each 500 lb of hydrazine to be resupplied (includes actual transfer and associated operations).

- o The spacecraft replacement cost was estimated to be 40% of the total program cost when the actual replacement costs could not be determined.

- Mission operational lifetime was extended beyond the program baseline if it would be technically or scientifically advantageous and consumables resupply was the primary constraint.

- A hybrid cryogenic system was assumed for the Large Deployable Reflector (LDR) to determine consumable quantities (e.g., a combination closed dewar and passive radiator system).

- Candidate missions scheduled prior to an operational OMV were assumed to incorporate integral propulsion or use a spacecraft bus to rendezvous with the orbiter for resupply.

<u>Fluid Transfer Parameteric Requirements</u>

Parametric techniques were used to make estimates of the types, amounts and annual fluid usage rates required by the resupply mission model. Quantities of associated pressurants such as He and N_2 were required in relatively minor amounts. In some cases, depending on the receiver propulsion subsystem used, no additional pressurants are required in the transfer process.

As expected, hydrazine and storable bi-propellants are the primary fluids to be carried. In addition, another significant fluid of interest was found to be liquid (primarily superfluid state) helium. Water, as used in MPS factories, is more suited to module replacement due to the need to retrieve products. The results of the fluid transfer parametric requirements analysis are shown in Table 2.

USER AND CONSUMABLE TYPE	RESUPPLY AMOUNT (LB)												
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
NASA													
HYDRAZINE	—	·400	3,830	1,100	5,430	1,100	6,694	5,100	1,100	1,100	5,100	1,100	1,100
LIQUID HELIUM	—	—	—	—	160	—	1,389	—	992	1,320	992	—	2,312
WATER	—	5,000	15,000	25,000	30,000	30,000	25,000	15,000	5,000	—	—	—	—
Xe-METHANE MIXTURE	—	—	—	—	30	85	—	—	85	—	—	85	—
COMMERCIAL (POTENTIAL)													
BI-PROP (N_2O_4/MMH)	—	—	—	—	—	—	818	2,482	2,307	3,318	4,694	2,414	4,694
HYDRAZINE	—	—	—	—	—	—	—	500	1,000	500	500	500	500
DOD*													
BI-PROP (N_2O_4/A-50)	—	14,000	14,000	7,000	21,000	14,000	28,000	—	35,000	7,000	7,000	28,000	14,000
HYDRAZINE	—	—	70	70	70	17,470	17,470	70	8,770	70	17,470	17,470	70
LIQUID HELIUM	—	—	—	—	—	2,400	2,400	—	1,200	—	2,400	2,400	—
DOD* (POTENTIAL)													
BI-PROP (N_2O_4/A-50)	—	—	—	—	—	—	8,000	15,000	2,000	1,000	15,000	2,000	14,000
HYDRAZINE	—	—	—	—	—	—	—	950	250	600	950	600	950
CONTINGENCY**	—	—	1,500	—	—	1,500	—	—	1,500	—	—	1,500	—

*SMALL QUANTITIES OF PRESSURANTS ALSO REQUIRED FOR SOME SATELLITES — IMPORTANT FOR DESIGN REQT

**ESTIMATE OF PROPELLANT RESUPPLY REQUIRED IN CONTINGENCY SITUATIONS

- HYDRAZINE USED FOR THE MOST NUMBER OF UMBILICAL ENGAGEMENTS
- GREATEST MASS OF FLUID FOR UMBILICAL TRANSFER IS BI-PROP
- WATER & SPECIAL GASES ARE TRANSFERRED VIA MODULE CHANGEOUT

Table 2. Fluid Parametric Requirements Summary

Candidate Spacecraft and Resupply Scenarios and Trade Studies

Activity 1.1.3 was concerned with screening all the missions from the mission model and selecting a smaller number for use in the development of alternate resupply scenarios and mission operations requirements. The selection of a representative set of missions occurred in two parts. The first was the selection of missions which included the technical performance requirements of all possible resupply candidates (e.g., mission, polar, GEO, etc.). The second step was a screening for missions most likely to benefit from resupply. The four general mission characteristics used are shown in Table 3.

GENERIC SPACECRAFT CLASS		MISSION OBJECTIVE DURATION	UNIT ON-ORBIT VALUE $M84 SPACECRAFT	DURATION CONSTRAINT (HISTORIC)	COST OF ACCESS (STS)
• SCIENTIFIC EXPLORERS	EUVE CREP	SHORT 6 MO-24 MO	VERY LOW $50-100	EXPERIMENT, FLUIDS	VERY LOW-MODERATE
• ASTRONOMIC OBSERVATORIES	GRO AXAF	CONTINUOUS	VERY HIGH $500-1200	EXPERIMENT, INSTRUMENT	LOW
• EARTH/WEATHER OBSERVATION	LANDSAT DMSP	CONTINUOUS	LOW-HIGH $80-300	SENSORS, POWER	MODERATE
• RECON/SURVEILLANCE		CONTINUOUS	HIGH-VERY HIGH		MODERATE
• NAVIGATION	GPS	CONTINUOUS	VERY LOW $50-100	UNKNOWN	HIGH
• COMMUNICATION-DELTA	H.S. 376	CONTINUOUS	LOW $75-125	TECHNOLOGY OBSOLETE	VERY HIGH
• ENVIRONMENTAL OBSERVATION	GOES	CONTINUOUS	?	?	VERY HIGH
• EARLY WARNING DOD		CONTINUOUS	?	?	VERY HIGH
• COMMUNICATION-IUS/TOS	TDRS INTEL VI	CONTINUOUS	MODERATE-HIGH $250-300	TECHNOLOGY OBSOLETE	VERY HIGH
• COMPLAT	PLANNED	CONTINUOUS	VERY HIGH	DESIGN REQUIREMENTS	VERY HIGH
• SMALL PLATFORMS	PROTEUS LEASE CRAFT	MEDIUM 120 MO	MODERATE $100-200	CHANGEOUT/INVENTORY	VERY LOW-MODERATE

LOW INCLINATION LEO	HIGH INCLINATION LEO	GEO
• AXAF • MPS • GRO • PROTEUS	• SIRTF • DMSP • DOD-1	• GEO PLATFORM • COMSATS

VARIOUS SINGLE & MULTI-SERVICING SCENARIO COMBINATIONS EXAMINED FOR THESE CANDIDATES

Table 3. Candidate Spacecraft/Platform Selections

Nine candidate spacecraft/platforms were selected for scenario development. They occupied the three general resupply locatons of low-inclination LEO, high-inclination LEO, and GEO. Various single and multi-servicing scenario combinations were then examined for these candidates. All of the candidates either require resupply or benefit highly from its use.

Using as input data the candidate spacecraft and space platforms, a comprehensive set of resupply scenarios was generated. Among the scenarios were some non-remote resupply options. In addition, certain scenario trade issues were addressed such as multiple versus single spacecraft configurations and wet versus dry launch. This data was used in the concurrent effectiveness anaysis to select the most promising scenarios for further definition. Mission operatonal requirements were derived for these scenario (and used) to develop system/subsystem/interface requirements for both the effectiveness analysis and the Design Reference Missions (DRM). The system/subsystem requirements data were also used to develop cost/risk benefits for the effectiveness analysis to support justification of the DRM's.

Ten general resupply scenarios, shown in Figure 8, were developed for operations in LEO. These scenarios included not only remote resupply but also orbiter-tended operations. A spacecraft in LEO can be resupplied using a resupply module with an OMV. Each of the remote supply options may perform multiple or single engagements. The spacecraft can also be resupplied using in-bay equipment being developed at JSC. Delivering the spacecraft to the orbiter bay can be accomplished using the spacecraft's own integral propulsion system (IP) or the orbiter's OMV capability.

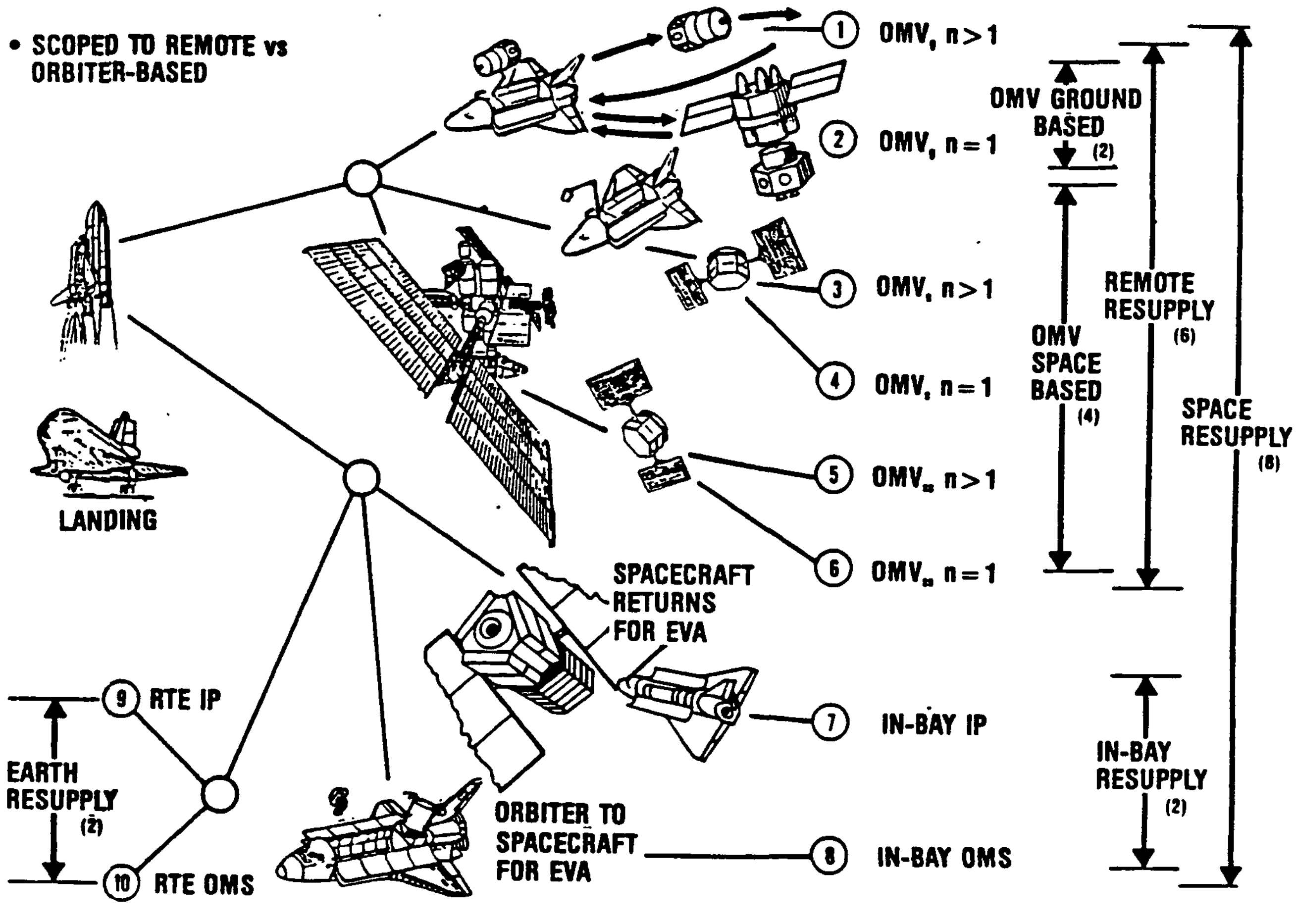


Figure 8. Low Earth Orbit Alternative Fluids Resupply Scenarios

Six trade studies were identified in the original proposal for evaluating resupply scenarios. The first examined the utility of nodal regression effects in multiple engagement mission planning. The second examined alternative space-basing options for the resupply module relative to ground-basing. This task also used much of the material developed in the first study on multiple engagements. The third study looked at the pros and cons of dry and wet launches of the resupply module itself. The fourth study was oriented toward GEO operations and examined the weight sensitivities involved with expending versus reusing elements of a GEO resupply system (OTV, OMV, ERM). Cost factors were also identified for use by the effectiveness analysis. The final two studies supported development of system/subsystem/interface requirements. Issues as to the appropriate levels of autonomy and redundancy for the resupply module were addressed. Both the OMV's capabilities and the potential role of man-in-the-loop were evaluated. Finally, critical issues in fluid transfer technologies concerning the required fluids were identified. Superfluid Helium was found to have a variety of issues associated with its transfer and thus would require closer study.

Effectiveness Analysis Summary

The groundrules and asumptions for the effectiveness analysis are summarized in Figure 9.

- **ALL ECONOMIC & COST ESTIMATES IN CONSTANT 1984 $ MILLIONS**
- **PARAMETRIC ESTIMATES ARE ROUGH ORDER OF MAGNITUDE (ROM)**
- **USAF SD UNMANNED SPACECRAFT COST MODEL CERs USED**
  - **OMV ACQUISITION (MSFC BASELINE CONFIGURATION)**
  - **EXPENDABLES RESUPPLY MODULE (ERM) ACQUISITION**
  - **CANDIDATE SPACECRAFT/PLATFORM ACQUISITION**
- **ROCKWELL ORBITER DATA BASE CERs & INDEPENDENT ESTIMATES**
  - **LAUNCH (STS) & INSERTION STAGES**
  - **FLIGHT & MISSION OPERATIONS/SUPPORT**
- **RISK & COMPLEXITY ANALYTIC HIERARCHY PROCESS**

BEST DESIGN REFERENCE MISSION DECISION RULE: SELECT CANDIDATE WITH HIGHEST OVERALL CONTRIBUTION TO CONFLICTING GOALS

Figure 9. Effectiveness Analysis Groundrules and Assumptions

LEO Benefits

As shown in Figure 10, expendables resupply capability is a necessary condition for enabling satellite system availability through on-orbit maintenance (which offers substantial cost efficiencies compared to the traditional "proliferation" and/or "endurance" approaches).

Expendables Resupply as a stand-alone capability (without concurrent repair, technology upgrade or routine maintenance), may not be sufficient except in those cases where the only constraint on the spacecraft's function is depletion of its on-board consumables supply.

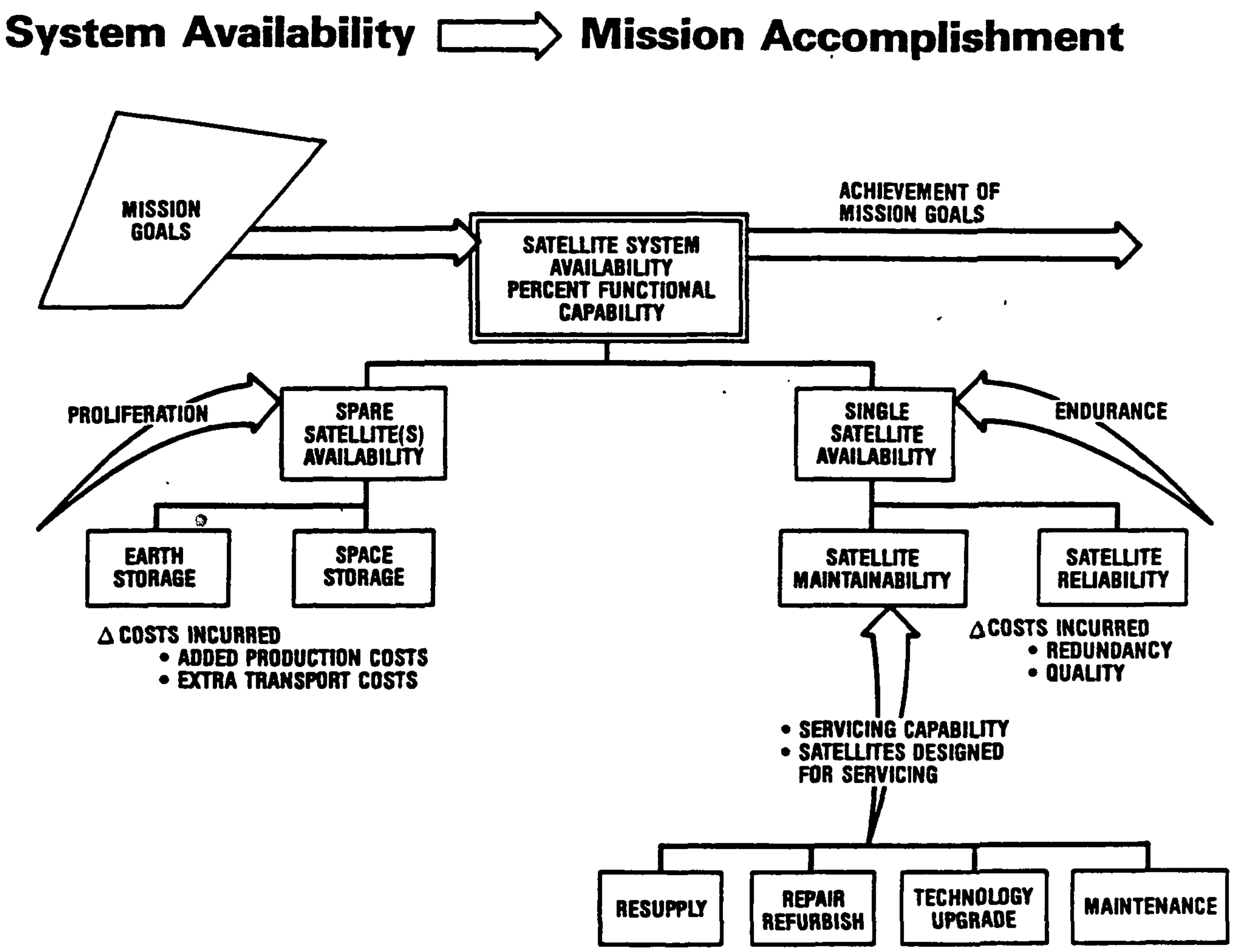


Figure 10. Satellite System Availability through Servicing

Results of the parametric economic benefits analyses shown in Figure 11 indicate that NASA LEO ETR Spacecraft programs could receive a net economic benefit by utilizing an Expendables Resupply capability, even without concurrent "full servicing". However, the marginal benefit to these programs received by taking advantage of comprehensive repair, instrument changeout, and fluids resupply is so substantial (nearly an order of magnitude improvement in net benefits) that there should be a strong motivation to opt for orbiter-based, man-in-loop repair until teleoperation maintenance is possible.

- **RESUPPLY (W/O CONCURRENT MAINTENANCE & REPAIR) (+) NET BENEFIT**

✓ **OBSERVATORIES & EXPLORERS**
- **HIGH UNIT-VALUE SATELLITES**
- **LOW COST ACCESS FOR RESUPPLY**

✓ **COST-EFFECTIVE ONCE PER PROGRAM**

SPACECRAFT	GROSS ECON BENEFIT $M84 RESUPPLY ONLY	COST TO RESUPPLY $M84	NET ECON BENEFIT $M84 RESUPPLY
AXAF	73-110	6-20	53-104
EUVE	23-34	7-21	2-27
GRO	65-98	15-29	36-83
LDR	144-216	9-43	101-207
PROTEUS	27-40	9-23	4-31
			196-452
			ONE RESUPPLY

- **RESUPPLY WITH CONCURRENT MAINTENANCE & REPAIR ⊕ NET BENEFIT**

✓ **ORDER OF MAGNITUDE INCREASE IN BENEFITS**

✓ **"FULL SERVICE" WILL BE PREFERRED OPTION**

SPACECRAFT	GROSS ECON BENEFIT $M84	COST TO RESUPPLY & REPAIR $M84	NET BENEFIT PER REPAIR MISSION $M84	NO ENGAGEMENTS PER PROGRAM	TOTAL PROGRAM NET ECONOMIC BENEFIT $M84
AXAF	219-329	23-80	139-306	4-6	558-1836
EUVE	29-43	8-14	15-35	1-2	15-70
GRO	220-330	32-87	133-298	2-4	267-1194
LDR	256-384	31-119	137-353	2-3	275-1060
PROTEUS	36-54	10-17	19-44	3-4	56-177
					1171-4337
					MULTIPLE ENGAGEMENTS

Figure 11. Net Economics Benefits Summary for NASA LEO ETR Spacecraft

The value of servicing with resupply is limited to the spacecraft's replacement cost (second unit + replacement launch and insertion). Still the net economic benefits received from full servicing in major NASA ETR programs far exceed the benefits of expendables resupply alone.

Since stand-alone resupply can be cost-effective only once during most programs, while on-orbit maintenance and repair can be cost-effective many times, the total benefits available from full servicing should drive most program offices to orbiter-based servicing until the advent of teleoperator in-situ servicing.

Figure 12 graphically presents the results of Figure 11 in the form of columns to more clearly illustrate the relative benefits of the two approaches.

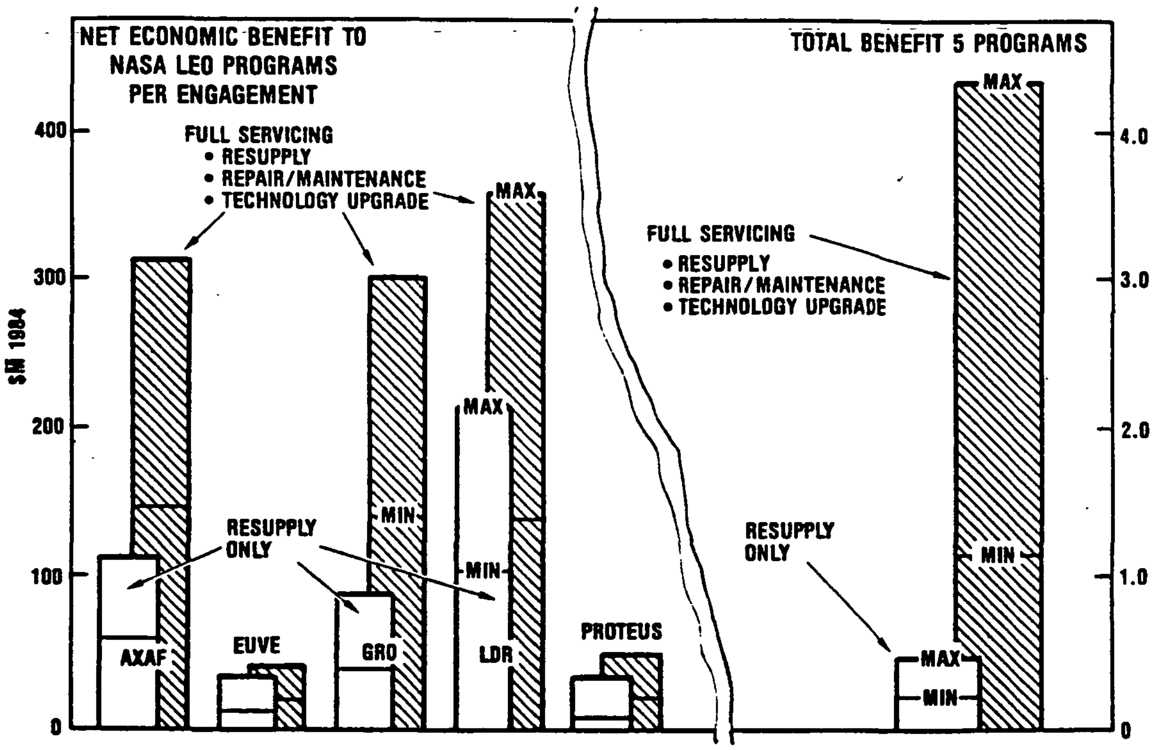


Figure 12. Economic Benefits of Full Servicing Relative to Resupply Only

GEO Benefits

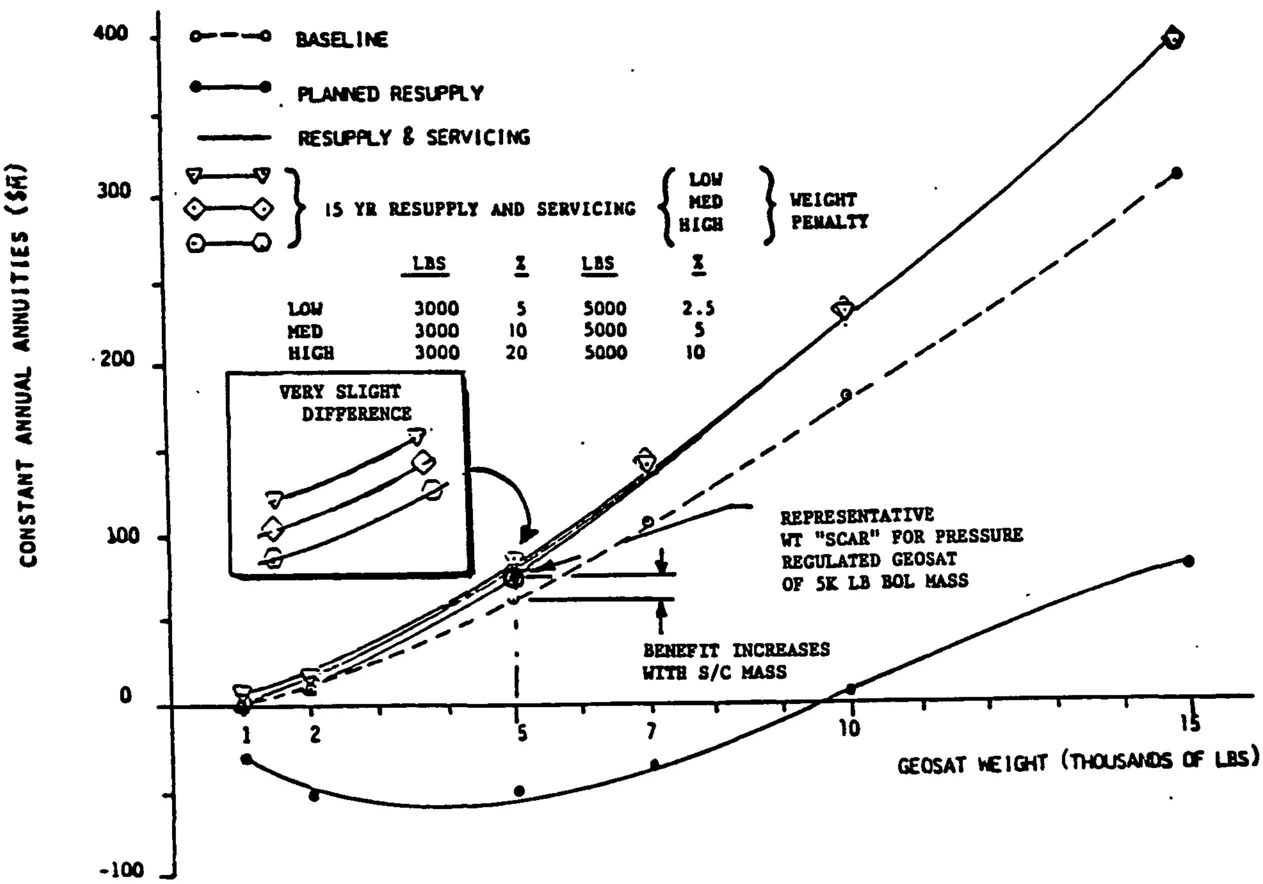


Figure 13. Lifetime Extension Options (10-15 Yrs) Relative Annual Annuities

Figure 13 depicts the result of an economic analysis performed to compare the relative annual annuities of a spacecraft which is resupplied and technologically upgraded (life incrase of 50%) versus a conventional ten-year life system (baseline). Rockwell studies indicate that the total weight penalty to enable resupply/concurrent module change-out servicing can be less than 10%. Even for this level of penalty, it is seen that as the mass of the spacecraft increases the economic advantage of resupply/servicing relative to the baseline approach becomes correspondingly greater.

The financial model used in the study was shown to produce stable results across a wide range of potential changes in key baseline numbers. Several implications for the development of GEO Resupply/Servicing can be drawn:

- Insurance rates have a high impact on the economic viability of resupply/servicing operations for satcom's. Rates of 15% or lower are required to make GEO operations beneficial. Based on historical experience, an overall confidence level of 95% or better is necessary for launch through competion of GEO operations.

- The cost/lb. figure for GEO resupply/servicing has a relatively minor influence on optimum servicing intervals and on the satcom's annual annuity value. Resupply/Servicing scenarios only need to keep their cost/lb. figures below about $50K/lb. to be economically viable. This includes not only the costs of getting to GEO, but associated usage fees (e.g., OMV, OTV, Servicer Kit, etc.).

- If satcom revenue decline rates average less than 6% over their lifetime, resupply/servicing is unlikely to be attractive. Obsolescence rates of about 9% and above make technological upgrading attractive. The key questions here are the technical feasibility of revenue restoration with upgrading and what combinations of space and ground segment modifications are required.

Further conclusions drawn for GEO satcom Remote Resupply include:

1) GEO Resupply without servicing offers a major benefit for contingency operations, including multiple resupply in GEO of several satellites from one STS launch. Lack of concurrent servicing, however, results in little benefit to resupplying GEO satellites. This is primarily due to the rapid (12% annual) rate of technological obsolescence.

2) The cost effectiveness of GEO operations increases by servicing larger satcoms. This analysis is, therefore, most applicable to large concentrations of capital as would occur with satellite clusters or a GEO platform. Lifetime extension is cost-effective with satcoms that are still functional at the end of their lives and only requiring additional ACS fuel. This, however, is quite expensive and is not seen as desirable without technological upgrading during the satellite's life.

3) Transponder replacement incurs increased satellite costs and insurance risks which are not completely covered by the increased revenue-generation capability.

4) The major unknown remaining from these studies are the actual costs of incorporating a spacecraft resupply subsystem into a communications satellite. Parametric estimates have shown that the weight/cost penalties associated with resupply and servicing are likely to be much less than the costs of providing for longer life without resupply and servicing.

The more satellites that can be resupplied from one flight, the greater the economic benefits. If an operational mode can be implemented before the advent of reusable OTV operations the most economical means of accomplishing the transfer to GEO would be to use the resupply module as a propellant tanker for the OMV (rather than expending a relatively expensive upper stage such as the Centaur). The propellant transfer would be made directly from the OMV after detaching from the resupply module (Figure 14).

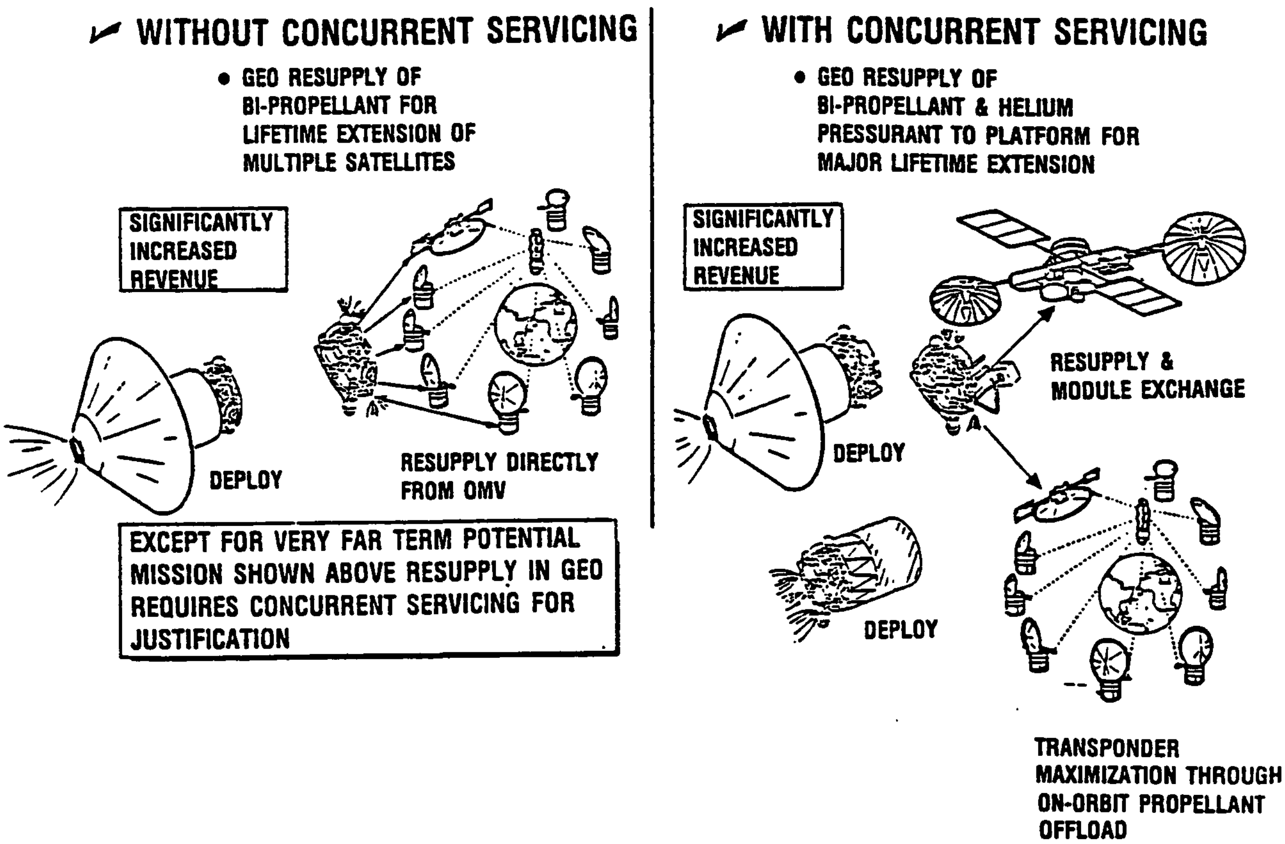


Figure 14. Expendables Resupply in GEO Potential Operating Modes

In this mode the servicer is attached to the front end of the OMV. Thus a truss structure separates the resupply module from the OMV to allow sufficient volume for the servicer. For this case the resupply (probably also including Helium) is directly from the OMV after separation from the resupply module.

Communication satellite transponder maximization can be accomplished by ACS propellant off-loading. If the same strategy described above is employed in conunction with technology up-dating at about the mid-point of the satellite design life, significant economic benefits can result. This mode has the potential to occur sooner than those described above, perhaps well before the availability of a space-based reusable OTV.

This study was conducted in coordination with related studies at Rockwell. One of these, NAS9-16994, "STS Propellant Scavenging System Study", performed for NASA-JSC in FY 84 and FY 85 has identified the potential for about 1.4 million pounds of storable bi-propellant (NTO/MMH) which could be delivered to 28° inclination LEO by the Orbiter throughout the 1990's at very low cost (117$/lb). Most Orbiters will not be fully loaded with payload, and therefore OMS pod and payload bay tankage would be available for proepllant storage and scavenging. Additional work performed under IR&D has identified relatively simple low-cost provisions by which the Orbiter can transfer propellants to the OMV/ERM (Figure 15). This propellant could then be transferred to a depot for later support of remote resupply operations in LEO.

CONCEPT	SCAVENGING FLIGHTS	COSTS ($ M)							DELIVERED PROPELLANT (1000 LB)	PROPELLANT COSTS ($/LB)
		TANKAGE	ELECTRICAL	INSTRUMENTATION	ORB MODS	OPS SUPPORT	OMV PROPELLANT	TOTAL		
1 TANK SIZE	165	51.8	14.4	3.4	40	41.3	12.6	163.5	1,409	117

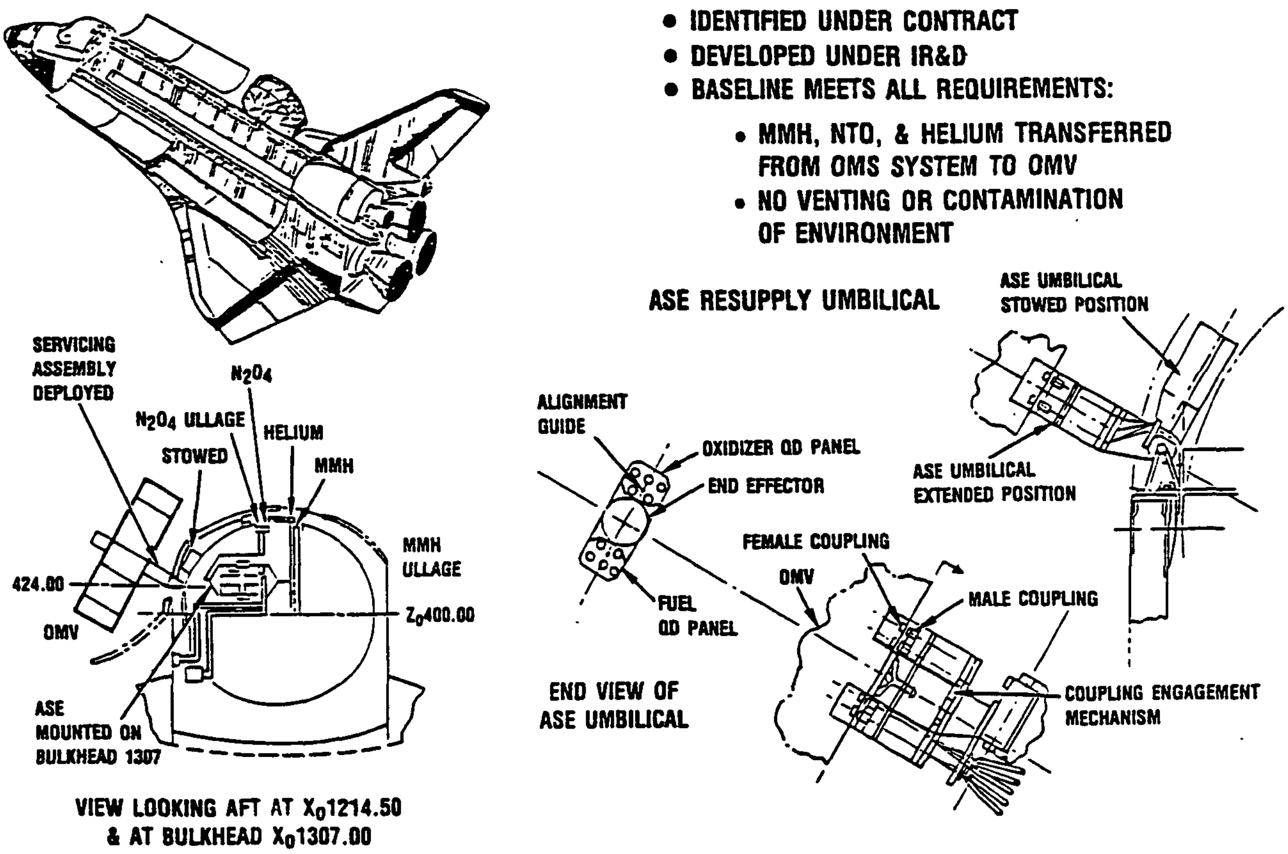


Figure 15. Storable Propellant Refueling from Orbiter OMS Pod Tanks and/or Cargo Bay Tank

The refueling scenario depicted in Figure 16 depicts a spacecraft being refueled by an OMV/ERM operating from a LEO depot. The depot would be supplied via storable propellant scavenging from many orbiter flights. Implementation of this concept could given economic benefits similar to those achievable by a Space Station-based OTV.

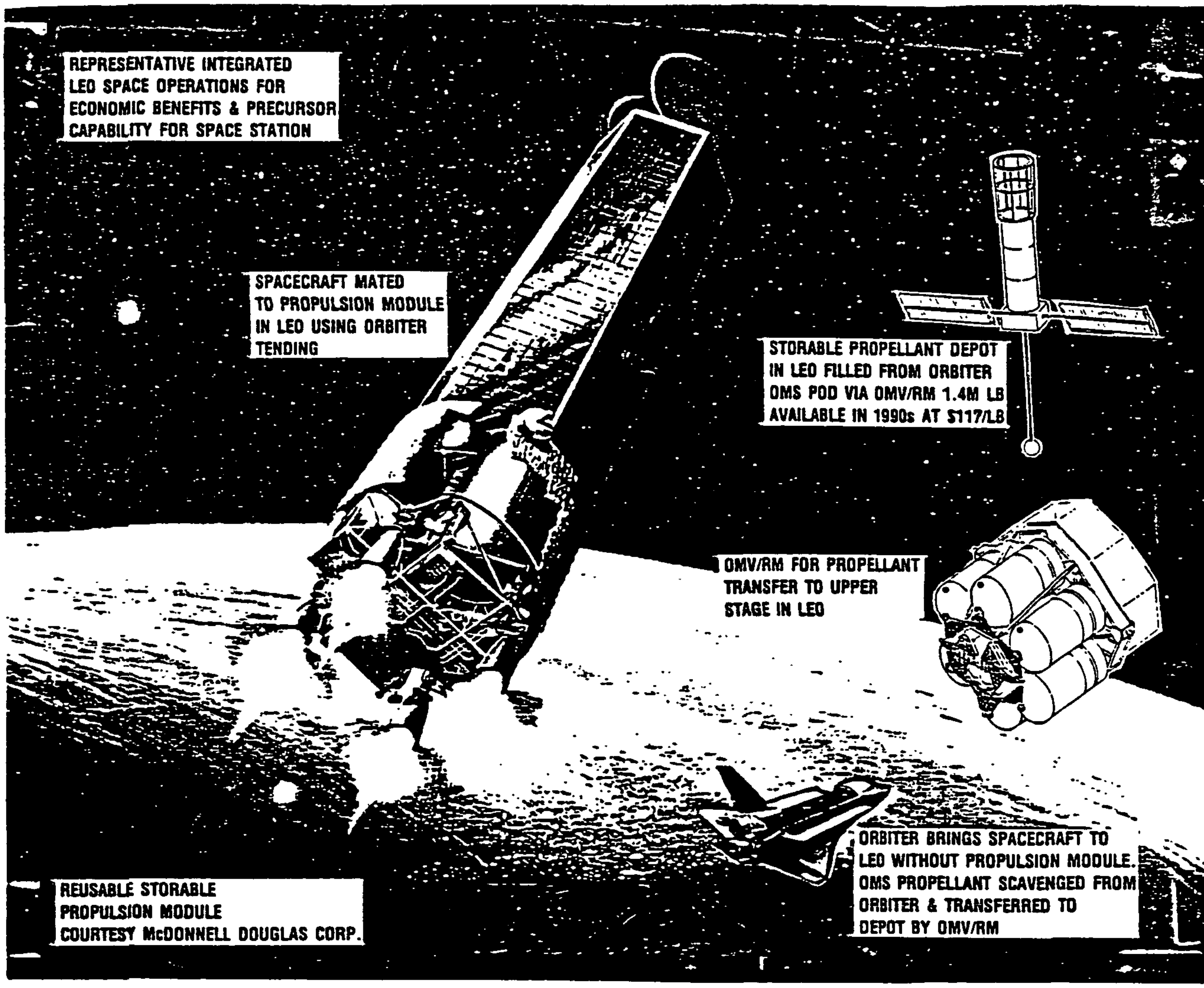


Figure 16. LEO Remote Refueling of Storable Stage Candidate Scenario

Figure 17 depicts a single satellite launch case for remote resupply in LEO allowing economic benefits to spacecraft subsequently transferred to GEO. This approach is based on the reconfiguration of a single relatively heavy integral propulsion satcom to take advantage of the full payload bay diameter. Currently, except for LEASAT (Syncom IV - about 3,000 lb. BOL mass in GEO) communication satellites are limited to about 12 feet in diameter so as to be Ariane compatible. This approach does not cause an STS transportation cost penalty because installed weight, rather than length, would determine the cost if a shorter installation was provided. The use of propellant top-off in LEO through remote resupply offers the possibility of achieving significant cost-savings through the use of a shorter installation in the payload bay.

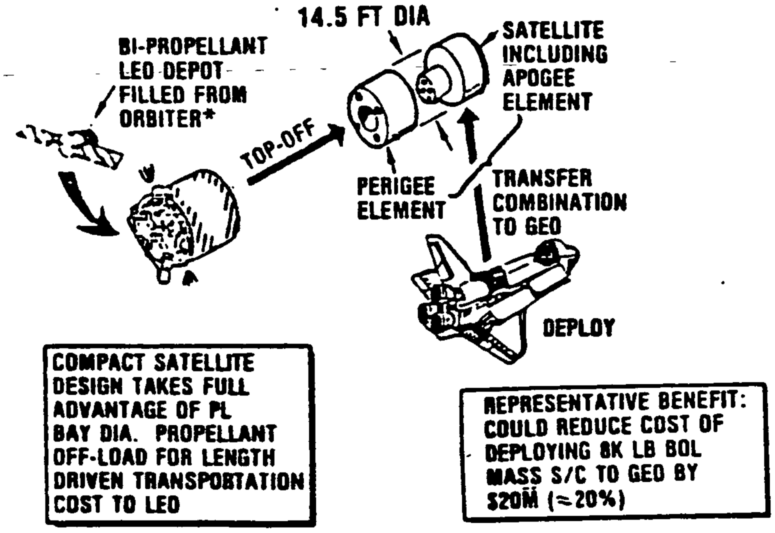
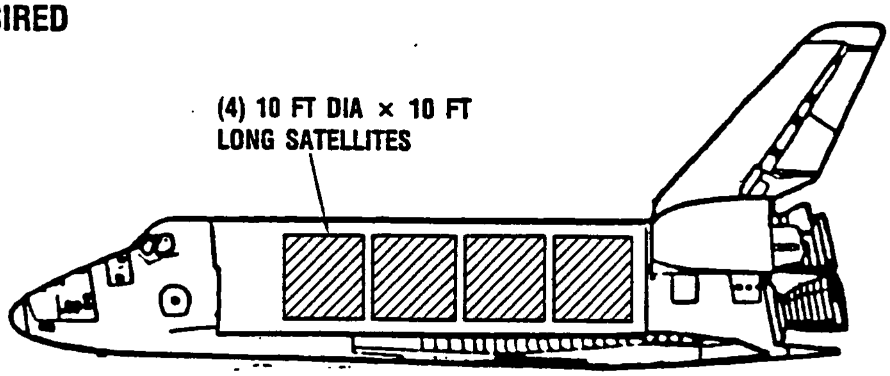


Figure 17. Top-Off of Storable Bi-Propellant Integral Propulsion Satellite in LEO

Our Satellite System Division provided support to the remote resupply study through presenting a satellite supplier's viewpoint. They assisted in estimating spacecraft impacts for fluid resupply/module change-out servicing and helped to identify potential applications for remote resupply. One suggestion was that it might be possible to reduce STS payload weight by off-loading fuel before launch and topping-off in LEO. For example, one specific DOD satellite under study (including maneuver propellant) is too heavy for the payload bay if four satellites are deployed to LEO via one STS Launch. It is highly desirable that the satellite weight not be reduced and that the capability to launch four satellites to LEO via one STS flight be provided. An option to allow this, would be to off-load propellant from one or all of the satellites and top-off the satellites using the OMV/resupply module in conjunction with a LEO storable propellant depot (Figure 18).

- **LAUNCH OF FOUR SATELLITES TO 150 NMI × 28.5° LEO IN ONE STS DESIRED**



- **TOTAL INSTALLED WEIGHT IN PL BAY APPROXIMATELY 77,000 LB SATELLITES FULLY FUELED**
- **OFF-LOADING 3000 LB PROPELLANT PER SATELLITE OR 12,000 LB FROM ONE SATELLITE ENABLES LAUNCH TO LEO BY STS OF ALL 4 SATELLITES**

Figure 18. Potential LEO Top Off of DoD High Energy Orbit Integral Storable Propulsion Satellites

The recommended mid-term review DRMs are shown in Figure 3. The common denominator between the recommended "best" design reference missions is bi-propellant fluid resupply. Ample evidence exists (e.g., Insat, Intelsat VI, and NASA/MSFC's baseline OMV) to indicate an evolution from hydrazine to bi-propellant forms of propellant storage on-orbit. The specific impulse advantage of bi-propellant, coupled with its availability through scavenging from the orbiter's OMS tanks suggests that NTO/MMH bi-propellant may become the "standard" of storable fluids (Figure 19).

- **REF FLUIDS FOR RESUPPLY ARE BI-PROPELLANTS**
  - **NTO & MMH**
- **RATIONALE:**
  - **LARGEST PROJECTED FUTURE QUANTITY**
  - **NATURAL EVOLUTION FROM N_2H_4 IN-BAY DEMONSTRATIONS**
  - **BASIC PROPELLANT FOR NUMEROUS FUTURE SPACECRAFT WHICH CAN BENEFIT FROM RESUPPLY**
    - **GEO**
      - **LARGE COMSATS (ALREADY USED ON INTELSAT VI)**
      - **FUTURE LARGE GEO PLATFORM**
    - **LEO**
      - **REFUELING OMV & HIGH PERFORMANCE STORABLE STAGE**
      - **POTENTIAL RESUPPLY DEPOT REQUIREMENT**
- **REFERENCE QUANTITY TBD**
- **CANDIDATE MISSIONS**
  - ✓ **LARGE GEO PLATFORM**
  - ✓ **FUTURE LARGE COMSATS**
  - ✓ **RESUPPLY IN LEO**
    - **DOD (MANEUVERING)**
    - **ORBITAL VEHICLES**

Figure 19. Mid-Term Review DRM Recommendations

3.2 Concept Definition

Selected Operational System Configuration

The ten basic mission scenarios/DRM's indicated in Figure 3 were evaluated for sizing requirements to the Resupply Module propellant requirements from 6,000 to 45,000 lbs. of storable bipropellants and Helium requirements from zero to 90 lbs. Scenario two is the driving requirement for GEO operations (avoids expending an OTV before the available timeframe of a reusable OTV). The full resupply module capacity is used to supply enough propellant to transfer an OMV plus its servicer kit to GEO. Resupply in this case would be directly from the OMV. Scenario five is the driving requirement for LEO remote resupply operations - refueling a high performance reusable storable OTV. Lesser levels of resupply module capability are provided by off-loading the module rather than removing tankage. The objective is to adapt one basic "core" resupply module design to many different uses.

The ERM in the various scenarios served as an OMV extended mission kit, a LEO refueling ERM, a LEO propellant and Helium storage depot, a precursor reusable upper stage, and a means to transfer orbiter scavenged storable propellant to a LEO depot.

A versatile, low-cost resupply module concept resulted from the trade analyses and design definition phases of the study. Some of the various trades and design characteristics included propellant transfer alternatives, weight trades for a pump-fed versus pressure regulated transfer system, propellant system schematics, transient and steady state pressure drop characteristics, fluid interface panel design, thermal control provisions, electrical power requirements and distribution, avionics and data processing interfaces, major subsystem weight breakdowns, user spacecraft impact assessment, general configuration layouts and key features. To provide the required propellant capacity, the resupply module configuration depicted in Figure 3 was selected.

As discussed earlier efficiency in combination with utilization of existing hardware for low development cost. The resupply module is supported at its forward end by an existing IUS upper stage forward cradle. This cradle includes load equalization capability which reduces the structural redundancy between the resupply module and the orbiter by one degree and allows a minimum of scar weight on the resupply module for attachment to the orbiter payload bay longerons and keel at its forward end. The resupply module uses six stretched OMS tanks. Also the OMS-type PMD's are replaced by a zero-g concept based on existing technology.

As shown in Figures 4 and 5, the basic structural components of the Resupply Module are very simple. Yet, the configuration is very effficient structurally. All fore and aft loads and part of the vertical loads are supported at two payload bay longeron attachment points in the main structural bulkhead. As a representative attachment to the OMV, six bolts are provided. For the case where the Resupply Module is detached from the OMV in GEO, these bolts may be explosive. The main bulkhead also has a keel attachment for the orbiter payload bay.

The tanks are supported by the main bulkhead fore and aft, as well as lateral and vertical loads. They are stabilized at their forward ends by machined fittings which attach to the cylindrical center body of the Resupply Module. This body provides the main bending stiffness of the ERM. NASTRAN finite element analysis showed that this concept meets the Orbiter fundamental response stiffness requirement of 7 Hz even when fully loaded with propellant. Most elements of the structure are machined aluminum plate, including the center body which is rolled to its proper shape after machining in quarter sections which are subsequently fastened together mechanically.

A design layout (Figures 4 and 5) was produced of the selected Resupply Module configuration. This layout was used in conjunction with a finite element analysis to develop a realistic weight estimate for the resupply module structure. Two adaptations are depicted, with and without servicing. In both cases the OMV is supported from the resupply module in the orbiter payload bay (OMV support fittings could be removed to reduce weight and cost). The combination OMV/ERM would be deployed from the payload bay using the orbiter ERMS. The adaptation depicted with the truss interstage (Figure 5) allows sufficient volume between the OMV and ERM for the OMV's servicer kit (for missions in which concurrent module change-out type servicing is required).

Flight Demonstration Program

The flight demonstration concept will include sufficient fidelity to test the essential functions of remote on-orbit resupply and demonstrate to the user community the viability and attractiveness of such a concept. In order to show proof-of-concept specific elements will be required to be tested on each side of the resupply interface.

Simplicity and economy are emphasized in the selected flight demonstration program. The principle test objective is to validate bi-propellant fluid transfer in a zero-gravity environment. Since the ERM engagement with a spacecraft is accomplished by the OMV with a remote manipulating arm, the remote manipulator system (RMS) on the Orbiter can approximate the OMV engagement capability. The systems on both the receiver and supplier test articles can be attached to either a MPESS (NASA owned) or a SPAS structure (structure only without any subsystems). As demonstrated in Figure 20, the Orbiter RMS will lift the receiver test article out of the cargo bay and engage the supplier test article. Repeated fuel transfer tests will then be performed.

Since the supplier test article has the greater need for power and electrical links to the Orbiter, we recommend it remain seated in the cargo bay. This avoids the need for complicated power and electrical links running through the RMS.

The system on both the receiver and supplier test articles can be attached to either a MPESS (NASA-owned) or a SPAS structure (shown). Grapple fixtures are provided on the receiver simulated vehicle for use in docking with the supplier vehicle and by the ERMS to transport the receiver vehicle from a berthed position to the docked position with the supplier vehicle. Tankage employing ullage control PMD's will be utilized. Fluid transfer system hardware will incorporate, to the greatest extent possible, final design pumps, compressors and disconnects.

The resupply module flight demonstration program supplier vehicle will utilize final design type hardware in the fluid transfer subsystems including the pumps, compressors and disconnects. The propellant tankage will be essentially off-the-shelf with PMD's that provide ullage positioning in zero-g to allow the ullage exchange process during resupply. The system plumbing and structural configuration of the supplier and receiver test vehicles will be to sufficient fidelity and detail to provide operational performance for the final resupply module flight article design. Figure 21 presents the resupply module flight demonstration supplier module transfer subsystem schematic.

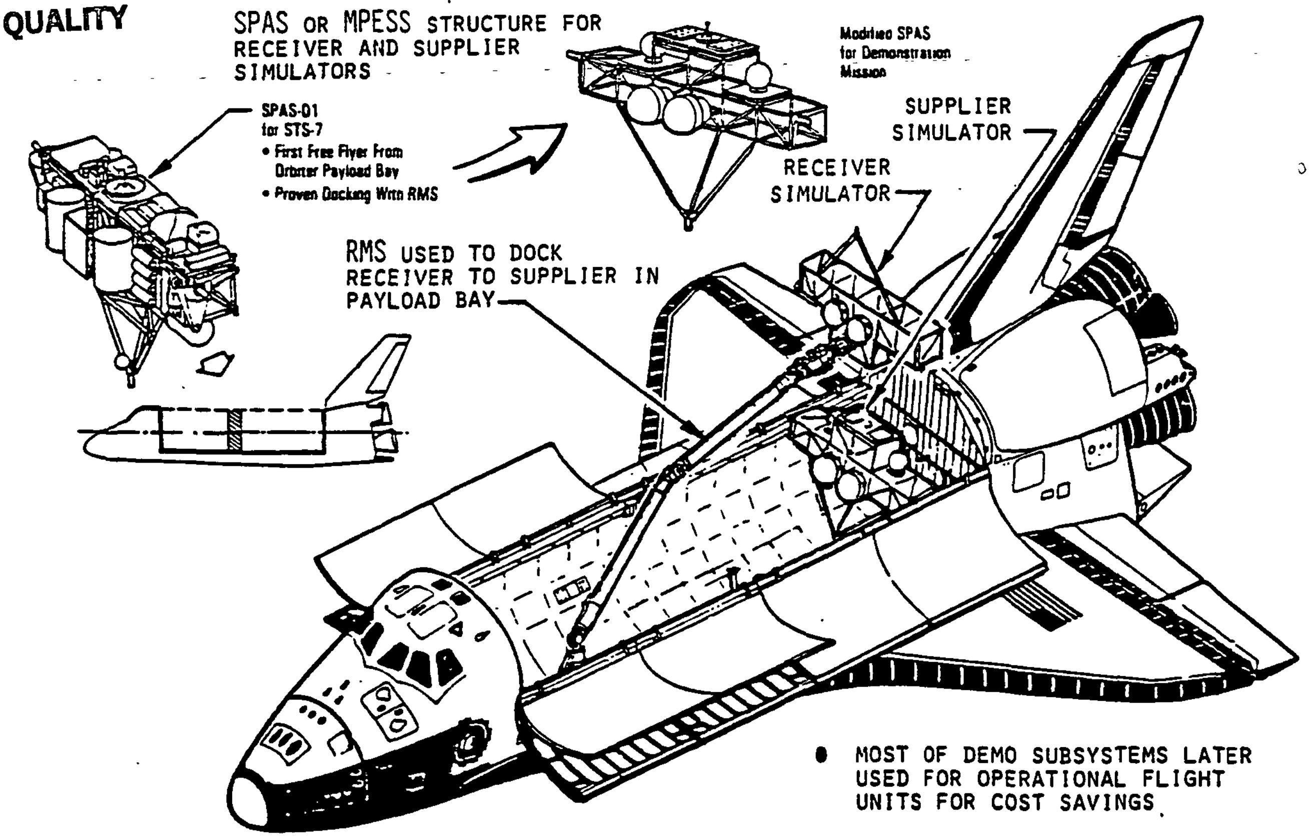


Figure 20. Bi-Propellant/Helium Transfer Flight Demonstration Concept

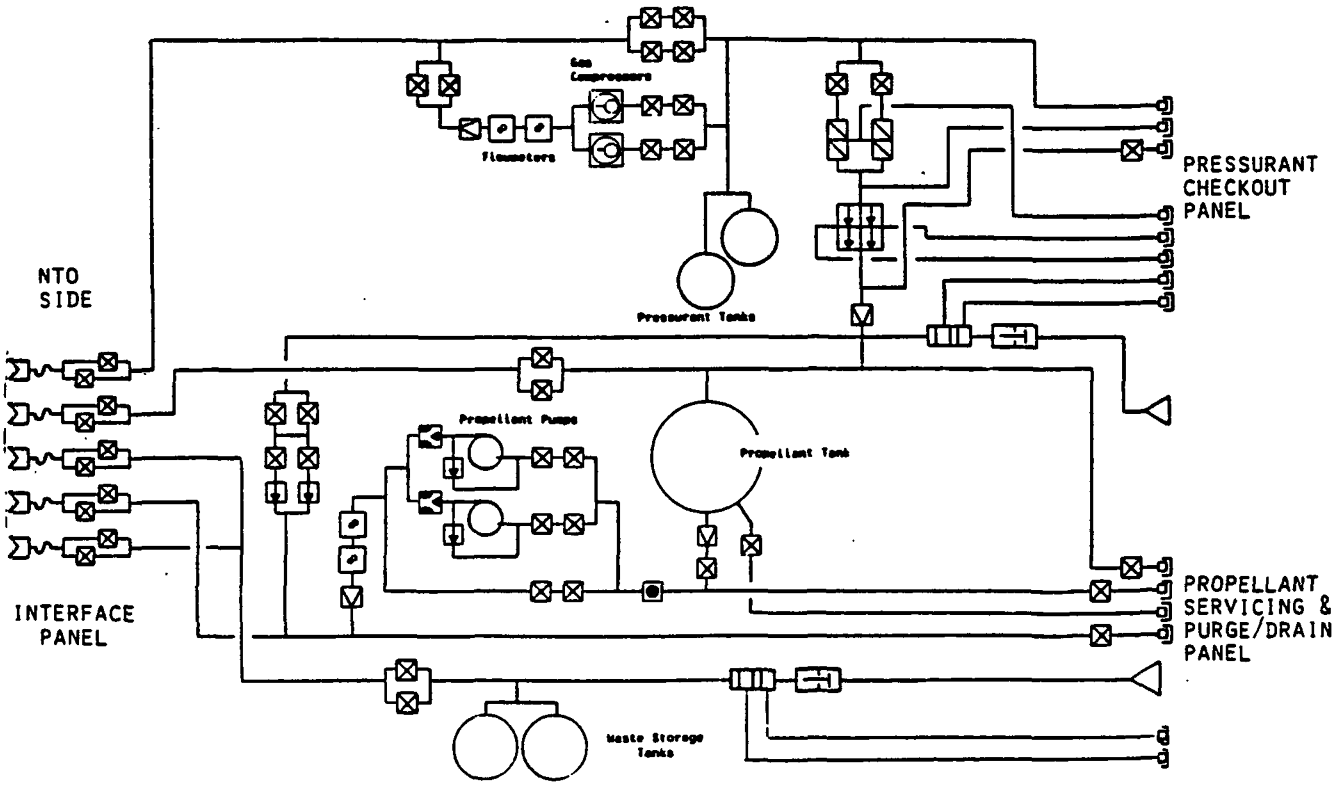


Figure 21. Resupply Module Flight Demonstration Program Supplier Schematic

3.3 Programmatic and Developmental Planning

The programmatic and developmental planning task included the definition of cost and schedule requirements for the resupply module operational program, technology development and flight demonstration programs.

Technology Development, Flight Demo, and ERM Program

The technology development program would precede both the flight demonstration program and the ERM phase C/D. All the technology requirements and their maturity status are shown in Figure 22. Standard NASA definitions were used to assess each technology's maturity level. By definition, those technologies with low maturities are the ones that need to be emphasized in the technology development program. The critical technologies are, (1) the gas compressor, (2) fluid pumps, (3) quick disconnects, contamination control, and leakage monitoring.

Two options were considered for the flight demonstration program: An early flight demonstration by the end of the FY 1988 and a late flight demonstration that is part of the ERM phase C/D program that flies a year later at the end of FY 1989. The schedule for the early flight demonstration option is shown in Figure 23. Breadboard testing precedes the verification testing. The verification testing could culminate with the flight demonstration.

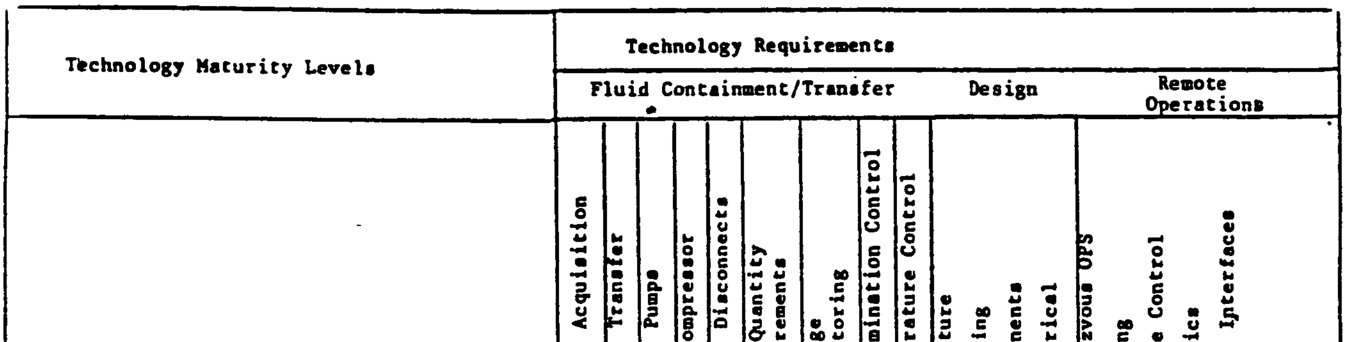


Figure 22. Status of Technology Required for ERM Program

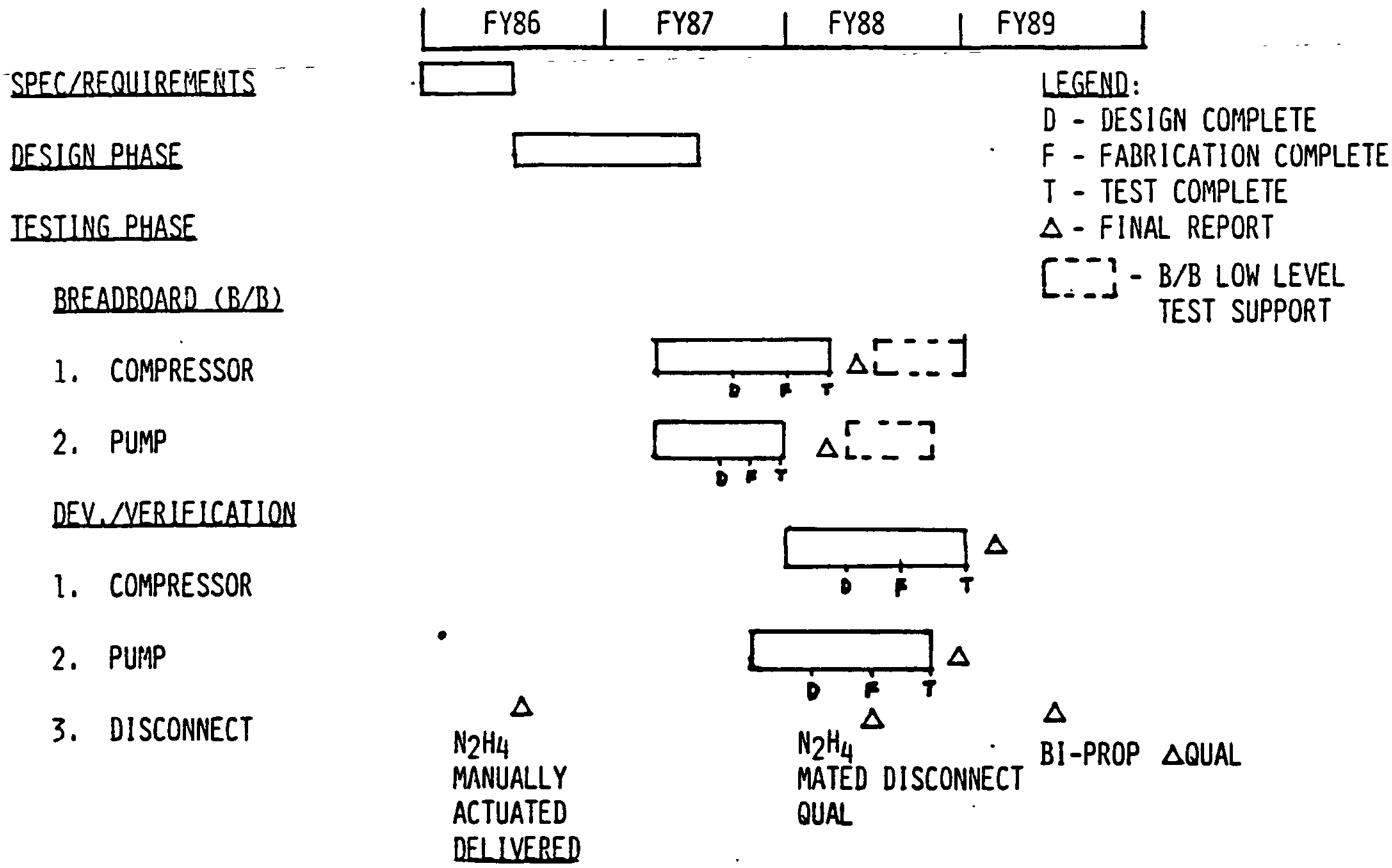


Figure 23. Development Schedule for Concept Feasibility

The schedule for the late flight demonstration option is shown in Figure 24. The technology development phase culminates with the successful verification of key predefined ground tests with breadboard test apparatus, probably by the end of FY 1987. Given a successful verification at the breadboard level, the ERM phase C/D could start. After the specification and requirements for the ERM program are defined, the flight demonstration program would begin. Changes to previous specification and requirements defined in the technology development program will probably result in a redesign/modification to the critical technology components in parallel with the design of the flight demonstration.

The Baseline Operational ERM program consists of two test articles (Developmental and Qualification) and two flight units (one from salvaging systems from the best articles. The earliest possible start for the phase C/D of the ERM program is the fourth quarter FY 1987, and the earliest possible operational flight is the last quarter of FY 1991.

Estimate Program Cost

Figure 25 presents cost estimates for the Technology Development and Flight Demonstration Programs, with all costs in constant 1984 dollars. STS launch costs are not included for either the flight demonstration cost or the first ERM operation flight. Costs for GSE and payload support, sustained mission operations/training, maintenance and refurbishment, and additional production units are not included in the baseline ERM program.

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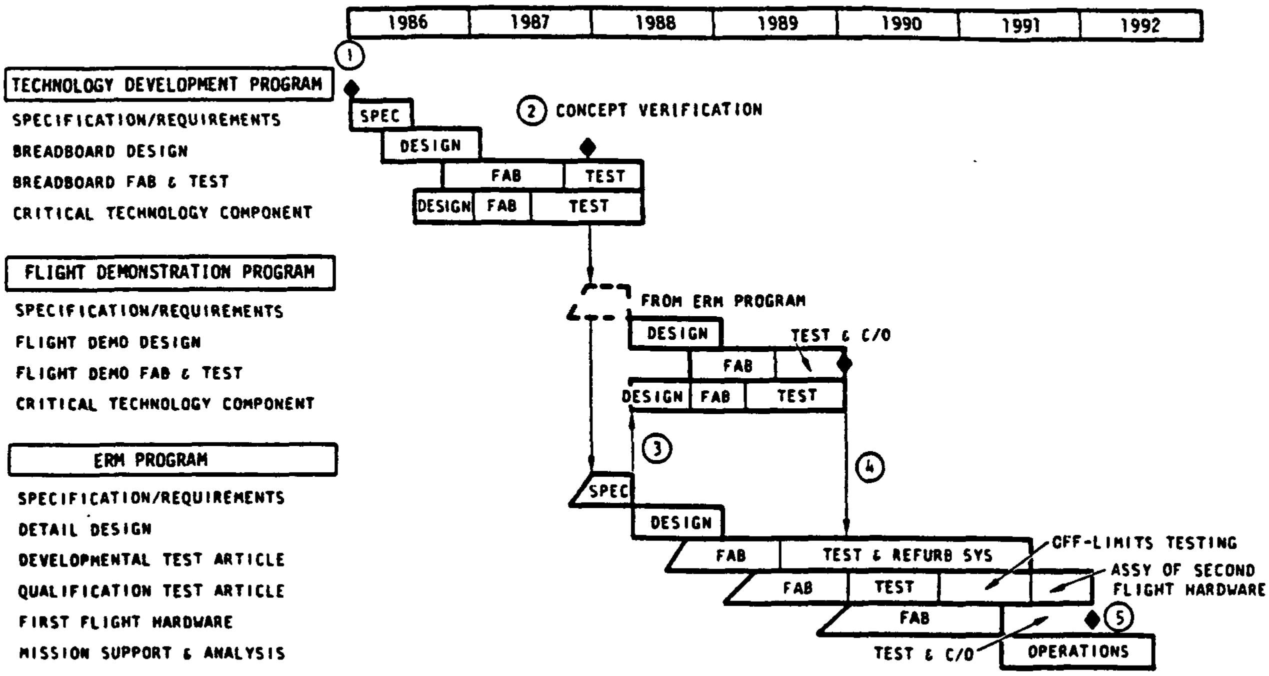

LEGEND

1 SPECIFICATIONS FOR BREADBOARD DESIGN
2 BIPROPELLANT TRANSFER VALIDATED WITH GROUND TESTING LEADS TO ERM PROGRAM PHASE C/D START
3 ERM SPECIFICATIONS DRIVES FLIGHT DEMONSTRATION PROGRAM
4 FLIGHT DEMONSTRATION HARDWARE AVAILABLE FOR REUSE ON FIRST ERM FLIGHT UNIT
5 FIRST ERM FLIGHT

Figure 24
Advanced Development
Flight Demonstration, and Resupply Module Program

TECHNOLOGY DEVELOPMENT AND FLIGHT DEMONSTRATION

	LOW		BEST ESTIMATE		HIGH
DIRECT HOURS	133,400 HR	-10%	148,200 HR	+20%	177,800 HR
LABOR RATE	$50/HR		$55/HR		$60/HR
% SUBCONTRACTED	30%		40%		50%
	9.5M		13.6M		21.3M
SPAS AND TANKS	1.9M		2.5M		3.4M
	11.4M		16.1M		24.7M

TECHNOLOGY DEVELOPMENT PROGRAM

	LOW		BEST ESTIMATE		HIGH
DIRECT HOURS	51,900 HR	-10%	57,700 HR	+20%	69,200 HR
LABOR RATE	$50/HR		$55/HR		$60/HR
% CONTRACTED	30%		40%		50%
	3.7M		5.3M		8.3M
TANKS	1.2M		1.6M		2.4M
TOTAL	4.9M		6.9M		10.7M

FLIGHT DEMONSTRATION PROGRAM

	LOW		BEST ESTIMATE		HIGH
DIRECT HOURS	81,500 HR	10%	90,500 HR	+20%	108,600HR
LABOR RATE	$50/HR		$55/HR		$60/HR
% CONTRACTED	30%		40%		50%
	5.8M		8.3M		13.0M
SPAs	0.7M		0.9M		1.0M
TOTAL	6.5M		9.2M		14.0M

Figure 25
Cost Estimate for Technology Development and
Flight Demonstration Programs

4.0 RECOMMENDATIONS FOR TECHNOLOGY DEVELOPMENT

Three major components can be identified as requiring special developmental testing to prove concept feasibility. These are the propellant pump, the helium compressor, and fluid disconnect.

The major test/demonstration items required to verify satisfactory component operation and performance are as follows:

- o Evaluate component design concept feasibility with a workhorse-type test unit.
- o Verify operation and performance of a flight-weight prototype test unit to flight application requirements.

The scope of the Test Program should encompass the following:

- o Breadboard-type tests using reference fluids and a development (workhorse) component test unit shall provide the basic data base for component functional design evaluation.
- o Development tests using reference fluids, propellants and prototype flight-weight test components will provide the basis for verification of the component design concept feasibility. These tests will assess operation and performance capabilities when subjected to flight environments, ground servicing and fluid transfer usage. In addition, component life will also be demonstrated.

5.0 Recommendations for Technology Development

The specifications and requirements for the Advanced Development Program must be oriented to the Resupply Module Program so that the critical technology components (pumps, compressors, and quick disconnects) developed are likely to be usable without extensive redesign. Most likely, considerable learning will take place during the Technology Validation Program and the Phase B study of the program. Thus, the critical technology components will probably require some redesign and consequently will be recertified in the Flight Validation Program. Of critical importance, is that all systems and hardware in the Flight Demonstration Program reflect the specifications and requirements of the operational ERM Program.

Timely program development could lead to a flight demonstration by late 1989 given the availability of qualified storable bi-propellant disconnects (derived from the GRO resupply tanker). The first operational remote resupply mission (probably in LEO) would be supported by the first OMV docking demonstration probably by late 1990 to early 1991. There is considerable potential for commonality between the NASA-JSC earth storable propellant tanker program (first refueling in-bay of GRO also planned for late 1990) and the remote resupply flight demonstration program. This synergysm could reduce the costs of both programs and any follow-on effort.