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Volume I

Final Report

June 1987

Executive Summary
and Study Results

STS Propellant Scavenging Systems Study – Part II

MARTIN MARIETTA

M I C H O U D   A E R O S P A C E

DR-6
Contract NAS8-35614

Volume I	Final Report	June 1987
Executive Summary and Study Results	STS PROPELLANT SCAVENGING SYSTEMS STUDY - PART II	

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FOREWORD

This document is part of the final report of the STS
Propellant Scavenging Systems Study, Part II, performed
under Contract NAS8-35614. It is a continuation of the
propellant scavenging studies documented in a report dated
February 1986. The final report was prepared in accordance
with DR-6 by Martin Marietta Michoud Aerospace in New
Orleans, Louisiana, for the NASA Marshall Space Flight
Center. The report was prepared in two volumes:

Volume	Title
I	Executive Summary and Study Results
II	Cost and WBS/Dictionary

The MSFC Study Manager was Milton A. Page and the Martin
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Kelleher. The work was performed under the direction of
Frank L. Williams, Director of Advanced Programs and
Program Development.

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ACRONYMS AND ABBREVIATIONS

ACC   Aft Cargo Carrier
ACS   attitude control system
ASE   airborne support equipment
ATP   Authority to Proceed
B   billion
BRM   Baseline Reference Mission
cg   center of gravity
CDR   Critical Design Review
CER   cost estimating relationship
CFMF   Cryogenic Fluid Management Facility
CPF   cost per flight
CY   calendar year
delta-V   delta velocity
DOD   Department of Defense
DOI   direct orbit insertion
ET   External Tank
FPR   flight performance reserve
fps   feet per second
FRF   Flight Readiness firing
g   gravity
GEO   geosynchronous Earth orbit
GHe   gaseous helium
GH2   gaseous hydrogen
GN&C   guidance, navigation and control (subsystem)
GN2   gaseous nitrogen
GO2   gaseous oxygen
GSE   ground support equipment

ACRONYMS AND ABBREVIATIONS

H2	hydrogen
He	helium
I/F	interface
I/T	intertank
IMU	inertial measurement unit
IOC	initial operating capability
IR&D	Independent Research and Development
Isp	specific impulse
JSC	Johnson Space Center
K	thousand
klb	thousands of pounds
KSC	Kennedy Space Center
lbf	pound-force
lbm	pound-mass
LCC	life cycle cost
LEO	low Earth orbit
LH2	liquid hydrogen
LO2	liquid oxygen
LWACC	Lightweight ACC
LWT	Lightweight External Tank
M	million
MAF	Michoud Assembly Facility
MFSC	Marshall Space Flight Center
misc	miscellaneous
mlb	millions of pounds
MLI	multilayer insulation
MLP	mobile launch platform
MMH	monomethyl hydrazine

MPS	main propulsion system
MRMS	mobile remote manipulator system
NASA	National Aeronautics and Space Administration
N2O4	nitrogen tetroxide
NCFI	North Carolina Foam Industries
nm	nautical mile
O2	oxygen
OMS	orbital maneuvering system
OMV	Orbital Maneuvering Vehicle
Ops	Operations
OTV	Orbital Transfer Vehicle
P/A	propulsion/avionics
P/S	propellant scavenging/system
PAM-D	Payload Assist Module, Delta Class Spacecraft
PDR	Preliminary Design Review
PMD	propellant management device
PPS	primary propulsion system
prop.	propellant
PS	propellant scavenging
psia	pounds per square inch (absolute)
PSS	payload support structure
PSV	Propellant Scavenging Vehicle
R&M	reliability and maintainability
RCS	reaction control system
RF	radio frequency
RI	Rockwell International
RMS	remote manipulator system
rqd	required
RSS	range safety system
RTLS	return to launch site
RUD	rematable umbilical disconnect
RZ	rendezvous

ACRONYMS AND ABBREVIATIONS

SDV	Shuttle Derived Vehicle
sec	second
SOFI	spray-on foam insulation
SOW	Statement of Work
SRB	solid rocket booster
SS	Space Station
SSME	Space Shuttle main engine
STA	Scavenge Tank Assembly
STA	Structural Test Article
STAS	Space Transportation Architectural Study
TBD	to be determined
TPS	thermal protection system
TVS	thermodynamic vent system
UCV	unmanned cargo vehicle
ULV	unmanned launch vehicle
WBS	Work Breakdown Structure
xfer	transfer
zero-g	zero gravity

1.0 EXECUTIVE SUMMARY

The major objective of the STS Propellant Scavenging (PS) Study is to define the hardware, operations, and life cycle costs (LCC) for recovery of unused Space Transportation System (STS) propellants.

Earlier phases of this study were concerned exclusively with the recovery of cryogenic propellants from the main propulsion system (MPS) of the manned STS. The phase of the study covered by this report (Part II Extension) modified the objectives to include cryogenic propellants delivered to orbit by the unmanned cargo vehicle (UCV).

The Part II Extension of the study had the following objectives:

1) Review STAS mission model for propellant transport opportunities;

2) Predict OTV propellant requirements from 1995 - 2010;

3) Investigate scavenging/transport tank reuse;

4) Determine optimum tank sizing and arrangement;

5) Develop hardware concepts for tanks;

6) Determine and quantify impacts to UCV;

7) Develop interface concepts; and

8) Update Part II cost and schedule estimates.

1.1 Concept Definition

The sidemount Shuttle Derived Vehicle (SDV) was directed to be our baseline UCV. Accordingly, we developed cryogenic tankage concepts suitable for transport to orbit in the large SDV payload bay. However, considerations of tank reuse led us to design configurations which would allow the tankage to be disassembled for return to Earth in the smaller STS Orbiter payload bay.

Three scavenging/transport tank concepts were considered. All concepts consisted of two liquid hydrogen (LH2) tanks and one liquid oxygen (LO2) tank, capable of transporting 61.4 klb of cryogens to orbit at a mixture of 6:1. The concepts were:

o Option 1 - Tanks mounted at the aft end of the payload (P/L) module of the SDV. The tanks would be built-in or deployable as a unit, depending on whether the P/L module visits the Space Station (SS).

o Option 2 - Tanks mounted at the forward end of the P/L module utilizing a portion of the P/L module nose cone volume. Again, the tanks could be built-in or deployable as a unit.

o <u>Option 2A</u> - A self-propelled tank assembly, based on Option 2. This concept would use much of the hardware and techniques proposed for the selected STS scavenging method (Concept 6) described in earlier phases of this study.

There are sufficient data to select one of the three options over the other two. However, such a selection depends on the operational mode to be adopted by the SDV, i.e.:

o Rendezvous and dock/berth with the SS; or

o Rendezvous at a distance from the SS and transfer cargo by OMV; or

o Deploy cargo in a significantly lower orbit than SS for OMV retrieval.

Option 2/2A offers the flexibility to cover all of these potential operational modes, while Option 1 can operate only in the first two modes.

We have identified no major weight, cost, or technology differences between Options 1 and 2. Although the self-propelled tank set (Option 2A) incurs some weight penalty when compared to the other concepts, it offers additional capabilities. Our studies indicate that Option 2A could be developed as a field kit modification to Option 2, if required. Figure 1.1-1 shows the UCV reference mission for Option 2A, while Figure 1.1-2 illustrates corresponding tankage concept in greater detail.

1.2   Life Cycle Cost Analysis

STS propellant scavenging (PS) can deliver cryogenic propellant at a lower cost per pound than the SDV.

The STS-based system can provide up to 144 klb/year of cryogenic propellant at approximately $420/lb. If more propellant is required--as indicated by the OTV traffic model--it can be supplied by the use of the SDV tanker.

If no STS propellant scavenging system (P/S) is developed and only the SDV propellant transport is used, the cost increases to approximately $850/lb. The scavenging of SDV propellant residuals offers some cost benefit by reducing the delivered cost by about $70/lb.

The combination of STS and SDV scavenging offers the lowest LCC for delivered propellant in excess of 144 klb/year. Using both systems to deliver 540 klb of propellant per year results in a delivered cost of $692/lb.
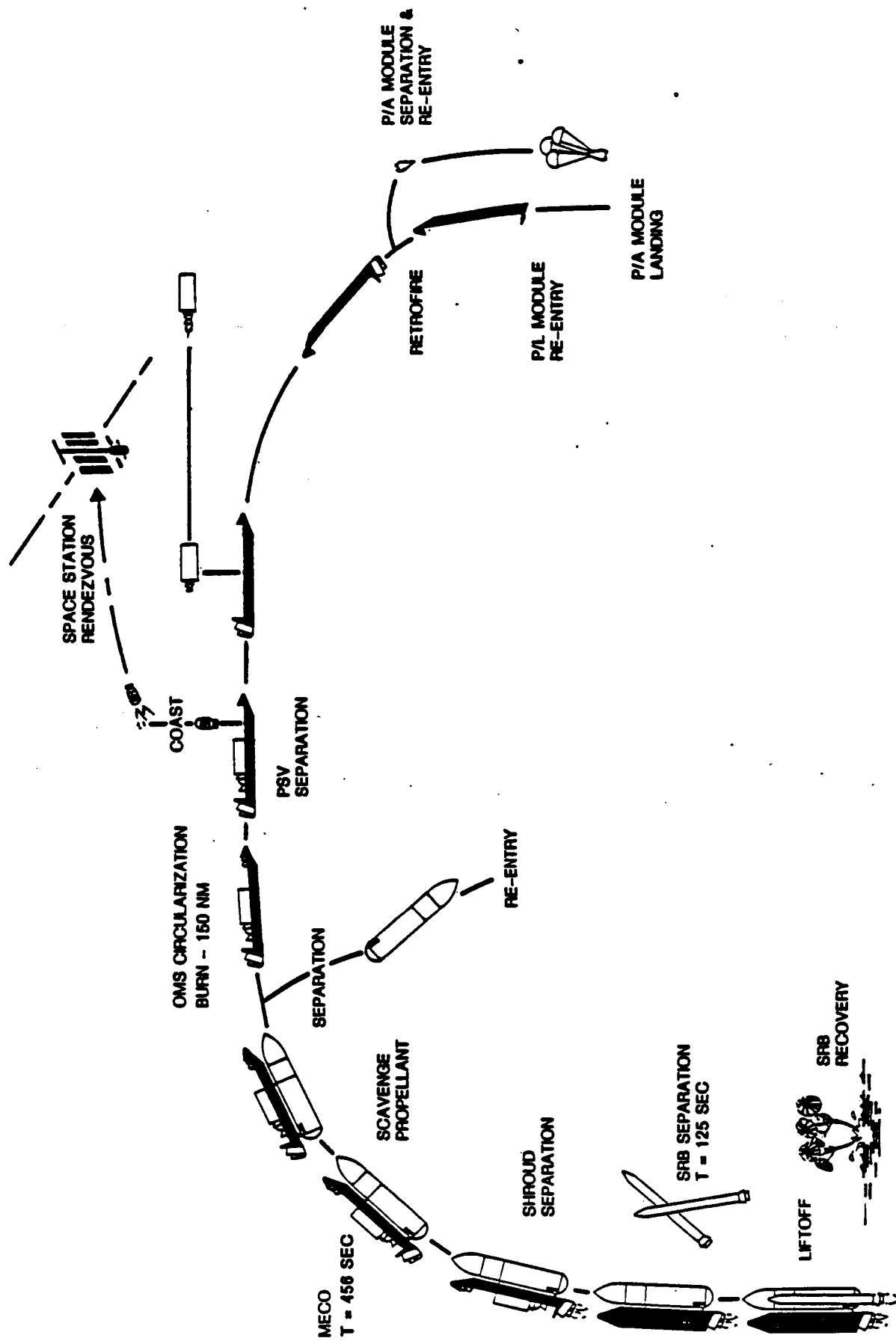
FIGURE 1.1-1 "UCV REFERENCE MISSION WITH SELF-PROPELLED TANK SET

SPACE STATION
RENDEZVOUS

OMS CIRCULARIZATION
BURN – 150 NM

COAST

PSV
SEPARATION

SEPARATION

RE-ENTRY

SCAVENGE
PROPELLANT

SHROUD
SEPARATION

MECO
T = 458 SEC

SRB SEPARATION
T = 125 SEC

SRB
RECOVERY

LIFTOFF

P/A MODULE
SEPARATION &
RE-ENTRY

RETROFIRE

P/L MODULE
RE-ENTRY

P/A MODULE
LANDING

3
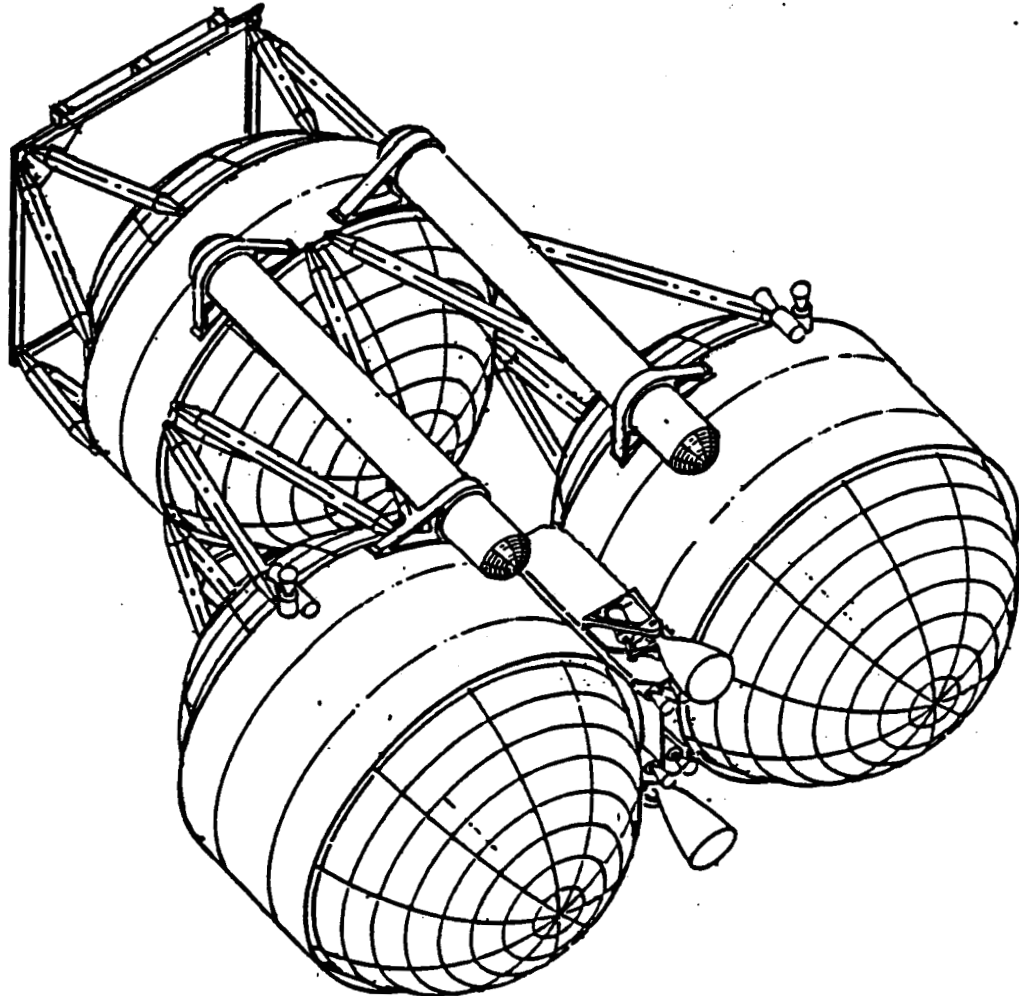
FIGURE 1.1-2   SELF-PROPELLED TANK SET - TRIMETRIC VIEW

The analysis showed that the transportation cost was the major cost driver. Operations costs were 99% of the total LCC while 87% of the operations cost was the SDV users charge. With these costs dominating the LCC, any changes in DDT&E and production costs would minimally effect the delivered propellant cost per pound.

1.3 TASK RESULTS

The most significant results of the Part II task results are summarized below. These results supplement the results presented in our previous report (Reference 1).

1) The Space Transportation Architectural Study (STAS) mission models were used with the PF20 Orbital Transfer Vehicle (OTV) mission model to identify the proportion of SDV capacity necessary to deliver cryogenic propellant to orbit. The parametric results (Figure 1.3-1) indicate that 45% of the total SDV annual capacity is required for propellant delivery for the baseline SDV launch rate of 8/year. The use of STS PS reduces the demand on the SDV to 35% of its annual capacity.

2) Our studies showed that SDV residuals scavenging --while cost-effective-- is not a major factor in propellant resupply because the SDV has a much larger cargo capacity than STS, while possessing the same residual propellants. Therefore, for a tanker mission, the SDV has an inherently higher ratio of capacity to residuals. For the mission models used, SDV propelled scavenging and transport delivered only 10% more propellant than propellant transport only.

3) The STAS mission models showed that 70% to 80% of the cargo mass and volume delivered to orbit must be returned to Earth. This factor causes problems for the potential reuse of PS hardware (e.g., tanks, etc.) since there does not appear to be sufficient transport cargo bay space available to return it from orbit. Although the mission models used have the STS and SDV to deliver payloads to orbit, only the STS is available to return them. An imbalance of capacity exists. However, we have designed our hardware such that it is capable of return in a STS cargo bay if sufficient capacity exists.

4) The interface concepts developed for the STS PS system may be used for the SDV system. Our goal is an interface design capable of use with standard orbital cryogenic disconnects applicable to both the OTV and the SS.
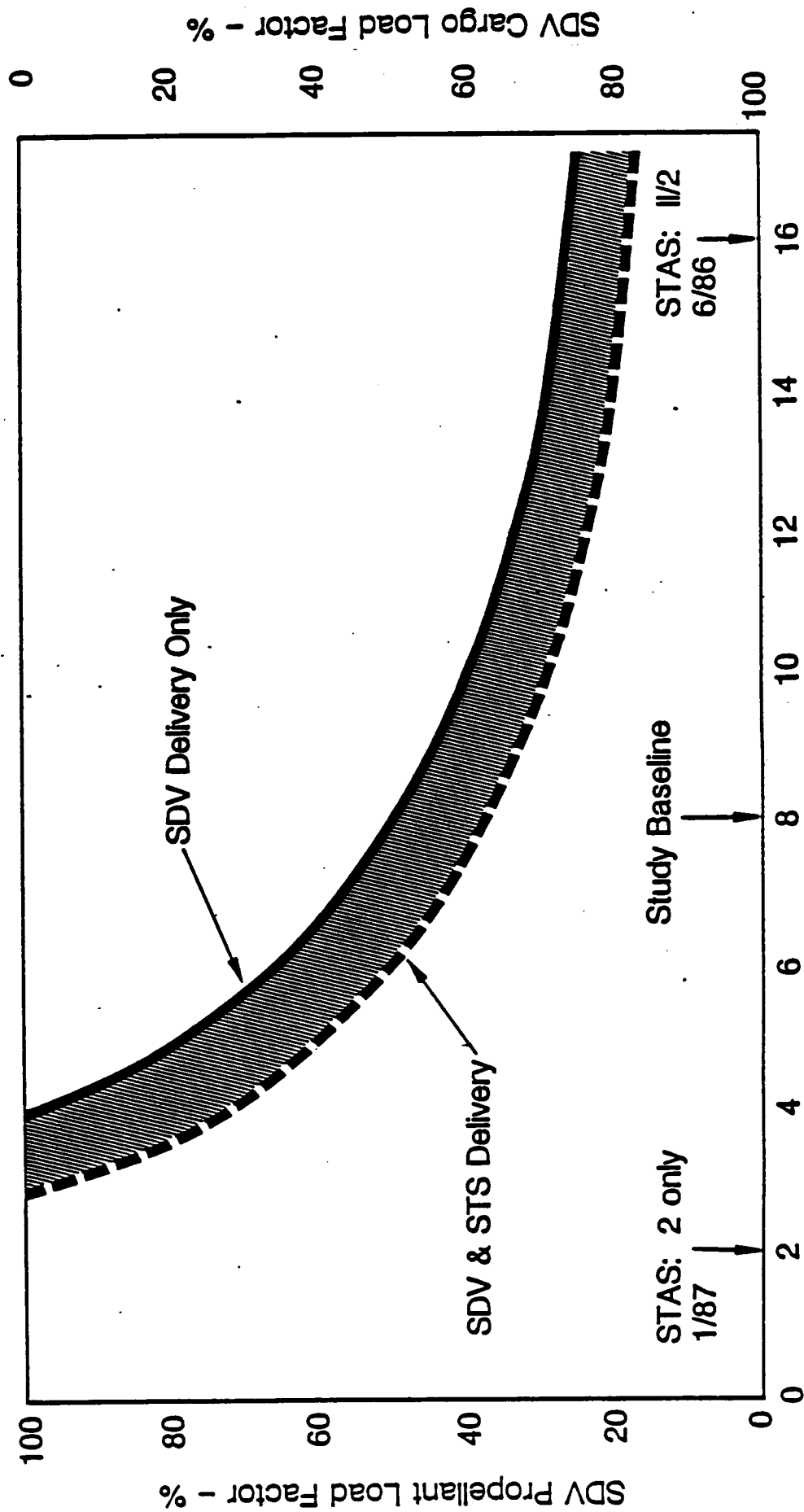
FIGURE 1.3-1   SDV LAUNCHES REQUIRED TO DELIVER OTV PROPELLANT

5) Hydrogen interfaces between the SDV and ground facilities (for the loading of the propellants to be transported) may be directly adapted from the STS/Centaur program. In particular, the Centaur rolling beam may be used, as well as disconnects, etc. The STS/Centaur uses LO2/GO2 connections within the Orbiter payload bay. If this were to be adopted for a sidemount SDV with a separate P/A module, an interface in the forward skin of the P/A module would be required. An alternative approach would be to develop an oxygen umbilical from the mobile launch platform (MLP) to the P/L module starboard side. This trade requires detailed cost studies which should be deferred to a later study phase.

6) The STS Propellant Scavenging Vehicle (PSV) is not the optimum configuration for use on the SDV. Our studies indicate that a more efficient use of the available P/L module volume is a three tank arrangement that has a total propellant capacity of 61.4 klb at a 6:1 mixture ratio. The two LH2 tanks and one LO2 tank may be arranged at one of two favored locations: the aft end or forward end of the P/L module. Each location offers benefits, but the major discriminator between them was the operational mode of the SDV, at present undefined. Until this mode is defined, a final tank configuration selection cannot be made. However, the forward-mounted tank set, which lends itself to deployment into a self-propelled vehicle, has the potential for greater operational flexibility.

7) Few negative impacts were found from the incorporation of cryogenic propellant transport into the SDV. These main impacts involved localized restressing, equipment relocation, and provision for propellant loading. Deployable or self-propelled tank sets minimally impact the SDV operations since they may be treated as normal deployable payloads.

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1.4 Conclusions

The following conclusions were reached as a result of this extension of the study.

1) Large quantities of LH2 and LO2 can be delivered to orbit using the SDV and STS.

2) STS and SDV PS are cost-effective. However, while scavenging is an essential element of economic propellant transportation by the STS, scavenging is not essential for the SDV. The SDV propellant tanker can be a straightforward transporter.

3) Current STS, SDV/UCV, and OTV mission models are compatible for propellant resupply. Our baseline models included 12 STS flights/year, 8 SDV flights/year, and 13 OTV flights/year. Our studies showed that the SDV/UCV was essential to maintain propellant resupply, while the STS PS operation could provide about 25% of the OTV requirement.

4) OTV propellant resupply is the largest single SDV/UCV user for the mission models examined: 45% of the total SDV annual lift capability is required to supply the OTV's annual requirement.

5) The return of the transport/scavenging tanks to Earth is severely restricted by the absence of return capacity. Since the baseline UCV does not have a reusable/returnable P/L module, the only return capability is provided by returning STS Orbiters. The mission models show that there is insufficient return capacity to allow reuse of a meaningful fraction of the tankage delivered.

6) The only major technology requirement identified continues to be the rematable cryogenic disconnect. This is the pacing development item for propellant resupply.

7) Propellant conditioning should be performed at the SS tank farm (OTV facility). The complexity of any propellant conditioning operation tends to mitigate against its incorporation into the relatively simple propellant resupply vehicle.

8) A three-tank arrangement is favored for the SDV propellant tanker. This configuration contrasts with the STS case where a tandem tank arrangement was selected. The SDV P/L module allows a 25 ft width, while the STS P/L bay allows only 15 ft. For volumetric efficiency,

three tanks are well suited to the SDV, while still offering the potential for the return of individual tanks as STS payloads. The single LO2 tank has a 52.7 klb capacity, while the two LH2 tanks each have a 4.35 klb capacity. These volumes provide a total of 61.4 klb·at a delivered mixture ratio of 6:1.

9) Propellant transport offers minimal negative impacts to the SDV. The principal negative impacts are the cost and weight of P/L module fixed airborne support equipment (ASE). A positive impact to SDV is the potential exists to perform an LO2 jettison in the event of SSME failure. This feature can allow an abort-to-orbit capability for the SDV. This capability is directly analogous to the STS/Centaur Transatlantic Abort/Landing Avoidance (TALA) mode.

1.5 Recommendations

1) The requirement to transport cryogenic propellant should be an element of the UCV design specification. As a minimum, UCV concepts should not preclude the incorporation of PS and/or transport.

2) The SS, OTV, and UCV programs should coordinate their activities to allow optimal integration of the cryogenic propellant resupply, especially propellant conditioning and interfaces.

3) A standard rematable cryogenic disconnect for space operations should be developed. This disconnect is the pacing technology item for on-orbit cryogenic propellant transfer.

4) Both the STS cryogenic PS system and the UCV/SDV cryogenic PS transport system should be developed. For large propellant demand (500 klb/year), the use of both systems provides the lowest overall costs.

5) The development of a low altitude logistics node should be considered. Significant increases (25% or more) in deliverable propellant mass can be achieved by basing the OTV facility/tank farm at an altitude of 50 nm or more below the SS.

2:0 STUDY RESULTS - BACKGROUND

2.0.1 Introduction

Large quantities of cryogenic LO2 and LH2 will be required in the vicinity of the SS to support the space based OTV.

A long-term propellant storage facility in the vicinity of the SS can be resupplied with the residual and surplus propellants recovered from the External Tank (ET) and MPS of the STS. Recovery of these propellants may offer significant savings over propellant resupply by a dedicated tanker vehicle.

Earlier phases of this study focused exclusively on scavenging cryogenic propellants from the STS. The current study extended the objectives to include cryogenic propellants delivered by the unmanned cargo vehicle (UCV).

Figure 2.0-1 gives the history of the PS study.

	PHASE	TIMEFRAME	VALUE
o	CONTRACT NAS8-35614	Sept. 19, 1983 - March 19, 1985	$244K
o	Part II Follow-on	April 19, 1985 - Feb. 19, 1986	$139K
o	Follow-on Change Order 10	Sept. 19, 1986 - Aug. 19, 1987	$ 75K

FIGURE 2.0-1 - STUDY HISTORY

A. Objectives

The study built on the results of the previous phases. The principal new elements were:

1) The use of a STAS mission model; and

2) The incorporation of UCV PS.

Also, the period of interest to be studied changed from 1993-2002 to 1995-2010.

The principal objectives were:

    o Review the STAS mission model for propellant transport opportunities;

    o Predict the OTV propellant requirements from 1995 - 2010;

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o Review the opportunities for scavenging/transport tank recovery
  - Feasibility/benefits of tank recovery/reuse;
o Identify requirements for UCV scavenging/transport tanks;
o Determine the optimum tank sizing and arrangement for UCV use
  - Compare with STS;
o Develop hardware concepts for tanks; and
o Update Part II cost/schedule estimates.

This phase of the study focused on the development of a tankage concept to allow the UCV to transport cryogenic propellant to orbit for use by a space based OTV.

B. Guidelines and Assumptions

The following guidelines, ground rules, and assumptions were used in this study.

o 1995 Mission Model was baselined:
  - STAS payload manifests were to be used "as is";
  * - DOD missions were excluded;
  - Mission model sensitivities were to be assessed.
o Launch vehicle architecture included 65 klb payload STS, 150 klb UCV, and a 30 klb Spaceplane or 65 klb STS II:
  - Payload capabilities consistent with STAS;
  - Sidemount SDV was baselined.
o Propellant required/available was to be assessed:
  - 1995 - 2010 time period;
  - STAS/OTV mission model;
  - Cryogenic space based OTV assumed to exist.
o Concept 6 PSV was the study baseline.

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* This ground rule was later changed to allow the assessment of the impact of including DOD missions, without requiring the use of classified data.

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2.0.2 STUDY - PARTS I AND II

All viable STS PS concepts were identified and evaluated during Part I of the study conducted during 1983 and 1985. Concept 6, carried in lightweight ACC, was selected as best based upon the most propellant scavenged at the lowest cost/lb. During Part II of the study, conducted during 1985-1986, this concept was refined and optimized. A detailed hardware description was made and the supporting research and technology required was identified.

Figure 2.0-2 illustrates the self-propelled Concept 6 PSV. This isometric view shows the relative location of the primary components. The main tanks have cassinian domes to minimize vehicle length.
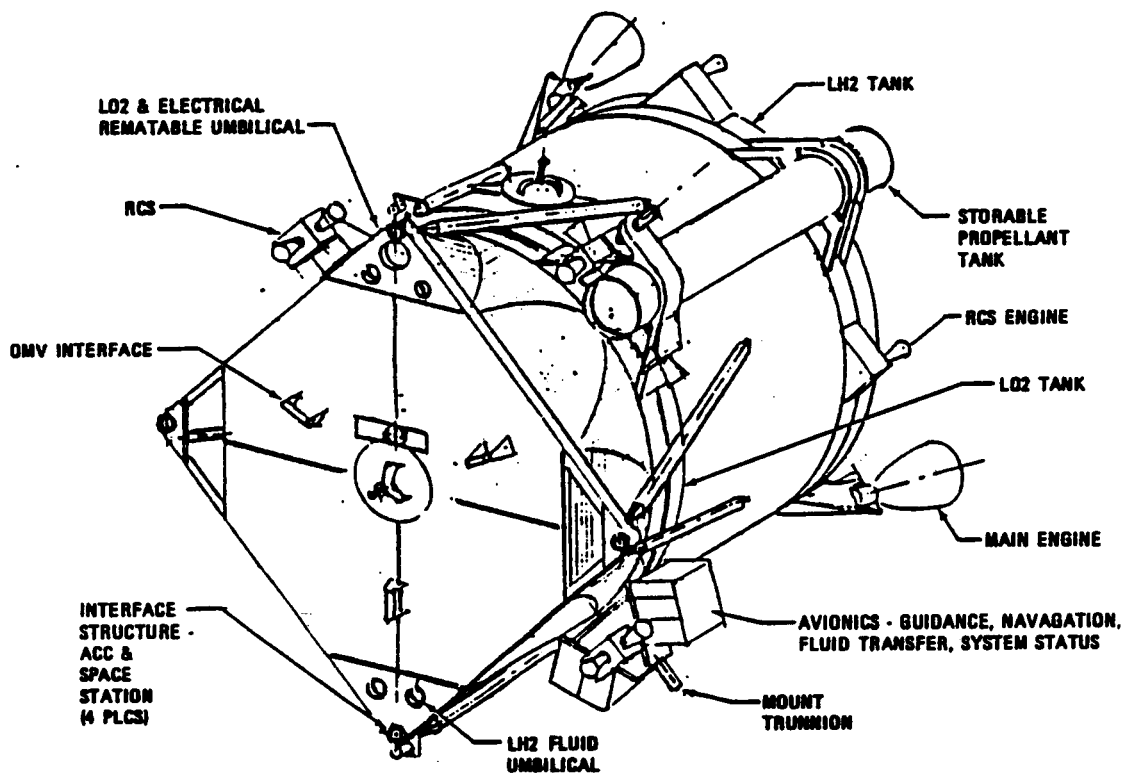
FIGURE 2.0-2 CONCEPT 6 PROPELLANT SCAVENGING VEHICLE (PSV)

The primary engines are 900 lb thrust storable bipropellant engines and the reaction control system (RCS) engines are 25 lb thrust engines. Both engines are currently used on the Orbiter RCS. The two storable bipropellant tanks are positive expulsion tanks which are baselined bellows-type tanks.

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The interface and support structure are located at the forward end of the vehicle. Trunnions, for mounting the empty tanks in the Orbiter cargo bay for return to Earth, are located near the assembly center of gravity (cg).

This design places the LO2 tank forward to minimize the structural moments produced during lift-off and ascent. The LH2 tank is mounted inline using a cylindrical skin stringer type intertank (I/T) structure fastened to the flanges at the equator of each of the two tanks.

Both tanks are 130.3 in diameter. The LO2 tank is 78 in. long and the LH2 tank is 82.5 in. long. The PSV dry weight is 34.1 klb based on a 2219 aluminum structure.

Figure 2.0-3 shows the baseline mission scenario for STS PS.
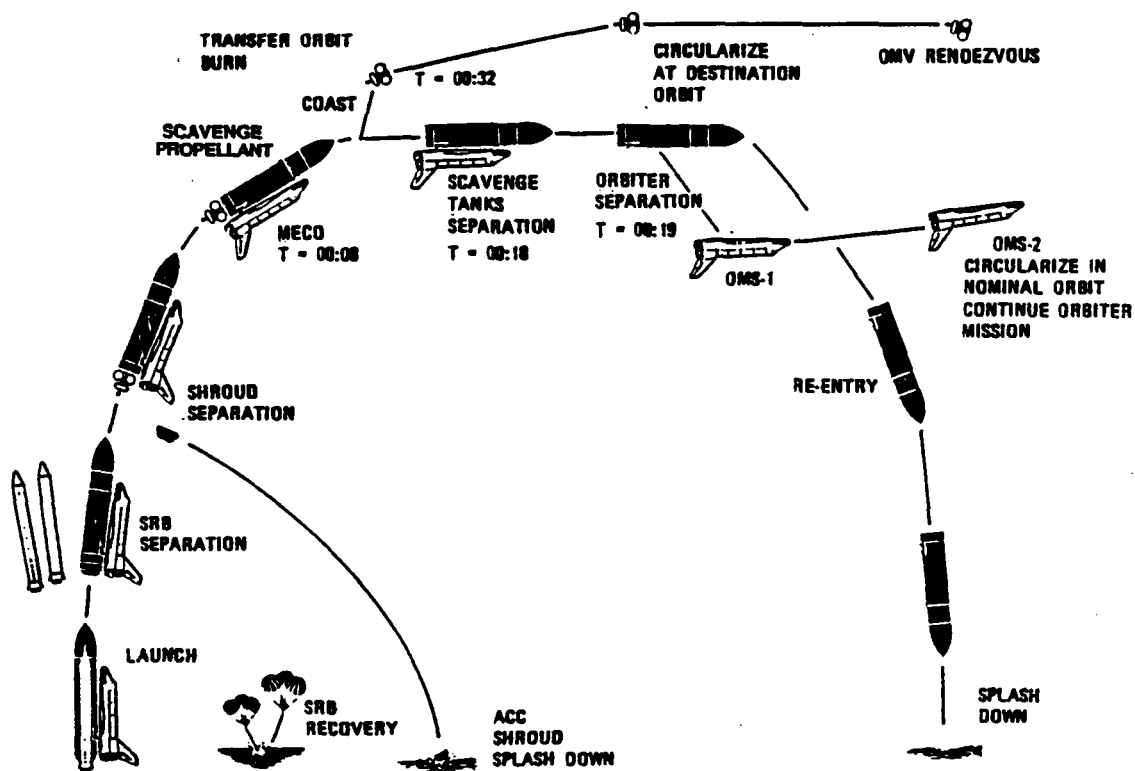
FIGURE 2.0-3   CONCEPT 6 MISSION SCENARIO

A typical STS scavenging mission scenario is as follows:

1) Partially load LO2 scavenging tank with a propellant mass equivalent to the surplus lift capability during ET loading;

2) Launch and solid rocket booster (SRB) separation;

3) Separate Aft Cargo Carrier (ACC) shroud;

4) Transfer residual propellant to scavenging tanks after main engine cutoff (MECO); (transfer time approximately 10 minutes);

5) Separate the PSV from the ET/ACC;

6) Fly PSV to orbit in vicinity of SS;

7) Orbital Maneuvering Vehicle (OMV) rendezvous with PSV and performs proximity operations for final berthing to the SS storage facility;

8) Orbiter separates from ET after PSV separation;

9) ET reenters atmosphere and the Orbiter resumes its primary mission, and

10) Empty PSV returned to Earth in the Orbiter bay when opportunity available.

Figure 2.0-4 shows the PSV separation, docking, and berthing operations in greater detail. This scenario illustrates the simplicity of the methods employed, as well as the utilization of the OMV for SS proximity operations.

A table of "quick" reference data is given in Figure 2.0-5. Further details, including an extensive hardware description, are available in Reference 1.

Separation, Docking, and Berthing Scenario
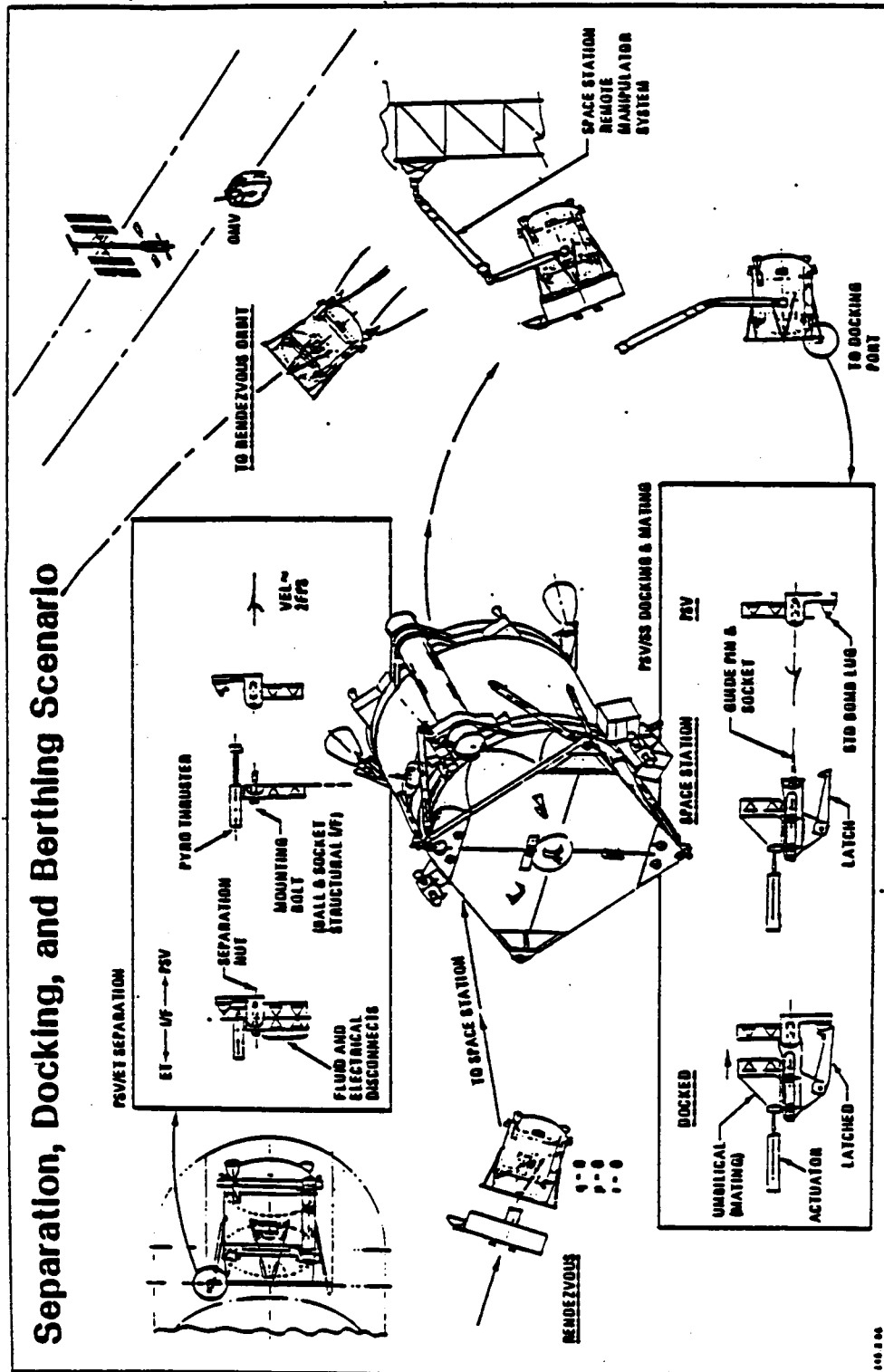
FIGURE 2.0-4   SEPARATION, DOCKING AND BERTHING SCENARIO

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<u>Dimensions</u>

Item	Length(in.)	Diameter(in.)
Overall PSV envelope	200	180
LO2 scavenge tank	78	130.3
LH2 scavenge tank	82.5	130.3
Storable propellant tanks (2)	120	20

<u>Capacities, Weights & Performance</u>

- LO2 tank capacity (4% ullage) = 30,000 lb
- LH2 tank capacity (4% ullage) = 2,000 lb
- N204 tank capacity = 1,540 lb
- MMH tank capacity = 960 lb
- PSV empty weight = 3,410 lb
  - Max delta-V capability = 654 fps
    max payload
  - Max delta-V capability = 2,422 fps
    min payload

<u>Major Subsystem</u>

- Main Propulsion by two 900 lbf Marquardt R40B
- RCS by sixteen 25-lbf Marquardt R1E engines
- Three axis-attitude control using inertial reference unit (IRU) and on board computer
- Response to hardwired or RF originating signals to operate RCS, inhibits tank venting systems and propellant transfer valves

FIGURE 2.0-5 STS PROPELLANT SCAVENGING VEHICLE QUICK REFERENCE DATA

The 1985-86 phase of the study also included detailed costing estimates showing that large cost savings could be made if scavenging were to be used to deliver cryogenic propellant to orbit versus using an STS tanker.

A comparison of the Concept 6 LCC with an STS tanker scenario indicated that a saving of $3.2B (80% reduction) could be realized (Figure 2.0-6).

17

$48

4

3

Program
LCC   2
($B)

1

0

• 1.96 Mlb Propellant Delivered

• OMV Operations Cost Not Included

DDT&E
Production
PS Operations
ACC Operations

STS
Tanker
Flights

Propellant
Scavenging
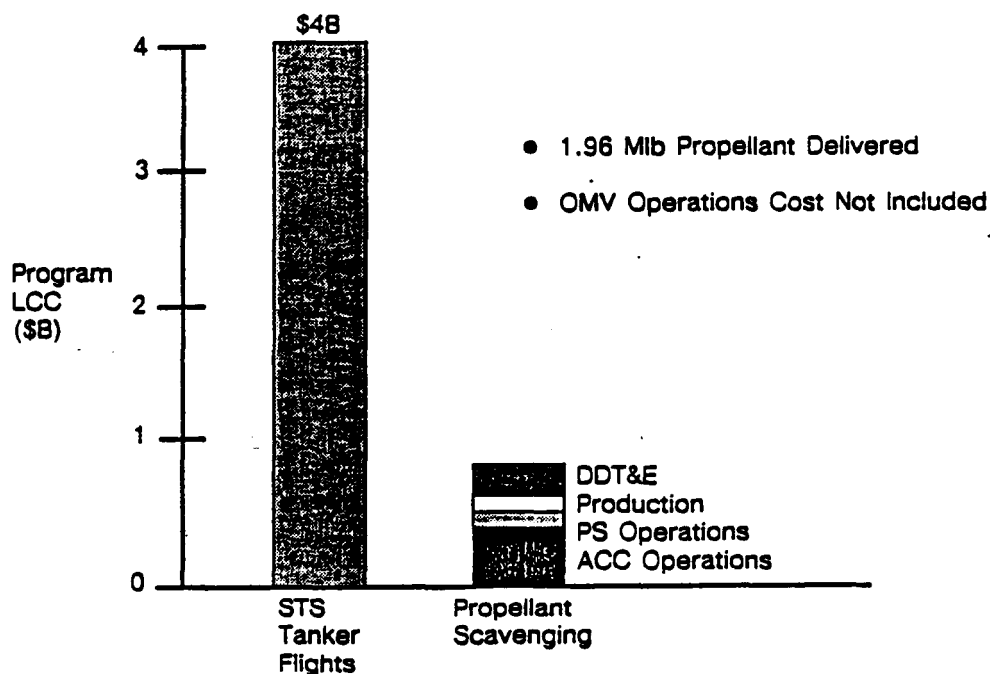
FIGURE 2.0-6 PROPELLANT SCAVENGING vs STS TANKER LCC

This saving resulted from taking advantage of the excess payload lift capability predicted for the STS in the years 1993 - 2002. The elimination of 39 dedicated STS tanker missions (to deliver 1.96 mlb propellant) more than compensated for the additional development, production, and operations costs. Further cost benefits would be realized if scavenging operations included DOD flights.

The STS tanker costs were based on the delivery of 50 klb propellant with a launch cost of $101.4M.

The results of the previous parts of this study are summarized as follows:

o STS cryogenic PS is technically feasible and cost effective;

o More than 2 mlb can be recovered and delivered to the SS in a 10 year period;

o PS is relatively insensitive to anticipated STS performance decrements:

o The free-flying PSV recovers the most propellant at the lowest cost with a minimal operations impact;

o No new technology is required except in fluid interfaces
  - New fluid interface technology is applicable to all space vehicle
    operations;

o OMV is essential for SS proximity operations;

o Payloads should be manifested with scavenging in mind;

o STS tankers can be eliminated by proper manifesting of payloads and
  propellants; and

o Combining Rockwell and Martin concepts delivers largest quantity of
  propellant at the lowest $/lb.

2.0.3 Inclusion of Unmanned Cargo Vehicle

The final phase of the STS P/S Study began in September 1986. The primary objective was to extend the concept of STS cryogenic PS to the UCV. We were directed to use the sidemount SDV as the baseline configuration for the UCV.

Figure 2.0-7 gives the configuration for the sidemount SDV.

This Shuttle Derived UCV configuration represents the class of UCVs capable of delivering 150 klb payload to orbit. These data are extracted from a 1984 Martin Marietta Michoud Aerospace study (Reference 6).

Noteworthy features are: the side-mounted P/L module, with internal dimensions of 25 ft diameter and 90 ft length; the conical nose fairing; and the separate P/A module, a recoverable unit containing three SSMEs, an orbital maneuvering system, and associated avionics.

The P/L module (Figure 2.0-8) provides the structural strongback:

o To support multiple payloads;

o To take thrust loads from the P/A module; and

o To provide aerodynamic shielding during the boost phase of the SDV
  mission.

The baseline UCV reference mission (Figure 2.0-9) is similar to a standard STS mission with the following differences:

o A payload shroud is jettisoned during ascent; and

o On reentry, the recoverable P/A module separates from the P/L module
  (which breaks up and is not recovered).
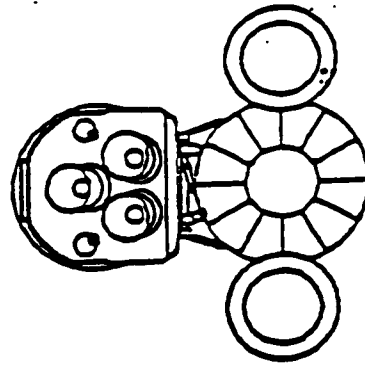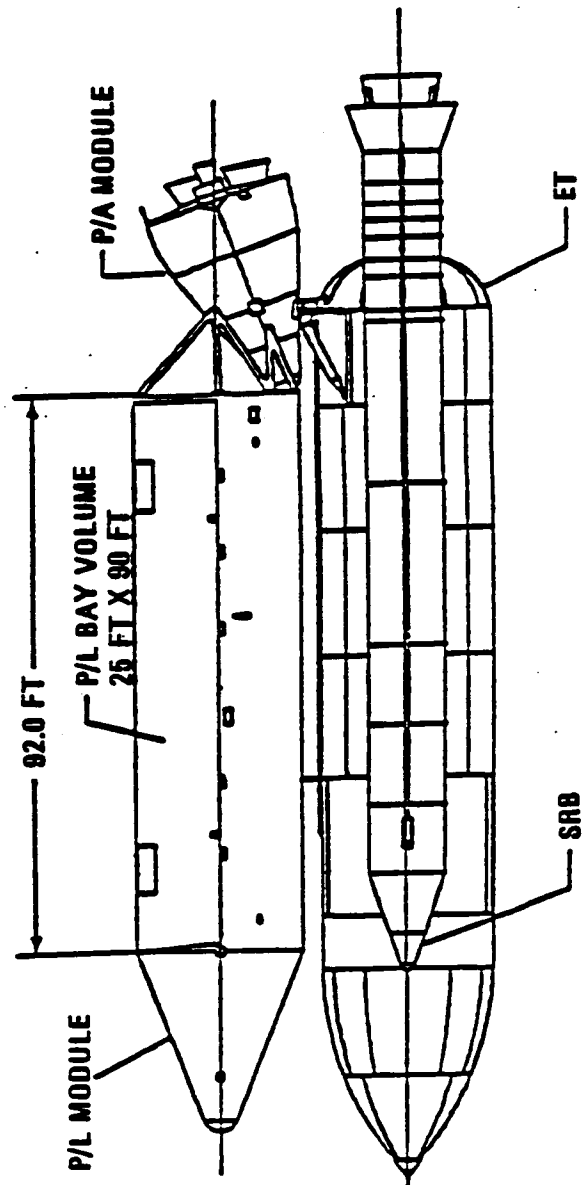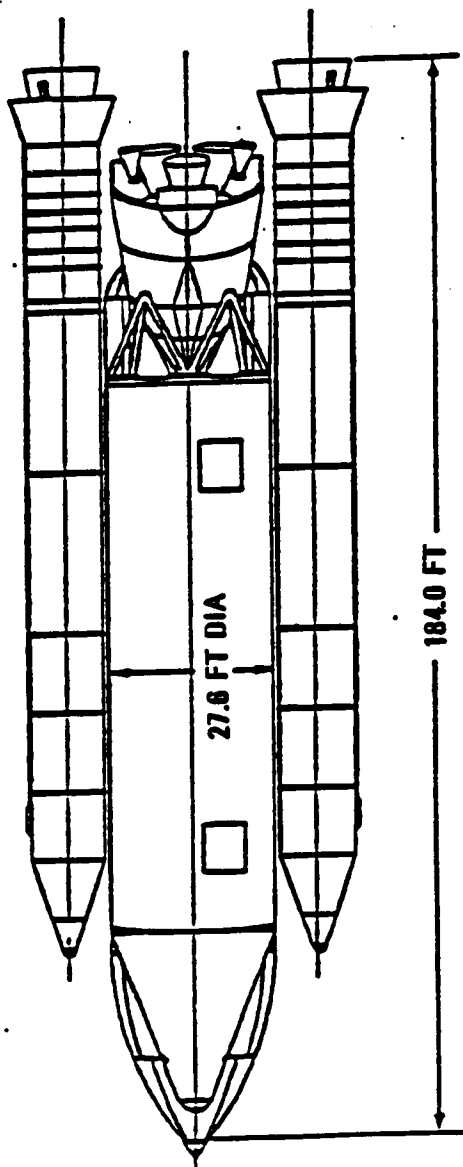
FIGURE 2.0—7   SDV/UCV CONFIGURATION

184.0 FT

27.6 FT DIA

P/A MODULE

ET

92.0 FT

P/L BAY VOLUME
25 FT X 90 FT

SRB
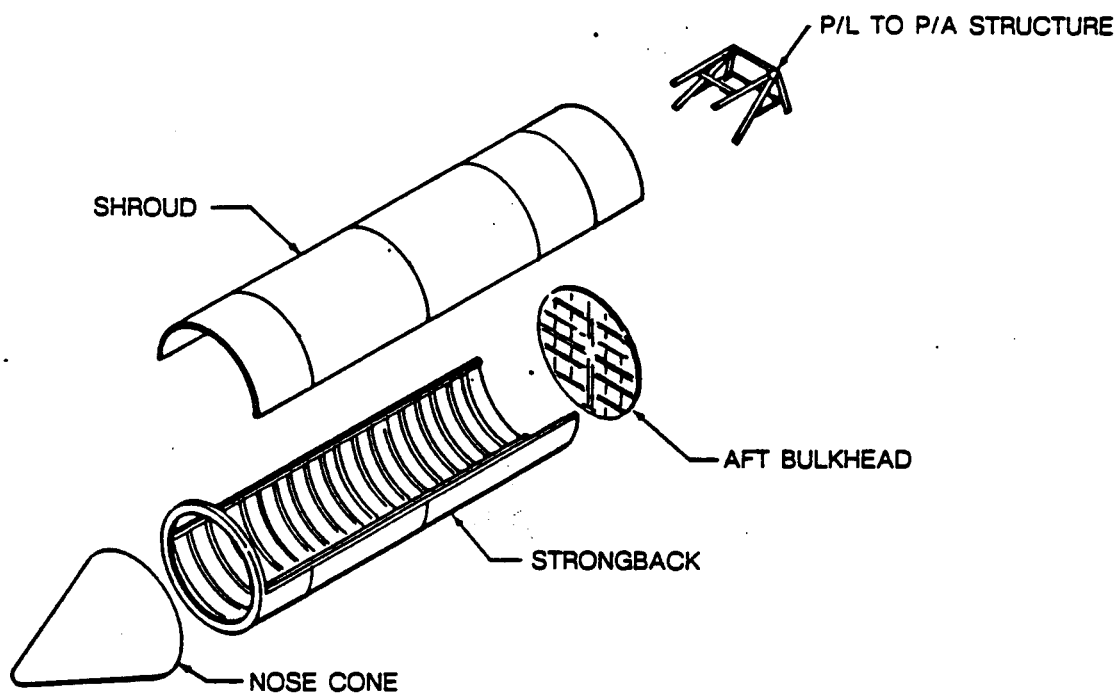
P/L MODULE

FIGURE 2.0-8   SDV PAYLOAD MODULE
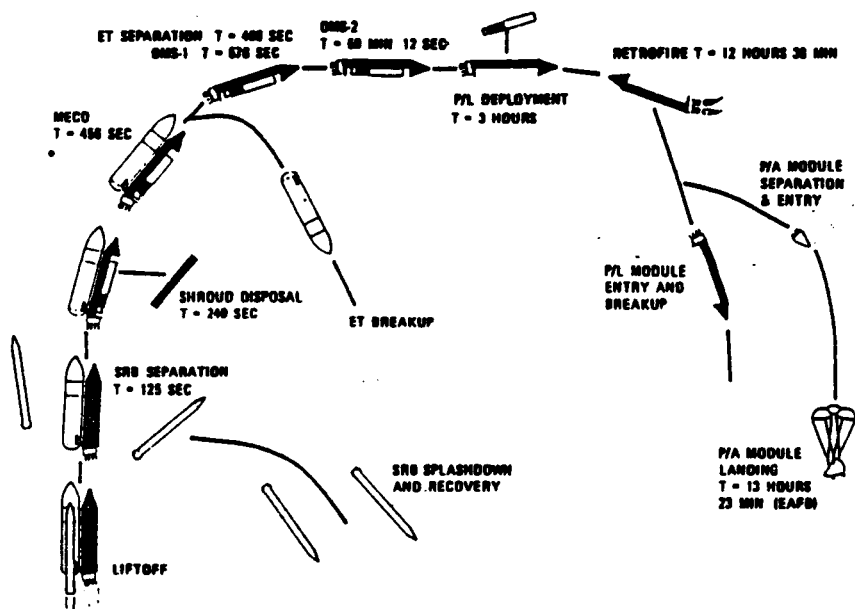
FIGURE 2.0-9 UCV REFERENCE MISSION

The baseline UCV mission may be impacted by the requirement to transport propellants. The scenario (Figure 2.0-10) offers little impact: it treats the propellant tanks as a payload to be removed and transported by an OMV. This and other scenarios have been examined during the study.
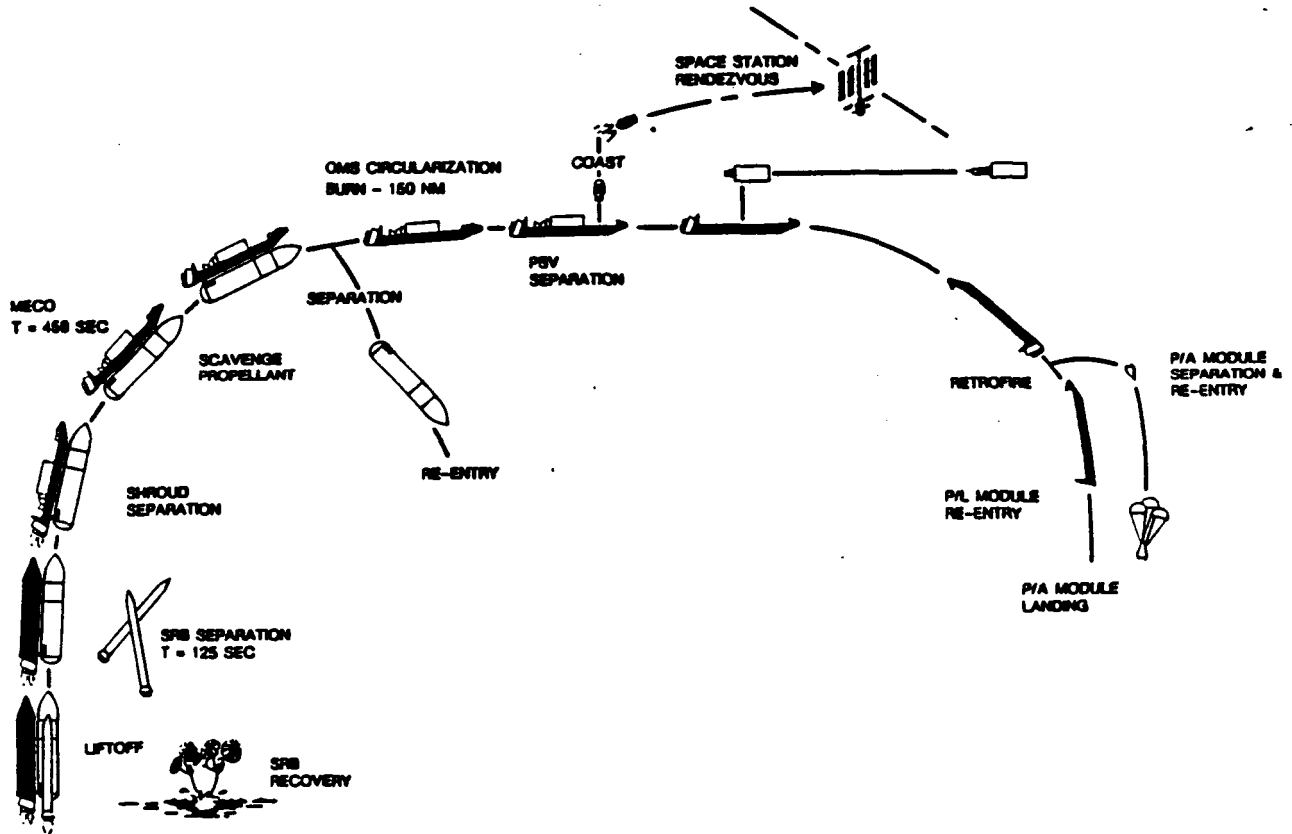
FIGURE 2.0-10   UCV REFERENCE MISSION WITH PROPELLANT SCAVENGING

The summary study plan is presented in Figure 2.0-11.   All scheduled work has been completed and all required documentation has been submitted with the completion of the approved final report.   Figure 2.0-12 is the study milestone schedule and documentation plan.
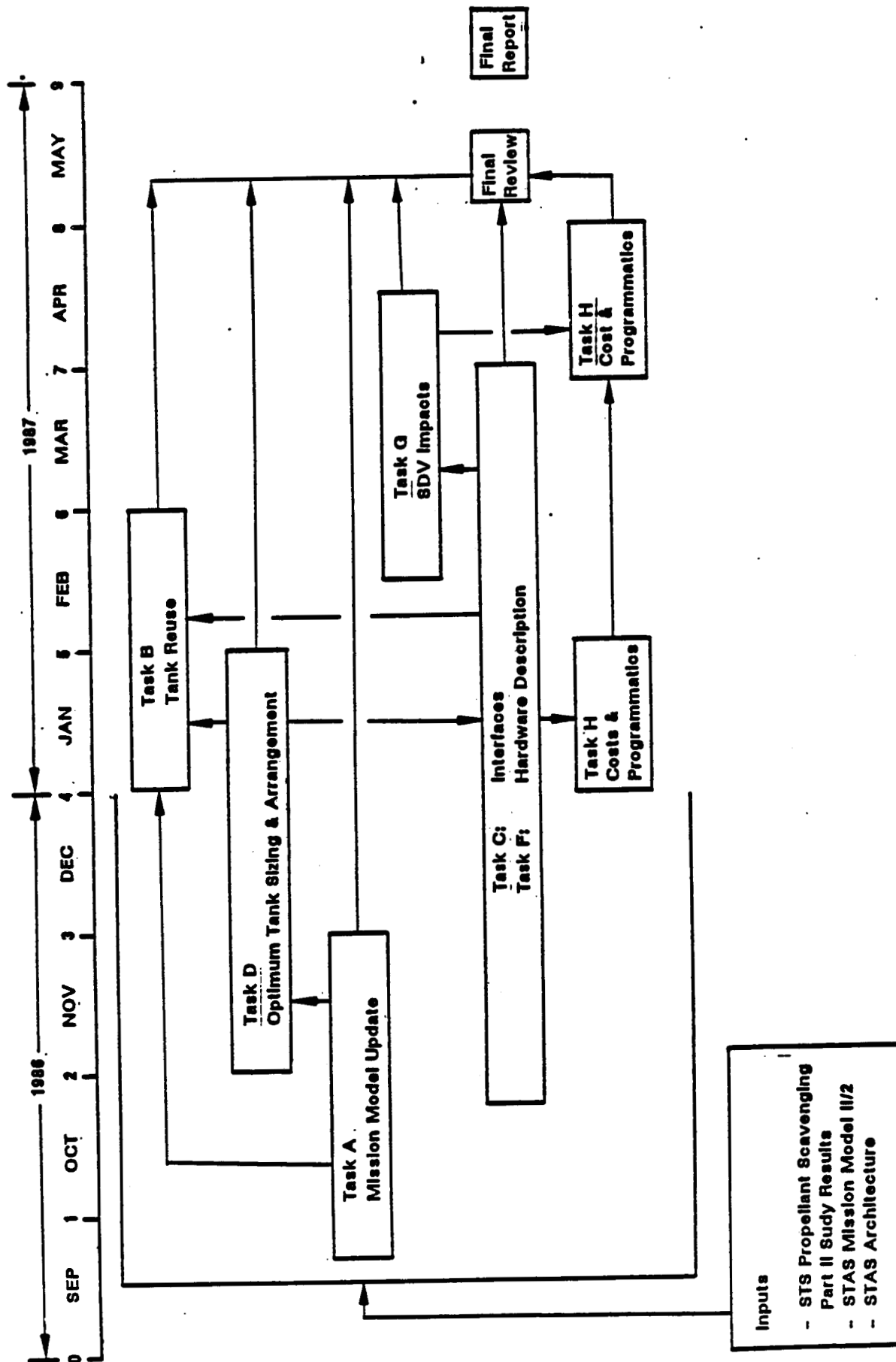
FIGURE 2.0-11 SUMMARY STUDY PLAN

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Contract Month — 1986 / 1987

Months: S | O | N | D | J | F | M | A | M | J | J

Program Reviews
- Orientation
- Perform Review
- Perform Review
- Perform Review
- Final Review

Study Tasks

Task A	Mission Model Update
Task B	Tank Reuse
Task C	Interfaces
Task D	Optimum Tank Sizing/Arrangement
Task F	Hardware Description
Task G	SDV Impacts
Task H	Cost & Programmatics

Data Requirements

DR-1	Study Plan
DR-2	Status Report
DR-3	Performance Review
DR-4	WBS Dictionary
DR-5	Program Cost
DR-6	Final Study Report
DR-7	SRT Report

Draft

FIGURE 2.0-12   STUDY MILESTONE SCHEDULE

2.1 TASK A - Mission Model Update

2.1.1 Preliminary Ground Rules and the STAS Mission Model

Preliminary ground rules and assumptions to be used in the UCV/SDV phase of this study were as follows. The study would utilize mission models, architectures, payload manifests, and launch vehicle definitions developed for the STAS. Additional payload manifests were not to be developed for this study.

1) STAS mission model II shall be used as the basis for this study. Payload manifests developed for STAS shall be used as is. Only civilian payloads shall be included to avoid security classification requirements. A reduced size model shall be defined that is approximately 50% of STAS model II. This reduced size model shall be assessed for impact on PS/transport and LCC.

2) The launch vehicle architecture shall consist of Shuttle I, 150 klb payload SDV and a 30 klb payload spaceplane. Shuttle I nominal payload shall be 65 klb; as assumed for the STAS. SDV shall be the sidemount configuration.

3) Propellant required and available shall be assessed over the period from 1990 to 2010. The STAS and OTV models shall be used to predict propellant requirements.

4) The Concept 6 PSV shall be the baseline scavenging tank configuration for both STS and SDV use.

The STAS models continued to evolve. Consequently, we examined a series of mission models and their effects on propellant delivery and requirements.

The first STAS mission models were derived from the results presented in two STAS reports dated May 1986 and June 1986 (References 2 and 3). Using these references, the payload manifests for the STAS mission model II were studied and several issues identified:

1) STAS mission models were volatile. It was difficult to identify an internally self-consistent model which covered STS, SDV, and OTV operations. Since the STAS was incomplete during our study, any model which we used was subject to revision.

2) Parameters

    (a)   SDV flights in the period 1999 - 2010 averaged 5 to 7 launches per year, including OTV tanker flights;

    (b)   The space based OTV became operational in 1999;

(c)   STS was replaced by spaceplane in 2001, thus indicating an
      incompatibility in timescale between STS scavenging and OTV usage.

(d)   Spaceplane flew approximately 25 missions/year with 30 klb
      payload.

This scenario resulted in annual civil cargo deliveries to LEO in 2010 being essentially the same as in 1995. This no growth scenario contrasted strongly with the rapid growth OTV model.

Therefore, by 2010, the OTV propellant was 44% of all SDV cargo (Figure 2.1-1).

We studied the available propellant from SDV operations 1995 - 2010. Assuming a load factor of 85% (similar to STS in PS-01, Rev. 7 [Reference 4]), between 100 klb and 150 klb of propellants may be delivered each year of space based OTV operations (Figure 2.1-2).

Figure 2.1-3 shows the OTV propellant requirements drawn from the STAS. The dashed line shows the trend through the annual data points. When these data are compared with Figure 2.1-2, it is clear that scavenging from the SDV with the SDV traffic model an 85% load factor is inadequate to cope with OTV demand.

In order to broaden our understanding of how the OTV requirement might be met by scavenging from SDV, we estimated the number of SDV flights which would be required to deliver OTV propellant, assuming that the SDVs were each carrying cargo at either an 85% or 70% load factor. This strawman mission model was then compared with the existing SDV (no tanker) model to highlight the differences.

Figure 2.1-4 indicates that SDV cargo load factors well below 70% would be necessary to meet OTV propellant requirements without increasing the SDV flight rate. In some years, the required cargo load factor would drop below 50%. It is questionable whether the OTV and the SDV models are compatible with scavenging as for delivering significant quantities of propellant.

Therefore, we reconsidered the fundamental PS principles which made it a cost-effective prospect for the STS. Parts I and II of the study showed that the major benefits of STS PS are:

o High annual propellant mass delivered (200 klb), and

o Low cost per pound ($420/lb).
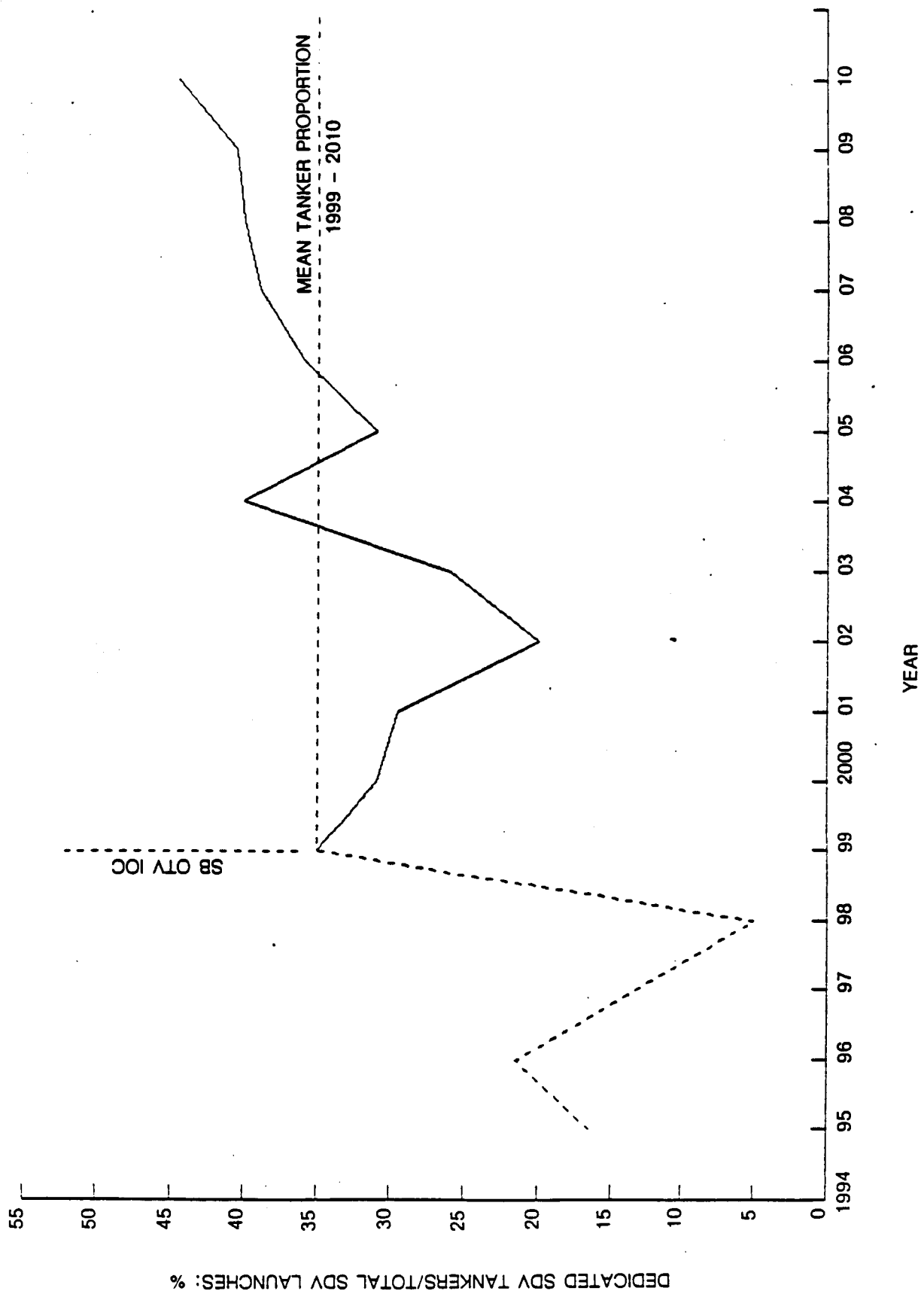
FIGURE 2.1-1 SDV TANKERS REQUIRED TO SUPPLY SPACE BASED OTV PROPELLANT 1995 – 2010

FIGURE 2.1-2 PROPELLANT RECOVERED 1995 – 2010

- STAS CIVIL MISSION MODEL II
- ARCHITECTURE 4
- 115 SDV FLIGHTS 1995–2010 – 85 SCAVENGABLE
- STS LOAD FACTORS APPLICABLE TO SDV – 15% OF TOTAL LIFT AVAILABLE FOR PROPELLANT

STS +SDV

SDV ONLY

PROPELLANT RECOVERED KLB

YEAR
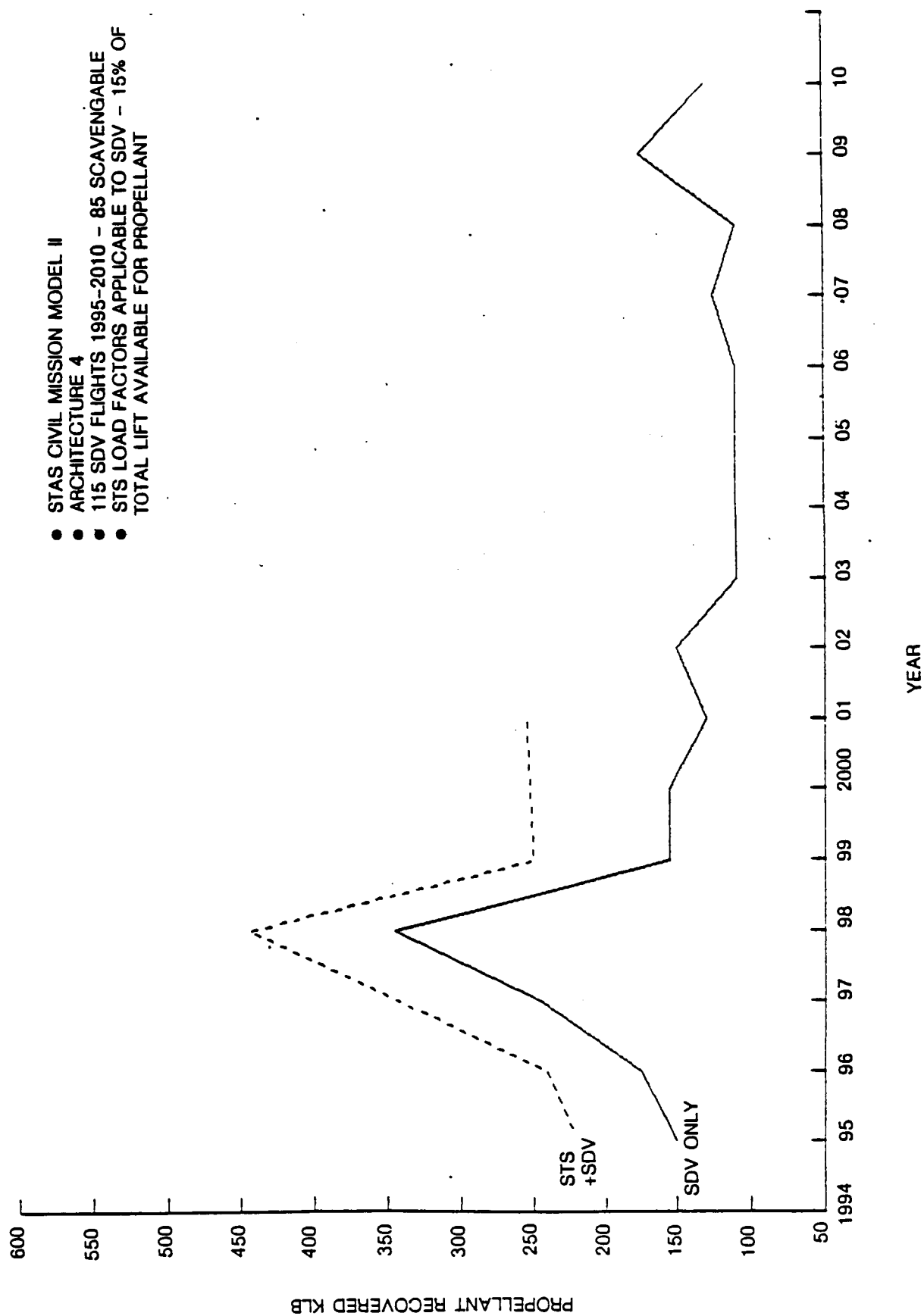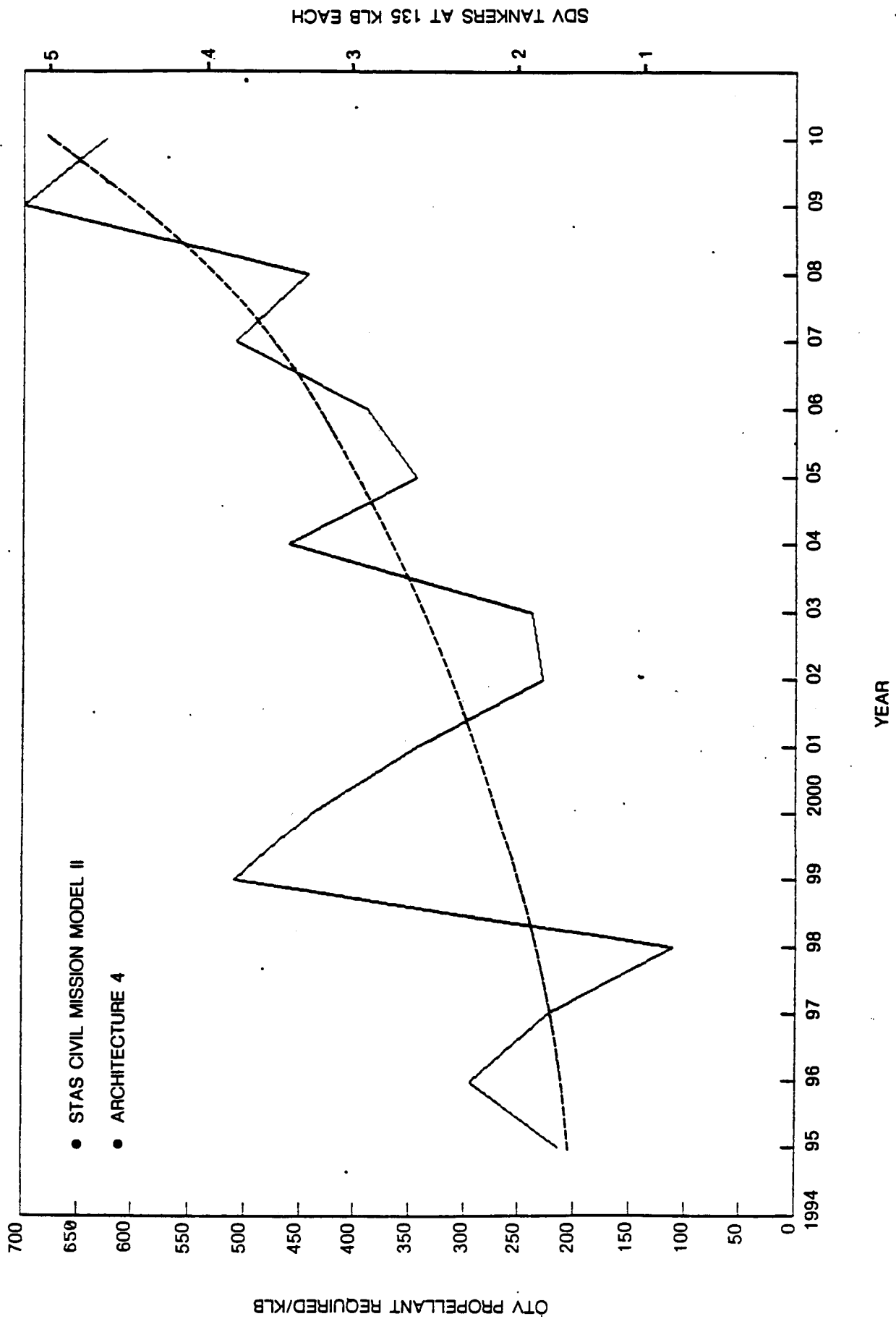
FIGURE 2.1-3 OTV PROPELLANT REQUIREMENTS
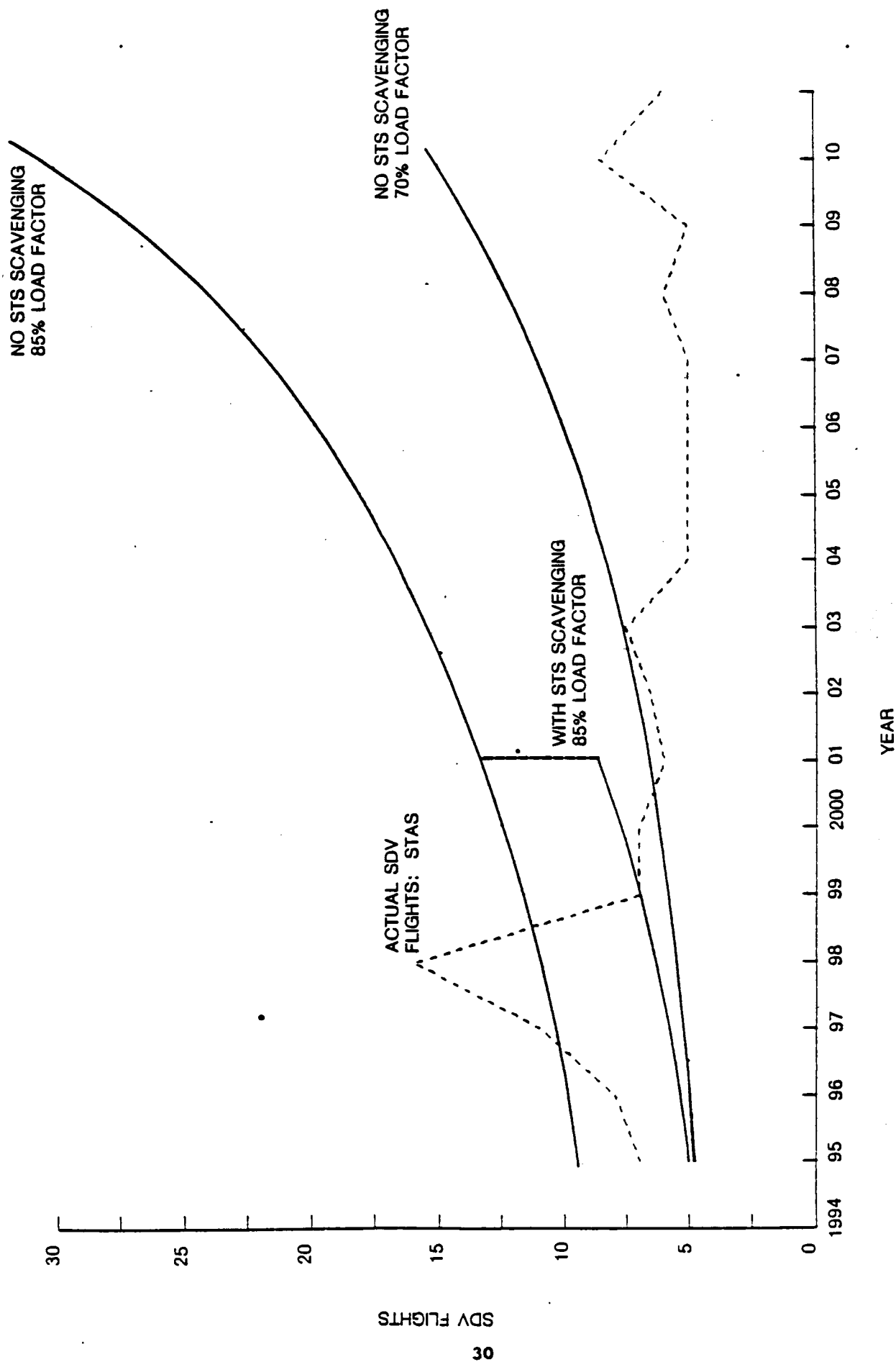
FIGURE 2.1-4 ANNUAL SDV FLIGHTS REQUIRED 1995–2010 TO MEET REQUIREMENT TRENDS

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These results came about mainly because of two factors in the STS mission models used:

o High annual flight rates (up to 30+ STS flights/year), which yield many PS opportunities and thus drive up the deliverable mass; and

o The STS residuals were a high proportion of the total propellants scavengeable (residuals plus surplus), tending both to drive up mass and drive down costs in more indirect ways. The STS residuals were generally 40% to 50% of the total mass scavenged.

In contrast to the STS case, the SDV had 20% to 25% of the flight rate, while the residuals were inherently a much smaller proportion of the available total lift capability. These factors reduced the deliverable propellant mass. In addition, the use of a separate P/A module increases the complexity of the scavenging operation compared to STS scavenging.

While our preliminary SDV scavenging results were disappointing, Figure 2.1-4 shows that a major reason for this was the projected demise of the STS in 2001--the advent of the Spaceplane removed the possibility of scavenging from the STS. However, alternative STAS models existed which substituted an "STS II" for the Spaceplane. Such a model might allow STS scavenging to continue in parallel with SDV scavenging operations.

2.1.2 Updated Mission Model

New NASA mission models continued to evolve, within and without the STAS. During our Orientation/First Quarterly Review at MSFC, we were informed that a new civil mission model would be available as part of continuing STAS activities. Also, a new OTV mission model became available from MSFC/PF20 during February 1987 (Reference 5).

Our initial ground rules referred to the analysis of civil models only when estimating available/required propellants. During the December 1986 review at MSFC, it was indicated that our study should include propellants available for the use of military launches.

The new STAS data were used to derive civil mission models for Architecture B: Shuttles I and II, 150 klb, and a space based OTV. Figures 2.1-5 and 2.1-6 show the required launch rates and the cargo profile for 1995 - 2010.

- Architecture B (With ACC)
- ETR, 28.5° Launch

Launch Vehicle	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	Total
Shuttle I 65K	11 V	12 V	9 V	12 V	11 W	12 V											67
Shuttle II 65K							17 W	15 W	16 W	16 W	20 W	16 W	22 W	22 W	20 W	18 W	182
UCV * 150K	2 1.7 W	2 1.4 V	2 1.5 W	2 1.2 V	2 1.3 W	2 1.4 V	2 1.4 W	2 1.7 W	2 1.5 V	2 2.0 V	2 1.6 W	2 1.9 W	3 2.4 W	2 1.7 W	2 1.9 W	3 2.3 W	34

* Fractional Launch Vehicles

W Weight Limited Manifest

V Volume Limited Manifest

FIGURE 2.1-5   CIVIL MISSION MODEL - OPTION II - VERSION 2.0

Year	Manned Cargo Up (Lbs)	Total Cargo Up (Lbs)	Down Cargo (Lbs)	Total Cargo Volume Up (Ft³)	Total Cargo Volume Down (Ft³)
1995	355139	507676	305680	115700	91808
1996	339938	453884	336923	119691	96807
1997	263732	396268	366841	102990	98178
1998	331674	425688	315264	111808	96474
1999	325084	440395	367947	104652	103040
2000	346457	463763	381270	121720	102520
2001	529398	648341	389082	159976	114291
2002	463722	610800	373528	139152	97246
2003	477770	608104	451732	150714	123280
2004	500632	652510	485086	166934	126649
2005	616287	760907	518741	172517	127806
2006	476769	642114	536163	149991	138558
2007	678546	894673	561375	211181	134436
2008	680152	833587	539193	201048	133815
2009	604379	771564	650722	169917	164132
2010	550721	757673	660807	168947	162722
Total	7,540,400	9,867,947	7,240,354	2,366,938	1,911,762

FIGURE 2.1-6   CARGO PROFILE, CIVIL MISSION MODEL - VERSION 2.0

Several points are noteworthy from this data:

1) Although Shuttle launch rates are consistent with the currently projected STS capabilities, the exclusion of military STS launches makes these rates questionable.

2) Since the UCV launches average two per year, there is little if any growth from 1995 - 2010.

3) Return cargo mass and volume are 75% - 80% of the cargo delivered to orbit. Given the existence of the UCV and also restrictions on STS landing weights, some extra provision for returning cargos would be required. The mission modeling assumes that the UCV is fully reusable and capable of returning cargo to Earth.

4) The STAS model as presented does not include the delivery of the OTV and its facility to orbit; it is assumed that this delivery takes place prior to 1995.

Figure 2.1-7 shows the civil OTV requirements 1995 - 2010. It is clear that the model shows little justification for a space based OTV prior to 2003 and traffic declines after this date. The total cargo delivered to GEO orbit averages 20 klb/year from 1995 - 2010. In all years but two, only one OTV mission is flown.

Year	Cargo Wt. To GEO (Lb)	No. Of OTV's @ 25K	Prop. Req'd To Destination (Lb)	Return Prop. Req'd (Lb)	Total Prop. Req'd (Lb)	Prop. Handling Factor	Total Prop. Req'd At Space Station
1995	1006	1	25500		25500	1.075	27413
1996	22753	1	59500		59500	1.075	65963
1997	10120	1	41000		41000	1.075	44075
1998	16462	1	50000				
Return	3554			33000	83000	1.075	89225
1999	1012	1	25500				
Return	2421			30000	55500	1.075	59663
2000	15393	1	48500				
Return	1777			26000	74500	1.075	80088
2001	13565	1	45500				
Return	21062	1		57000 48500	151000	1.075	162325
2002	8062	1	37500				
Return	1777			26000	63500	1.075	68263
2003	49841	2	62500 62000		124500	1.075	133838
2004	19705	1	55000		55000	1.075	59125
2005	22856	1	59500		59500	1.075	63963
2006	24248	1	61500				
Return	1777			26000	87500	1.075	94063
2007	44971	2	39000 62500		101500	1.075	109113
2008	15210	1	48000				
Return	1777			26000	74000	1.075	79550
2009	9775	1	40000		40000	1.075	43000
2010	22425	1	59000		59000	1.075	63425

Total   1,241,093

FIGURE 2.1-7   OTV PROPELLANT REQUIREMENTS - STAS MODEL OPTION II

The reason for the exceptionally low OTV usage is evident from STAS mission model ground rules; only "limited" commercial activity was considered and COMSATS were specifically excluded. Military payloads were also excluded.

The new MSFC/PF20 OTV mission model (Revision 10, dated February 6, 1987) included military OTV use. It was noted that only 15% of the total OTV flights were civil, the remaining 85% being DOD missions. However, the model did not define military payload masses, consistent with its unclassified status.

At this point, we adopted modified ground rules to generate realistic mission models while using the STAS and PF20 data as key reference points.

The following launch system ground rules were adopted:

o All STS flights were assumed to carry a lightweight ACC and a PSV. The average delivered propellant quantity per flight was assumed to be 12 klb. This scavenging capability was based on the results of our Part I and II scavenging studies.

o The SDV payload factors were based on STS data. Although the nominal SDV maximum payload continued to be 150 klb, but a payload weight load factor of 70% and a volume load factor of 80% were assumed. The cargo bay was assumed to be 25 ft diameter and 90 ft long.

o Eight SDV launches/year were assumed to take place from ETR. These launch rates were based on LC39 limitations, as well as STAS data. Also, post-51L studies indicate that 12 STS flights/year is the maximum sustainable flight rate. The eight SDV flights/year were based on launch pad/VAB limits of approximately 20 launch events/year (12 STS /8 SDV). This factor allowed two civil and six DOD SDV launches from ETR per year, which is consistent with some STAS models. This approach also allowed the study to use unclassified data while providing an estimate of the propellant available from civil and military launches.

The OTV mission model was handled in a way similar to the SDV mission model. We addressed the issue of the DOD portion of the model by assuming that it was a scaled up version of the civil model.

The PF20 mission model, Revision 10, covers the period 1995 - 2010. It consists of the following missions:

o 29 Civil missions "up";

o 11 Civil missions "down";

o   4 Reflights; and

o 176 Generic DOD missions.

Ten of the eleven civil down missions were to be combined with up missions, yielding a total of 210 OTV missions in the 16 year period. This figure corresponds to an average mission rate of a little more than one per month.

Total civil cargo masses, 1995 - 2010 were:

o   330 klb "up"; and

o   46 klb "down"

The DOD payloads were undefined as to payload masses. The only DOD mission information other than flight rate was some detail of the destination orbits. 55% of the military OTV missions were to go into GEO orbit, the other 45% destined for mid-inclination orbits. No other details are given.

We made the following assumptions in order to deal with the military portion of the mission mode:

o DOD missions to be identical to civil missions in terms of cargo masses and up/down mission ratio, i.e. simple scaling.

o Mid-inclination missions depart from the OTV facility at 28° inclination, similar to the GEO missions. Since the destination orbit was otherwise undefined, we assumed the required delta-V for the plane change to be identical to that required for GEO insertion and circularization.

o The four reflight missions were payload delivery only which would minimally effect the overall model.

All OTV missions were assumed to be the same in terms of up/down payloads. Over the period 1995 - 2010, this assumption allowed smooth annual· requirements to be derived.

Therefore, average OTV mission flown 210 times consists of the following two elements:

1. Delivery of 11.5 klb payload; and

2. Retrieval of 3.6 klb payload.

This reference mission was then evaluated to calculate the OTV propellant requirements. For study purposes, the OTV (with LO2/LH2 propulsion) was assumed to be reusable and space based.

The OTV performance calculated for this study assumes that the mission requires three burns plus aerobraking. The two insertion burns total 12.3k fps. The return burn is 4.8k fps, followed by 7.5k fps aerobraking maneuver.

Figure 2.1-8 illustrates the OTV performance assumed for delivery of payloads. Payload retrieval performance is shown in Figure 2.1-9.
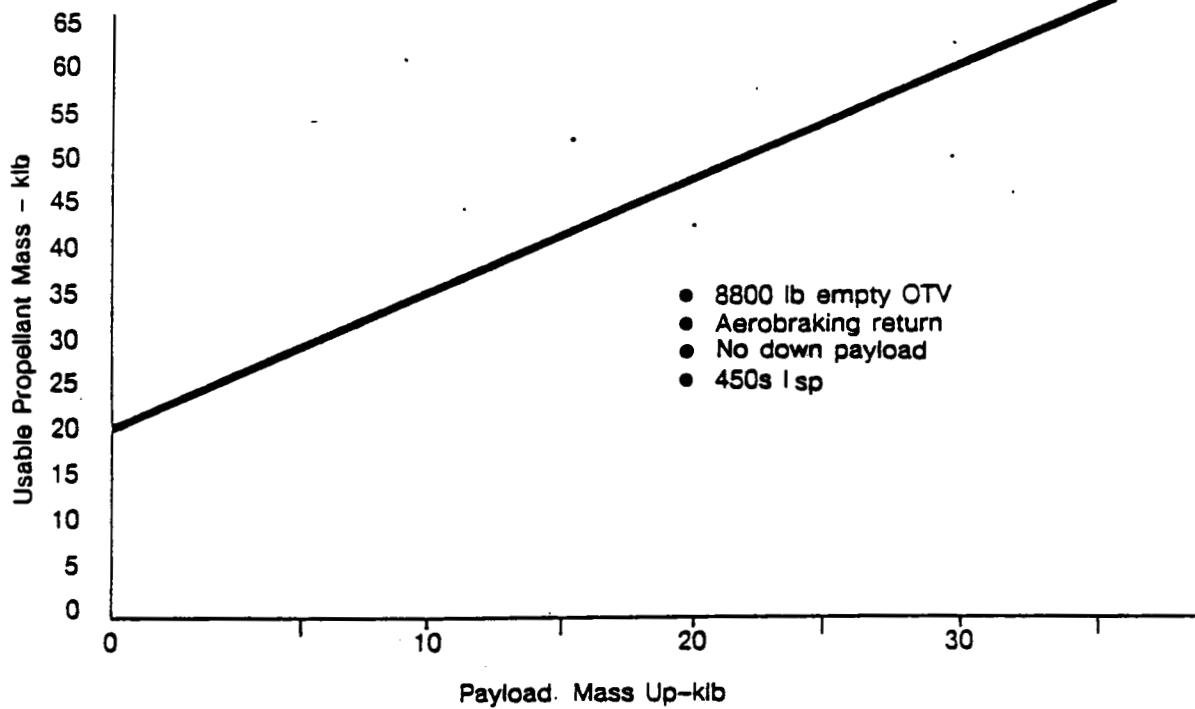
FIGURE 2.1-8   OTV PERFORMANCE - UP

Legend (upper figure):
- 8800 lb empty OTV
- Aerobraking return
- No down payload
- 450s I sp

Axis labels: Usable Propellant Mass – klb (vertical), Payload. Mass Up–klb (horizontal)
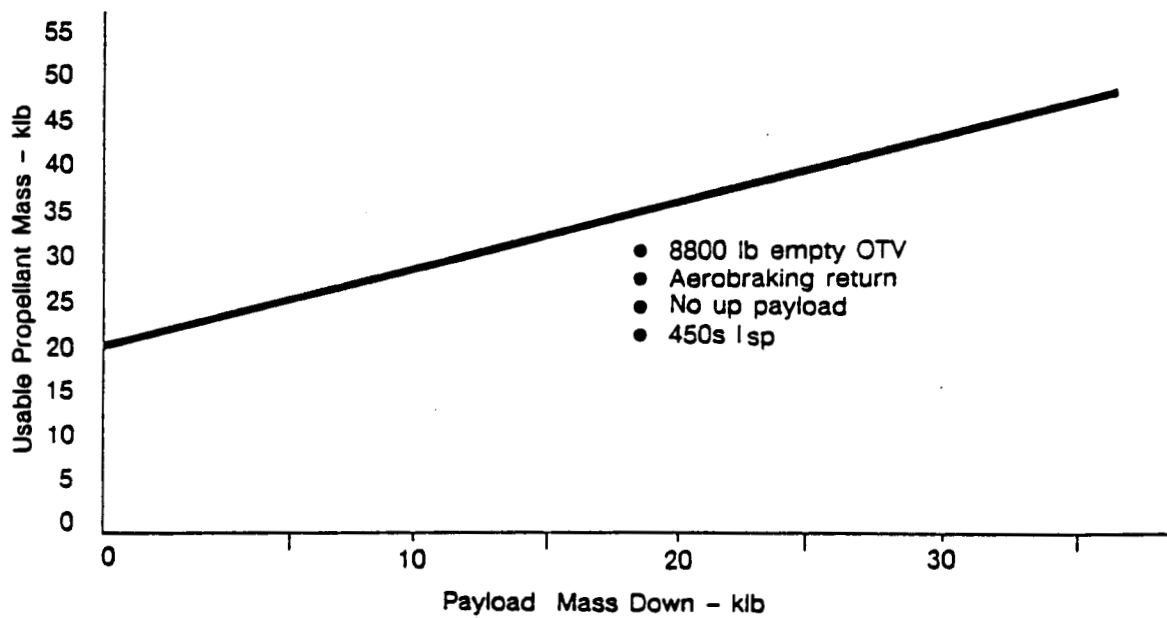
FIGURE 2.1-9   OTV Performance - Down

Legend (lower figure):
- 8800 lb empty OTV
- Aerobraking return
- No up payload
- 450s I sp

Axis labels: Usable Propellant Mass – klb (vertical), Payload Mass Down – klb (horizontal)

Use of this average mission over the 210 OTV missions shows that 8.68 mlb of LO2 and LH2 (at a 6:1 mixture ratio) would be required between 1995 - 2010, including the 1.075 propellant handling factor from the STAS.

Since the OTV mission model is relatively invariant year-to-year, an estimate of the annual OTV propellant requirement was made by dividing the total of 8.68 mlb by the number of years (16). This procedure yielded an annual propellant requirement of 540 klb.

2.1.3 Compatibility of OTV, SDV, and STS Models

The new "baseline' mission model was used to estimate the capabilities of the SDV and STS to deliver OTV propellant to orbit.

The analysis showed that the projected annual propellant requirement could be met by SDV delivery when the cargo weight load factor was 50% or less. If STS scavenging was also employed, the maximum allowable SDV load factor rose to 63%. Figure 2.1-10 illustrates the reduction in propellant delivered using an increasing cargo load factor.
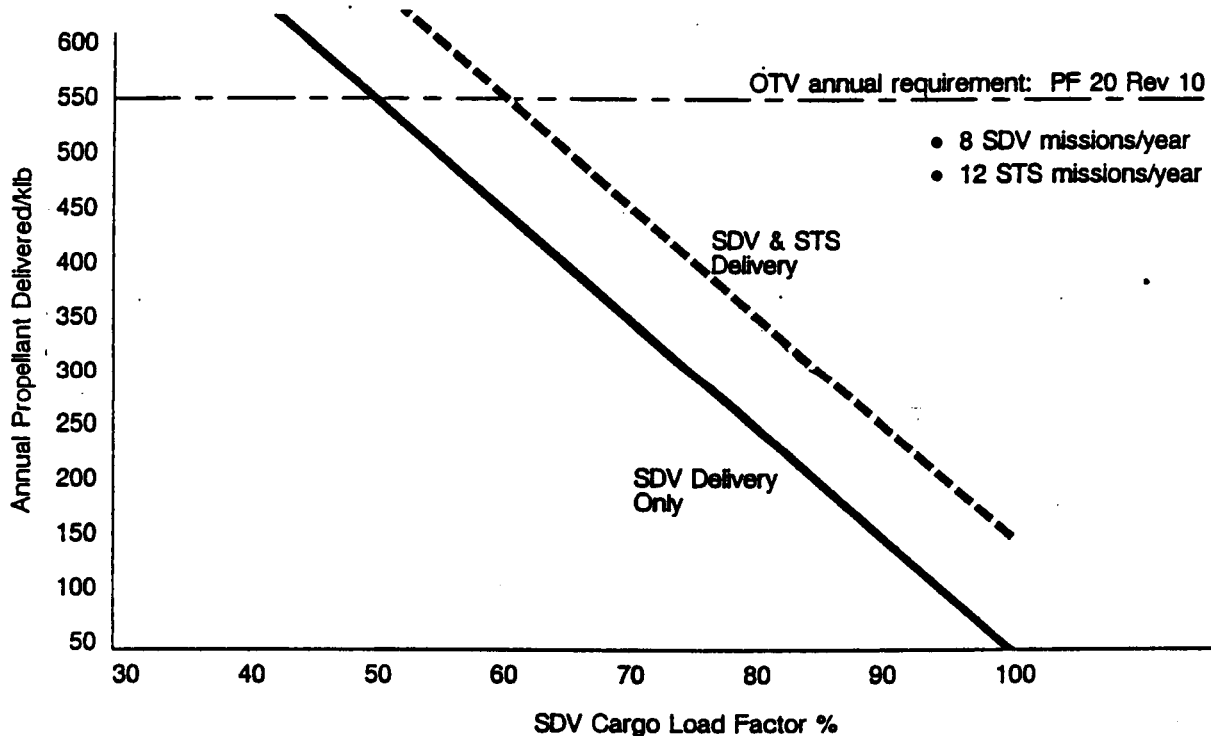
FIGURE 2.1-10   PROPELLANT DELIVERED PER YEAR

The results of Figure 2.1-10 indicated that the baseline mission model (8 SDV launches/year) might not meet the requirements of the OTV model, particularly during periods of sustained high cargo load factors. Accordingly, we conducted a parametric study of the effects of varying the SDV launch rates and the load factor. It was assumed that 540 klb of OTV propellant was required per year. Figure 2.1-11 shows the results of this parametric study.
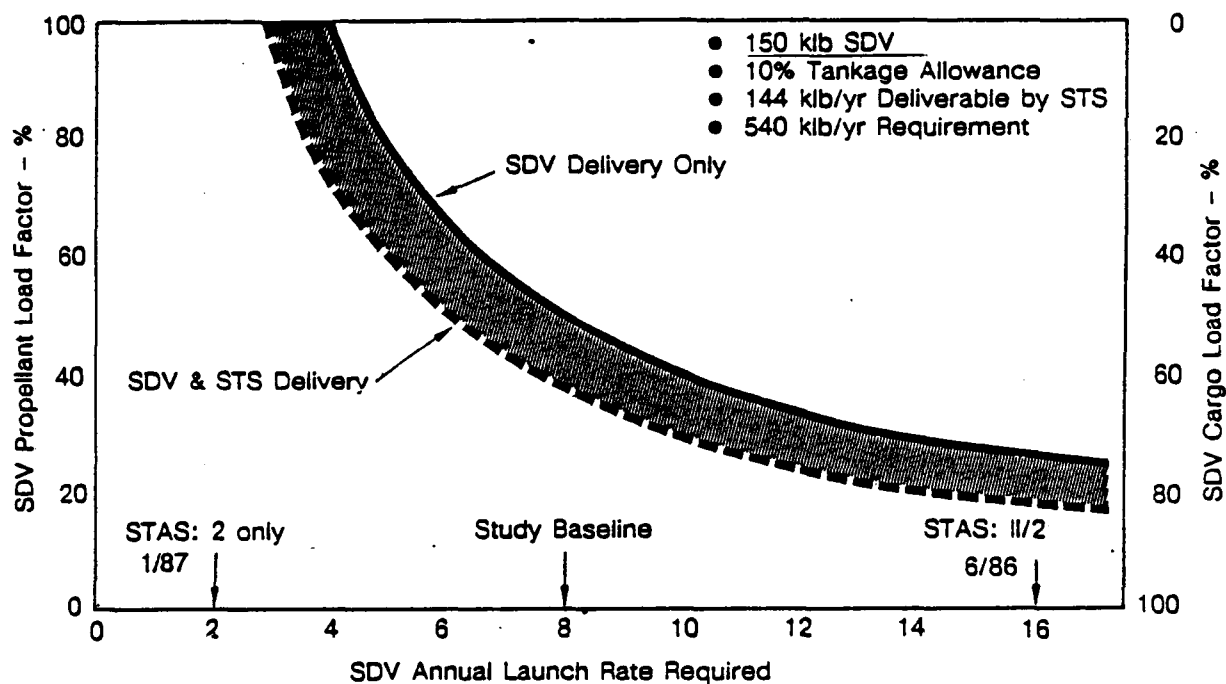
FIGURE 2.1-11   SDV LAUNCHES REQUIRED TO DELIVER OTV PROPELLANT

As the SDV launch rate increased, the available unused or surplus lift capability increased, for a fixed load factor. This means that the maximum allowable cargo load factor to allow delivery of propellant as surplus also increased.

Figure 2.1-11 covers the range of SDV launch rates existing in several recent STAS mission models and also shows the effects of STS scavenging to augment SDV deliveries.

Any combination of launch rate and load factor to the right of, and above, the curve will satisfy the OTV requirements.

SDV residuals scavenging appears to offer only marginal benefits. For residuals of around 6 klb/flight, and 8 flights/year, the total contribution of residuals scavenging is less than 10% of the OTV annual requirement. Therefore, SDV residuals scavenging becomes an option which is based on cost effectiveness issues rather than essentials. The baseline SDV propellant delivery mission becomes a tanker rather than a scavenger/tanker.

2.1.4 OTV Facility Basing Altitude

Significant gains in propellant delivered may be realized by basing the OTV propellant depot in an orbit lower than that of the SS.

For a dedicated SDV tanker mission, gains of only 10% or less can be made. However, for mission models involving the use of surplus lift capability for propellant resupply, gains of 25% or more can be achieved. This capability may save the equivalent of one or more dedicated SDV missions/year (Figure 2.1-12).
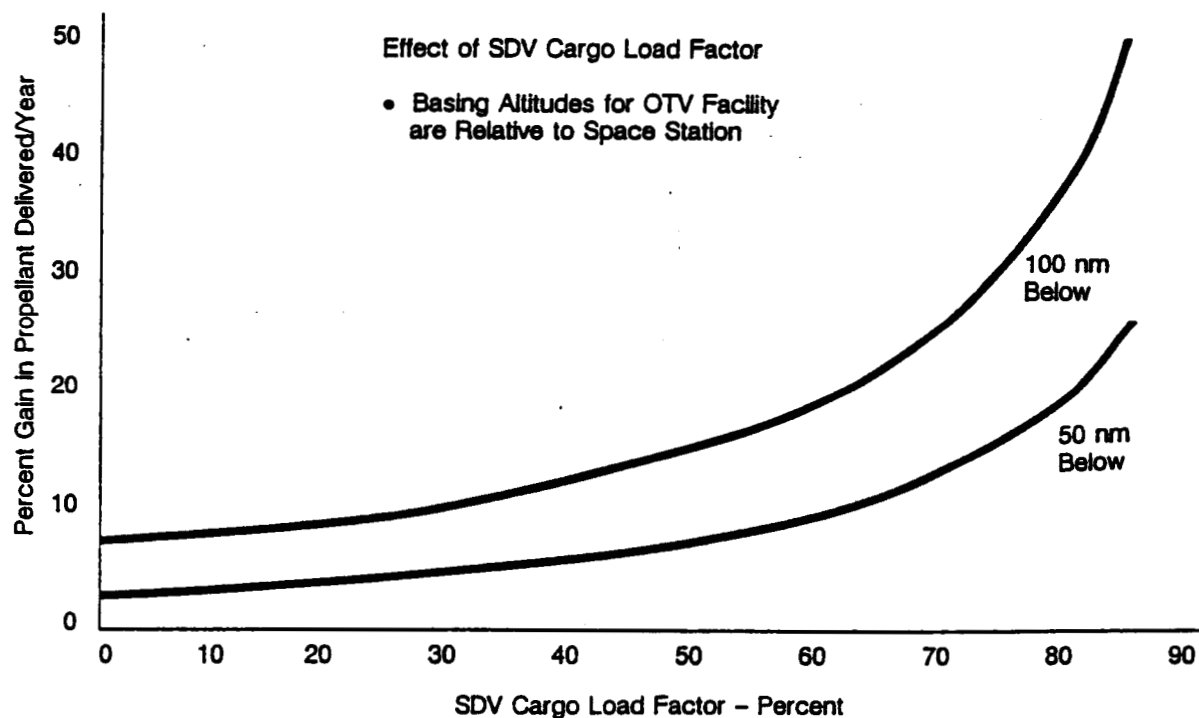
FIGURE 2.1-12   OTV PROPELLANT DELIVERED BY SDV VS FACILITY BASING ALTITUDE

The reason for this effect is that SDV lift capability decreases with increasing destination altitude. If propellant flies on a space available basis to create weight-limited missions, lower destination altitudes will give higher surpluses and, thus, more propellant.

The OTV delta-V requirements were only minimally increased by basing the depot at a lower altitude.

2.2 TASK D - Optimum Tank Sizing and Arrangement

Previous phases of the study developed an effective method of STS PS based on a PSV located in the ACC.

Extension of the study to include the UCV led to tankage requirements which dictated the review of alternate arrangements and capacities. Factors governing the final selection of UCV propellant supply tankage are:

1. Desirability of commonality with the PSV proposed for the STS;

2. Reusability of tankage (interaction with Task B);

3. Mode of operation of UCV, i.e. does it visit the SS or close vicinity, or does it deploy payloads into a lower orbit for retrieval by the OMV? Is the UCV cargo bay itself a reusable/flyback item?

4. Available surplus lift capability/volume flight-to-flight between 1995-2010 (interaction with Task A);

5. Desirability of scavenging residuals from the ET/MPS, i.e., with low annual flight rates and large surpluses, residuals become a smaller proportion of the propellant available than for the STS;

6. For the purposes of this study, we examined 15' and 25' diameter bays. Several other sizes were considered in the STAS ranging from 15' x 60' to 25' x 90'. Other studies have considered larger sizes.

Consideration of the above requirements led to a range of possible options for UCV tankage. Figure 2.2-1 lays out some of the interactions between these requirements.

2.2.1 Optimum Tank Sizing

The Task A results indicated that fewer scavenging opportunities will be available from the SDV than the STS. However, the total mass available per flight would be greater due to the larger lift capability of the SDV.

Task A showed an OTV annual propellant requirement of about 500 klb, coupled with an SDV launch rate of about 8/year, and an STS launch rate of 12/year.

The Task A results led to the following tank sizes:

o If STS PS is developed, the SDV will be required to deliver about 45 klb OTV propellant per SDV mission.

o If no STS PS is projected, each SDV mission must deliver approximately 62 klb propellant.

UCV Characteristics / Operation Mode

Issues	Operational Mode		Payload Bay Volume, Shape, Lift Capability			Reusability Of UCV Cargo Bay	
	UCV Visits To Space Station	Deploy Cargo Away From Space Station	Large Bay, Weight - Limiting	Small Bay, Volume-Limiting	Diameter Considerations	Reusable, Flyback	Disposable
Commonality With STS Scavenging	Concept 5 Or Built-In Tankage	Concept 6 PSV In-Bay Or ACC	In-Bay Tankage: Built-In Or Concept 5/6	Concept 6 PSV In ACC	15' Diameter Tank Unit Preferred	No Direct Impact - Cost Issue	15' Diameter Tank - Unit Required For Recovery. Favors Concept 5/6 PSV
Reusability Of Tankage	Concept 5 Can Return In UCV Or STS	Concept 6 Can Return In UCV Or STS	Built-In Tankage Requires Reusable UCV Cargo Bay	Concept 6 Can Return In STS Or UCV	Tank Units Larger Than 15' Diameter Cannot Return In STS	Built-In Tankage Preferred	Concept 5/6 PSV Preferred But Cargo Down May Overload STS Capacity
Residuals Scavenging	Not a Significant Impact Launch Rate Determines Cost Effectiveness		Residuals Become Higher Proportion Of Recoverable Propellant	Unlikely To Be Cost Effective	No Major Impact	No Direct Impact	Separate P/A Module May Complicate Scavenging System

FIGURE 2.2-1   INTERACTION OF ULV CHARACTERISTICS WITH TANK SIZING/ARRANGEMENT TASK

For design purposes, it was assumed that there will be no STS PS. However, if the SDV can accommodate the larger tanks required by this scenario, it can also accommodate the smaller tanks utilized should STS scavenging be developed. Alternatively, the larger tanks would fly fewer SDV missions. For study purposes, we selected the 137-in. diameter tanks as our baseline. Two LH2 tanks and one LO2 tank will fit into the 25 ft diameter payload bay, allowing clearance for installation/removal as a unit. In addition, individual tanks can be returned to Earth inside the 15 ft diameter cargo bay.

Allowing for a 5% ullage volume, the LO2 tank can contain 52.7 klb LO2, and the two LH2 tanks a total of 6.5 klb LH2. This capacity yields a delivered mixture ratio of 8:1.

Incorporating short barrel sections into the two LH2 tanks allows use of a similar dome geometry for all tanks, reducing the mixture ratio to the required 6:1. This change provides significant savings in tooling and manufacturing costs while allowing efficient use of the available P/L bay space.

Each LH2 barrel section is 30 in long yielding a total LH2 capacity of 8700 lb.

Figure 2.2-2 summarizes the leading characteristics of the tanks.

	DIAMETER(IN)	LENGTH(IN)	ULLAGE VOLUME	CAPACITY(LB)
LO2 TANK	137	137	5%	52700
LH2 TANK	137	167	5%	2 x 4350

FIGURE 2.2-2   TANK DIMENSIONS AND CAPACITIES

The combined capacity of the LO2 and LH2 tanks is 61.4 klb. This capacity corresponds to 41% of the SDV lift capability. Allowing 6 klb for tanks, the lines and support structure will require 45% of the SDV lift capability for propellant resupply.

2.2.2 Tank Arrangement Options

The results of Task A, the mission model update, showed that many SDV cargo flights were manifested with multiple (10 to 15) payloads. This model produced great uncertainty as to the size and shape of the remaining cargo volume(s). In addition, STAS manifesting did not consider SDV cg limitations or payload packaging for each mission as was done for previous scavenging studies. Therefore, our tank arrangement studies could not consider SDV cg limitations or payload packaging.

Our evaluation of candidate tank arrangements was driven by two main considerations.

1) The tanks used should minimally impact the SDV cargo capacity, i.e., the payload bay volume occupied by the tanks should be at a minimum.

2) Requirements for scavenge tank return dictate that tanks fit into the STS cargo bay. This factor restricts individual tanks to less than 15' diameter, although a multi-tank arrangement may exceed this parameter when assembled.

We examined four tank arrangement/installation options. They were:

1) Concept 6, PSV (identical to the STS based system);

2) Fixed or built-in tankage (located in the SDV payload module);

3) Deployable tankage (located in the SDV P/L module against the aft bulkhead); and

4) Deployable tankage (located in the nose cone of the SDV P/L module).

Application of the Concept 6 PSV to the sidemount SDV configuration is straightforward. Consequently, it employs a LWACC and operates identically to the STS PS system. Figure 2.2-3(a) shows its use, assuming the cargo bay to be volume limiting.

Figure 2.2-3(b) shows the Concept 6 PSV in the weight limited SDV. In this case, the PSV is mounted in the cargo bay, but facing aft when compared with the ACC installation. This placement simplifies propellant interfaces and may allow the PSV to be cantilevered from the cargo bay aft bulkhead.
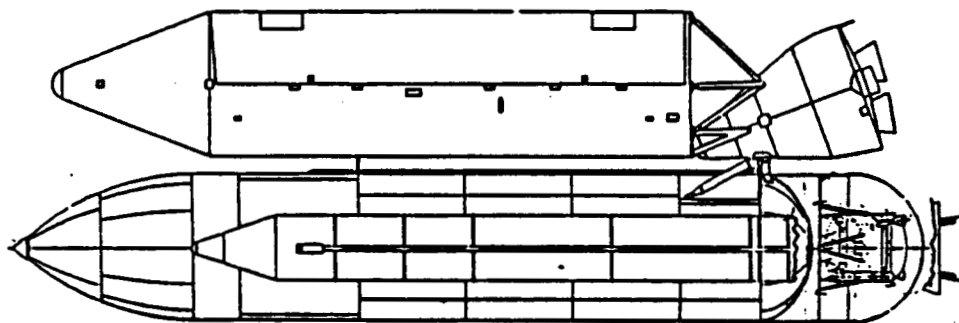
(a) PSV in LWACC
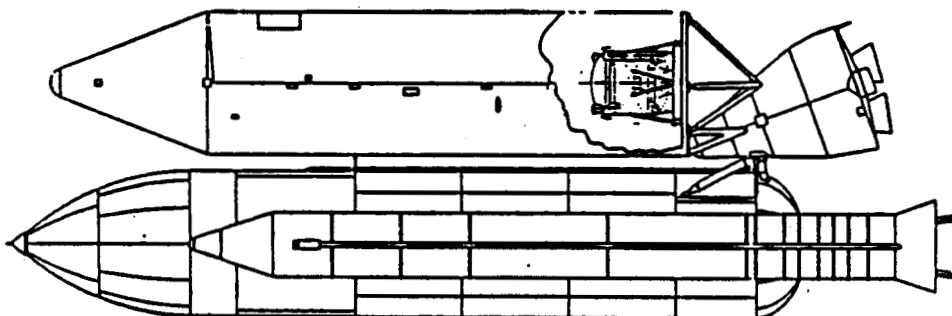
(b) PSV in P/L Module

FIGURE 2.2-3 CONCEPT 6 PSV ALTERNATIVE INSTALLATIONS

The Concept 6 PSV is inappropriate to apply to SDV, particularly in view
of the STAS mission model. The PSV is sized at 30 klb LO2 capacity and 2 klb
LH2 capacity. These sizes derived from the of STS manifesting process and the
incorporation of residuals scavenging. The SDV's increased lift capability
and reduced launch rate favor larger tank capacities where the tanks are

filled on all occasions, rather than the available surplus approach used on
the STS. The PSV tanks may be increased in length by the insertion of barrel
sections. This approach could evolve into an SDV pure tanker which would be
capable of return inside the STS P/L bay. However, the PSV inefficiently uses
the available P/L module diameter since the PSV is sized at an overall
diameter of 15' for return in the STS P/L bay. Using the optimum tank
capacity (derived in Section 2.2.1) results in a tank set length of 44' if the
PSV tank diameter and arrangement are to be retained. However, the use of a
self-propelled tank unit may be viable if it is optimized around the SDV P/L
module dimensions.

To permit the optimum use of remaining cargo volume consideration was
given to installing separate LO2 and LH2 tanks in the SDV .
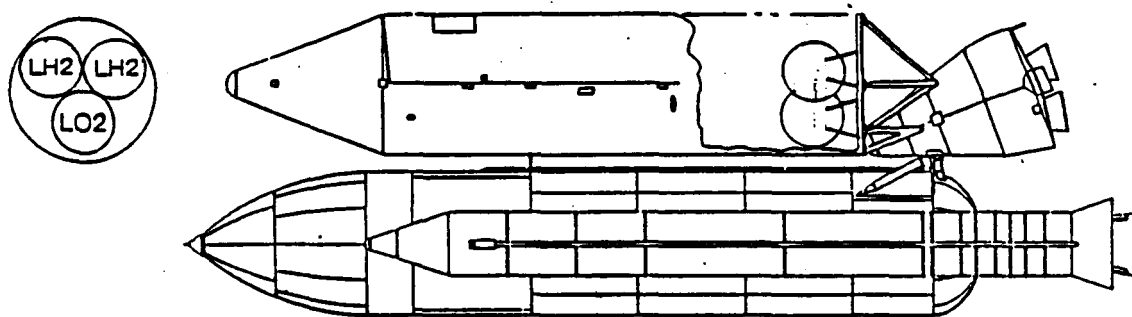
FIGURE 2.2-4   SDV WITH BUILT-IN TANKAGE

Figure 2.2-4 illustrates a concept for fixed or built-in tankage. The
tanks shown take advantage of a 25' diameter bay and provide a simple,
lightweight installation with the minimum length. In addition, the individual
built-in tanks were sized to fit in a 15' diameter bay which may be useful if
more than one UCV bay diameter is developed.

Fixed or built-in tankage has the initial attraction of being
operationally simpler, avoiding the installation and checkout of tank/P/L
module interfaces at the launch site. However, it is potentially costly if
the P/L module is not reusable and the OTV and SDV mission models fluctuate.
Built-in tanks may be a feature of a particular SDV that may be disposed of
without having been used.

Therefore, we studied two further alternative configurations which would permit tank deployment and give maximum operational flexibility. The two configurations have most components in common, but represent different installations within the SDV P/L module.

Option 1 involves placing the three tanks in the nose section of the P/L module (Figure 2.2-5). Option 2 also requires three tanks, but they are located at the aft end of the P/L module, supported against the aft bulkhead: (Figure 2.2-6). The geometry of Option 2 requires a minor reduction in tank diameters; short barrel sections are inserted to compensate for this reduction.

In both cases, tank sets are deployable and reusable as units. If no vehicle is available to return them as a unit, the individual tanks will fit within a 15' diameter cargo bay. Tank sets would be installed as P/Ls at KSC and loaded with propellants on the pad exactly as Shuttle/Centaur or SDV/Centaur.

No strong discriminators were found between the forward and aft mounted tank sets. Points considered were:

1) The forward-mounted tank unit offers a better use of the available P/L module volume. The nose cone location minimizes the intrusion into cargo volume. This factor may become important if the SDV P/L module is reduced in length from the present 90' nominal.

2) The aft mounted unit requires a less complex propulsion installation. Essentially, the saving consists of the deletion of an additional 90' of plumbing for loading and venting.

3) The P/L module cg tends to follow the location of the propellant tanks which has implications for the required SSME gimbal angles. Also, a forward cg would yield a minor overall performance improvement for a sidemount SDV, due to the reduced offset of the vehicle thrustline from the flight path vector.

2.2.3 Tank Configuration Selection

Factors governing the final selection of the tankage configuration were outlined in the introduction to this Section 2.2. Our studies narrowed the major uncertainty to one: the operational mode of the SDV. In summary, the SDV can operate in one of three ways: (1) It can visit and berth with the SS;
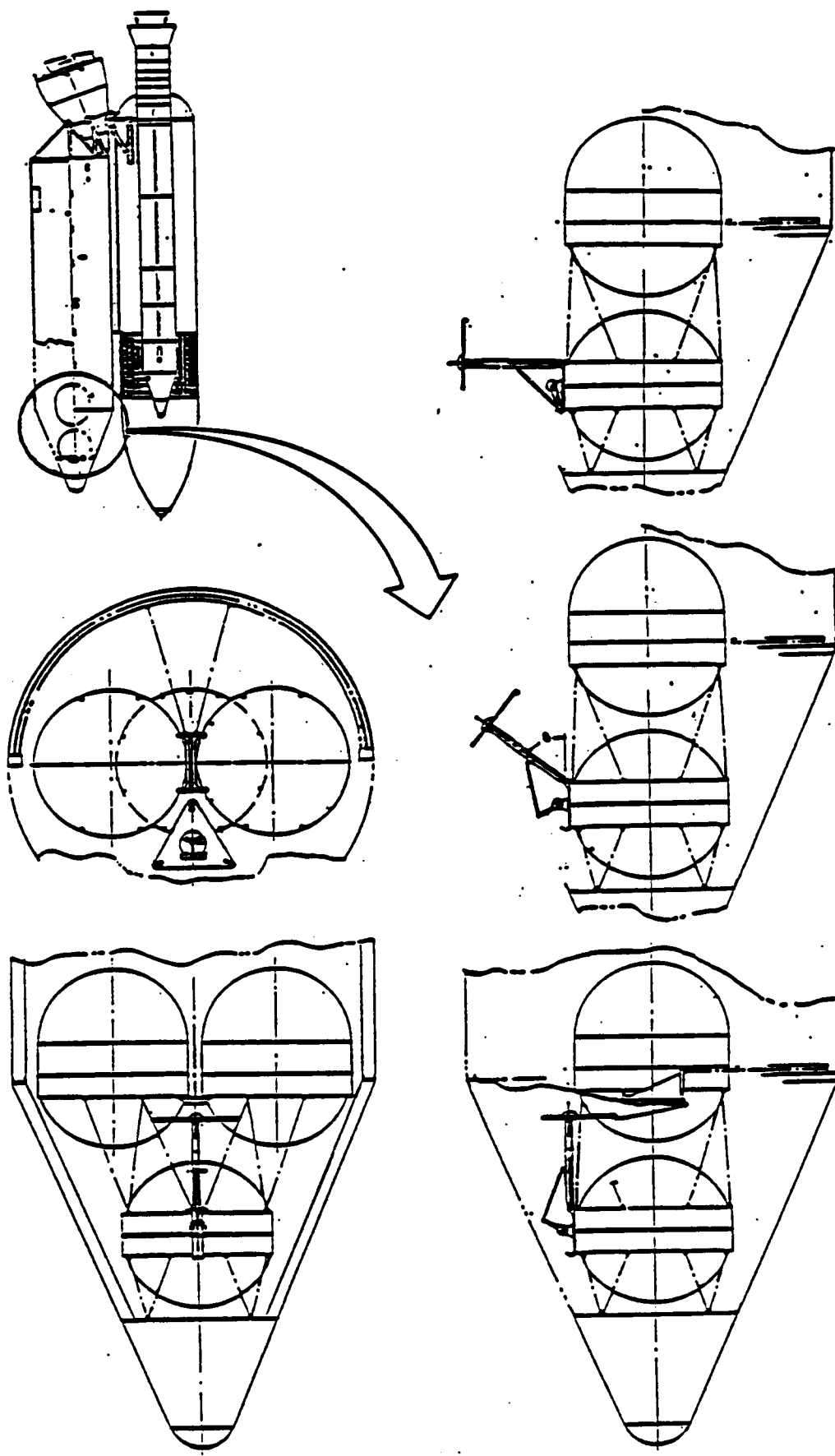
FIGURE 2.2-5   FORWARD MOUNTED TANK SET

OMV DOCKING INTERFACE
(STOWED)
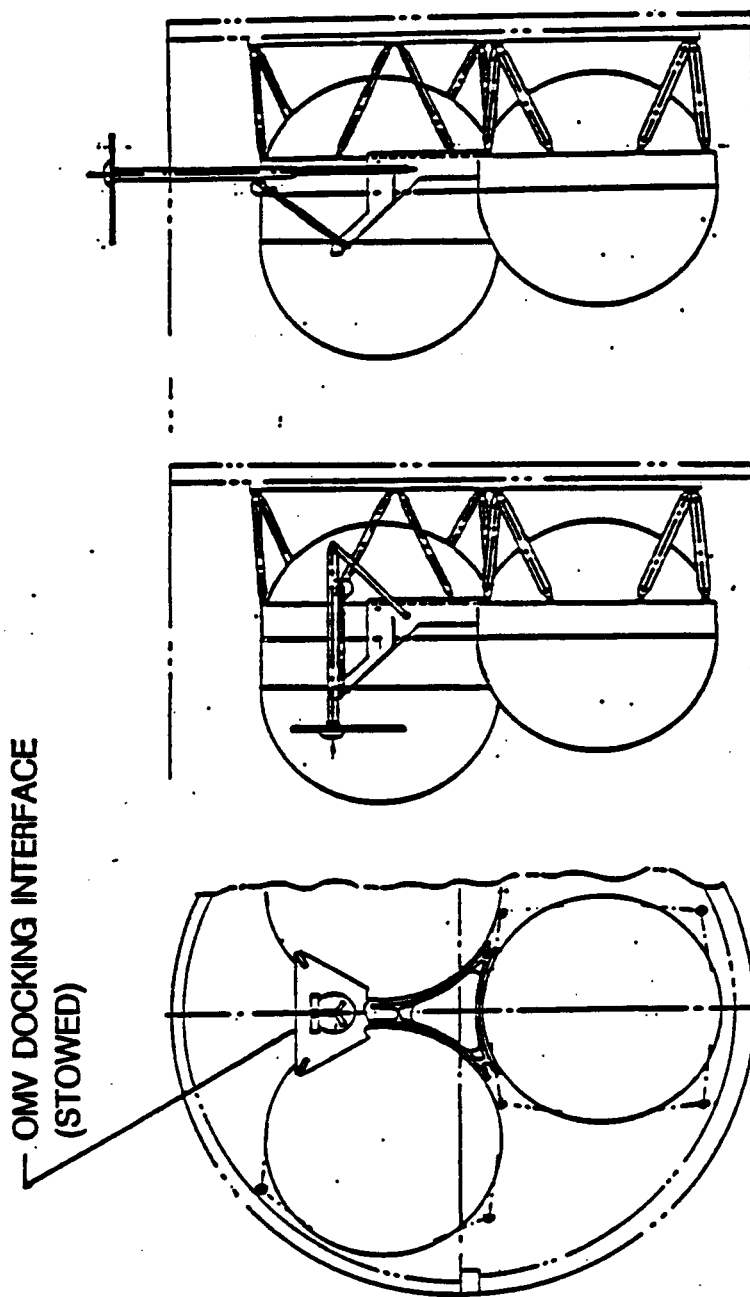
FIGURE 2.2-6   AFT MOUNTED TANK SET

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(2) it can rendezvous in the vicinity of the SS using the OMV to deploy its cargo; or (3) it can inject itself into an orbit below the SS using the OMV to give the large delta-V required to each of its cargo elements. For each of these operational modes, there is a preferred tank mode of operation:

o   Built-in tankage for SS visits by a berthing SDV;

o   Deployable PSV for use on a vicinity SDV; and

o   Self-propelled PSV for use where the SDV does not visit the vicinity of the SS.

In view of the uncertainty of the SDV's mode of operation which is outside the scope of this study we selected the deployable tankage concept for further detailing for the following reasons:

o   It is readily adaptable to become built-in at a later stage--the corollary being not necessarily true; and

o   The forward-mounted tank set possesses biaxial symmetry which lends itself to development into a self-propelled vehicle or PSV.

2.2.4 Self-Propelled Tank Unit

Previous phases of this study showed that a self-propelled tank set was advantageous for STS PS. Our experience in developing this concept, coupled with the SDV operational issues (mentioned in Paragraph 2.2.3) led us to consider the potential benefits of applying the self-propelled tank concept to the SDV.

Major factors favoring such a vehicle are:

1) <u>Operational Flexibility</u>

The SDV does not have to visit the OTV facility in order to deliver propellant to it. There are reasons (largely outside the scope of this study) why the OTV facility might not be co-located with the SS. The use of the self-propelled tanker vehicle allows the SDV to visit the SS while the tanker visits the OTV facility. The tanker can perform orbital phasing and altitude changes independently of the SDV.

2) <u>The OMV Workload Can Be Reduced</u>

In the case of an SDV mission which does not visit the OTV facility, a high total impulse mission may be required to deliver the tank set from the SDV to the facility. The use of an integral propulsion system allows the high impulse transfer to be made without committing the

valuable resource of the OMV. For such a mission, the OMV would only be used for the proximity operations, i.e., bringing the tank set into a berthing condition at the OTV facility. This scenario is similar to that developed in Reference 1 for the STS scavenging system. Figure 2.2-7 illustrates the STS/PSV transfer and berthing scenario.

o <u>Tank Disposal Methods Are Simplified</u>

If sufficient transport capacity is available to return tank units to Earth (Section 2.1), the tanks must be deorbited in a controlled manner. The self-propelled tank set offers a self-deorbit feature, simplifying disposal operations, and eliminating the risk of losing the OMV on a deboost/reboost trajectory. The overall propellant expenditure would also be minimized.

Figure 2.2-8 shows the mission scenario for an SDV/UCV equipped with a self-propelled tank set. The use of the tank set can have minimum impact on UCV operations. The tank set can be deployed like a self-propelled P/L and can transport its propellant to the SS/OTV facility independently.

Docking and Berthing Scenario
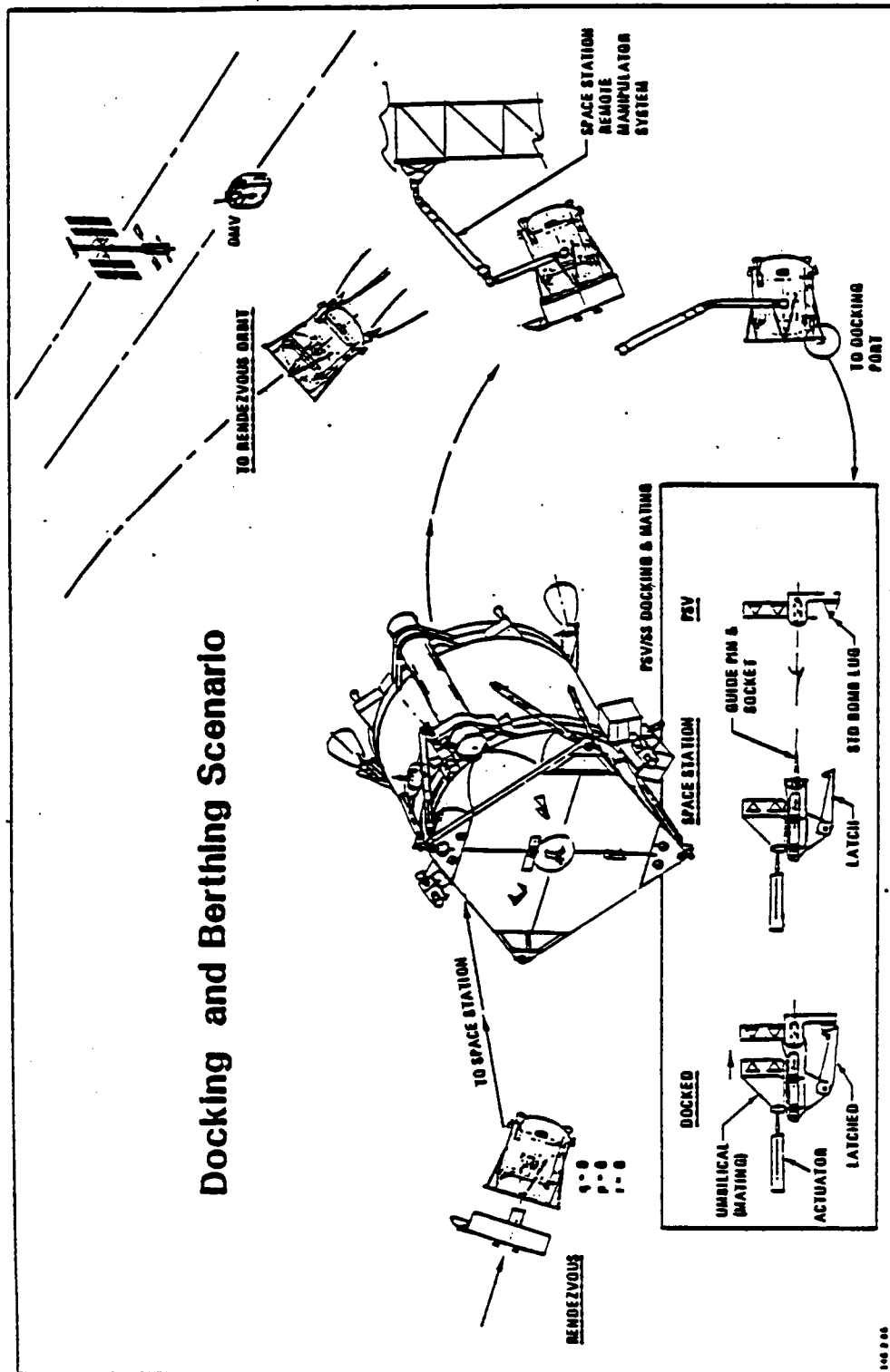
FIGURE 2.2-7   STS/PSV DOCKING AND BERTHING SCENARIO

54
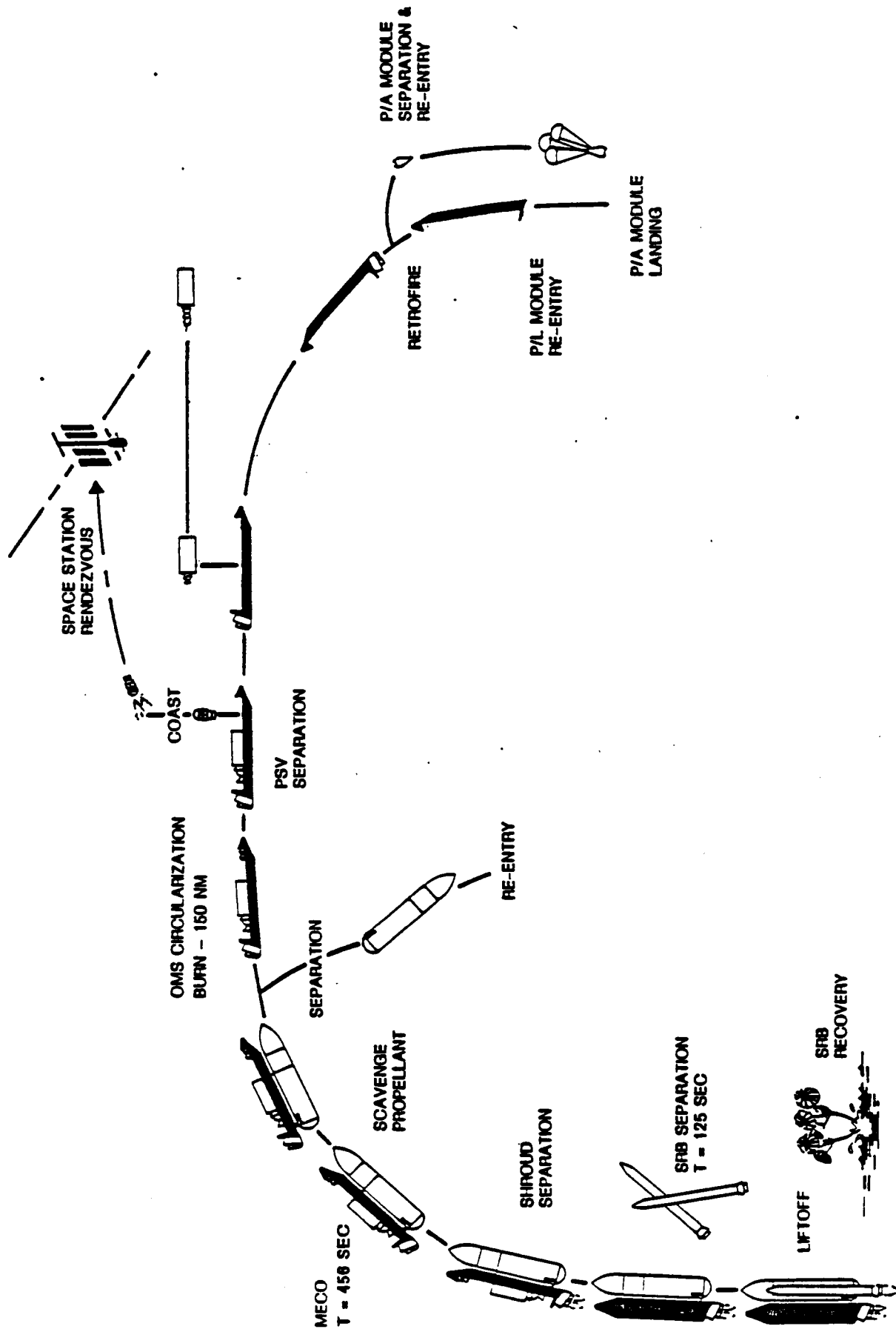
FIGURE 2.2-8   UCV REFERENCE MISSION WITH SELF-PROPELLED TANK SET

SPACE STATION
RENDEZVOUS

OMS CIRCULARIZATION
BURN – 150 NM

COAST

PSV
SEPARATION

P/A MODULE
SEPARATION &
RE-ENTRY

RETROFIRE

P/L MODULE
RE-ENTRY

P/A MODULE
LANDING

SEPARATION

RE-ENTRY

SCAVENGE
PROPELLANT

MECO
T = 458 SEC

SHROUD
SEPARATION

SRB SEPARATION
T = 125 SEC

LIFTOFF

SRB
RECOVERY

55

2.3 TASK C - Interfaces

The operations required of the PSV impose a large number of functions on the interfaces. Structural interfaces must be made with the SDV P/L bay and the SS, as well as the OMV (for some concepts). In addition, fluid and electrical interfaces are required with the SDV P/L bay, the SS and the MLP or tower.

Overall functions which must be performed by the interfaces are:

o Structural support;   o Venting;

o Docking/berthing;   o Status/checkout; and

o Separation;   o Electrical power

o Fluid transfer;

Most of these functions are common to any space vehicle interface. However, for continuity with OTV and SS, we proposed that standardized, universal interfaces be developed. Such standardized umbilical assemblies would include liquid, gas, and electrical disconnects. These disconnects would be automatic, remotely controlled, minimize leakage, and be compatible with the space environment. During an earlier phase of the PS study (Reference 1), we developed a concept for such a disconnect (Figure 2.3-1).
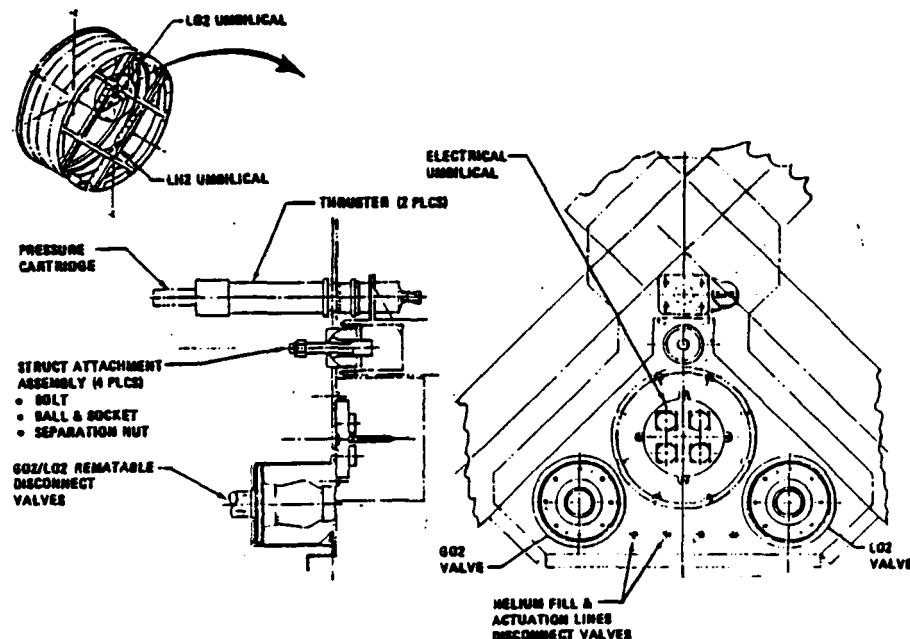
FIGURE 2.3-1 PSV/ACC ATTACHMENT AND UMBILICALS

The SDV's deployable tanks will use the same standard I/F proposed for the PSV during the earlier phases of this study. These I/Fs consist of a LO2 and LH2 disconnect, each incorporating fluid and electrical disconnects as well as structural I/Fs.

The PSV structure attaches to the ACC by four bolts that fit through ball and socket joints secured by pyrotechnic separation units. The separation nuts use USBI 10SPC-062 SRB parachute release nut components repacked into a ball fitting assembly.

The PSV attaches to the SS by two latches that engage standard 1 klb class bomb lugs (MS3314). Attachment occurs after the PSV ball fittings mate with the sockets at the SS OTV facility.

The umbilicals are match tool-machined structures that precisely locate the fluid disconnect valves and electrical connectors relating to the ball or socket. Therefore, when the PSV is mated--to either the ACC or SS--the opposing valves and connectors are brought into alignment for mating, separation, and remating.

2.3.1 Ground Interfaces

By contract direction the sidemount SDV was selected as the baseline UCV for this study. In the area of ground interfaces, this has the advantage of a LH2/GH2 umbilical (already developed for the STS/Centaur program) which can be used for the scavenging system. However, an inline SDV configuration would not enjoy the same advantage.

Figure 2.3-2 shows the geometry of the Centaur rolling beam, as modified from the STS configuration to the UCV (sidemount SDV) Figures 2.3-2 and 2.3-3 are taken from a Martin Marietta Michoud Aerospace study, August 1984, under AFSD Contract F04701-82-C-01152, SBL-03 (Reference 6).

Compared to the Orbiter, the larger size UCV causes the following modifications to the Orbiter-Centaur rolling beam: a 175-in. increase in height, a 7° increase in operating angle; and a 44-in. outboard change in the retract start position. These modifications would require a retest of the rolling beam umbilical system.

The STS/Centaur uses LO2/GO2 connections inside the Orbiter P/L bay. Should these connections be adopted for the sidemount SDV with a separate P/A module, an interface would be required in the forward skin of the P/A module.
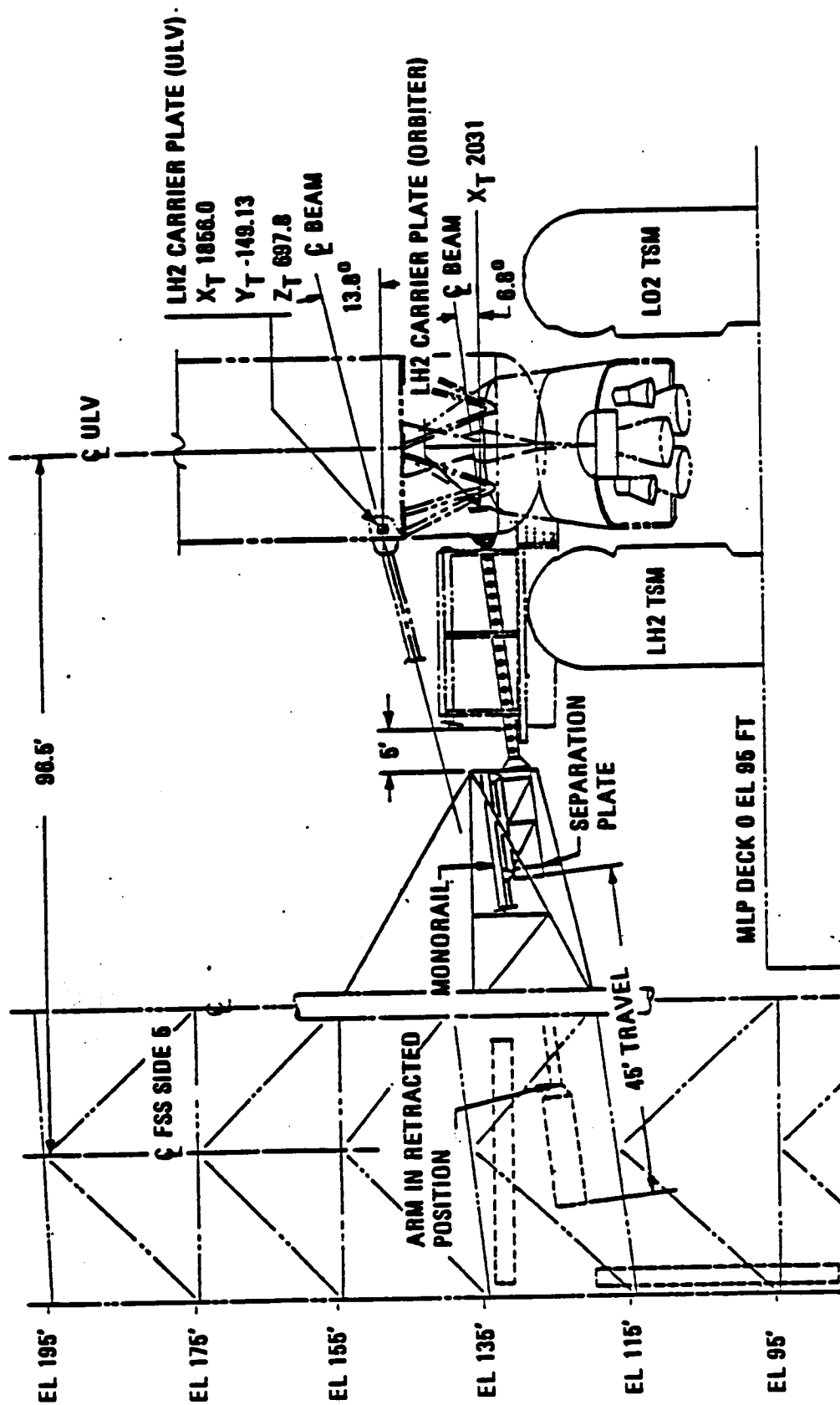
FIGURE 2.3-2   ULV GROUND INTERFACE – CENTAUR

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FIGURE 2.3-3   ULV CENTAUR INTERFACE KIT

Figure 2.3-3 further details the ULV/Centaur interface kit. Of particular interest for this study are the P/A-to-P/L module LO2 connection and the LH2 disconnect on the port side of the P/L module. This concept is directly applicable to a cryogenic tanker using the sidemount SDV.

An alternate approach to the P/L-to-P/A module LO2 interface would be an oxygen umbilical directly from the MLP to the P/L module starboard mid-body.

The use of a dedicated umbilical from the MLP directly to the P/L module provides operational simplicity and potential cost savings. These propellant loading procedures would be simpler than the STS/ACC or ULV/Centaur concepts since they would be largely independent of ET loading operations. The T-0 umbilical separation is also potentially simpler than the in-flight closure of a disconnect in an aerodynamic surface of the P/A module.

The major difficulty is defining an acceptable retraction sequence and location to avoid damage on launching. Major MLP and/or TSM changes would be required. Our 1982 SDV Technology Study (Reference 7) addressed a similar case and suggested that a separate short tower should be built to accommodate such a LO2 umbilical.

We conclude that the option to develop a dedicated LO2 loading umbilical should be examined in conjunction with detailed cost studies. Accordingly, this trade should be deferred until a later phase of the program.

2.3.2 Flight Interfaces

Many of the issues generally relating to interface operation on orbit were dealt with in the introduction to Section 2.3. The operational scenario for SDV PS interfaces is similar to that for STS PS (Section 2.0, and Reference 1).

However, the LO2 disconnect incorporates a feature not used on the STS based system, i.e., a provision to perform an emergency LO2 dump in flight. In the event that the SDV should suffer an engine failure during the latter part of its powered flight, a dump of the 53 klb of LO2 in the tankage assembly may allow the SDV an abort-to-orbit instead of a lost mission. This concept is an extension of the Shuttle/Centaur TALA mode. The design concept for the LO2 dump system is shown in Figure 2.3-4. The discharge line may have to be extended along the P/L module to avoid LO2 impingement on the ET or P/A module. This is an element requiring further study.

3" LINES (2)

3" EMERGENCY DUMP VALVE
AND DISCONNECT (2)

4 1/2" DISCHARGE LINE
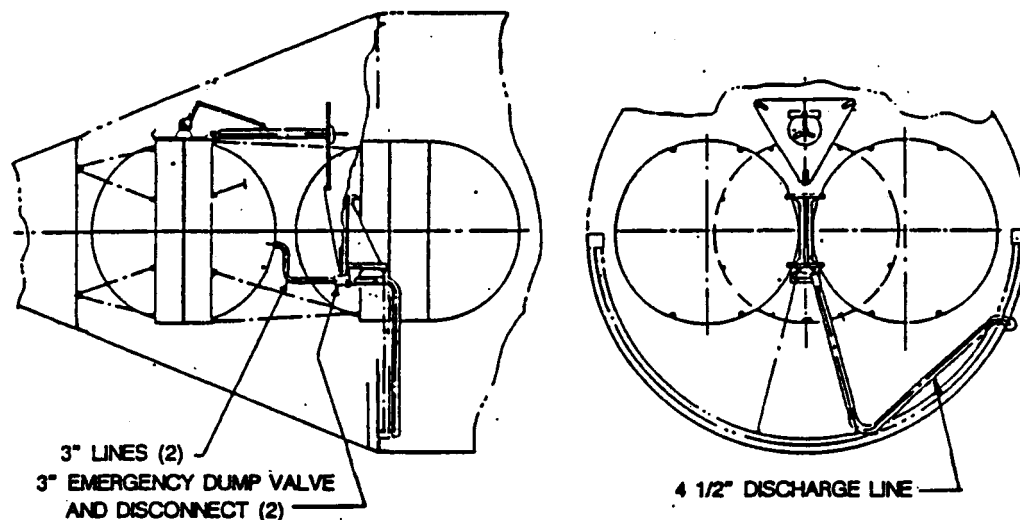
FIGURE 2.3-4   FORWARD TANK CLUSTER LO2 FLIGHT EMERGENCY DUMP

A second major difference between STS and SDV in flight interface requirements is that, unlike the STS based system, no residuals scavenging is baselined for the SDV based system (Section 2.1.3). Thus, no fluid interface is required between the P/A and the P/L modules for in-flight transfer of propellants. However. the LO2 ground loading may require such an interface (Section 2.3.1).

2.3.3 Propellant Conditions

Interface units on the scavenging/transport tanks and at the SS should be capable of handling propellants at a range of saturation conditions. Propellants will be loaded into the tanks at a saturation pressure of about 15 psia. Transit times to the SS and heat leaks will ensure that saturation pressures will rise above this pressure.

Typical transit times to the SS will be one to three days. Incoming heat flux will result in approximately 1 psi/day rise in LO2 tank pressure and 2 psi/day in the LH2 tank pressure. If residual scavenging is to be incorporated, a further rise in saturation pressure (up to 4 psi) may result. Therefore, in the general case, the propellants delivered to the SS will be saturated between 16 and 25 psia.

This saturation rate may impact the design of the orbital cryogenic storage facility. To avoid boiloff losses, the stored propellants are maintained below 25 psia, the storage facility should be designed to chill the delivered propellants before mixing them with the bulk storage. This approach indicates a possible requirement for the orbital storage facility to incorporate a "front-end" propellant conditioning unit for incoming propellant.

2.4 TASK F - Hardware Description

The three tank configurations developed under Task D were described in Section 2.2. For convenience they will be referred to as follows:

Option 1   -   The tank set mounted in the aft end of the P/L module.

Option 2   -   The tank set mounted in the forward end of the P/L module, intruding into the nose cone.

Option 2A -   Option 2 with the addition of a storable propellant propulsion system, i.e., a self-propelled tank unit.

Weight summaries for these options are presented in Figure 2.4-1.

The three configurations have many common features although there are minor structural differences and, in one case, a storable propulsion system which accounts for the weight differences.

These weights do not include ASE or modifications to the UCV/SDV. These issues are quantified elsewhere in this report (Section 2.6).

The majority of the tank set structures are assumed to be aluminum lithium alloys. The use of these alloys was discussed extensively in the previous phase of the study (Reference 1).

For the self-propelled vehicle, a storable propellant load of 2.5 klb would be sufficient to transfer the vehicle from a 160 nm to a 250 nm circular orbit.

	TANK SET WEIGHTS (lb)*		
Subsystem	Option 1	Option 2	Option 2a
Structure	673	600	597
LO2 Tank	337	347	347
LH2 Tanks	535	566	566
TPS	199	199	202
O2/H2 Tank Propellant Management	440	440	440
O2/H2 Plumbing Systems	498	498	498
Avionics/Electrical	94	94	189
Storable Propulsion System	---	---	691
TOTAL DRY WEIGHT	2776	2744	3530**

*   Includes 10% Contingency
** Plus Storable Propellants up to 5000 lb (Mission Dependent)

FIGURE 2.4-1   WEIGHT SUMMARIES - TANK SETS

Appendix I gives detailed weight summaries for the three options.

2.4.1 SDV Payload Module

Figure 2.4-2 shows the largest structural modification made to the SDV P/L ·
module. The change consists of removing part of the nose cone and attaching
it to the jettisonable shroud. This change has two beneficial results:

o Access to a forward mounted tank set is improved, since this tank
   option takes advantage of the previously empty nose cone volume; and

o By transferring part of the nose cone to the jettisonable shroud, a
   gain in SDV lift capability is made. Since the shroud is jettisoned
   only 240 seconds into flight, a significant portion of the nose cone
   structure does not have to be transported to orbit.

Equipment changes to P/L module systems, caused by the nose cone
modifications, are limited to the relocation of RCS components. Figure 2.4-3
shows the Option 2/2A tank set (PSV) mounting frame at Sta. 558 of the P/L
module RCS components.

In addition to the PSV mounting frame, the Option 2 or 2A tank set also
has a support frame at P/L module Sta. 808 (Figure 2.4-4).

2.4.2 Tank Sets

The self-propelled tank set, Option 2A, is shown in Figure 2.4-5. This
view focuses on the simple structural concept of the tank set. The
propulsion system is also shown.
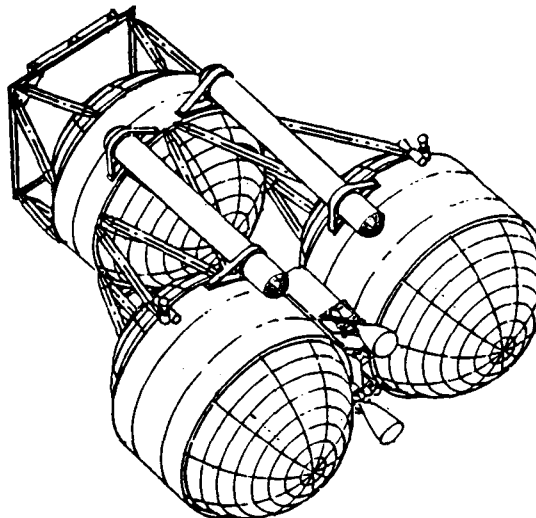
FIGURE 2.4-5 OPTION 2A - TRIMETRIC VIEW
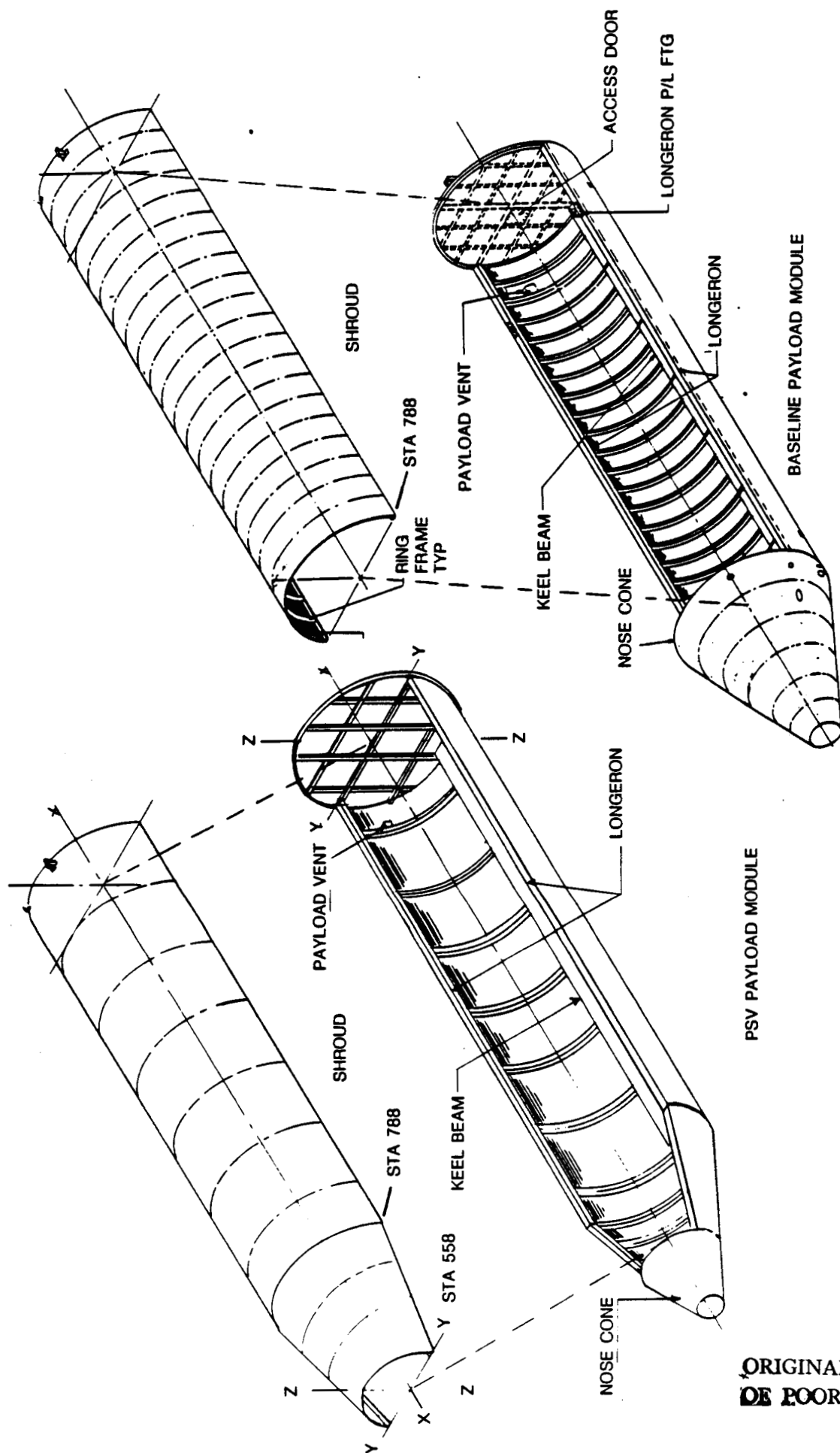
FIGURE 2.4-2 SDV P/L MODULE AND SHROUD

SHROUD

STA 788

RING
FRAME
TYP

ACCESS DOOR

LONGERON P/L FTG

LONGERON

BASELINE PAYLOAD MODULE

PAYLOAD VENT

KEEL BEAM

NOSE CONE

SHROUD

STA 788

STA 558

PAYLOAD VENT

LONGERON

KEEL BEAM

NOSE CONE

PSV PAYLOAD MODULE

SEPARATION SYSTEM
NOSE CONE

15"
.15
.10

RCS ENGINES

SHELL

RCS PWR HE TKS
LO2/GO2
LINES
N204
LH2/GH2
LINES

MMH

STA 543
LKG AFT

C-C
.25
.08
2"
.25
2"
.25
8"

B-B
5
C
C
90
8
15

A-A
SUPPORT FRAME
EXISTING STRINGER
TIE-IN
C
C
110"
8
15

STA 558
LKG FWD
A
B
A
B

FIGURE 2.4-3: MOUNTING FRAME FOR PSV

66
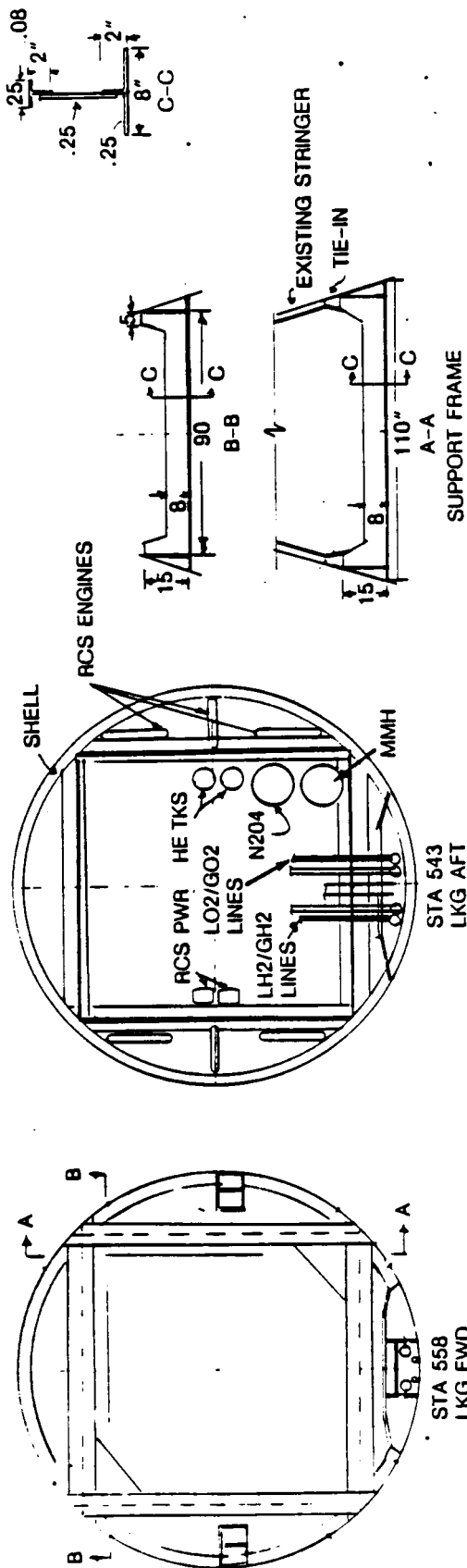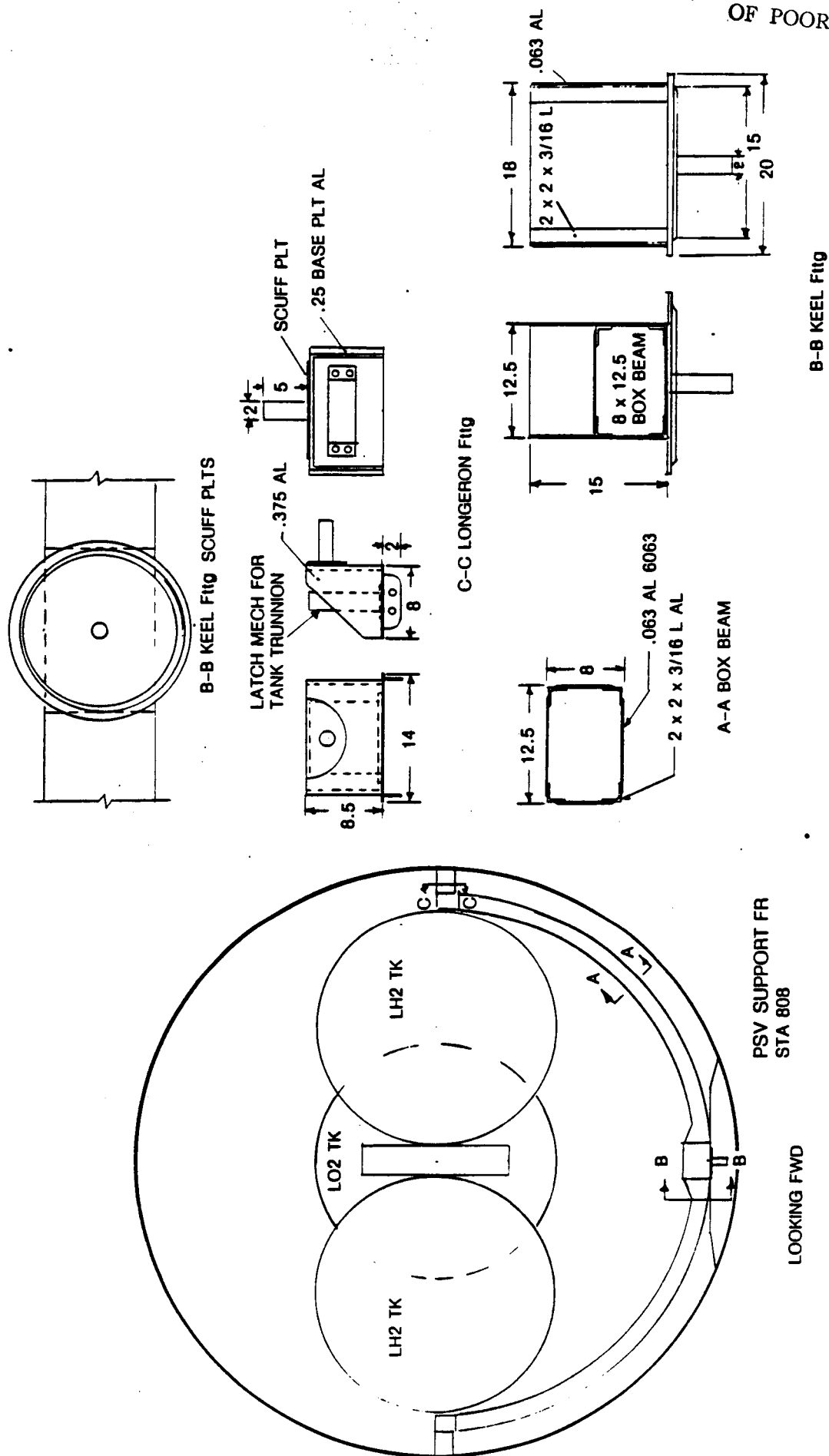
FIGURE 2.4-4: PSV SUPPORT FRAME

Noteworthy features are:

o Standard berthing interface - identical to that of the STS/Concept 6
   PSV; commonality with the OTV is high recommended;

o The composite leaf-spring on the forward interface;

o Accessibility and compactness of the central propulsion/avionics unit;

o 12 STS secondary RCS thrusters (25 lbf bipropellant units) for attitude
   control;

o 2 STS primary RCS thrusters (900 lbf bipropellant units) for primary
   propulsion; and

o One pair of positive-expulsion storable propellant tanks with a
   provision for a second pair to meet future mission requirements.

The storable propellant propulsion system installed on this tank set is
adapted from the Concept 6 PSV. Each oxidizer tank holds 1.54 klb of N204,
while each fuel tank (of identical volume) contains 960 lb of MMH.

One pair of storable tanks gives the tank set a maximum delta-V capability
of 315 fps with a full P/L of 61.4 klb cryogens. Ten% of the theoretically
available delta-V has been allowed for RCS expenditure.

Thus, one N204/MMH tank pair will allow the self-propelled tank set to
transfer itself from an initial 160 nm circular orbit to a 250 nm circular
orbit. A second tank pair will double this capability.

Figure 2.4-6 shows a three-view drawing of the Option 2A vehicle installed
in the SDV P/L module. Since this vehicle will be deployed from the P/L
module to journey to the SS, we have considered the elements necessary to
perform a successful deployment.
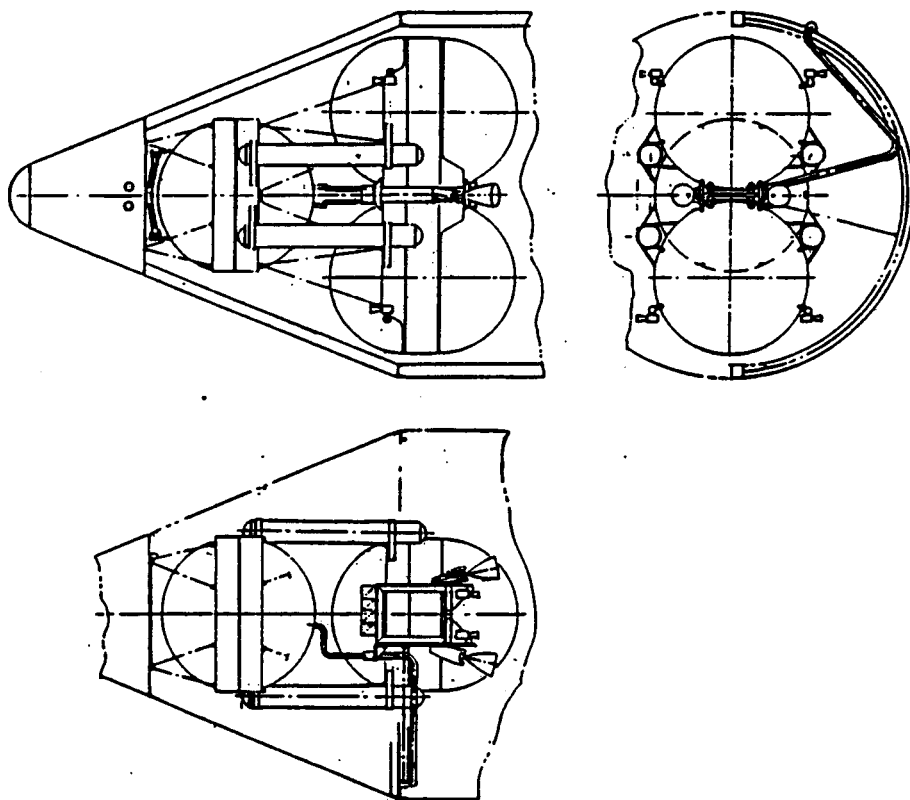
FIGURE 2.4-6   SELF-PROPELLED TANK SET (PSV)

Figures 2.4-7(a) and (b) illustrate part of the deployment sequence.

The deployment scenario starts (at time T) with the firing of four explosive nuts at the forward PSV/P/L module interface.   The PSV clock sequencer then starts.   The release of the interfaces allows a preloaded, composite, leaf spring to move the PSV four inches aft.   The pivoting bipod assembly guides the PSV.

(a)   **(b)**
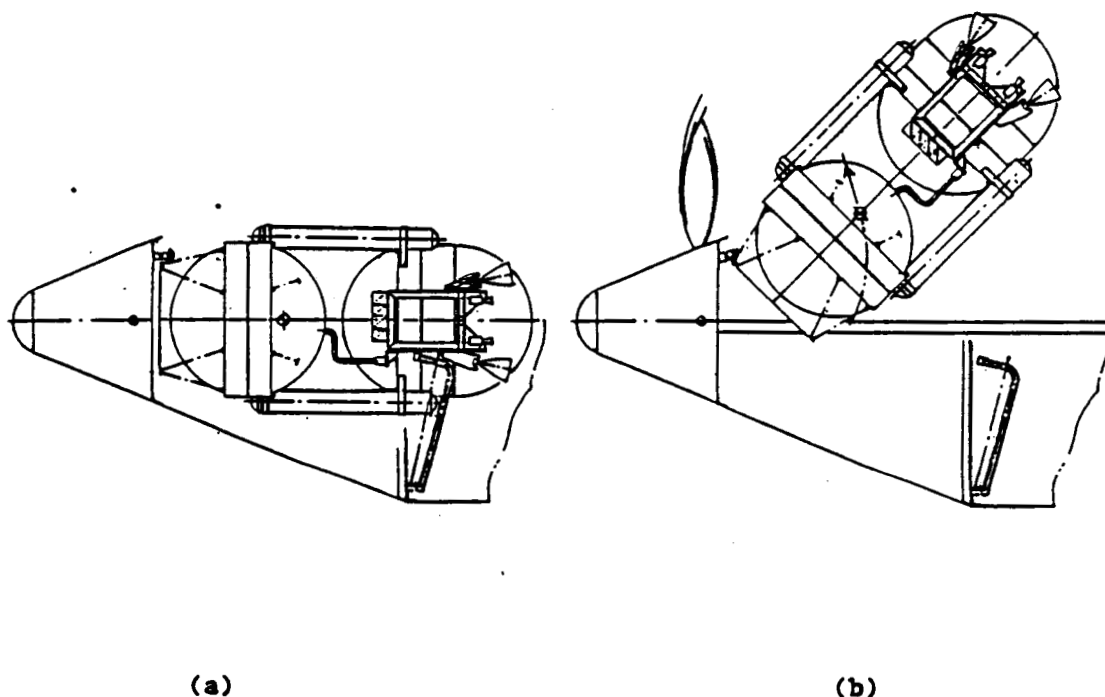
FIGURE 2.4-7   SELF PROPELLED TANK SET (PSV) DEPLOYMENT

The bipod separates at T+0.5 seconds taking with it the emergency LO2 dump umbilical (Figure 2.4-7(a). Simultaneously, a brief firing of the P/L module RCS produces a -Z acceleration. This action starts the PSV rotating about the pivot.

After 45° PSV pitch rotation, the P/L module RCS stops firing and the PSV pivots off the release link, with adequate linear and angular velocities to complete the separation (Figure 2.4-7(b). As the PSV pitch angle relative to the P/L module approaches 90°, the clock fires the two forward RCS thrusters on the PSV to cancel the pitch rate; this also adds separation velocity. After a 200 ft separation is achieved, the independent PSV mission starts and the vehicle injects itself into its transfer orbit to the SS.

A backup scenario exists should the RCS fail in the P/L module. If the PSV fails to detect any pitch rate, it fires four RCS thrusters to produce a pitch couple about the release link. The remainder of the scenario is similar to the primary mode.

The opportunities for the use of common components for STS and SDV tank sets or PSVs are:

o Interfaces - Mechanical, electrical and fluids interfaces can be identical. The benefits of simpler and cheaper development apply also to the SS OTV facility where the use of a universal interface for PS/transport and for OTV would bring significant benefits (Section 2.3).

o Avionics - The avionics systems of the Concept 6 PSV and the Option 2A tank set can be identical.

o Propulsion - All active storable propulsion system components (e.g., positive expulsion tanks, RCS and PPS engines, valves) used on the Option 2A tank set are identical to those used on the Concept 6 PSV. In addition, the RCS and PPS engines are standard STS RCS items.

o Tank Units - Cryogenic fill and drain systems -- including the active propellant management device -- can be identical.

2.4.3 Test Plan - Update

In general, the testing requirements remain the same as developed in Reference 1. The only major development item required, which is not currently being studied, is a rematable cryogenic disconnect for universal application. Further leading test plan issues may be summarized as follows:

o The primary goal remains the same as for STS/PSV - successful micro-gravity propellant management;

o CFMF/E will provide critical baseline data for tank thermodynamics and fluid transfer; and

o Ground tests will yield additional thermal control data.

2.5 TASK B: Tank Reuse

At the start of this task, we considered the factors affecting the reusability of the UCV PS tanks. Initial results from Task A (Mission Model Update) showed that a severe shortage of down cargo capacity resulted if the UCV cargo bay were not reusable, i.e., was not a flyback. The STS Orbiters alone could not supply the required capacity for return cargo. The implication of this was that the STAS mission model could not support STS or

UCV reusable PS tankage unless a flyback UCV was developed.

Figure 2.5-1 illustrates the significant requirements for return cargo, from a typical STAS model. Typically, 70% to 80% of the cargo mass and volume delivered to orbit must be returned. With the STS and SDV available for delivery, but only the STS available for return, an imbalance of requirements exists.

Year	Manned Cargo Up (Lbs)	Total Cargo Up (Lbs)	Down Cargo (Lbs)	Total Cargo Volume Up (Ft^3)	Total Cargo Volume Down (Ft^3)
1995	355139	507676	305680	115700	91808
1996	339938	453884	336923	119691	96807
1997	263732	396268	366841	102990	98178
1998	331674	425688	315264	111808	96474
1999	325084	440395	367947	104652	103040
2000	346457	463763	381270	121720	102520
2001	529398	648341	389082	159976	114291
2002	463722	610800	373528	139152	97246
2003	477770	608104	451732	150714	123280
2004	500632	652510	485086	166934	126649
2005	616287	760907	518741	172517	127806
2006	476769	642114	536163	149991	138558
2007	678546	894673	561375	211181	134436
2008	680152	833587	539193	201048	133815
2009	604379	771564	650722	169917	164132
2010	550721	757673	660807	168947	162722
Total	7,540,400	9,867,947	7,240,354	2,366,938	1,911,762

FIGURE 2.5-1   CARGO PROFILE CIVIL MISSION MODEL - VERSION 2.0

Figure 2.5-2 shows the problem in graphical form: the STAS return cargo requirement exceeds the STS capacity around the years 2004-2005. However, if the requirement to return empty PS tanks from eight SDV missions/year is added, the return capacity is exceeded in all years.

These results confirmed our initial estimation that the STAS Mission Model cannot support reusable PS tankage unless a flyback UCV is developed.

2.5.1 Reusability Design Features

For study purposes, we assumed that the issue of providing sufficient return transport capacity would be met. Accordingly, we have developed tank concepts which allow reusability.

Reusability considerations interact with our tank arrangement and hardware description (Tasks D and F). For example, deployable tank concepts must not preclude return to Earth either as integral units or in subassembly form. We have examined four modes of operation for the SDV/UCV based tankage:

o Concept 6 - a PSV, identical to the STS based system;

o Fixed or "built-in" tankage located in the SDV P/L module;

o Deployable tankage located in the SDV P/L module against the aft bulkhead; and

o Deployable tankage located in the nose cone of the SDV P/L module.

A discussion of the factors governing the selection of a configuration may be found under "Task D, Optimum Tank Sizing and Arrangement". Tank reuse considerations led to the incorporation of design features specifically related to reusability.

The first two tankage categories do not require further discussion of reusability - the Concept 6 PSV is in the STS P/L bay as normal cargo - while the built-in tankage is reusable if the SDV cargo bay is reusable, and disposed with the bay if it is not.

The two deployable tankage designs incorporate the following design reusability features:

o Return tankage assemblies can be remounted inside the SDV P/L module on standard trunnion supports;

o Tanks are sized at 11.5' diameter, allowing the tankage assembly to be disassembled onorbit for return within a 15' diameter cargo bay; and

o Tank valves that can be latched open to vacuum inert to allow safe repressurization during reentry.

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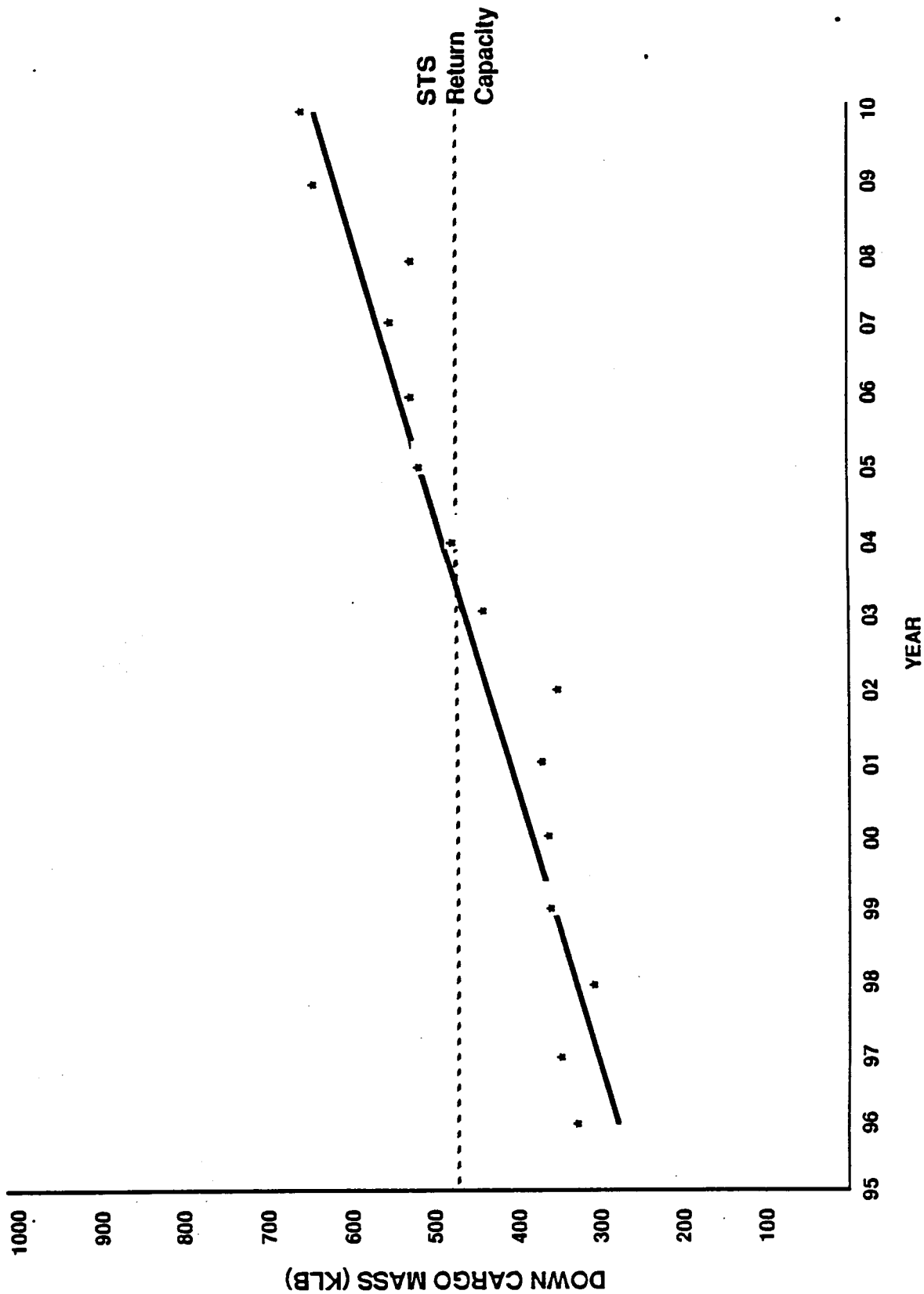
FIGURE 2.5-2 RETURN CARGO CAPACITY LIMITATIONS

007.LJ

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In all cases, the return ASE requirements are for structural support only: no electrical, pneumatic or other active service support is required by the tanks while in the returning cargo bay.

2.5.2 Tank Sets Required

The previous phase of the study (Reference 1) indicated that 11 PSVs, with 14 to 25 scavenging missions per year would be required to maintain a service based solely on STS PS.

The STAS and OTV mission models used during the current phase of the study indicate that, with the SDV in service, 8 SDV and 12 STS missions/year will transport propellant to the OTV facility.

Our tank sizing and arrangement (Task D) and cost studies indicated that the STS and SDV PSVs would not be identical or directly interchangeable. Since tank volume requirements led to different optimum configurations, two PSV types will be operated if both PS/transport systems are developed.

Many of the subsystems and components from the STS based PSV are also common to the SDV based system, e.g., interfaces, propulsion system, avionics. The complexity of turnaround of the two vehicles is conceptually similar. We have extrapolated our PSV requirements from the results of our detailed 1985 study (Reference 1). The results show that 6 PSVs are required to maintain the STS PS service, and 4 PSVs are needed for use on the UCV/SDV.

2.6 TASK G - SDV Impacts

2.6.1 Weight Impacts

In general, the impacts on the SDV of PS/transport are minor. Although most impacts (e.g., weights, additional systems complexity) are by definition negative, some impacts are positive.

The SDV/STAS and OTV mission models show that 35 to 45% of the SDV P/L will be cryogenic propellant. To accommodate this requirement, we propose to incorporate a set of cryogenic transport tanks on every SDV launch. This operational scenario results in two significant positive impacts:

1) Carrying a large P/L propellant mass offers an opportunity to avoid SDV loss of mission in the event of engine failure. This loss would be avoided by rapidly dumping the 53 klb LO2 in the transport tanks, allowing SDV abort-to-orbit mode (Section 2.3.2).

2. Cryogenic propellant is of a significantly higher density than most cargos. For example; a 15' x 60' bay is ample to transport 135 klb LO2 and LH2 at a 6:1 mixture ratio. However, optimum cargo manifesting results in a smaller (approximately 60 klb) capacity tank set which allows P/L density differences to be normalized and fully utilize the larger bays.

The potential to use the nose cone volume of the SDV shroud further minimizes the impact on the SDV cargo bay volume.

Hardware impacts on the SDV have been examined to allow estimates to be made of the weight and performance impacts of incorporating propellant transport or scavenging. If scavenging in flight is required the SDV in-bay tanks require interfaces between P/L and P/A modules . The complexity of these interfaces, together with the low residuals/surplus ratio of the SDV, mitigates against SDV scavenging.

Should STS/ACC scavenging be developed, the SDV/ACC scavenging tanks would use an identical facility and installation. No additional impact would be felt by the SDV over STS. STS impacts are described in detail in Reference 1.

Baseline SDV weights were taken from a previous Martin Marietta Michoud Aerospace study (Reference 6). The impacts derived were for the worst case, i.e., the forward mounted tank set.

Significant modifications include:

o P/L modulè structural modifications at the forward end of the bay, including a new forward bulkhead;

o Provision of cryogenic plumbing with TPS, inside the P/L module; and

o Modifications to the jettisonable fairing: because of the increased jettisonable weight, the impact on lift capability is not as great as the weight impact.

Figure 2.6-1 summarizes the weight and lift capability impacts of incorporating PS on the SDV. These weights do not include the scavenging tank system weights which are described in Section 2.4. Figure 2.6-1 shows the ASE and scar weight impacts resulting from provisions for SDV PS.

	Baseline SDV (lb)	SDV + * Scavenging(lb)	WEIGHT * INCREASE (lb)
STRUCTURE	41,066	42,127	1,061
SEPARATION SYSTEM	2,267	2,494	227
PAYLOAD SUPPORT	550	1,409	859
ENVIRONMENTAL CONTROL	3,549	4,021	472
AVIONICS/ELECTRICAL	100	130	30
GROWTH (10%)	4,753	5,018	265
	52,283	55,198	2,915

* NOTE: 1445 lb reduction in lift capability

FIGURE 2.6-1 ASE/SCAR WEIGHT IMPACT ON SDV

A more detailed breakdown of the Figure 2.6-1 summary data is presented in Figure 2.6-2.

COMPONENTS	BASELINE ULV		PSV ULV		WEIGHT	
STRUCTURE						
Payload Bay		24521		245221		0
Shell	2902		2902		0	
Frames	3700		3700		0	
Longerons	3208		3208		0	
Doublers	887		887		0	
Cable Tray	443		443		0	
Keel Beam	1401		1401		0	
Stringers	7808		7808		0	
Aft Bulkhead	554		554		0	
P/A Truss	2400		2400		0	
Fasteners	1218		1218		0	
Nose Cone		3378		2882		-496
Shell	1197		752		-445	
Frames	425		416		-9	
Stringers	1497		536		-961	
Longerons	0		722		+722	
Cable Tray	0		99		+99	
Keel Beam	0		122		+122	
Doublers	98		98		0	
Fasteners	161		137		-24	
Shroud Jettison		13086		14643		+1557
Shell	2839		3277		+438	
Frames	2231		2427		+196	
Stringers	6369		7039		+670	
Longerons	758		920		+162	
Doublers	231		283		+52	
Fasteners	658		697		+39	
Shroud Non-Jettison		81		81		0
Shell	43		43		0	
Fasteners	38		38		0	
STRUCTURAL TOTAL		41066		42127	+1061	

FIGURE 2.6-2(a) DETAILED ASE/SCAR WEIGHT IMPACT ON SDV

COMPONENTS	BASELINE ULV		PSV ULV		WEIGHT	
SEPARATION SYSTEM		2267		2494·		+227
ET/PL Mod Sep Motors	172		172		0	
Support Structure	50		50		0	
Separation Longeron	948		1163		+215	
Separation Fr Fwd	261		119		-142	
Separation Fr Aft	246		246		0	
Expanding Tubes	260		374		+114	
Hinges	150		150		0	
Spring Thrusters	80		120		+40	
ET/PL Mod Attachment	100		100		0	
SEPARATION SYSTEM TOTAL		2267		2494		+227
PAYLOAD SUPPORT		550		1409		+859
Payload ASE	550		550		0	
PSV Plumbing	0		547 *		+547	
PSV Support	0		312		+312P	
PAYLOAD SUPPORT TOTAL		550		1409		+859
ENVIRONMENTAL CONTROL		3549		4021		+472
TPS Shell	777		559		-218	
TPS Plumbing	0		191 *		+191	
Acoustical Blanket	2772		3271		+499	
ENVIRONMENTAL CONTROL TOTAL	3549			4021		+472
AVIONICS/ELECTRICAL		100		130		+30
P/L Carrier	100		100		0	
PSV	0		30		+30	
AVIONICS/ELECTRICAL TOTAL		100		130		+30
GROWTH 10%		475		5018		+265
P/L TOTAL WEIGHT		52283		55198		+2915

FIGURE 2.6-2(b)   DETAILED ASE/SCAR WEIGHT IMPACT ON SDV

2.6.2 Operational Impacts

The SDV delivered propellant is required at the SS storage tanks in a 220/250 nm circular orbit. It is not clear at this time what scenario will be adopted for the SDV to deliver its other cargos to orbit (including non SS cargos).

The operational options open to the SDV to deliver cargo to orbit were detailed in Section 2.2. They are:

1. SDV rendezvous and berthing at the SS - this favors built-in tankage.

2. SDV rendezvous without berthing - this favors OMV transfer of tank set to the SS.

   - Similar to Concept 5 in the earlier phases of this study (Reference 1).

3. An SDV mission to a significantly lower orbit favors a self propelled tank set.

   - Similar to Concept 6, the baseline STS scavenging system.

There would be a significant SDV operational impact if built-in tanks were used. This change would:

o Require the berthing of the SDV cargo bay at the SS; and

o Impose SDV launch window constraints to avoid excessive boiloff losses from non-optimum trajectories.

In order to minimize the operational impacts on SDV, we selected the forward-mounted tank set, which is adaptable to a self-propelled vehicle as well as the normal deployable or built-in tank arrangement. Figure 2.6-3 illustrates the operational scenario for normally deployable tanks. For operational purposes, the propellant tanks may be treated as any other SDV P/L.

Figure 2.6-4 shows the self-propelled tank set scenario; operational impacts to the SDV are minor.

Also we examined a tether as an alternative method for propellant delivery for SDV missions which do not visit the SS.

The tether operational scenario (Figure 2.6-5) is as follows:

1) SDV injected into a 100 x 200 nm orbit;

2) Payload deployed: tank set ejects while attached to tether;

3) 15 nm tether deploys between the tank set and P/L and P/A modules;

4) The kinetic energy transfer resulting from tether use gives delta-V to both elements: 200 fps posigrade to the tank unit, and 120 fps retrograde to the P/L and P/A modules;
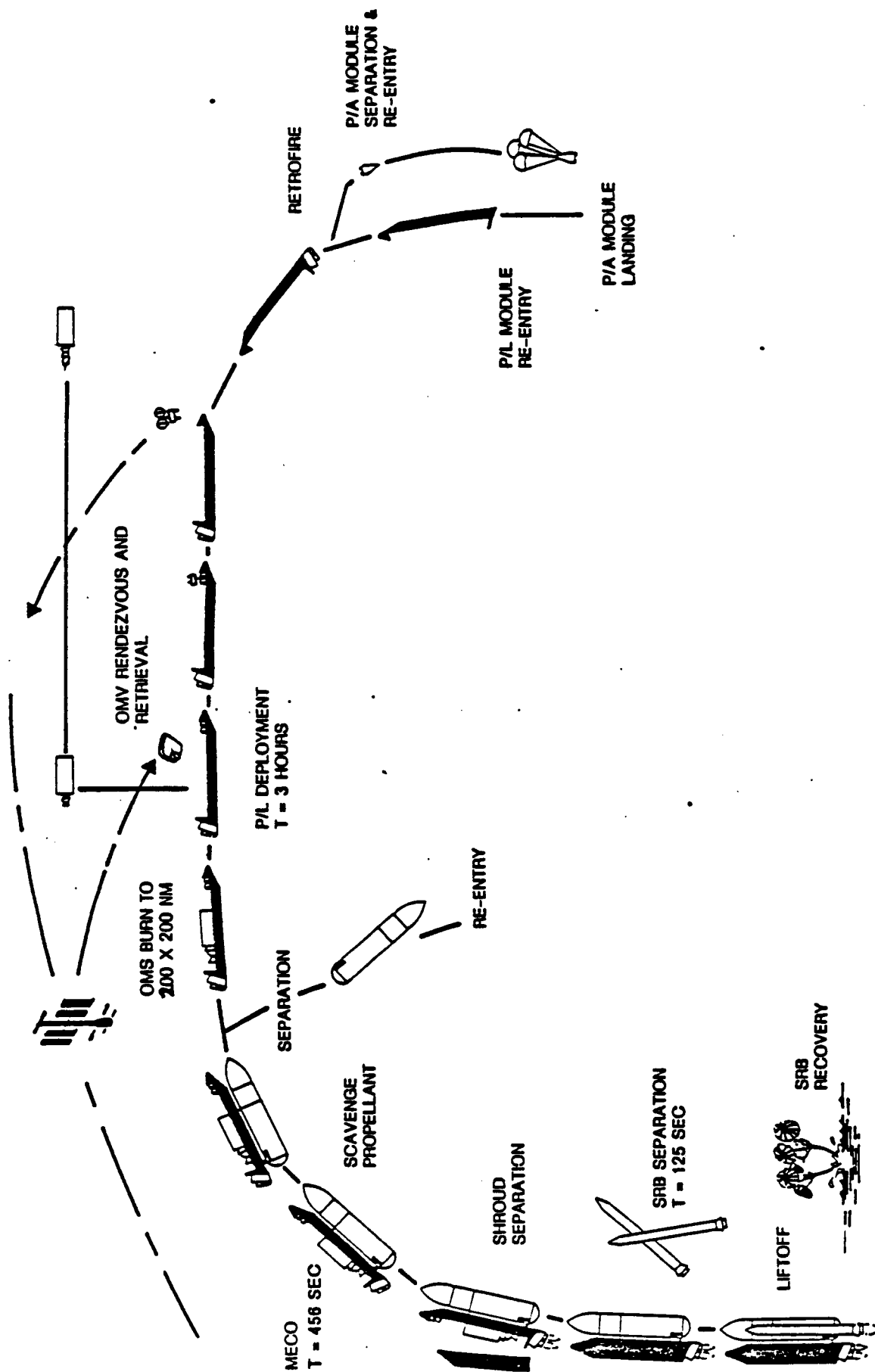
FIGURE 2.6-3   UCV REFERENCE MISSION WITH PROPELLANT SCAVENGING

SPACE STATION RENDEZVOUS

OMS CIRCULARIZATION BURN – 150 NM

COAST

PSV SEPARATION

SEPARATION

RE-ENTRY

SCAVENGE PROPELLANT

SHROUD SEPARATION

SRB SEPARATION T = 125 SEC

LIFTOFF

SRB RECOVERY

MECO T = 456 SEC

P/A MODULE SEPARATION & RE-ENTRY

RETROFIRE

P/L MODULE RE-ENTRY

P/A MODULE LANDING
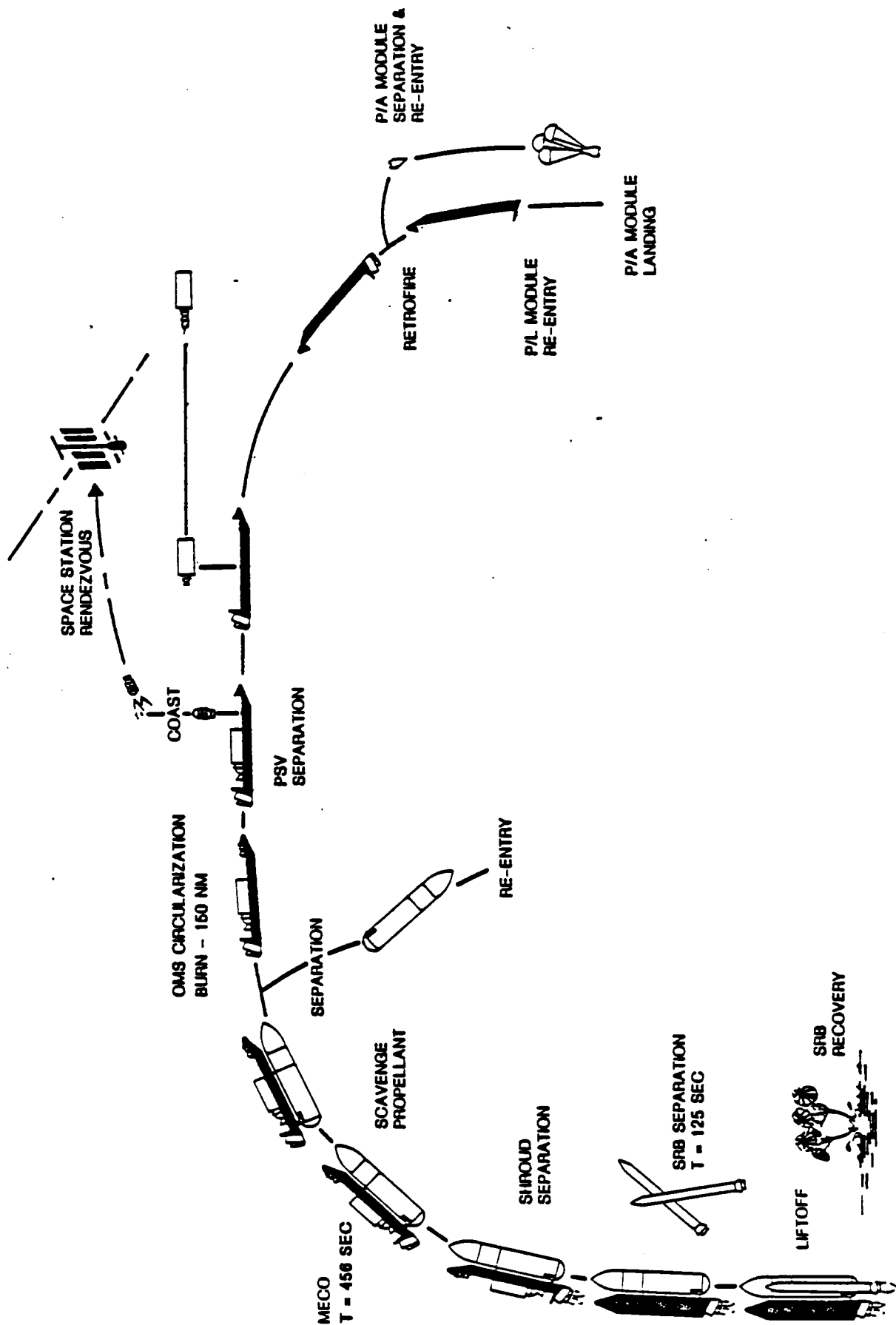
FIGURE 2.6-4   UCV REFERENCE MISSION WITH SELF-PROPELLED TANK SET

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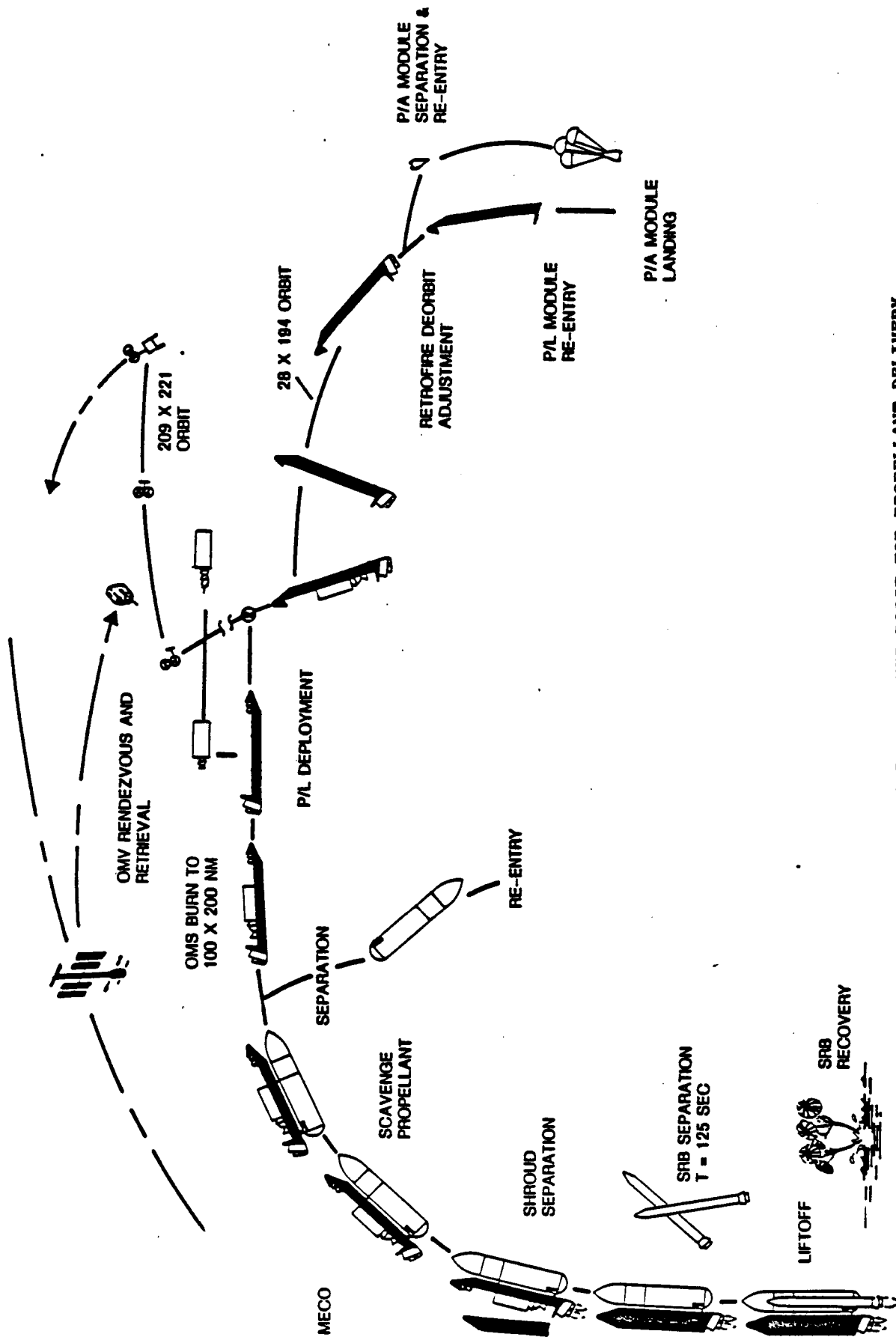
FIGURE 2.6-5   TETHER BOOST FOR PROPELLANT DELIVERY

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5) Tank unit in near circular 210 x 220 nm orbit;

6) Payload and P/A modules in descending 30 x 190 nm orbit (minimal OMS use required for deorbit); and

7) Tether saves about 2.6 klb storable bipropellant -- tether system mass approximately 1.3 klb for a net mass saving of 1.3 klb.

For all methods of propellant delivery, the operational impact of propellant loading is similar.

The methods of propellant loading proposed are discussed in Section 2.3. Briefly, it is proposed that LH2 loading should take place through the Centaur Rolling Beam System, developed for the STS/Centaur program. LO2 loading may take place through the P/A module or through a new umbilical at the starboard mid-body. No severe operational impact is expected from the propellant loading requirements. The STS/Centaur timelines and procedures can form a basis for timeline development.

3.0 REFERENCES

1. "STS Propellant Scavenging Systems Study - Part II", Final Report, Contract NAS8-35614, Martin Marietta Michoud Aerospace, February 1986

2. "Space Transportation Architecture Study", Special Report Number One (CDRL 023A2), Contract NAS8-36618, Martin Marietta Denver Aerospace, May 1986

3. "Space Transportation Architecture Study", Third Interim Progress Report, Contract NAS8-36618, Martin Marietta Denver Aerospace, June 19, 1986

4. "Nominal Mission Model (FY 1983 - 2000), Revision 7 (SS), Space Station Advocacy", NASA Marshall Space Flight Center/PS01, July 1984

5. "OTV Mission Model - Rev. 10", OTV-86-002(10), NASA Marshall Space Flight Center/PF20, February 6, 1987.

6. "Sidemount Unmanned Launch Vehicle (ULV) Costs Study", Final Report, Contract F04701-82-C-0152, Martin Marietta Denver Aerospace, Michoud Division, August 1984

7. "Shuttle Derived Vehicles (SDV) Technology Requirements Study", Volume V, "External Tank Aft Cargo Carrier Study", Phase II, Final Report, Contract NAS8-34183, Martin Marietta Denver Aerospace, Michoud Division, May 1982

APPENDIX I - DETAILED TANK SET WEIGHT BREAKDOWNS

This appendix gives detailed weight breakdowns for the appendix three tank set options which were studied for SDV cryogenic propellant transport.

Option 1:   The tank set mounted in the aft end of the P/L module;

Option 2:   The tank set mounted in the forward end of the P/L module, intruding into the nose cone; and

Option 2A: Option 2, with the addition of a storable propellant propulsion system — a self-propelled tank unit.

All options include two LH2 tanks and one LO2 tank and are capable of containing 61.4 klb of cryogenic propellants at a mixture ratio of 6:1.

PROPELLANT SCAVENGING VEHICLE

OPTION 1

<u>AFT MOUNTED TANK SET</u>

GRP	ELEMENT	WEIGHT
	SUMMARY	(lb)
2.0	Structures	673
3.0	Propellant Tanks	872
4.0	Propulsion	938
8.0	Communication & Data Handling	59
9.0	Electrical Power	35
10.0	Thermal Control	199
	DRY WEIGHT	2776
15.0	Fluids	
	Fuel - LH2	8700
	Oxidizer - LO2	52700
	Helium	15
	TOTAL VEHICLE WEIGHT	64191

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PROPELLANT SCAVENGING VEHICLE
OPTION 1
AFT MOUNTED TANK SET

GRP	ELEMENT	WEIGHT		
2.0	STRUCTURES			673
2.1	Air Frame		493	
	Center Tank Support	266		
	Clamp Mechanism	38		
	Struts LO2 Tank	14		
	Struts LH2 Tanks	22		
	Attach Hardware	12		
	Aft Support Frame	64		
	Attach Hardware	13		
	Contingency	64		
2.3	Equipment Mounts		50	
	Avionics	5		
	Electrical	4		
	Propellant Plumbing & Valves	18		
	Pressurization System	15		
	Vent System	3		
	Contingency	5		
2.4	Handling and Storage		130	
	OMV Pickup Arm	64		
	Grapple Fitting and OMV Latches	49		
	Contingency	17		
3.0	PROPELLANT TANK			872
3.1	Tank Structure		822	
	LO2 (1)	291		
	LH2 (2)	456		
	Contingency	75		
3.2	Tank Mounts		50	
	LO2	15		
	LH2	30		
	Contingency	5		

PROPELLANT SCAVENGING VEHICLE

OPTION 1

AFT MOUNTED TANK SET

GRP	ELEMENT	WEIGHT	
4.0	PROPULSION		938
4.1	Pressurant and Pneumatic System		167
	Valves (20)	26	
	Regulators	9	
	Lines and Attachments	20	
	Helium Spheres	90	
	Contingency	22	
4.2	Propellant FV&D Fuel		189
	Valves (16)	64	
	Lines, Bellows, Disconnects	100	
	Contingency	25	
4.3	Propellant FV&D Oxygen		73
	Valves (8)	32	
	Lines, Bellows, Disconnects	31	
	Contingency	10	
4.4	Prop Utilization & Management System		343
	Channels	150	
	Screens	10	
	Perforated Plates	28	
	Standpipes and Nozzles	60	
	Attach Hardware	50	
	Contingency	45	
4.5	Vent System (Nonpropulsive)		97
	Valves (3)	24	
	Lines, Vent I/F & Attach Hardware	60	
	Contingency	13	
4.6	Umbilicals		69
	Umbilicals	60	
	Contingency	9	

PROPELLANT SCAVENGING VEHICLE

OPTION 1

<u>AFT MOUNTED TANK SET</u>

GRP	ELEMENT	WEIGHT		
8.0	COMMUNICATION AND DATA HANDLING			59
8.1	Communication		59	
	Transponder	25		
	Power Amplifier	6		
	Antennas/Switches (2)	10		
	Instrumentation	10		
	Contingency	8		
9.0	ELECTRICAL POWER			35
9.5	Power Distribution		35	
	Batteries	20		
	Wiring	10		
	Contingency	5		
10.0	THERMAL CONTROL			199
10.1	Insulation		179	
	LH2 - MLI	33		
	LH2 - SLA	96		
	LO2 - MLI	27		
	Contingency	23		
10.2	Thermal Control		20	
	Propulsion Lines	7		
	Electrical System	5		
	Instrumentation (Htr Tape)	5		
	Contingency	3		

PROPELLANT SCAVENGING VEHICLE

OPTION 1

<u>AFT MOUNTED TANK SET</u>

GRP	ELEMENT	WEIGHT		
15.0	PROPELLANTS			61400
15.1	Propellants		61400	
	LH2	8700		
	LO2	52700		

PROPELLANT SCAVENGING VEHICLE
OPTION 2
FORWARD MOUNTED TANK SET

GRP	ELEMENT	WEIGHT
	SUMMARY	(lb)
.2.0	Structures	600
3.0	Propellant Tanks	913
4.0	Propulsion	938
8.0	Communication and Data Handling	59
9.0	Electrical Power	35
10.0	Thermal Control	199
	DRY WEIGHT	2744
15.0	Fluids	
	Fuel – LH2	8700
	Oxidizer – LO2	52700
	Helium	15
	. TOTAL VEHICLE WEIGHT	64159

PROPELLANT SCAVENGING VEHICLE
OPTION 2
FORWARD MOUNTED TANK SET

GRP	ELEMENT	WEIGHT		
2.0	STRUCTURE			600
2.1	Airframe		411	
	Forward Support Frame	41		
	Center Ring Frame	29		
	LH2 Tank Center Support	85		
	LH2 Tank End Support	136		
	LO2 Tank Struts	22		
	LH2 Tank Struts	14		
	Attach Hardware	30		
	Contingency	54		
2.3	Equipment Mounts		50	
	Avionics	5		
	Propellant Plumbing and Valves	18		
	Pressurization System	15		
	Vent System	3		
	Electrical	4		
	Contingency	5		
2.4	Handling and Storage		159	
	OMV Pickup Arm	89		
	Grapple Fitting and OML Latches	49		
	Contingency	21		
3.0	PROPELLANT TANK			913
3.1	Tank Structure		822	
	LO2 (1)	291		
	LH2 (2)	456		
	Contingency	75		
3.2	Tank Mounts		91	
	LO2 Tank Mounts	24		
	LH2 Tank Mounts	52		
	LH2 Tank Trunnions	7		
	Contingency	8		

PROPELLANT SCAVENGING VEHICLE

OPTION 2

FORWARD MOUNTED TANK SET

GRP	ELEMENT	WEIGHT	
4.0	PROPULSION		938
4.1	Pressurant and Pneumatic Systems		167
	Valves (20)	6	
	Regulators	9	
	Lines and Attachments	20	
	Helium Spheres	90	
	Contingency	22	
4.2	Propellant FV&D Fuel		189
	Valves (16)	64	
	Lines, Bellows, Disconnects	100	
	Contingency	25	
4.3	Propellant FV&D Oxygen		73
	Valves (8)	32	
	Lines, Bellows, Disconnects	31	
	Contingency	10	
4.4	Prop Utilization and Management System		343
	Channels	150	
	Screens	10	
	Perforated Plates	28	
	Standpipes and Nozzles	60	
	Attach Hardware	50	
	Contingency	45	
4.5	Vent System (Nonpropulsive)		97
	Valves (3)	24	
	Lines, Vent I/F and Attach Hardware	60	
	Contingency	13	

PROPELLANT SCAVENGING VEHICLE
OPTION 2
FORWARD MOUNTED TANK SET

GRP	ELEMENT	WEIGHT		
4.6	Umbilicals			69
	Umbilicals	60		
	Contingency	9		
8.0	COMMUNICATION AND DATA HANDLING			59
8.1	Communication		59	
	Transponder	25		
	Power Amplifier	6		
	Antennas/Switches (2)	10		
	Instrumentation	10		
	Contingency	8		
9.0	ELECTRICAL POWER			35
9.5	Power Distribution		35	
	Batteries	20		
	Wiring	10		
	Contingency	5		
10.0	THERMAL CONTROL			199
10.1	Insulation		179	
	LH2 - MLI	33		
	LH2 - SLA	96		
	LO2 - MLI	27		
	Contingency	23		
10.2	Thermal Control		20	
	Propulsion Lines	7		
	Electrical System	5		
	Instrumentation (Htr Tape)	5		
	Contingency	3		

PROPELLANT SCAVENGING VEHICLE

OPTION 2

FORWARD MOUNTED TANK SET

GRP	ELEMENT	WEIGHT		
15.0	PROPELLANTS			61400
15.1	Propellants		61400	
	LH2	8700		
	LO2	52700		

PROPELLANT SCAVENGING VEHICLE

OPTION 2A

SELF-PROPELLED TANK SET

GRP	ELEMENT	WEIGHT	
	SUMMARY	(lb)	
2.0	Structures	597	
3.0	Propellant Tanks	1322	
4.0	Propulsion	1034	
5.0	Main Engines	56	
6.0	Reaction Control System	130	
7.0	Guidance Navigation Control	54	
8.0	Communication and Data Handling	100	
9.0	Electrical Power	35	
10.0	Thermal Control	202	
	DRY WEIGHT	3530	
12.0	Propellants		
	Non Propulsive		61400
	Fuel – LH2	8700	
	Oxygen – LO2	52700	
	Propulsive		
	MMH/N2O2		3160
	INERT WEIGHT		68090

PROPELLANT SCAVENGING VEHICLE
OPTION 2A
SELF-PROPELLED TANK SET

GRP	ELEMENT	WEIGHT		
2.0	STRUCTURE			597
2.1	Airframe		411	
	Forward Support Frame	41		
	Center Ring Frame	29		
	LH2 Tank Center Support	85		
	LH2 Tank End Support	136		
	LO2 Tank Struts	22		
	LH2 Tank Struts	14		
	Attach Hardware	30		
	Contingency	54		
2.2	Thrust Structure		28	
	Engine Truss	25		
	Contingency	3		
2.3	Equipment Mounts		77	
	REMS	10		
	Avionics	18		
	Electrical	6		
	Vent System	3		
	Pressurization System	15		
	Propellant Plumbing and Valves	18		
	Contingency	7		
2.4	Handling and Storage		81	
	RMS Grapple Fitting	28		
	OMV Latches	20		
	PSV Spring Latch	25		
	Contingency	7		

PROPELLANT SCAVENGING VEHICLE

OPTION 2A

SELF-PROPELLED TANK SET

GRP	ELEMENT	WEIGHT		
3.0	PROPELLANT TANKS			1322
3.1	Tank Structure			1143
3.1.1	Non-Propulsion Tanks		822	
	LO2 (1)	291		
	LH2 (2)	456		
	Contingency	75		
3.1.2	Propulsion Tanks		321	
	N2O2 (2)	146		
	MMH (2)	146		
	Contingency	29		
3.2	Tank Mounts			179
3.2.1	Non-Propulsion Tank		91	
	LO2 Tank Mounts	24		
	LH2 Tank Mounts	52		
	LH2 Tank Trunnions	7		
	Contingency	8		
3.2.2	Propulsion Tank		88	
	N2O2 Mounts	40		
	MMH Mounts	40		
	Contingency	8		

PROPELLANT SCAVENGING VEHICLE
OPTION 2A
SELF-PROPELLED TANK SET

GRP	ELEMENT	WEIGHT		
4.0	PROPULSION			1034
4.1	Pressurant and Pneumatic Systems			167
	Valves (20)	26		
	Regulators	9		
	Lines and Attachments	20		
	Helium Spheres	90		
	Contingency	22		
4.2	Feed Vent & Drain Fuel			241
4.2.1	Non Propulsion - Fuel		189	
	Valves	64		
	Lines, Bellows, Disconnects	100		
	Contingency	25		
4.2.2	Propulsion - Fuel		52	
	Valves and Plumbing	47		
	Contingency	5		
4.3	Feed, Vent & Drain Ox			117
4.3.1	Non Propulsion - Ox		73	
	Valves	32		
	Lines, Bellows, Disconnects	31		
	Contingency	10		
4.3.2	Propulsion - Ox		44	
	Valves and Plumbing	40		
	Contingency	4		
4.4	Prop Utilization & Management System			343
	Channels	150		
	Screens	10		
	Perforated Plates	28		
	Standpipes and Nozzles	60		
	Attach Hardware	50		
	Contingency	45		

PROPELLANT SCAVENGING VEHICLE

OPTION 2A

SELF-PROPELLED TANK SET

GRP	ELEMENT	WEIGHT		
4.5	Vent System (Nonpropulsive)			97
	Valves	24		
	Lines, Vent I/F and Attach Hardware	60		
	Contingency	13		
4.6	Umbilicals			69
	Umbilicals	60		
	Contingency	9		
5.0	MAIN ENGINES			56
5.1	Engines		31	
	R-40B Engines (2)	28		
	Contingency	3		
5.2	Gimbal System		25	
	Electrical Gimbal System	22		
	Contingency	3		
6.0	REACTION CONTROL SYSTEM			130
6.1	Thruster		88	
	R-1E Engines (16)	80		
	Contingency	8		
6.3	Plumbing		42	
	Plumbing and Valves	38		
	Contingency	4		
7.0	GUIDANCE, NAVIGATION AND CONTROL			54
7.1	Guidance and Control		54	
	Inertial Reference Unit	37		
	Reaction Control Driver	12		
	Contingency	5		

PROPELLANT SCAVENGING VEHICLE

OPTION 2A

SELF-PROPELLED TANK SET

GRP	ELEMENT	WEIGHT		
8.0	COMMUNICATION AND DATA HANDLING			100
8.1	Communication		72	
	Signal Conditioner	14		
	Transponder	25		
	Power Amplifier	6		
	Antennas/Switches (2)	10		
	Instrumentation	10		
	Contingency	7		
8.2	Data Handling		28	
	Computer	25		
	Contingency	3		
9.0	ELECTRICAL POWER			35
9.5	Power Distribution		35	
	Batteries	20		
	Wiring	10		
	Contingency	5		
10.0	THERMAL CONTROL			202
10.1	Insulation		179	
	LH2 - MLI	33		
	LH2 - SLA	96		
	LO2 - MLI	27		
	Contingency	23		
10.2	Thermal Control		23	
	Propulsion Lines	9		
	Electrical System	5		
	Instrumentation	7		
	Contingency	2		

PROPELLANT SCAVENGING VEHICLE

OPTION 2A

SELF-PROPELLED TANK SET

GRP	ELEMENT		WEIGHT			
15.0	PROPELLANTS					64560
15.1	Propellants				64560	
15.1.1	Non Propulsive			61400		
	LH2		8700			
	LO2		52700			
15.1.2	Propulsive			3160		
	N2O2	1580.2	3160			
	MMH					