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Volume III

System And Program Trades

Orbital Transfer Vehicle Concept Definition And System Analysis Study 1985

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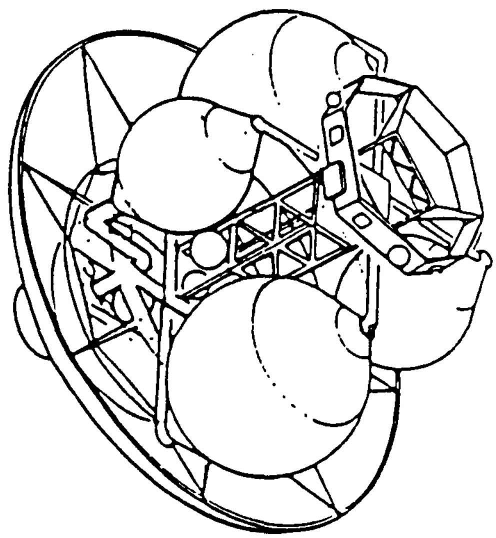

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ORBITAL TRANSFER VEHICLE
CONCEPT DEFINITION AND SYSTEM ANALYSIS STUDY

VOLUME III
SYSTEM AND PROGRAM TRADES

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FOREWORD

This final report, Volume III-System and Program Trades, was prepared by Martin Marietta Denver Aerospace for NASA/MSFC in accordance with contract NAS8-36108. The study was conducted under the direction of NASA OTV Study Manager, Mr. Donald R. Saxton, during the period from July 1984 to October 1985. This final report is one of nine documents arranged as follows:

Volume I	Executive Summary	
Volume II	OTV Concept Definition and Evaluation	
	Book 1	Mission and System Requirements
	Book 2	OTV Concept Definition
	Book 3	Subsystem Trade Studies
	Book 4	Operations
Volume III	System and Program Trades	
Volume IV	Space Station Accommodations	
Volume V	Work Breakdown Structure and Dictionary	
Volume VI	Cost Estimates	
Volume VII	Integrated Technology Development Plan	
Volume VIII	Environmental Analyses	
Volume IX	Study Extension Results	

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ACRONYMS AND ABBREVIATIONS

ACC	Aft Cargo Carrier
Adv	advanced
Ave.	average
CB	STS cargo bay
cmd	command
cond	condition
cryo	cryogenic
DDT&E	design, development, test and engineering
del	delivery
DRM	Design Reference Mission (?)
ET	External Tank
EVA	extravehicular activity
EXU	expendable non-man-rated vehicle
flt	flight
FMEA	Failure Modes Effects Analysis
Fo	fail ops
FR	failure rate
Fs	fail safe
g	gravity
GB	ground based
GBM	55 klb GB man-rated vehicle
GBU	45 klb GB non-man-rated vehicle
GEO	geosynchronous Earth orbit
GPS	Global Positioning System
GVTA	Ground Vibration Test Article
hr	hour
Hx	heat exchanger
Hdlr	Handler
IMU	inertial measurement unit
IOC	Initial Operational Capability
Isp	initial specific impulse
IVA	intravehicular activity
K	thousand
$K	thousands of dollars
klb	thousands of pounds

ACRONYMS AND ABBREVIATIONS

lb	pound
LCC	life cycle cost
LEO	low Earth orbit
LH2	liquid hydrogen
LO2	liquid oxygen
M	million
$M	millions of dollars
mlb	millions of pounds
MECO	main engine cutoff
MODS	modifications
MPTA	Main Propulsion Test Article
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NM	nautical mile
OMV	Orbital Maneuvering Vehicle
OPS	operations
ORB	Orbiter
OTV	Orbital Transfer Vehicle
P/L	payload
PM	program management
pmp	pump
Prod.	Production
PRP	propellant
PV	present value
pwr	power
QD	quick disconnect
Reg	regulator
RF	radio frequency
RFP	Request for Proposal
ROI	return on investment
R&T	research and technology
SB	space based
SBM	55 klb SB man-rated vehicle
SBU	55 klb SB non-man-rated vehicle
SDV	Shuttle Derived Vehicle

S&EI	Systems Engineering and Integration
SS	Space Station
STA	Static Test Article
STAS	Space Transportation Architecture System
STS	Space Transportation System
TBD	to be determined
TLM	telemetry
TVC	thrust vector control

1.0 INTRODUCTION

This volume documents the key system and program trade studies performed during the initial contract period (through 15 October 1985) to arrive at a preferred Orbital Transfer Vehicle (OTV) system concept and evolutionary approach to the acquisition of the requisite capabilities. These efforts were expanded to encompass a Space Transportation Architecture Study (STAS) mission model and recommended unmanned cargo vehicle in a study extension reported on in Volume IX. The basis for these initial trade studies and comparisons is the system requirements identified as part of contract SOW Task 1 and the concept synthesis and trade studies performed under contract SOW Tasks 2 and 3.

The most important factors affecting the results presented in this volume are the mission model requirements and selection criteria. The reason for conducting the OTV concept definition and system analyses study is to select a concept and acquisition approach that meets a delivery requirement reflected by the mission model. There are two potential justifications for an OTV: to compete with existing expendable upper stages, and to provide a heavy lift and man-rated capability that does not now exist. The latter reason does not support an early start of OTV development. The heavy lift requirement identified in the Revision 8 Low Mission Model (20 klb to geosynchronous Earth orbit [GEO]) falls in 1999 and the man-rated payload occurs in 2008. The one compelling reason for considering a near time OTV capability is to improve the economics of space transportation and make the NASA Space Transportation System competitive with existing and emerging foreign and commercial delivery systems. As a consequence, our system and program selection criteria has been structured to reflect economic factors such as front end cost, return on investment, and economics of the system after it is in place as well as considerations of risk and flexibility.

Figure 1.0-1 summarizes the sequence of program development followed in this study. Our pre-contract IR&D studies had developed a reference ground based Aft Cargo Carrier (ACC) configuration. By the March 1985 mid-term review, high potential cryogenic and storable concepts had been identified, and subsystem trades had selected the preferred subsystem configurations. At this time, the mission model underwent a significant change. Our concepts and subsystem decisions were reassessed and changes were incorporated. We then proceeded to identify and trade alternative acquisition strategies. The net outputs of this phase of the study were configurations capable of meeting the mission delivery requirements of the Revision 8 Low Mission Model in the most desirable way, and the program that should be pursued in this development. Only study recommendations that could be justified on the basis of the low model were made at the request of MSFC. The selection procedure is further described in the following paragraphs.

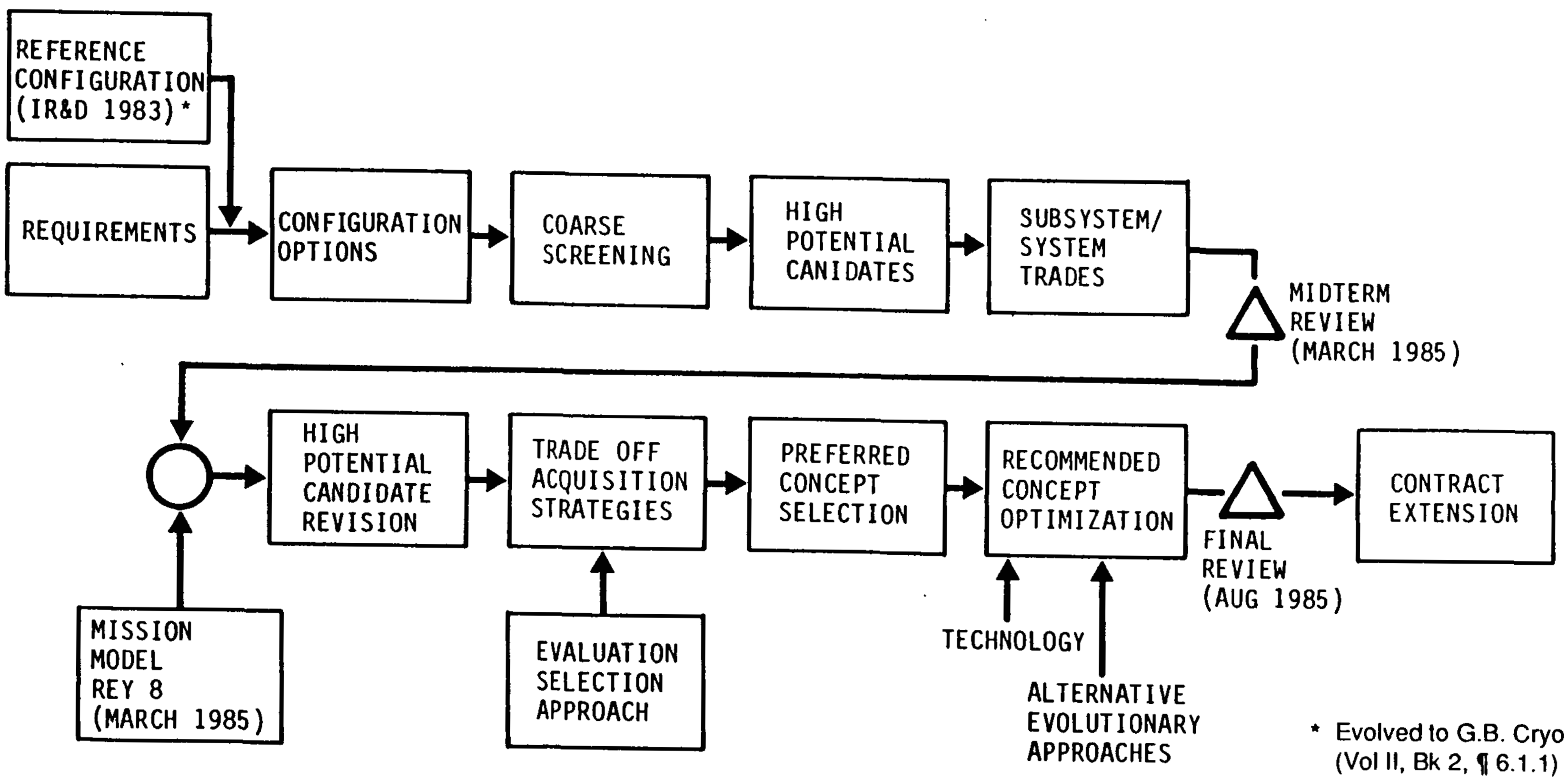

FIGURE 1.0-1 PROGRAM DEVELOPMENT SEQUENCE

1.1 Decision Summary

There are three basic viable approaches to providing orbital transfer for the high altitude missions to be conducted in the coming decades: Growth of existing cryogenic expendable vehicle; Development of a new storable, reusable, pump fed OTV; Or development of a new, reusable cryogenic OTV. The decision network in Figure 1.1-1 summarizes the evolutionary paths these approaches could follow and identifies the trade studies conducted at points along the path. We carried a program reflecting growth of the current expendable ground based vehicle fleet through the entire mission model to establish a cost comparison reflecting as little change as possible to the current way of providing space transportation. We laid out programs that reflected development of both storable and cryogenic reusable OTVs that evolved from ground based to space based operation. These propellant options were developed through the point where space basing impacts were understood before a selection was made between them. Engine selection, delivery mode for ground based vehicles (ACC vs Cargo bay), and the merit of man-rating the ground based vehicle were considered. Space base accommodations were compared, as was the preferred time for introducing man-rating in a space based vehicle. At this point, all the data required to make the propellant selection was available, and this selection was made. Final program comparisons were made to select the OTV program best able to provide the capability required by the Revision 8 OTV Low Mission Model.

Trade studies were conducted to implement the decision tree shown in Figure 1.1-1. This sequence of trades identified preferred alternatives for key program elements and served as a basis for selecting a preferred overall OTV evolutionary strategy for transitioning from an initial ground based OTV configuration to a man-rated configuration for space based operations with the availability of the Space Station in 1999.

The trade studies shown in this report include:

Section 2.1	Aeroassist vs All-Propulsive Retrieval
Section 2.2	IOC Cryogenic Engine Selection
Section 2.3	Evolutionary Path to Man-Rating and Cost Effective Reliability Requirements
Section 2.4	Space Based Propellant Acquisition
Section 2.5	Space Based Tank Farm Selection
Section 2.6	Cryogenic Versus Storable Upper Stages
Section 2.7.2	ACC OTV Delivery/Scavenging Versus STS Cargo Bay OTV Delivery/Scavenging
Section 2.7.3	Overall OTV Program Evolutionary Strategy

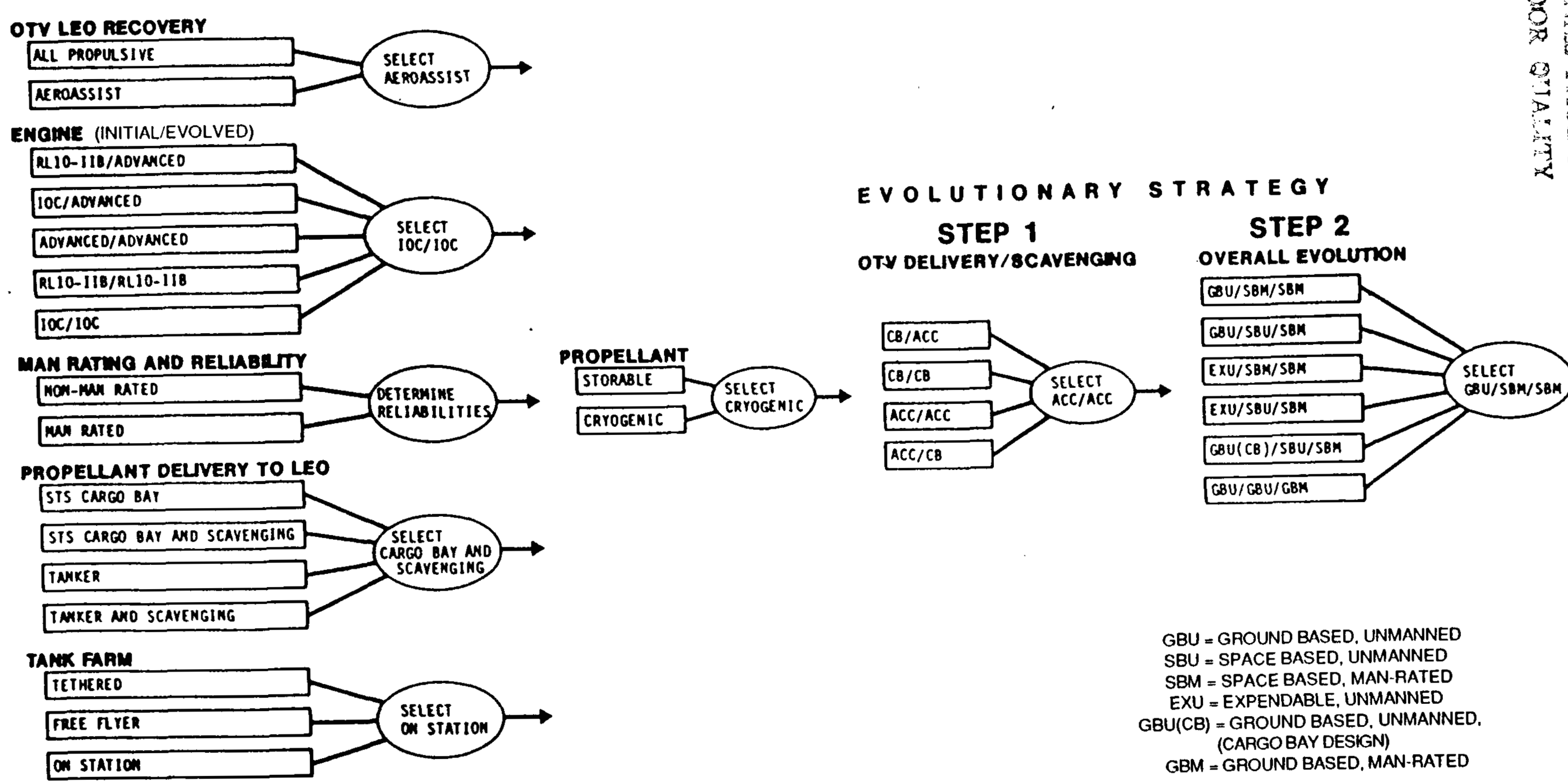

FIGURE 1.1-1 DECISION NETWORK

1.2 Mission Model

This study was initiated with the objective of meeting the mission requirements delineated in Revision 7 of the MSFC OTV Mission Model. The major characteristics of this model are summarized in Table 1.2-1. At the midterm review, a new Revision 8 mission model, Table 1.2-2, was issued for use through the remainder of the basic study. The study contractors were instructed to make recommendations that were justifiable based on the Revision 8 Low Mission Model.

The constituency of the Revision 8 model is essentially the same as Revision 7 except for the elimination of the 14 klb/14 klb manned GEO mission. This mission was a driver for OTV but is now replaced with a more modest manned mission payload of 7.5 klb/7.5 klb. The elimination of the manned lunar mission from the low model is not significant in discounted economic terms but does impact the sizing of OTV stages.

The major revision impact is the reduction in projected annual and total traffic for OTV. Revision 7 reflected an average of 27 flights per year on the nominal model while the Revision 8 Low Mission Model has only 9. This impacts the expected economic benefits that can be accrued and, therefore, the amount of return on investment.

Even with these changes, the effective average OTV delivery requirement changed very little. The Revision 7 Nominal Mission Model had an average propellant requirement of 43 klb and the Revision 8 Low Mission Model has an average propellant requirement of 42.7 klb. This close relationship reflects the fact that multiple delivery and DOD payloads dominate both models.

TABLE 1.2-1 REVISION 7 MISSION MODEL COMPOSITION

PAYLOAD NO. SERIES	MISSION GROUP	WEIGHT (LB) UP/DOWN	LENGHT (FT)	MISSION MODEL LOW	MISSION MODEL NOM	IOC
13000	EXPERIMENTAL GEO PLATFORM	12000/0	30	1	1	1990/1994
13000	OPERATIONAL GEO PLATFORM	20000/0	35	11	18	2000/1996
13000	UNMANNED GEO PLAT. SERVICING	7000/4500	9	8	16	2000/1995
15000	MANNED GEO SORTIE	6500/6500 OR 14000/14000	15 OR 23	8	9	2003/1997
15000	GEO STATION ELEMENTS	13000–20000/0	15 – 20	2	3	2001/2002
15000	UNMANNED GEO STA. LOGISTICS	10000/2700	15	19	0	2000/ –
15000	MANNED GEO STA. LOGISTICS	16500/9000	27.6	0	34	2012/2002
17000	PLANETARY	2000–31000/0	< 25	12	21	1998/1994
17000	UNMANNED LUNAR	5000–20000/0	20	3	3	2001/2001
17000	MANNED LUNAR SORTIE	80,000/15,000	60	3	3	2007/2006
17000	LUNAR BASE ELEMENTS	80,000/0	53	3	3	2009/2008
17000	LUNAR BASE SORTIE/LOGISTICS	80,000/10,000	60	2	6	2010/2009
18000	MULTIPLE GEO PAYLOAD DELIVERY	9000–15300/2000	22–42	31	51	1998/1994
18000	LARGE GEO SATELLITE DELIVERY	10000–20000/0	20–36	27	36	1998/1994
18000	UNMANNED GEO SAT. SERVICING	7000/4500	9	0	86	2002/1999
19000	DOD			137	137	1993/1993
			SUBTOTALS	267	426	
10100	REFLIGHTS			16	26	1994/1994
			TOTALS	283	452	

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TABLE 1.2-2 REVISION 8 MISSION MODEL COMPOSITION

PAYLOAD NO. SERIES	MISSION GROUP	WEIGHT (LB) UP/DOWN	LENGTH (FT)	MISSION MODEL		IOC
				LOW	NOM	
13000	EXPERIMENTAL GEO PLATFORM	12000/0	30	1	1	2000/1996
13000	OPERATIONAL GEO PLATFORM	20000/0	35	5	6	2004/1998
13000	UNMANNED GEO PLAT. SERVICING	7000/4500	8	1	1	2001/1996
15000	MANNED GEO SORTIE	7500/7500	10	3	17	2008/2002
15000	GEO SERVICE STATION ELEMENTS	13000/0	15 – 20	2	2	2002/1998
15000	GEO SERVICE STA. LOGISTICS	12000/2000	15	5	26	2004/1998
17000	PLANETARY	2000–40000/0	5–35	6	14	1994/1994
17000	UNMANNED LUNAR	5000–20000/0	20	2	2	2007/2001
17000	MANNED LUNAR SORTIE	80,000/15,000	50	0	3	2015/2008
17000	LUNAR BASE ELEMENTS	80,000/0	53	0	3	2020/2008
17000	LUNAR BASE SORTIE/LOGISTICS	80,000/10,000	60	0	8	2021/2009
18000	MULTIPLE GEO PAYLOAD DELIVERY	12000/2000	25	46	79	1994/1994
18000	LARGE GEO SATELLITE DELIVERY	20000/0	20–35	3	7	2001/1997
19000	DOD (GENERIC)	12000–20000 (EQUIV.)		68	85	1994/1994
			SUBTOTALS	142	262	
10100	REFLIGHTS			3	5	1998/1997
			TOTALS	145	267	

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Table 1.2-3 shows the design reference missions from the nominal Revision 8 model. The one difference from the low model, aside from the change in operational dates, is the 80 klb/15 klb manned lunar mission. We used the low model in our trade studies for selection of configuration and evolutionary strategy and then noted the design and programmatic implications of going to the nominal model.

TABLE 1.2-3 DESIGN REFERENCE MISSION, REVISION 8 NOMINAL MODEL

MISSION TYPE	MISSION NUMBER	FIRST FLIGHT DATE	
Multiple Payload 12000/2000	18912	1994	GB OTV Performance Driver
Unmanned GEO Missions 7000/4510	13002	1996	First Long Duration Mission - 10 Days Rendezvous to Perform Servicing
GEO Delivery 20000/0	18040	1997	Performance Driver
Manned GEO Sortie 7500/7500	15700	2002	Mission Duration - 18 Days
GEO Platform 20000/0	13700	1998	Low g Requirement
Manned Lunar Sortie 80000/15000	17203	2006	Multiple Configuration Requirement

Tables 1.2-4 and 1.2-5 compare the design reference missions derived from the low Revision 7 and Revision 8 models.

The multiple payload mission stayed approximately the same. The MOLNIYA (and GPS missions) were not individually specified and the low g mission was added. The mission duration of 18 days was added although this was also a reliability driver under Revision 7.

TABLE 1.2-4 DESIGN REFERENCE MISSION, REVISIOM 7 LOW MISSION MODEL

MISSION TYPE	SELECTED DRM MISSION MODEL NUMBER	FIRST FLIGHT DATE	
Multiple Payload Delivery 12876 Up 2166 Down	Remanifested 18903	1993	Performance Driver for ground-based OTV
Molniya and GPS Missions	Unique Delivery Missions	1993	Mission Operation Difficulty for Space-Based Operation
Unmanned Service 7K Up 4.51K Down	13002	1995	First Rendezvous and Docking Autonomous Rendezvous and Docking Drives Flight Operations and Equipment Complexity
GEO Delivery 20K Up 0 Down	13003	1996	Earliest Required Mission Most Frequent Mission

TABLE 1.2-5 DESIGN REFERENCE MISSION, REVISION 8 LOW MISSION MODEL

MISSION TYPE	MISSION NUMBER	FIRST FLIGHT DATE	
Multiple Payload 12000/2000	18912	1994	GB OTV Performance Driver
Unmanned GEO Missions 7000/4510	13002	2001	First Long Duration Mission - 10 Days Rendezvous to Perform Servicing
GEO Delivery 20000/0	18040	2001	Performance Driver
Manned GEO Sortie 7500/7500	15700	2008	Mission Duration - 18 Days
GEO Platform 20000/0	13700	2004	Low g Requirement

1.3 Selection Criteria

The selection criteria to be used in differentiating among alternative OTV system and program options depends on the environment in which the system operates. A competitive environment, one where capital for investment is scarce, influences how the decision is made for a new venture. The OTV is in a competitive environment and is being considered for development on the basis of the attractiveness of reducing the cost of payload delivery. The effectiveness of OTV in reducing the recurring cost of payload delivery must be balanced against acquisition cost in terms of several economy factors. If its advantage is significant, it makes the STS and OTV more attractive to users.

Non-economic factors are also important. The mission model is a projection of the expected OTV marketplace and should not be viewed as a fixed or absolute opportunity. The potential growth and flexibility of each option is important, i.e., the ability to adjust to possible requirement changes or to be used for future missions. It provides a measure of the capability to evolve or grow to satisfy changes in the market. Also, the risks attendant with candidate OTV options and acquisition strategies are important because they reflect the possibility of increased cost. Key external risk factors to be assessed are those that cannot be mitigated or controlled by the OTV design.

Cost data projected for OTV systems development is compared against the cost of competitive systems which exist or possess proven technology. The economic advantage of the OTV system over its competition must be present to provide a measure of its viability.

In the trade studies, the cost data in 1985 constant and discounted dollars is provided and the economic factors are derived and presented. Economic decisions are made using Present Value (PV) dollars. Present value is a time projection of the value of money when inflation and the discounted value of the dollar are taken into account. In accordance with the ground rules, the PV used in the studies incorporates a zero percent inflation rate and a ten percent discount rate.

Several economic factors are used to help determine the best alternative. Depending on the nature of the study, different economic factors may be selected for the analysis. Three principal economic factors used for all studies, except the Man Rating and Reliability Trade Study, are Design Development Test and Engineering (DDT&E), Benefit, and Return on Investment (ROI). The nature of the Man Rating and Reliability study is different in that reliability values are determined for use on all OTVs rather than making a selection among a number of proposed alternatives.

The economic factors used in the trade studies are described below. These factors are used individually and in combination with one another to help provide an indication of the best alternative. As can be seen, some of the factors are nested in others. For example, DDT&E is used as a subfactor in the ROI analysis. It should also be noted that any single factor may not be sufficient to reach a valid conclusion by itself. For instance, the ROI may identify an alternative as the best buy, but the DDT&E cost of the alternative may not be affordable in view of available budget.

Once the economic factors of the alternatives have been determined, a score is provided. The preferred alternative for each economic factor is given a score of 10 and the other alternatives are given a score relative to the alternative marked with a 10.

An explanation of the economic factors used in this report is shown below:

a. Design, development, test and evaluation (DDT&E). DDT&E is a representation of the investment cost to develop a product.

b. Benefit. Benefit determines the value or profit of an alternative vis-a-vis the competition (which is generally not taking any action at all), it is determined by finding the difference between the cost of the competition doing the task and the cost of a particular alternative doing the task. For example, the benefit of a particular OTV alternative would be represented by finding the difference between the cost per flight of competing (Cpf_c) systems and this cost per flight of the OTV (Cpf_o). The total benefit would be represented by multiplying this difference by the number of flights (N_c and N_o) projected in the mission model.

$$\text{Benefit} = CPF_c * N_c - CPF_o * N_o$$

c. Return on Investments (ROI). ROI is a measure of the best buy. It is determined by dividing benefit (described in b above) by DDT&E to produce a best profit to cost ratio. To normalize the equation, one is subtracted from the result. If the ratio is negative, the option is not a viable economic venture. If the ratio is zero, the venture retrieves the investment but is not profitable. A positive ratio indicates the venture is profitable, i.e., worthwhile vis-a-vis not undertaking the venture and relying on existing capabilities.

The algorithm for ROI is:

$$\text{ROI} = \frac{CPF_c * N_c - CPF_o * N_o}{\text{DDT\&E}} - 1$$

All costs used for the benefit and ROI equations are 1985 discounted dollars.

d. Life Cycle Cost (LCC). LCC is a representation of total costs over the life of a system. Martin Marietta uses a LCC computer model developed with company funding. The model calculates all phases of cost based on the technical description of the OTV, the operational scenarios, and the requirements of any supporting program, e.g., Space Station, Aft Cargo Carrier.

Typical inputs to the LCC model include the following:

- OTV stage weight for the subsystem component level;
- Test hardware requirements;
- Annual mission and propellant requirements;
- Operational turnaround times;
- Intravehicular activity (IVA) and extravehicular activity (EVA) requirements;

- o Key implementation schedule dates;
- o Supporting program data; and
- o Specific payload transportation requirements.

e. Cost per flight, competition (Cpf_c). Cpf_c represents the per flight operations cost of the competing system(s).

f. Cost per flight, option (Cpf_o). Cpf_o represents the per flight operations cost of the option under consideration, i.e., OTV or program option.

g. Payback. Payback represents the amount of projected economic advantage realized after the implementation of the system. It provides a measure of how quickly the investment is captured in revenues. It is typically plotted along with the investment cost (DDT&E) to determine the cross over point where the advantage of going to the new system is first realized. Several alternative systems may be plotted together for the purpose of comparison.

h. Growth and flexibility. Growth and flexibility is the ability to adjust to possible requirements changes or to continued use for future missions.

i. Risk. Risk is an assessment of what cost related factors might go wrong in the future if an alternative is selected. It considers both the probability and the potential seriousness of something going wrong.

j. Uniform vs Discrete Discount Methodologies. Within these trade studies, two different ways of determining discounted costs were employed. The first method involves spreading the costs year by year (using 1985 dollars as the base year). Mathematically this is represented as follows. Let

Ci = Costs incurred in Year i
Pi = Discount factor for Year i
Di - Discounted costs for year i, then

Di = Pi * Ci, and
D = Sum (Pi * Ci) for all i

For the case of uniform funding distributions:

Ci = Ci-1 for all i where i-1 does not equal 0, and
C = Ci for all i
D = C * Sum (Pi), thus
P = Sum (Pi) can be expressed as a constant factor.

2.0 TRADE STUDIES

2.1 All-Propulsive Versus Aeroassist Trade Study.

The purpose of this trade study is to evaluate the economic factors of recovering the OTV at low Earth orbit (LEO) from high altitude missions using the all-propulsive and aeroassist recovery concepts and to identify which of the two concepts provides the best economic solution.

Earlier Phase A studies conducted from 1979-1981 by Boeing and General Dynamics show the viability of returning upper stage vehicles and their payloads from high orbit to LEO. These studies were based mainly on the all-propulsive concepts. Current concepts using an aeroassist device to take out the delta velocity of an OTV or OTV-and-payload upon return to LEO have been examined. An analysis produced for our first quarter report showed the potential advantage the aeroassist recovery concept holds over the all-propulsive concept. This analysis is summarized in Figure 2.1-1. The curves on the figure show the percentage of propellant the aeroassist concept can save over the all-propulsive concept as a function of the aerobrake weight/recovery weight- rated. In a 20K delivery mission, an aerobrake weight/recovery weight ratio of 0.22 is realized, i.e., brake wt. 1885 / (return stage wt. 8404 + prop. wt 200) = 0.22. For a 14K roundtrip mission, a ratio of 0.08 is realized, i.e., brake wt 1885 / (return stage wt. 8880 + prop wt 250 + PL wt 14,000) = 0.08. As can be seen on Figure 2.1-1, extension of these aerobrake weight/recovery weight ratios show a 14 and 45 percent aeroassist propellant savings over the all-propulsive concept for the 20K delivery and 14K roundtrip missions, respectively.

2.1.1 Approach

Costing of the all-propulsive and aeroassist concepts is made based upon OTV mission traffice identified in the Revision 7 Nominal Mission Model. An analysis is made for both ground and space based modes of operation to determine if OTV design concepts are capable of accomplishing the missions as well as identifying the economic viability of the concepts. Cost figures are compared against the competition which is represented by a Centaur upper stage vehicle. The Centaur is chosen as the currently available vehicle most capable of accomplishing missions contained in the mission model.

Derived cost figures for the all-propulsive and aeroassist concepts and the competition are run through an economic analysis to help determine the advantages one concept holds over the other.

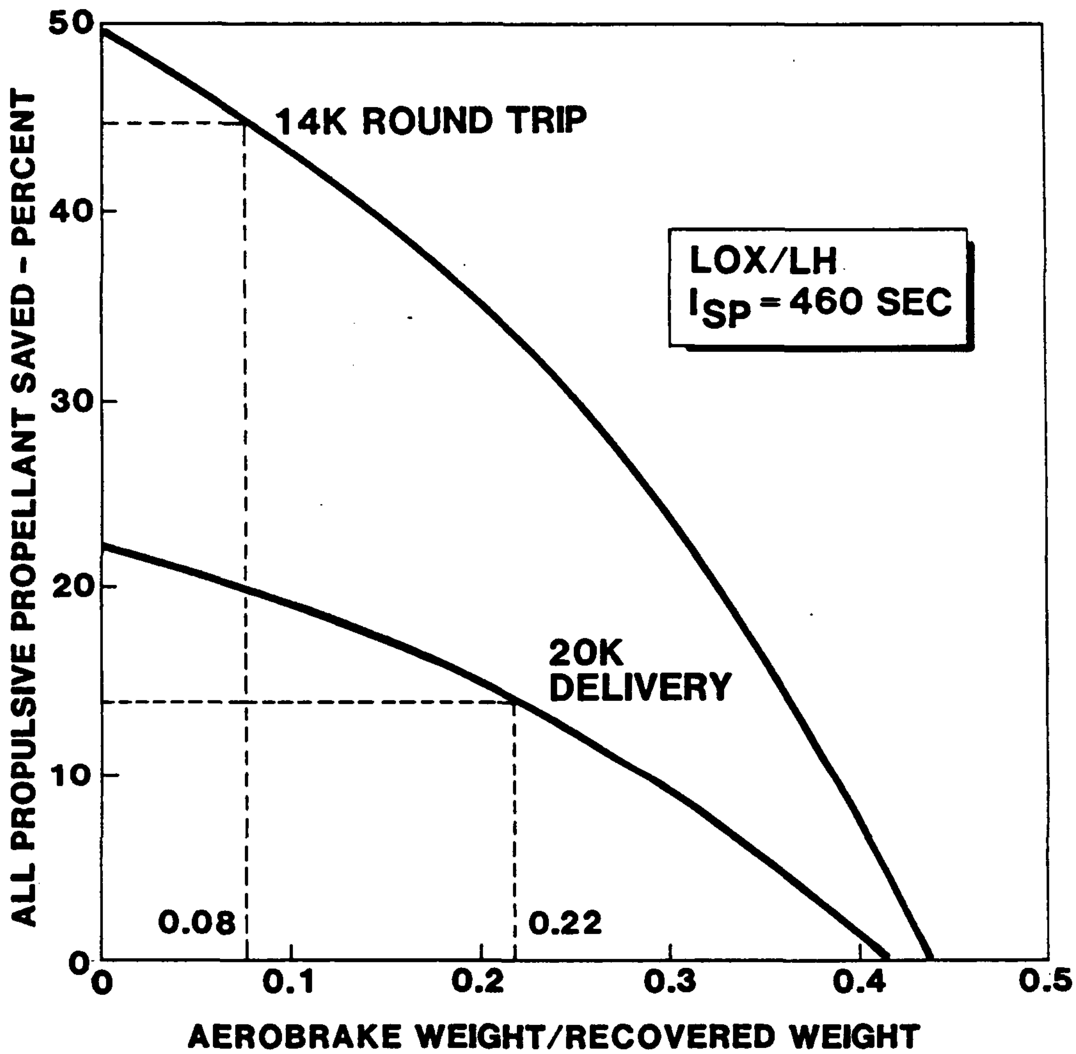


FIGURE 2.1-1 ALL-PROPULSIVE VS AEROASSIST ANALYSIS

2.1.2 Ground Rules and Assumptions

Ground Rules and assumptions used for the study are shown below.

O The following ground rules are constant for both options

- o Constant fiscal year 1985 dollars excluding fee & contingency
- o Space based cryogenic configurations: IOC is 1994
- o No evolution over the 17 year operations period
- o Ground test hardware includes Ground Vibration Test Article (GVTA), Static Test Article (STA), Main Propulsion Test Article (MPTA), and Functional Test Article (FTA)
- o Space station requirements are assumed similar for both concepts. Therefore, cost impacts are not included
- o Initial OTV production requirements: 2 units
- o Flight test article and GVTA refurbished for operational stages
- o 2 OMV uses per mission
- o Ground mission operations at 35 man-yrs/yr
- o IVA & mission Ops costs: $16,000/hr; EVA cost: $48,000/hr
- o IVA/mission = 80 hrs; EVA/mission = 4 hrs
- o 2 STS deliveries per OTV: 0.2 STS deliveries per engine set

O Reference all-propulsive

- o 29.2 mlb of propellant for 389 missions
- o 4 hrs/mission for space based mission operations
- o 20 equivalent operations spares (excluding engines)
- o Engine life = 15 missions (460K isp Pratt & Whitney)

O Reference aeroassisted OTV

- o 19.9 mlb of propellant for 389 missions
- o 6 hrs/mission for space based mission operations
- o 20 equivalent operations spares (w/o engine or aerobrake)
- o Engine life = 20 missions (460K isp Pratt & Whitney)
- o Aerobrake life = 5 flights
- o 0.33 STS deliveries per aerobrake

2.1.3 Alternatives

Two basic alternatives are evaluated in this study: the all-propulsive concept and the aeroassist concept. The all-propulsive concept employs the upper stage engine to slow the OTV or OTV and payload for LEO. The vehicle evaluated for the all-propulsive alternative uses a liquid oxygen/liquid hydrogen engine with an Isp of 460 seconds.

The aeroassisted alternative uses a device to perform an aeroassist maneuver to slow the OTV (or OTV and return payload) for low Earth orbit. The aeroassist maneuver uses the earth's atmosphere to reduce the vehicle's velocity, thereby reducing the rocket burn required to enter low earth orbit when returning from GEO or other high orbits. This aeromaneuver is accomplished by grazing the upper atmosphere and converting the vehicle's kinetic energy to heat. To correct for density variations and navigational uncertainties during the aeropass, precise aerodynamic control is required. We have evaluated a vehicle that uses vehicle lift for control. This vehicle uses the deployable conical fabric lifting brake. (Reference: Subsystem Trade Studies, Volume II, Book 3, Section 2.2).

2.1.4 Cost of Alternatives

An evaluation of the all-propulsive concept in both the ground based and space based modes was made. The all-propulsive ground base mode is not feasible when flown against Revision 8 of the MSFC Low Mission Model. This was shown by running a 12 klb GEO delivery payload through a flight simulation model. This simulation uses an OTV with a 55 klb propellant capacity and with no aerobrake. The following results were produced:

- o Propellant required: 59,037 lb (ergo exceeds the OTV 55 klb tank capacity)

- o Weight of OTV, propellant, and payload: 77,472 lb (ergo exceeds the STS 72 klb payload capacity)

This analysis alone does not eliminate the all-propulsive alternative. As an evolutionary option, expendable upper stage vehicles could be used during the ground based mode of the mission model. The all-propulsive operation could be begun during the space based mode of the mission model. However, this approach is at more of a disadvantage relative to aeroassist than is the case in the space based operational mode. Due to the greater propellant requirements of certain payloads, an all-propulsive GBOTV would require separate STS manifesting of payload and stage/propellants, thus incurring transportation costs well beyond the single STS requirement of an aeroassist concept. For this reason, we elected to complete the all-propulsive versus aeroassist trade in the space based mode. If aeroassist wins in this mode, it will also be a winner in the ground based mode.

Life cycle costs for DDT&E, production and operations are shown on Table 2.1-1. AFE costs are included in DDT&E. Note the principal delta under operations cost is propellant. Additionally, different stage sizes caused higher airframe refurbishment and IVA costs for the all-propulsive candidate.

The cost per flight for each alternative and the competition is shown in Table 2.1-2. The cost per flight for the all-propulsive and aeroassist concepts are derived by dividing the operations cost by the number of missions flown and adding the cost for delivering the payload to LEO. Payload delivery is included to make OTV costs comparable with the competition.

The Centaur, which is used to represent the competition, represents the vehicle which could best be upgraded to accommodate the mission model requirements. The cost per flight of this vehicle is figured at $123M based on the following:

- o Centaur unit cost $50M

- o STS delivery to LEO 73M

TABLE 2.1-1 ALL-PROPULSIVE VS AEROASSIST LCC (CONSTANT $)

	ALL PROP.	AEROASSIST	DELTA (Savings)
DDT&E	$1245.60M	$1316.50M	-$70.80M
Stage	891.30	949.60	-58.30
Systems	354.40	366.90	-12.30
Production	58.10	61.50	-3.40
Operations	20086.60	16574.60	3512.00
Miss Ops. SB	211.60	317.60	-106.00
Miss Ops. GB	35.90	35.90	
Launch Ops. SB	235.70	235.70	
Launch Ops. GB	3151.00	3973.00	-822.00
Program Support	381.90	453.00	-71.30
Propellant	14617.50	9937.00	4680.50
Stage Ops			
Airframe Refurbish	880.30	818.70	61.60
IVA/EVA Air Frame (AF)	572.60	491.70	80.90
Brake Refurbish		230.90	-230.90
IVA/EVA (Brake)		80.90	-80.90
Total LCC	$21390.40M	$17952.60M	$3437.80M

TABLE 2.1-2 COST PER FLIGHT

Alternative	Cost Per Flight (Constant $)	Cost Per Flight (Discounted $)
All-propulsive	$97M	$15.8M
Aeroassist	$86M	$14.4M
Competition	$123M	$22.7M

If the two OTV concepts prove to be cost effective over the existing Centaur configuration, they certainly will be cost effective over a more expensive upgraded Centaur configuration required for some of the missions in the OTV mission model.

A benefit analysis is shown in present value in Table 2.1-3. The value shown for this analysis represents the cost advantage, or benefit, the alternative concepts hold over the competition.

TABLE 2.1-3 BENEFIT ANALYSIS (PV)

Alternative	Cost Per Flight Competition (Discounted $)		Cost Per Flight Option (Discounted $)		No Flights		Benefit (Disc.$)
All-propulsive	(22.7M	-	15.8M)	x	389	=	2684
Aeroassist	(22.7M	-	14.0M)	x	389	=	3384

A return on investment (ROI) calculation is shown in Table 2.1-4 which factors in DDT&E to provide a benefit to investment ratio.

TABLE 2.1-4 RETURN ON INVESTMENT (PV)

Alternative	Cost Per Flight Competition (Discounted $)		Cost Per Flight Option (Discounted $)		No Flights		DDT&E (Disc $)	Adj.	ROI
All-propulsive	((22.7M	-	15.8M)	x	389	/	1775.8M)-	1	=2.5
Aeroassist	((22.7M	-	14.0M)	x	389	/	1819.9M)-	1	=3.1

2.1.5 Alternative Comparison

An alternative comparison is shown in Table 2.1-5. To aid in evaluating each economic factor, a score is provided at the bottom of the table. A value of 10 is given to the best option for each economic factor and a proportionate value is given to the other option.

Figure 2.1-2 provides a graphic view showing the payback difference between the two alternatives. The aeroassist option provides both an earlier break even point and a greater benefit over the postulated life of the mission model.

TABLE 2.1-5 ALL-PROPULSIVE VS AEROASSISTED COMPARISON (PV)

Economic Factor	All-Propulsive	Aeroassist
Benefit (Discounted $)	2684	3384
ROI	2.5	3.1
Investment (Discounted $)	775.8	819.9
Score		
Benefit	7.9	10
ROI	8.1	10
Investment	10	9.5

2.1.6 Conclusion

The aeroassisted concept provides the greatest economic advantage of the two options in both the ground based and space based modes of operation. In the ground base mode of operation, the all-propulsive concept is not feasible in that propellant required to fly a GEO mission both exceeds the OTV 55,000 lb capacity of the OTV tanks and the STS 72 klb payload lift capacity. The additional STS flights required to service payloads exceeding the Shuttle lift capability would drive all-propulsive costs well beyond the aeroassist operations costs.

In the space based mode of operations, the investment cost of both options is reasonably affordable. The economic analysis for both benefit and return on investment show aeroassist to be the winner. A payback analysis also shows the aeroassist concept to have an earlier payback and greater overall return over the full term of the mission model.

The conclusion of the trade study is therefore to select the aeroassist concept over the all-propulsive concept.

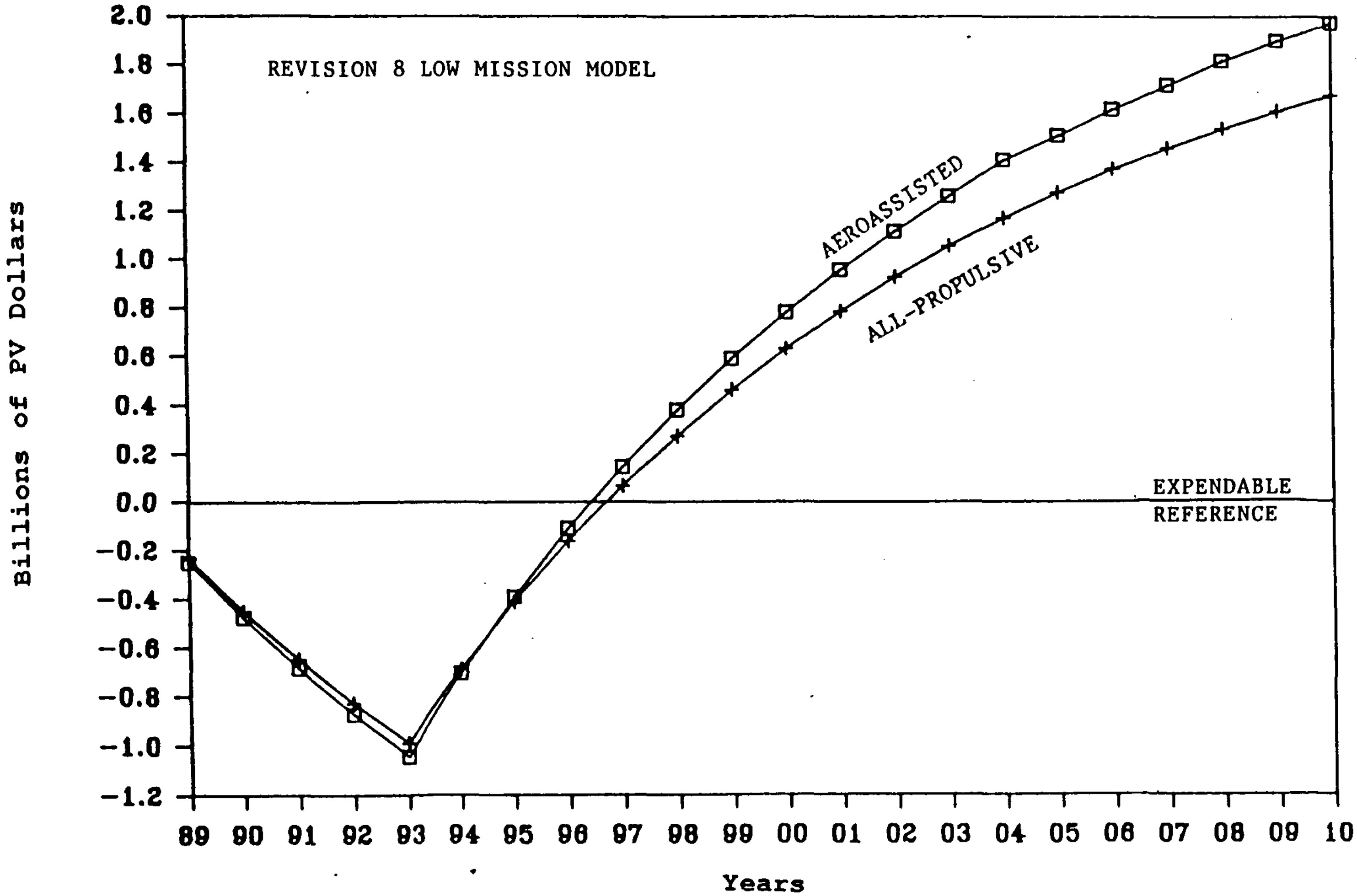


FIGURE 2.1-2 ALL-PROPULSIVE VS AEROASSIST PAYBACK

2.2 OTV Engine Trade Study

The purpose of this trade study is to select an Orbital Transfer Vehicle (OTV) cryogenic engine which provides optimum benefits under Revision 8 of the Marshall Space Flight Center (MSFC) Mission Model. At mid-term, when cost analysis were based upon the 453 flights of the Revision 7 Nominal Mission Model, study results showed that a $350M investment cost was justified to develop an advanced engine with an Isp of 483 seconds. This study reexamines the economic impact of the engine trade using the much more modest Revision 8 Low Mission Model which postulates only 145 flights over the 12 year life of the mission model.

2.2.1 Approach

The following steps are used in conducting this trade study.

- Identify engine alternatives
- Identify propellant costs by year for each alternative
  - Compute propellant consumption
  - Compute propellant cost in constant and present value dollars

- Identify engine replacement cost by year for each alternative
  - Compute the number of engine replacements required
  - Compute engine replacement cost in constant and present value dollars
- Compute combined propellant and engine replacement costs
- Compute cost of existing engine (competition)
- Compare engine alternative with the competition and with one another

2.2.2 Groundrules and Assumptions

The following ground rules and assumptions are used for this trade study:

- 1985 dollars
- Propellant cost delivered to LEO is $1,500 per pound
- Present value:
  - Inflation: 0 percent
  - Discount: 10 percent
- Cost to deliver engine to LEO: $6.8M (54" Cargo Bay length charged per ground rules at time trade conducted)

Engine competition:
- RL 10A-3-3A
- ISP : 440 seconds
- Life: One hour
- Unit cost: $1.5M

- Typical mission
  - To GEO: 12.4 klb payload
  - Return: 2.4 klb payload

2.2.3 Alternatives

Three developmental engines are used to form different engine strategies that serve as the alternatives used in this study. First the engine types will be discussed followed by the alternative strategies.

The three developmental engines are the RL10-IIB, an initial operational capability (IOC) engine, and an advanced engine. The existing RL10A-3-3A engine is also used as the "competition" to serve as the baseline to determine the profitability of each developmental engine. Basic cost and performance information on these engines is shown in Table 2.2-1.

The RL10-IIB engine represents a low risk development which improves the performance of existing engine technology (i.e., the technology used by the RL10A-3-3A engine).

The IOC engine uses an advanced technology, new cycle engine which possesses an Isp approximately equal to the practical limit of the existing technology engines (e.g. RL10A-3-3A and RL10-BII engines). The IOC engine in reality is an intermediate step. It provides improved efficiency without requiring full development to the expected potential of the new cycle engines.

The advanced engine possesses an Isp near the expected limit of the new cycle engines. This engine will be the most efficient in terms of propellant consumption.

The alternatives selected for this study are formed by using these engines in different combinations for ground based (GB) and space based (SB) operations. These alternatives are:

- Alternative 1. RL10-IIB engine GB to advanced engine SB.
- Alternative 2. IOC engine GB to advanced engine SB.
- Alternative 3. Advanced engine for both GB and SB.
- Alternative 4. RL10-IIB for minimum certification for both GB and SB.
- Alternative 5. IOC engine for both GB and SB.

TABLE 2.2-1 ENGINE COST AND PERFORMANCE DATA

ENGINE	THRUST (KLB FORCE)	ISP (SEC)	DDT&E (CONSTANT $M)	UNIT COST (CONSTANT $M/ENG)	LIFE (HRS)
RL10-IIB	15	460	98.2	1.9	5
Initial Operational Capability	7.5	475	175	2.85	5
Advanced	7.5	483	350	3.0	10
RL 10A-3-3A	16.5	440	0	1.5	1.25

2.2.4 Cost of Alternatives

2.2.4.1 Propellant Cost

Propellant requirements are determined for each engine by flying an average GEO mission on a simulation model using a 12.4 klb up payload and a 2400 lb down payload. A 45 klb propellant tank capacity is used for ground based missions and a 55 klb propellant tank capacity is used for space based missions. Burnout weight for the 45 klb vehicle is 5,689 lb and for the 55 klb vehicle is 8,090 lb.

Propellant requirements for this mission, as calculated by a flight simulation model, are shown for each type of engine in Table 2.2-2. Table 2.2-3 provides a summary of propellant weights and delivery costs for each engine. The propellant requirements are extended over the duration of the Revision 8 Low Mission Model. Propellant delivery is figured at $1,500/lb.

2.2.4.2 Engine Replacements

Engine replacement cost calculations are based upon the unit cost of the engine. Cost for engine installation and checkout are included in the unit cost price. The frequency of engine replacement is based upon the burn time requirement of the missions and the life expectancy of the engine. Table 2.2-4 summarizes engine replacement costs.

2.2.4.3 Total Costs

Engine replacement and propellant costs from Tables 2.2-3 and 2.2-4 are summarized in Table 2.2-5. DDT&E costs are shown in Table 2.2-6.

Total cost for the competition engine, RL10A-3-3A, are calculated to be as follows:

- Total Cost (Constant $) $10,662.0M
- Total Cost (PV $) $ 2,302.4M
- Cost per Flight (PV $) $ 73.5M

The competition cost estimates, along with the engine operations cost summarized in Table 2.2-5 and engine DDT&E costs shown in Table 2.2-6 are used in the economic analysis calculations in paragraph 2.2.4.4 below. Note that the DDT&E cost of Alternative 1, in constant $, is the sum of Alternatives 3 and 4. The DDT&E cost of Alternative 2, in constant $, is increased $65M over Alternative 3 because of the stretched out, two step nature of the program.

TABLE 2.2-2 PROPELLANT REQUIREMENTS

VEHICLE ENGINE PERFORMANCE / TANK SIZE	PROPELLANT REQUIRED 45,000 (LB)	PROPELLANT REQUIRED 55,000 (LB)
RL 10-IIB 460 Isp	44,997	49,746
IOC 475 Isp	43,615	45,613
Advanced 483 Isp	41,370	38,896
RL 10A-3-3A 440 Isp	50,104*	52,400

* Used to price 'competition', not a viable candidate

TABLE 2.2-3 PROPELLANT COST (REVISION 8 LOW MISSION MODEL)

Alternative/ Engine	Propellant in MLB GB	Propellant in MLB SB	Propellant Del Cost ($M PV) GB	Propellant Del Cost ($M PV) SB	Total Combined Cost ($M PV)
Alternative 1					
RL 10-IIB	1.6		835		1844
Advanced		4.3		1009	
Alternative 2					
IOC	1.5		809		
Advanced		4.3		1009	1818
Alternative 3					
Advanced	1.4		758		1767
Advanced		4.3		1009	
Alternative 4					
RL 10-IIB	1.6		835		2126
RL 10-IIB		5.5		1291	
Alternative 5					
IOC	1.5		809		2009
IOC		5.0		1200	

TABLE 2.2-4 ENGINE REPLACEMENT COST (REVISION 8 LOW MISSION MODEL)

Alternative	Engine Replacements GB	Engine Replacements SB	Engine Costs ($M PV) GB	Engine Costs ($M PV) SB	Total Combined Costs ($M PV)
Alternative 1					
RL10-IIB	3		1.95		9.18
Advanced		6		7.28	
Alternative 2					
IOC	3		2.93		10.21
Advanced		6		7.28	
Alternative 3					
Advanced	2		2.93		10.21
Advanced		6		7.28	
Alternative 4					
RL10-IIB	3		1.95		17.15
RL10-IIB		10		15.2	
Alternative 5					
IOC	3		2.93		19.63
IOC		12		16.7	

TABLE 2.2-5 ENGINE OPERATIONS COSTS ($M PV)

Alternative/ Engine	Propellant Cost	Engine Replacement Cost	Total Costs
Alternative 1 RL10-IIB (GB) Advanced (SB)	1844	9.18	1853
Alternative 2 IOC (GB) Advanced (SB)	1818	10.21	1828
Alternative 3 Advanced (GB) Advanced (SB)	1767	10.21	1767
Alternative 4 RL10-IIB (GB) RL10-IIB (SB)	2126	17.15	2143
Alternative 5 IOC (GB) IOC (SB)	2009	19.63	2029

TABLE 2.2-6 ENGINE DDT&E ($M PV)

ALTERNATIVE	DDT&E	
	Const $	PV
Alternative 1 RL10-IIB (GB) Advanced (SB)	$448.2M	$258.7M
Alternative 2 IOC (GB) Advanced (SB)	415.	254.8
Alternative 3 Advanced (GB) Advanced (SB)	350.	251.1
Alternative 4 RL10-IIB (GB) RL10-IIB (SB)	98.2	70.2
Alternative 5 IOC (GB) IOC (SB)	175.	125.1

2.2.4.4 Economic Analysis

A benefit analysis is shown in Table 2.2-7 for each engine option. This analysis is based upon the algorithm: Competition Operations Cost - Engine Operations Cost = Benefit. Table 2.2-7 shows the greatest operational benefit, not including development cost, comes from the use of the advanced engine.

A Return on Investment (ROI) analysis is shown in Table 2.2-8 for each engine option. This analysis provides a best buy rates by dividing the benefit by the investment (DDT&E) costs. This algorithm is:

$$\frac{\text{Competition Operations Cost} - \text{Engine Operations Cost}}{\text{Investment}} - 1 = \text{ROI}$$

The greatest ROI is offered by the RL-10 engine, with the IOC engine second.

The pay back economics factor represents the number of missions required to amortize the DDT&E investment for each engine option (Table 2.2-9). Table 2.2-10 identifies the number of missions required before the payback is realized. The algorithm used is:

$$\frac{\text{DDT\&E Cost}}{CPF_c - CPF_o} = \text{Number of flts to pay back}$$

where CPF_c = cost/flt, competition
CPF_o = cost/flt, engine option

The earliest investment pay back is achieved with the RL10 derivative engine, with the IOC engine second.

TABLE 2.2-7 ENGINE TRADE BENEFITS ($M PV)

OPTION	COMPETITION OPS COST	-	OPTION OPS COST	=	BENEFIT
1 RL10/ADV	2302	-	1853	=	449
2 IOC/ADV	2302	-	1828	=	474
3 ADV/ADV	2302	-	1767	=	535
4 RL10/RL10	2302	-	2143	=	159
5 IOC/IOC	2302	-	2029	=	273

TABLE 2.2-8 ENGINE TRADE ROI

OPTION	$\frac{\text{BENEFITS (PV)}}{\text{DDT\&E (PV)}} - 1 = \text{ROI}$
1 RL10/ADV	$\frac{449}{258.7} - 1 = 0.73$
2 IOC/ADV	$\frac{474}{254.8} - 1 = 0.86$
3 ADV/ADV	$\frac{535}{251.1} - 1 = 1.13$
4 RL10/RL10	$\frac{159}{70.2} - 1 = 1.26$
5 IOC/IOC	$\frac{273}{125.1} - 1 = 1.18$

TABLE 2.2-9 PAYBACK - MAIN ENGINE

OPTION	MISSIONS
1 1 RL10/ADV	83
2 2 IOC/ADV	78
3 3 ADV/ADV	68
4 4 RL10/RL10	64
5 5 IOC/IOC	66

Figure 2.2-1 provides a graphic portrayal of each engines payback vis-a-vis the competition. It also shows a comparison of the payback among the engine options. This figure shows the advanced engine providing the most benefit over the 145 mission planning horizon. It also shows the RL10-IIB engine having a quicker payback but providing the least advantage over the 145 mission scenario.

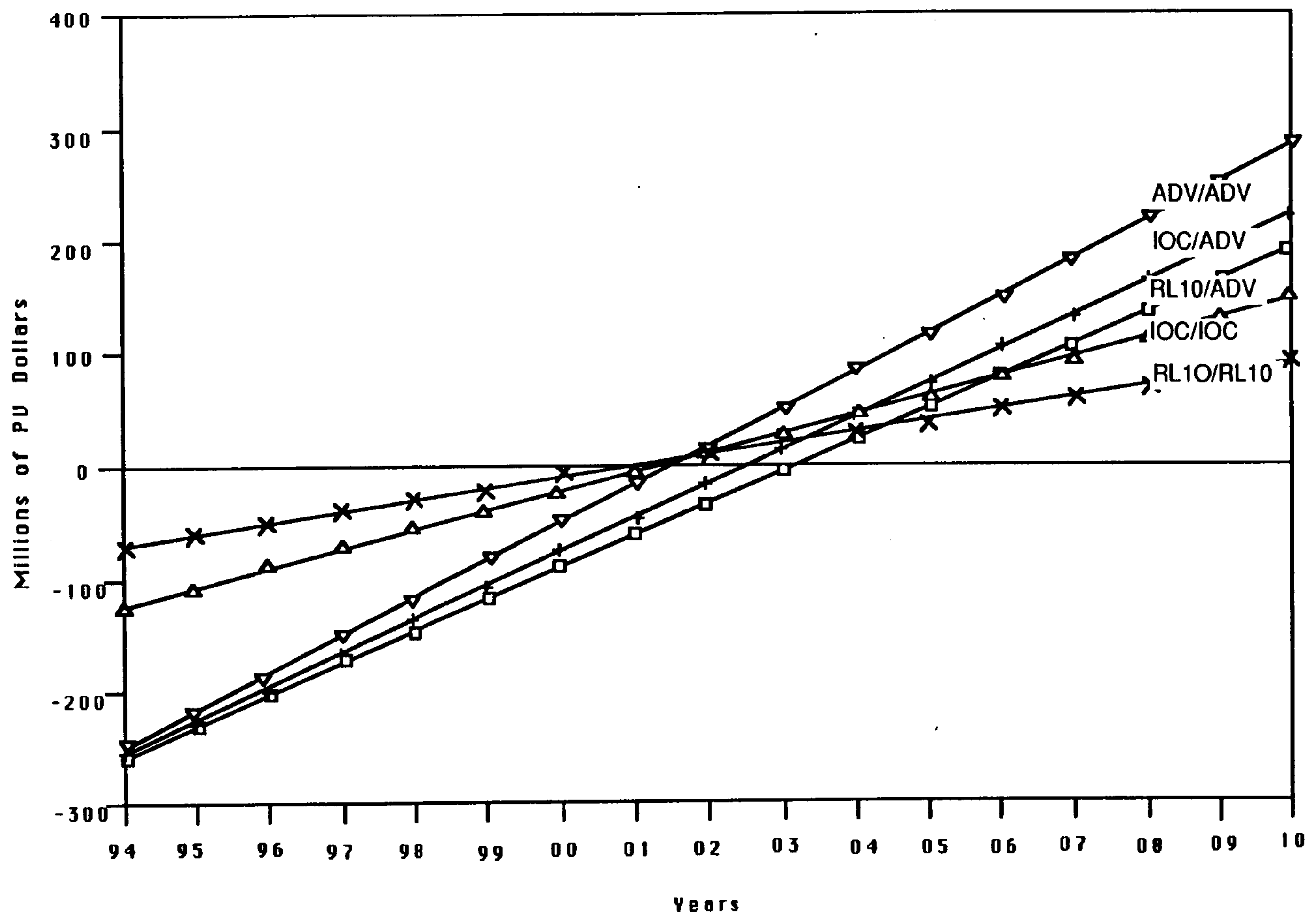


FIGURE 2.2-1 ENGINE PAYBACK FOR VARIOUS OTV ENGINES

2.2.5 Alternative Comparison

Table 2.2-10 provides a comparison of the economic analysis factors. Each factor provides a different measurement of economic merit. All factors should be weighted individually and together to determine the best engine alternative. To aid this comparison, a scoring is provided where the most favorable alternative is given a 10 and the other alternative a value in relation to the alternative scored 10.

TABLE 2.2-10 ENGINE TRADE RESULTS

ECONOMIC FACTOR	ALTERNATIVE RL10/ADV 1	IOC/ADV 2	ADV/ADV 3	RL10/RL10 4	IOC/IOC 5
ROI (PV)*	0.73	0.86	1.13	1.26	1.18
Benefits (PV)*	449.0	474.0	535.0	159.0	273.0
Investment (DDT&E) (PV)*	258.7	254.8	251.1	70.2	125.1
LCC (PV)*	2112.0	2083.0	2018.0	2213.0	2154.0
Payback Missions	83	78	68	64	66
Cost per Flight (PV)*	59.1	58.4	55.1	66.2	62.2
* Millions of dollars ($M)					
SCORE					
ROI	5.8	6.8	9.0	10.0	9.4
Benefits	8.4	8.9	10.0	3.0	5.1
Investment	2.7	2.8	2.8	10.0	5.6
LCC	9.6	9.7	10.0	9.1	9.4
Payback Missions	7.7	8.2	9.4	10.0	9.7
Cost per Flight	9.3	9.4	10.0	8.3	8.9

2.2.6 Conclusion

The engine trade scores in Table 2.2-10 show mixed results. Alternative 4 [RL10-IIB (GB)/RL10-IIB (SB)] scores high on investment and payback missions. ROI is also scored high for alternative 4, but this figure is tempered by the relatively low benefit. The benefits score for alternative 4 is disproportionately low vis-a-vis the other alternatives.

Alternative 3 [ADV (GB)/ADV (SB)] scores high on benefits, cost per flight, and life cycle cost, however the risk associated with this alternative is greater than the other alternatives since it calls for the highest Isp (483) and embarks on a new technology high performance engine.

Alternative 5 [IOC (GB)/IOC (SB)] represents a good compromise. All economic factors except LCC fall between alternatives 3 and 4 in scoring. Alternative 5 does not have as great a risk as alternative 3 and can serve as a stepping stone to the more efficient advanced engine. By starting out with the same engine for ground based operations, experience and greater confidence will be realized in the engine for initial space based operations and later for man-rated operations.

The conclusion of this study is that the IOC engine should be developed for both ground based and space based OTV operations.

2.3 Man Rating and Reliability Trade Study

The objective of this study is to establish data to permit the selection of a man-rating policy and then to implement that policy in the OTV configurations. The mission model is dominated by unmanned missions so it is also the objective of the study to define the redundancy configuration of unmanned OTV concepts. This step in the OTV concept definition is crucial since it establishes the equipment lists and thereby has major influence of design and weight.

2.3.1 Approach

The following approach is used in the analysis.

- Establish cost data to permit definition of a man-rating policy.
- Incorporate redundancy needed to meet the policy in the manned OTV.
- Configure the unmanned OTV redundancy to be consistent with current expendable stages.

The first step in the approach established the sensitivity of life cycle cost to various failure policies. The failure policies considered are shown in Table 2.3-1. In this analysis, 368 GEO delivery mission are used and the space based cryogenic reference configuration serves as the basis for characterizing the configurations for each failure policy. The equipment complement of the reference configuration is adjusted through a functional Failure Modes Effects Analysis (FMEA) to be consistent with the failure policies. This means examining the Failure Modes in each flight phase, determining if a failure met the policy and, if not, adding redundancy until the policy is satisfied.

Step two reexamines the reference configuration through a FMEA to specifically meet the stated man-rating policy.

Step three determines the consistency of the redundancy policy with current expendable reliability capability.

TABLE 2.3-1 MAN-RATING POLICY CONCEPTS

Concept	Failure Tolerance	Remarks
Single String	0	
Fail Safe	1	Assumes a rescue capability is available for man-rating.
Fail Operational/Fail Safe	2	
Fail Operational/Fail Operational/Fail Safe	3	

2.3.2 Ground Rules

The following ground rules are used in the man-rating analysis:

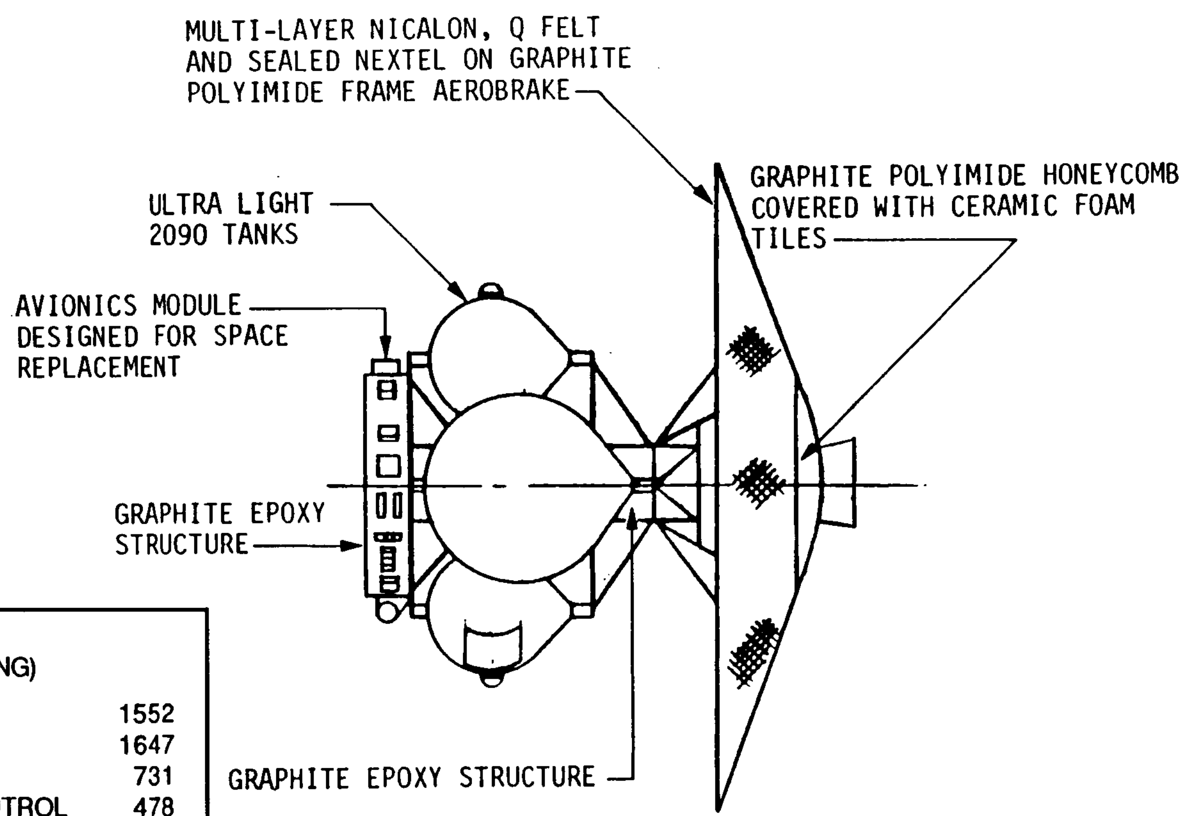
- o Reference Missions (Rev 7 Nominal Mission Model)
- o 14 manned 14 klb up, 14 klb down GEO servicing missions.
- o 354 unmanned 12,445 lb up, 4,711 lb down GEO servicing missions.
- o Mission duration: 480 hours manned missions
  51 hours unmanned missions
- o Reference OTV design
  Space based cryo - (Figure 2.3-1)
  Single engine configuration 15 klb thrust 478.6 Isp
  Dual engine configuration 7.5 klb thrust 471.3 Isp
  Three engine configuration 5 klb thrust 475.8 Isp

2.3.3 Analysis

This section documents the results of the investigations to establish manned and unmanned redundancy for the candidate OTV concepts.

2.3.3.1 Man Rating Policy

The redundancy required to implement the four failure policies is shown in Table 2.3-2 together with the computed reliabilities. These data form the basis for characterizing conceptual cryo stages. Feasible layouts were sketched and weight statements (Table 2.3-3) were developed. These data are used for performance analysis to determine propellant required to capture the GEO missions. The resulting performance data is presented in Tables 2.3-4 and 2.3-5. The performance and the design data form the basis of the life cycle cost analysis shown in Table 2.3-6 and Figure 2.3-2. It is noted that propellant requirements resulting from stage weight dominates the LCC difference and that progression from single string to Fail Operational, Fail Operational, Fail Safe is exponential in cost of mission capture.



WEIGHTS
(SINGLE STRING)

AEROBRAKE	1552
TANKS	1647
STRUCTURE	731
ENVIRONMENTAL CONTROL	478
MAIN PROPULSION	1015
ORIENTATION CONTROL	299
ELECTRIC POWER	443
AVIONICS	353
CONTINGENCY (15%)	978
DRY WEIGHT	7496
PROPELLANTS, ETC	84000
LOADED WEIGHT	91496

CAPABILITY: 14000 LB ON GEO SORTIE

FIGURE 2.3-1 SPACE BASED CRYO REFERENCE CONFIGURATION

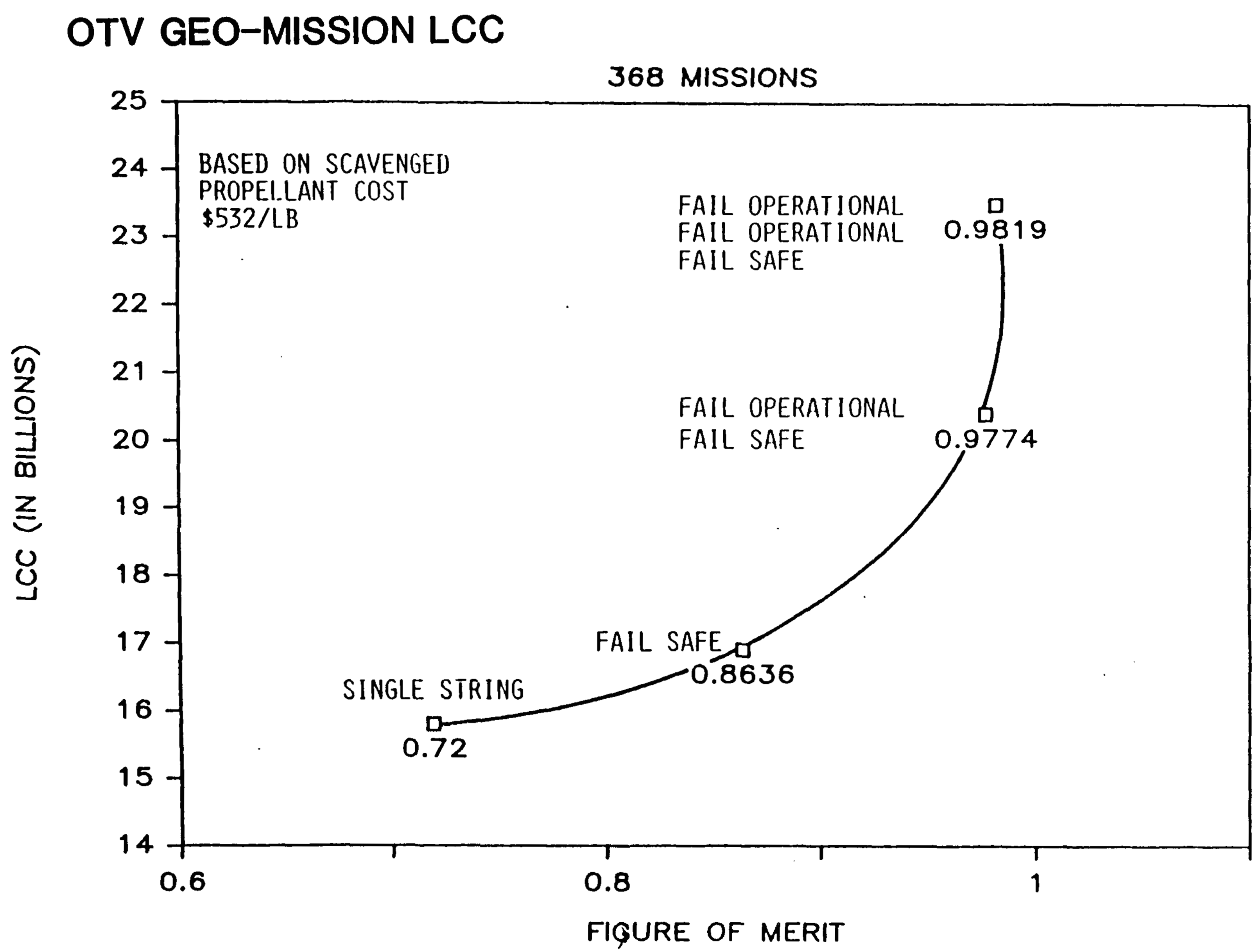


FIGURE 2.3-2 FAILURE POLICY COST COMPARISON

TABLE 2.3-2 FAILURE POLICY EQUIPMENT/RELIABILITY ALLOCATION

	RELIABILITY DATA OTV SINGLE STRING		RELIABILITY DATA OTV FAIL SAFE		RELIABILITY DATA OTV OPS SAFE		RELIABILITY DATA OTV OPS OPS SAFE	
COMPONENT	QUANTITY	RELIABILITY	QUANTITY	RELIABILITY	QUANTITY	RELIABILITY	QUANTITY	RELIABILITY
Structure	1	0.9995201150	1	0.9995201150	1	0.9995201150	1	0.9995201150
L02 Tank	2	0.9995680930	2	0.9995680930	2	0.9995680930	2	0.9995680930
LH2 Tank	2	0.9995680930	2	0.9995680930	2	0.9995680930	2	0.9995680930
Lines & Fit	1	0.9995201150	1	0.9995201150	1	0.9995201150	1	0.9952011500
Main Engine	1	0.9803000000	1	0.9803000000	2	0.9996119100	3	0.9999698690
TVC Act	2	0.9991747400	2	0.9991747400	4	0.9999998290	6	0.9999999990
SOL Valves	4	0.9908263370	4	0.9990788240	10	0.9999998910	14	0.9999999960
QD's	19	0.9990884160	19	0.9990884160	23	0.9988966090	27	0.9987048390
Check Valves	2	0.9990404610	4	0.9980818420	8	0.9961673630	16	0.9999999990
Filters	4	0.9999136040	6	0.9999567990	6	0.9999567990	6	0.9999999990
Thermo VT	4	0.9597078150	4	0.9958613870	8	0.9999957040	12	0.9999999950
PU Valve	2	0.9907312220	2	0.9907312220	2	0.9907312220	2	0.9907312220
PNEU Valve	2	0.9907312220	2	0.9907312220	4	0.9999995660	6	0.9999997990
ELE I/F SS	4	0.9999558410	4	0.9999558410	4	0.9999558410	4	0.9999558410
ACS Engine	4	0.9996000000	4	0.9762151370	4	0.9998560070	8	0.9999991360
GH2 Tank	2	0.9995680930	2	0.9995680930	2	0.9995680930	2	0.9995680930
GO2 Tank	1	0.9997840230	1	0.9997840230	1	0.9997840230	1	0.9997840230
Lines & Fit	1	0.9995201150	1	0.9995201150	1	0.9995201150	1	0.9995201150
SOL Valves	8	0.9817368300	16	0.9999936300	24	0.9999999940	32	0.9999999990
QD's	17	0.9991843330	26	0.9987527780	43	0.9979381290	60	0.9971241430
Check Valves	2	0.9990404610	4	0.9980818420	4	0.9980818420	8	0.9999999990
Reg's	2	0.9943520100	4	0.9999998390	6	0.9999999980	8	0.9999999990
HX	1	0.9985610360	1	0.9985610360	2	0.9999999790	2	0.9999979290
Turbo Pump	1	0.9966456380	2	0.9999964300	3	0.9999999930	4	0.9999999990
Aero ACTS	6	0.9646402930	6	0.9646402930	6	0.9997523500	6	0.9999999890
Fuel Cells	1	0.9943726790	1	0.9949726790	2	0.9999999990	3	0.9999999990
Radiators	1	0.9995201150	1	0.9995201150	2	0.9999994950	3	0.9999999990
FC Power Cond	1	0.9952115020	1	0.9952115020	2	0.9999770700	3	0.9999998900
Star Tracker	1	0.9904459330	2	0.9999087190	3	0.9999991270	4	0.9999999910
IMU	1	0.9531337870	2	0.9978035580	3	0.9998970610	4	0.9998970610
Computer	1	0.9531337870	2	0.9978035580	3	0.9998970610	4	0.9998970610
Flight Control	1	0.9952115020	2	0.9999770700	3	0.9999998900	4	0.9999999990
TLM Power Supply	2	0.9999900000	2	0.9999985610	3	0.9999999980	4	0.9999999930
CMD & Data Hdlr	2	0.9999100000	2	0.9999770700	3	0.9999998900	4	0.9999995620
Transponder	2	0.9999100000	2	0.9999087190	3	0.9999991270	4	0.9999999910
RF Amplifier	1	0.9952115020	2	0.9999770700	2	0.9999998900	3	0.9999998900
GPS Receiver	1	0.9952115020	1	0.9952115020	2	0.9999998900	3	0.9999998900
GPS Antenna	1	0.9999568010	1	0.9999568010	2	0.9999999980	3	0.9999999990
Sequencer	1	0.9952115020	2	0.9999770700	3	0.9999998900	4	0.9999999990
Deploy Timer	1	0.9952115020	1	0.9952115020	2	0.9999770700	2	0.9999770700
Battery	1	0.9931595030	1	0.9931595030	3	0.9999532070	3	0.9999996790
Motor Switch	3	0.9857031840	3	0.9994241660	6	0.9990404600	7	0.9999997410
Steer Antenna	2	0.9999900000	2	0.9999983220	2	0.9999998320	3	0.9999999970
Diplexer	2	0.9990404610	2	0.9990404610	2	0.9990404610	2	0.9990404610
Meteor Shield	1	0.9995201150	1	0.9995201150	1	0.9995201150	1	0.9995201150
Wiring	1	0.9952115020	1	0.9999770700	1	0.9999770700	3	0.9999998900
TOTALS		0.7200587420		0.8636410530		0.9773908000		0.9819766330

TABLE 2.3-3 CONFIGURATION RELIABILITY VS WEIGHT
SPACE BASED CRYO - 84 KLB PROPELLANT LOAD
(Weight Lb)

Description	Single String	Fail Safe	FO/ FS	FO/FO/FS
Orientation Control	299	352	430	550
ACS Subsystem	227	280	350	478
Rocket Engine Modules	40	40	40	80
Accumulators	62	62	62	62
Mtg. Provisions - REMs & Acc.	10	10	10	14
Conditioning Units/Mtg. Prov.	46	65	106	125
Valves, Sw., Mtg. Prov., etc.	46	80	117	157
Tubing & Instl.	23	23	23	40
Aerobrake Deployment	72	72	72	72
Actuators	48	48	48	48
Support Struct. & Attach	24	24	24	24
Electrical	443	443	660	801
Battery	35	35	105	105
Power Conversion & Dist.	150	150	200	250
Fuel Cell System	45	45	90	135
Reactant Tank - GH_2	70	70	70	70
Reactant Tank - GO_2	45	45	45	45
Radiator System	33	33	65	98
Water System	25	25	25	25
Fuel Cell Pwr. Cond.				
Mounting Provisions	40	40	60	73
Structure	3930	3930	3969	3992
Basic Airframe	631	631	631	631
LO_2 Tank	596	596	596	596
LH_2 Tank	1051	1051	1051	1051
Aerobrake	1412	1412	1350	1309
Aerobrake Doors - Engine	140	140	241	305
Boom - ACS REMs	12	12	12	12
Boom - Avionics	23	23	23	23
P/L Attach (8)	40	40	40	40
Mod. RMS Grapple Fixture (5)	25	25	25	25

Continued

TABLE 2.3-3 CONFIGURATION RELIABILITY VS WEIGHT SPACE BASED
CRYO - 84 KLB PROPELLANT LOAD (Continued)
(Weight Lb)

Description	Single String	Fail Safe	FO/ FS	FO/FO/FS
Environmental Control	478	478	506	534
Thermal Protection	58	58	86	114
LO_2 Tank	0	0	0	0
LH_2 Tank	0	0	0	0
Engine Truss/Compt.	16	16	16	16
ACS Tanks	10	10	10	10
Prop. Lines, Comp., & etc.	32	32	60	88
Meteoroid Protection	420	420	420	420
Main Propulsion System	1015	1015	1437	1643
Engine	393	393	697	784
Propellant Feed System	195	195	201	208
Pneumatic System	114	114	156	198
Pressurization System	99	99	123	147
Vent System	182	182	196	210
Actuators - Electrical	32	32	64	96
Avionics	353	489	709	924
Avionics	321	445	645	840
Mounting Provisions	32	44	64	84
Dry Weight	6518	6707	7711	8444
Contingency (15%)	978	1006	1157	1267
Total Dry Weight	7496	7713	8868	9711

TABLE 2.3-4 MANNED MISSION PERFORMANCE DATA

Configuration: SB Cryo Ref (Fig 2.3-1)
Mission: Manned GEO Servicing
Payload: Up 14 klb: Down 14 klb

Failure Policy	Dry Weight (lb)	I_{SP} (ϵ = 640:1) (sec)	Thrust Engine (lb)	No. Engine	Propellant Weight (lb)	Gross Weight (lb)
Single String	7496	478.6	15000	1	69526	91022
Fail Safe	7713	478.6	15000	1	70209	91922
FO/FS	8868	476.3	7500	2	74526	97394
FO/FO/FS	9711	475.8	5000	3	77381	101092

TABLE 2.3-5 UNMANNED MISSION PERFORMANCE DATA

Configuration: SB Cryo Ref (Fig 2.3-1)
Mission: Unmanned GEO Servicing
Payload: Up 12445: Down 4711

Failure Policy	Dry Weight (lb)	I_{SP} (ϵ = 640:1) (sec)	Thrust Engine (lb)	No. Engine	Propellant Weight (lb)	Gross Weight (lb)
Single String	7496	478.6	15000	1	38585	53816
Fail Safe	7713	478.6	15000	1	39247	54694
FO/FS	8868	476.3	7500	2	43128	59730
FO/FO/FS	9711	475.8	5000	3	45816	63261

TABLE 2.3-6 OTV RELIABILITY OPTIONS LCC (USING DELIVERED PROPELLANT) (1985 $B)

	Single String		Fail Safe		Fail Op Safe		Fail Op/ Fail Op/ Fail Safe	
DDT&E	0.8		0.9		1.1		1.2	
PRODUCTION	0.3		0.3		0.4		0.6	
REFURB	4.8		5.6		8.0		10.4	
Manned		0.1		0.1		0.1		0.1
Unmanned		4.7		4.7		4.7		4.7
FLIGHT OPS	2.1		2.1		2.1		2.1	
Manned		0.1		0.1		0.1		0.1
Unmanned		2.0		2.0		2.0		2.0
IVA	0.2		0.2		0.2		0.2	
Manned		0.004		0.004		0.004		0.004
Unmanned		0.2		0.2		0.2		0.2
PROPELLANT	30.7		31.2		33.3		36.4	
Manned		1.3		1.3		1.4		1.5
Unmanned		29.4		29.9		32.9		34.9
TOTAL COST	38.9		40.3		46.1		50.9	
Manned		1.5		1.6		1.7		2.0
Unmanned		36.3		37.5		42.4		47.1
DDT&E - Production		1.1		1.2		1.5		1.8

These data resulted in the NASA establishing the following manned safety policy:

No single credible failure shall preclude the safe return of the crew.

2.3.3.2 Man-Rating Policy Implementation

The Failure Modes Effects Analysis to implement the man-rating policy resulted in the redundancy shown in Table 2.3-7. It is noted that for a 480 hour mission the reliability of the manned configuration falls between the Fail Safe and the Fail Operational, Fail Safe concepts shown in Figure 2.3-2. This redundancy configuration meets the failure policy and provides a mission success probability that is judged to be acceptable based on expected loss costs. Table 2.3-8 summarizes the reliabilities of the manned and single string concept which meets the criteria of being as good as current expendable stages. The unmanned 51 hour mission has good probability (0.966) of mission success. A comparison of the equipment compliment for the manned and unmanned concepts is shown in Table 2.3-9.

TABLE 2.3-8 RELIABILITY

Configuration	28 Day Mission	51 Hour Mission
Manned	0.946	0.996
Unmanned (Single String)	0.72	0.996

2.3.3.3 Man Rating Costs

The cost of man-rating is of course of interest. It is estimated at this point in the development of the OTV concept that the cost differences between all unmanned and manned operations are based on the LCC data in Table 2.3-6 as follows:

Investment (DDTE & Production)	$400M
Operations 368 Missions	$4370M

Operations costs ignore the reduced losses resulting from a higher reliability. The expected losses for single string and the man-rated concepts is given by

(1-R)N x Expected Loss Cost

TABLE 2.3-7 MAN-RATED CONFIGURATION EQUIPMENT

COMPONENT	FAILURE RATE	QUANTITY	RELIABILITY
Structure	1.00000000E-6	1	.9995201150
LO_2 Tank	4.50000000E-7	2	.9995680930
LH_2 Tank	4.50000000E-7	2	.9995680930
Lines & Fit	1.00000000E-6	1	.9995201150
Main Engine	---------	2	.9996119100
TVC Act	1.25000000E-5	4	.9999998290
SOL Vlvs	4.80000000E-6	10	.9999998910
QD's	1.00000000E-7	23	.9988966090
Check Valves	1.00000000E-6	8	.9961673630
Filters	4.50000000E-8	6	.9999567990
Thermo VI	2.14200000E-5	8	.9999957040
Pu Valve	9.70000000E-6	2	.9907312220
Pneu Valve	9.70000000E-6	4	.9999995660
Ele. I/F SS	2.30000000E-8	4	.9999558410
ACS Eng	---------	4	.9998560070
GH_2 Tank	4.50000000E-7	2	.9995680930
GO_2 Tank	4.50000000E-7	1	.9997840230
Lines & Fit	1.00000000E-6	1	.9995201150
SOL Valves	4.80000000E-6	24	.9999999940
QD's	1.00000000E-7	43	.9979381290
Check Valves	1.00000000E-6	4	.9980818420
Reg's	5.90000000E-6	6	.9999999980
Hx	3.00000000E-6	2	.9999999790
Turbo Pump	7.00000000E-6	3	.9999999930
Aero Acts	1.25000000E-5	6	.9997523500
Fuel Cell	1.05000000E-5	2	.9999999990
Radiators	1.00000000E-6	2	.9999994950
FC Pwr Cond	1.00000000E-5	2	.9999770700
Star Tracker	2.00000000E-5	2	.9998997535
IMU	1.00000000E-4	2	.9975935185
Computer	1.00000000E-4	2	.9975935185
Flt Control	1.00000000E-5	2	.999974826
TLM Pwr Supply	2.50000000E-6	1	.9987432903
Cmd & Data Hdlr	1.00000000E-5	1	.9949826293
Transponder	2.00000000E-5	1	.9899904325
RF Amplifier	1.00000000E-5	1	.9949826293
GPS Rcvr	1.00000000E-5	1	.9949826293
GPS Antenna	9.00000000E-8	2	.9999999980
Sequencer	1.00000000E-5	2	.999974826
Deploy Timer	1.00000000E-5	2	.9999770700
Battery	1.43000000E-5	1	.9999845581
Motor SW	1.00000000E-6	2	.9999845581
Steer Ant	2.70000000E-6	2	.9999998320
Diplexer	1.00000000E-6	2	.9990404610
Meteor Shield	1.00000000E-6	1	.9990000000
Wiring	1.00000000E-5	1	.9999770700
		Total	.946447

TABLE 2.3-9 COMPARISON OF UNMANNED/MANNED EQUIPMENT REQUIREMENTS

Equipment	Manned	Unmanned
Structure	1	1
LO_2 Tank	2	2
LH_2 Tank	2	2
Line & Fit	1	1
Main Engine	2	1
TVC Act	4	2
SOL Valves	10	4
QD's	23	19
Check Valves	8	2
Filters	6	4
Thermo Vt	8	4
PU Valve	2	2
Pneu Valve	4	2
Ele I/F SS	4	4
ACS Eng	4	4
GH_2 Tank	2	2
GO_2 Tank	1	1
Lines & Fit	1	1
SOL Valves	24	8
QD's	43	17
Check Valves	4	2
Reg's	6	2
Hx	2	1
Turbo-Pmp	3	1
Aero Acts	6	6
Fuel Cell	2	1
Radiators	2	1
FC Pwr Cond	2	1
Star Tracker	2	1
IMU	2	1
Computer	2	1
Flight Control	2	1
TLM Pwr Supply	1	2
Cmd & Data Hdlr	1	2
Transponder	1	2
RF Amplifier	1	1
GPS Receiver	1	1
GPS Antenna	2	1
Sequencer	2	1
Deploy Timer	2	1
Battery	1	1
Motor SW	2	2
Steer Antenna	2	2
Diplexer	2	2
Meteor Shield	1	1
Wiring	1	1

The expected cost for an average loss was obtained as follows:

Payload Value	$194M
Payload Delivery to GEO (20 klb x $2K)	40M
OTV Fuel to GEO (64.5 klb x $2K)	129M
Operations	5M
Worst Case Cost	$368M
Expected Loss Cost (W/C x 50%)	$184M

The reduction of worst case loss cost by 50% reflects an average loss cost across all the missions. Computing the losses for simple string and man-rated we get:

Single String:	
Manned	$ 720M
Unmanned	$2210M
	$2930M

Man Rated:	
Manned	$139M
Unmanned	$261M
	$400M

Now it is clear that in combination of these cost factors the cost of man-rating is

Investment	$400M
Operations	$4370M + 400M - 2930M = 1840M which is equivalent to about $5M per manned mission (operations cost/missions)

These data should be viewed as only indications of the cost of man-rating. However, based on this relative immature concept data, the increased flexibility of manned mission capability is achieved for a modest increase in cost per flight.

2.3.4 Conclusion

Reliability figures are based upon the NASA policy that "no single credible failure shall preclude the safe return of the crew". The resulting reliability requirement for a manned 28 day mission is 0.946 and for a manned 51 hour mission is 0.996. The resulting unmanned single string reliability requirement for a 28 day mission is 0.72 and for an unmanned 51 hour mission is 0.966. The cost of upgrading from unmanned to man-rated is $2.2B.

The question of evolutionary strategy is not answered by this analysis; whether to start single string and then transition by block change to a man-rated OTV or start out man-rated. These decisions are properly a part of the evolution strategy trades in Section 2.7.

2.4 Propellent Delivery Trade Study

The purpose of this trade study is to select a preferred method for delivering cryogenic propellant to LEO for use in space based OTV operations. At issue are two questions: would a new propellant delivery system be more economically viable than using the existing Space Transportation System (STS) cargo bay; and, if so, what new system would be the most economically viable.

This study is a necessary prerequisite for the evolutionary strategies for the acquisition of an OTV that captures the mission model. (Ref paragraph 2.7.3, Preferred Overall Evaluation). The selection of the preferred propellant delivery approach is a key issue in the economics of establishing OTV as a viable venture. The single most costly factor is delivering propellant to LEO and therefore the cost per pound of the delivery system has a major influence on whether the OTV will be competitive with existing stages and existing LEO delivery methods.

The study addresses only cryogenic propellant and considers only the Aft Cargo Carrier (ACC) for use in propellant scavenging. If storable propellant had been selected over cryogenic propellant, then a follow-on propellant delivery trade would have been required using storable propellant as a basic consideration. (Ref paragraph 2.6, Storable versus Cryogenic Trade Study). Likewise, if the cargo bay had been selected over the ACC for propellant scavenging, then a follow-on propellant delivery trade would have been required using cargo bay scavenging as a basic consideration (Ref paragraph 2.7.2, ACC versus Cargo Bay for OTV Delivery/Scavenging).

2.4.1 Approach

The approach used in this trade is to create a simplified delivery problem and evaluate the economic benefits of the delivery concepts. The fundamental decision involved in the trade is whether it is justified to embark on an acquisition of a tanker, a scavenging system, or both; or whether to use the STS as a delivery system. The following cost benefit [i.e., Return on Investment (ROI)] ratio will be the principle measure.

$$\frac{\text{STS PROPELLANT DEL. COST} - \text{OPTION PROPELLANT DEL. COST}}{\text{OPTION INVESTMENT COST}} - 1 = \text{ROI}$$

If the ratio is negative, the option is not a viable economic venture. If the ratio is zero, the venture retrieves the investment but is not profitable. A positive ratio indicated the venture is profitable.

2.4.2 Ground Rules and Assumptions

The ground rules and assumptions listed below are used in the trade study. Costs are in millions of constant 1985 dollars, unless otherwise indicated as present value [PV] dollars.

- OTV
  - Mission Traffic: 10 missions per year, 1999-2010
  - Configuration: 55 klb stage with 483 sec Isp
  - Payload: 12.4 klb to GEO
24 klb return
  - Propellant: LH_2/LO_2
  - Propellant Rqmt: 41.37 klb per mission
  - Total Prop. Rqmt
(41370 x 120 missions): 4.9644 mlb

- Scavenging
  - Scavenging System: STS ACC
  - Scavenging System Acquisition: 1995-1998
  - STS Scavenging Flights: 328
  - Prop. Scavenged/Flight: 14 klb
  - Total prop. Scavenged: 4.592 mlb
  - DDT&E: $212M
  - DDT&E [PV] ($212M x 2.16 / 4 yrs): $114.5M
  - Propellant Delivery Cost: $1167M
  - Cost per flight ($1167M / 328): $3.6M
  - Propellant Delivery Cost [PV] ($1167M x 1.97 / 12 yrs): $191.6M (see Section 1.3 for uniform discounting)

- STS Cargo Bay
  - DDT&E: $4M
  - DDT&E [PV]: $2.2M
  - Prop. Delivery Rqmt. 4.9644 mlb
  - STS Delivery Capacity: 65 klb
  - STS Flights
  - (4.9644M/65 klb): 76.4
  - STS cost per flight: $73M
  - Propellant Delivery Cost
(76.4 x $73M): $5577
  - Propellant Delivery Cost [PV]
($5577M x 1.97 / 12 yrs): $915.4M

- SDV Tanker
  - SDV Tanker Acquisition: 1995-1998
  - DDT&E: $2200M
  - DDT&E [PV]a
($2200 x 2.16 / 4 yrs): $1188M
  - Propellant Delivery Rqmt: 4.9644 mlb
  - SDV Delivery Capacity: 181 klb
  - SDV Flights
(4.9644M / 181 klb): 27.4
  - SDV Cost per Flight: $75M
  - Propellant Delivery Cost
(27.4 x $75M) $2055M
  - Propellant Delivery Cost [PV]
($2055 x 1.97 / 12 yrs): $337.4M

- STS Cargo Bay/Scavenging
    - DDT&E ($4M + $212M): $216M
    - DDT&E [PV] ($2.2M + $114.5M): $116.7M
    - Scavenge Prop. Delivery: 4.592 mlb
    - STS CB Prop. Del. (4.9644M - 4.592M): .372 mlb
    - STS Flights (0.372M/65 klb) 5.7
    - STS CB Del Cost (5.7 x $73M): $416M
    - ACC Scavenging Prop. Del. Cost: $1167M
    - Total Prop. Delivery Cost ($416 + $1167): $1583M
    - Total Prop Delivery Cost [PV] ($1583M x 1.97 / 12 yrs): $260.2M

- SDV Tanker/Scavenging
    - DDT&E ($2200 + $212M): $2412M
    - DDT&E [PV] ($1188M + $114.5M): $1302.5M
    - Scavenge Prop. Delivery 4.592 mlb
    - SDV Tanker Prop. Delivery (4.9644M - 4.592M): .372 mlb
    - SDV Tanker Flights (0.372M/181,000): 2.1
    - SDV Tanker Del. Cost (2.1 x $75M): $157M
    - ACC Scavenging Prop. Delivery Cost: $1167M
    - Total Prop Delivery Cost ($157 + $1167): $1324M
    - Total Prop. Delivery Cost [PV] ($1324M x 1.97 / 12 yrs): $217.0M

2.4.3 Alternatives

The following alternative methods for propellant delivery to LEO are considered in the trade study.

- Alternative 1 - STS/scavenging.

  This option provides cryogenic propellant for use at LEO by combining two propellant delivery methods. One, excess propellant, left over from STS launches, is acquired through a scavenging system contained in the ACC. This propellant, in turn, is off loaded at the Space Station.

  The second method uses tanks carried in the STS cargo bay to carry additional propellant to the Space Station to complete the on-orbit propellant availability requirements.

- 0 Alternative 2 - Shuttle Derived Vehicle (SDV) Tanker.

  The tanker used for this alternative is a vehicle specifically designed to launch heavy payloads into orbit. This vehicle, when configured as a tanker, is capable of delivering large amounts of propellant (181 klb) to the Space Station.

- 0 Alternative 3 - Tanker and Scavenging.

  This alternative combines the scavenging concept with a tanker to provide propellant at the Space Station.

- 0 Competition

  The competition for the alternatives used in this study is propellant tanks carried in the STS cargo bay. This option is selected as the competition since technology for the concept is presently available.

2.4.4 Cost of Alternatives

An economic analysis for each alternative is shown for benefit in Table 2.4-1 and for ROI in Table 2.4-2. The data in these tables are extracted from the list of ground rules and assumptions in paragraph 2.4.2 and converted to discounted dollars.

The present value calculations for discounted dollars assumes a constant distribution of cost and therefore can be simplified to a single factor for propellant delivery and for investment (i.e., DDT&E).

- o Propellant delivery factor: 1.97
- o Investment factor: 2.16

TABLE 2.4-1 BENEFITS (DISCOUNTED $M)

Alternative	STS Prop. Del. Cost	-	Option Prop. Del. Cost	= Benefit
1 STS/Scavenging	$915.4	-	$260.2	= $655.2
2 SDV Tanker	$915.4		$337.4	= $577.0
3 Tanker/Scavenging	$915.4		$217.0	= $698.4

TABLE 2.4-2 RETURN ON INVESTMENT
(Discounted $M)

Alternative	Benefit	Investment (DDT&E)	Adj.	ROI
1 STS/Scavenging	(655.2	/ 116.7)	- 1	= 4.6
2 SDV Tanker	(577.0	/ 1118.0)	- 1	= -0.5
3 Tanker/Scavenging	(698.4	/ 1302.5)	- 1	= -0.5

2.4.5 Alternative Comparison

The results of the propellant delivery analysis are summarized in Table 2.4-3. Alternative 1, scavenging combined with STS cargo bay propellant delivery, is clearly the most advantageous option. The ROI analysis shows a negative value for both Alternatives 2 and 3 indicating that they are not economically viable ventures. The relatively low investment cost of Alternative 1, has a significant effect on the trade study results since it is also a factor used in the ROI and LCC calculations.

The benefit analysis shows a fairly even score among the alternatives with the greatest advantage lying with Alternative 3, SDV/Scavenging. Scavenging, utilized by Alternatives 1 and 3, boosts the benefit score of these alternatives over that of Alternative 2.

The difference in scores between Alternatives 1 and 3 are due to the bulk delivery modes of the options, i.e., cargo bay versus SDV Tanker. As can be seen the SDV Tanker provides the greater benefit of the two.

TABLE 2.4-3 PROPELLANT DELIVERY RESULTS
(Discounted $M)

Economic Factor	OPTION 1 STS/Scavenging	2 SDV/Tanker	3 Tanker/Scavenging
ROI	4.6	-0.5	-0.5
Benefits	$655.2	$577.0	$698.4
Investment (DDT&E)	$116.7	$1188	$1302.5
LCC (DDT&E Ops Cost)	$376.9	$1525.4	$1519.5
SCORES			
ROI	10	0	0
Benefits	9.3	8.2	10
Investment	10	1.0	.9
LCC	10	2.5	2.5

2.4.6 Conclusion

Alternative 1, scavenging combined with STS Cargo Bay propellant delivery, provides the most favorable economic means of delivering propellant to LEO for use in OTV operations. The investment costs associated with the development of SDV tanker makes the use of Alternatives 2 and 3 uneconomical when applied to the Revision 8 Low Mission Model.

It shall be noted that Alternatives 2 and 3 would become more attractive if a greater demand for bulk delivery of propellant to LEO existed, or if the SDV tanker DDT&E was shared with another program (e.g., Space Station). As shown in the study, scavenging provides the most economical means of delivering propellant to LEO, however, the amount of propellant acquired by the scavenging is limited. Space based OTV propellant requirements under the Revision 8 Low Mission Model are mostly satisfied by the scavenging concept. Delivery of the relatively small amount of propellant remaining to meet the on-orbit demand can be satisfied by the STS for less than the cost of developing a new more efficient propellant delivery vehicle. If mission requirements change whereby greater quantities of propellant must be delivered to LEO in bulk, then the use of the SDV tanker becomes more attractive.

The bulk delivery requirement can be affected in two ways. One by a greater demand for propellant at LEO to satisfy OTV operational needs; and, two by the percentage of this demand supplied through scavenging decreasing. In essence, the economic benefit received from a greater number of bulk propellant delivery missions would be needed in order to offset the investment cost of a new tanker vehicle.

2.5 Tank Farm Trade Study

The purpose of the tank farm trade study is to determine the most advantageous means for storing propellant in the vicinity of the Space Station. A free-flying propellant farm, a tethered propellant farm, and a propellant farm located on the Space Station were considered. The technical trades conducted are reported in Volume IV, Section 8.2, of this Final Report. A scoring based on objective and subjective considerations was conducted and the Space Station location was a clear winner for both storable and cryogenic propellants.

We baselined the on-station tank farm as the lowest cost and lowest risk solution, and this approach is reflected in subsequent analyses.

2.6 Storable versus Cryogenic Propellant Trade Study

The purpose of this trade study is to select between storable propellant and cryogenic propellant for use by the OTV.

2.6.1 Approach

This trade includes an analysis of DDT&E, production, and operations costs. These costs are converted from constant dollars to present value dollars and run through return on investment, benefit, and investment analyses in order to provide discriminators useful for making a selection.

2.6.2 Ground Rules and Assumptions

Data used for this trade study were developed under the Revision 7 Nominal Mission Model. The cost of propellant when the mission calculations were run was $500/lb for cryogenic and $600/lb for storable. This cost includes production and delivery to LEO. Although these data were developed using Revision 7, we believe they provide a realistic enough representation of Revision 8 propellant cost to make a selection between the cryogenic and storable propellant options.

Other ground rules and assumptions used in the study follow:

- All costs are in 1985 dollars and exclude fees.
- All cost estimates reflect midterm data (weight, mission model, etc) generated for the cryogenic and storable stage families.
- DDT&E

  Maximum sharing of engineering & tooling efforts between stages was assumed where applicable.

  Ground test hardware includes Static Test Article (STA), Ground Vibration Test Article (GVTA), Main Propulsion Test Article (MPTA) and Functional Test Article.

  Dedicated flight tests required for the ground based OTV; no space based configuration flight test assumed.

  Flight test articles refurbished to operations spares.

  Space Station assessment limited to tank farm impacts.

- Production

  Each unique stage assumes an initial production run of 2 units (1 operation, 1 spare (flight test/GVTA Article refurbished for ground based).

  92% Wright learning curve assumed; learning shared across stages.

  Transportation charges for space based production hardware included in production (68.5M/STS flt) (1.5 flts/full SB stage)

- Operations

  Payload delivery costs assumed the same, transportation costs not included; no reflights included.

  Propellant usage based on 421 missions extracted from the midterm, nominal mission model (32 GB, 389 SB)

  Eastern Test Range Launch only; STS Cost Per Flight (CPF) = $68.5M; Aft Cargo Carrier CPF = 2.3M

  Mission operations at 35 man-yrs/yr

  Full STS user charge for GB OTV; return flight assumed available; storable pays additional transportation charges for the Apogee Kick Motor.

- Space Based

  - IVA = 80 hrs/mission @ $16K/hr; EVA = 4 hrs/mission @ $48K/hr.
  - 2 OMV uses per SB mission per MSFC guidelines (propellant use approx. 500 lb per mission)
    Mission Ops - $16K/hr
    Hardware delivery assumed at 1 STS flight per stage (less brake).

  Aerobrake Life = 5 flights; transportation at 0.33 STS flts./brake
  Engine Life = 20 flights; 0.1 STS flight/engine
  Avionics, Environmental Protection System, structural life = 40 flights; 1 STS flt/replacement

- Facilities

  As clear discriminators for ground based facility cost estimates were not identified at this time, the same requirements were assumed for both items.

2.6.3 Alternatives

The two alternatives identified for this study are storable propellant and cryogenic propellant. The storable propellant considers the combination of N_2O_4/MMH. The cryogenic propellant considered the combination of liquid hydrogen and liquid oxygen.

2.6.4 Cost of Alternatives

The life cycle cost of storable and cryogenic propellants is summarized in Table 2.6-1 and shows the cost for DDT&E, production, and operations in both constant and discounted dollars. It should be noted that cryogenic costs are lower than storable by a factor of 21 percent in constant dollars and 13 percent in discounted dollars. This indicates that the advantage cryogenics hold over storable is reduced as the cost of providing propellants at LEO is reduced. This is significant since the primary cost of the OTV is propellant. If propellant were free, the DDT&E and production costs would be the discriminators and, as indicated in Table 2.6-1, the two alternatives would be essentially equal.

Table 2.6-2 provides a breakout of DDT&E and shows the delta costs for each element. Note that tank farm costs are included. Conceptual designs and equipment lists were developed for the tank farms to determine if this element, along with propellant costs, is a major discriminator. As can be seen, this is not the case since there is only a $21M difference in favor of cryogenic propellants.

Table 2.6-3 provides a breakout of operations cost and shows the delta cost for each element. The table also provides a cost per flight for using storable propellant ($61.24M) and for using cryogenic propellant ($45.50M).

Placed at the end of this trade study section are Tables 2.6-7 and 2.6-8 which contain spread sheets that show greater detail on how LCC were developed for the OTV using both storable and cryogenic propellants. Table 2.6-9, also placed at the back of this section, provides a spread sheet of OTV competition costs. Competition costs represent costing of the mission model using the STS with existing upper stage vehicles or derivatives thereof. The competition cost totals shown at the bottom of the spread sheet are also placed on Tables 2.6-7 and 2.6-8 for ease of comparison.

Table 2.6-4 shows the calculations for a benefit analysis. Calculations for return on investment are shown in Table 2.6-5.

A payback computation is graphically shown in Figure 2.6-1. This computation is based upon a propellant cost of $500/lb for cryogenic and $600/lb for storable-propellant. The delta propellant cost per pound for onorbit propellant is due to the difference in STS delivery requirements and scavenging opportunity. The delta reflects a conservative estimate of the additional storable propellant requirements and subsequent higher propellant unit cost of the scavenging/delivered mix. As shown in the Figure, the cryogenic propellant holds an advantage over storable propellant. This advantage will change proportionally with the amount of propellant required, thus a more optimistic mission model would show a proportionally greater advantage for cryogenic propellants.

TABLE 2.6-1 STORABLE VS CRYOGENIC STAGE TOP LEVEL COMPARISON

CONSTANT $M	STORABLE	CRYO	DELTA
DDT&E	1238.23	1364.73	-126.50
PRODUCTION	314.28	237.84	76.56
OPERATIONS	8879.45	6598.15	2281.30
	--------	-------	-------
TOTAL	10431.96	8200.72	2231.24
	Cryo % Reduction = 21		

DISCOUNTED $M	STORABLE	CRYO	DELTA
DDT&E	586.90	670.40	-83.50
Production	74.60	56.40	18.20
Operations	1956.60	1552.00	404.60
	--------	-------	-------
TOTAL LCC	2618.10	2278.80	339.30
	Cryo % Reduction = 13		

Competition LCC* 25365 (Constant $M)
4974 (Discounted $M) (See Table 5.7.3-23)

*Does not include DDT&E

TABLE 2.6-2 STORABLE VS CRYOGENIC STAGE DDT&E COMPARISON (CONSTANT $M)

	STORABLE	CRYOGENIC	DELTA
D&D	398.10	491.50	-93.40
ASE/GSE/SSE	39.80	39.30	0.50
Software	71.80	69.00	2.80
Tooling	19.40	19.50	-0.10
SE&I	91.80	108.00	-16.20
Test Hardware	128.50	142.50	-14.00
Test Ops	22.50	26.10	-3.60
Test Fixtures	3.90	4.50	-0.60
Prog Manage.	46.60	54.00	-7.40
Stage DDT&E	822.40	954.40	-132.00
Level II			
PM, SE&I, Test	156.30	171.80	-15.50
Test Flts	68.50	68.50	0.00
Tank Farm	191.00	170.00	21.00
Program Management	16.60	14.80	1.80
D&D/SE&I	141.80	122.20	19.60
Tooling	15.80	13.70	2.00
Test Hardware	5.30	9.60	-4.30
Test Ops/Fixtures	11.50	10.30	1.20
DDT&E Total	1238.20	1364.70	-126.50

TABLE 2.6-3 STORABLE VS CRYOGENIC STAGE OPERATIONS COMPARISON (CONSTANT $M)

	STORABLE	CRYOGENIC	DELTA
PROP OPS/GB DELIVERY	7363.80	5217.60	2146.20
Mission OPS	44.10	44.10	0.00
IVA	145.30	145.30	0.00
EVA	21.10	21.10	0.00
Stage Hw Refur/Spares	55.30	49.00	6.30
Eng Replacement	15.50	18.30	-2.80
Aero Replacement	100.70	162.10	-61.40
OMV Use	66.70	66.70	0.00
Prog Management	72.00	62.80	9.20
Sustaining Eng	32.30	35.00	-2.80
TOTAL	7916.70	5822.0	2094.70
STS Del of Eng & Str & Prod Hdw	309.90	220.80	89.10
STS Del of Aerobrake	607.30	498.60	108.70
Tank Farm Ops	45.60	56.80	-11.20
*Compressor Repair	6.10	8.90	- 2.80
*Major Overhaul	22.30	18.80	3.50
EVA for C/O	17.20	17.30	- 0.10
Boiloff	-	11.80	-11.80
TOTAL OPS	8879.50	6598.20	2281.30
CPF COMPOSITE	61.24	45.50	15.73

* Includes related EVA/IVA

TABLE 2.6-4 STORABLE/CRYOGENIC BENEFIT (DISCOUNTED $M)

Alternative	Competition Cost		Propellant Cost		Benefit
Storable	4974	-	2618	=	2356
Cryogenic	4974	-	2278	=	2696

TABLE 2.6-5 STORABLE/CRYOGENIC STAGE RETURN ON INVESTMENT

Alternative	Competition Cost	Propellant Cost	DDT&E	ROI
Storable	((4974 -	2618)	/ 586.9) - 1 =	3.01
Cryogenic	((4974 -	2278)	/ 670.4) - 1 =	3.02

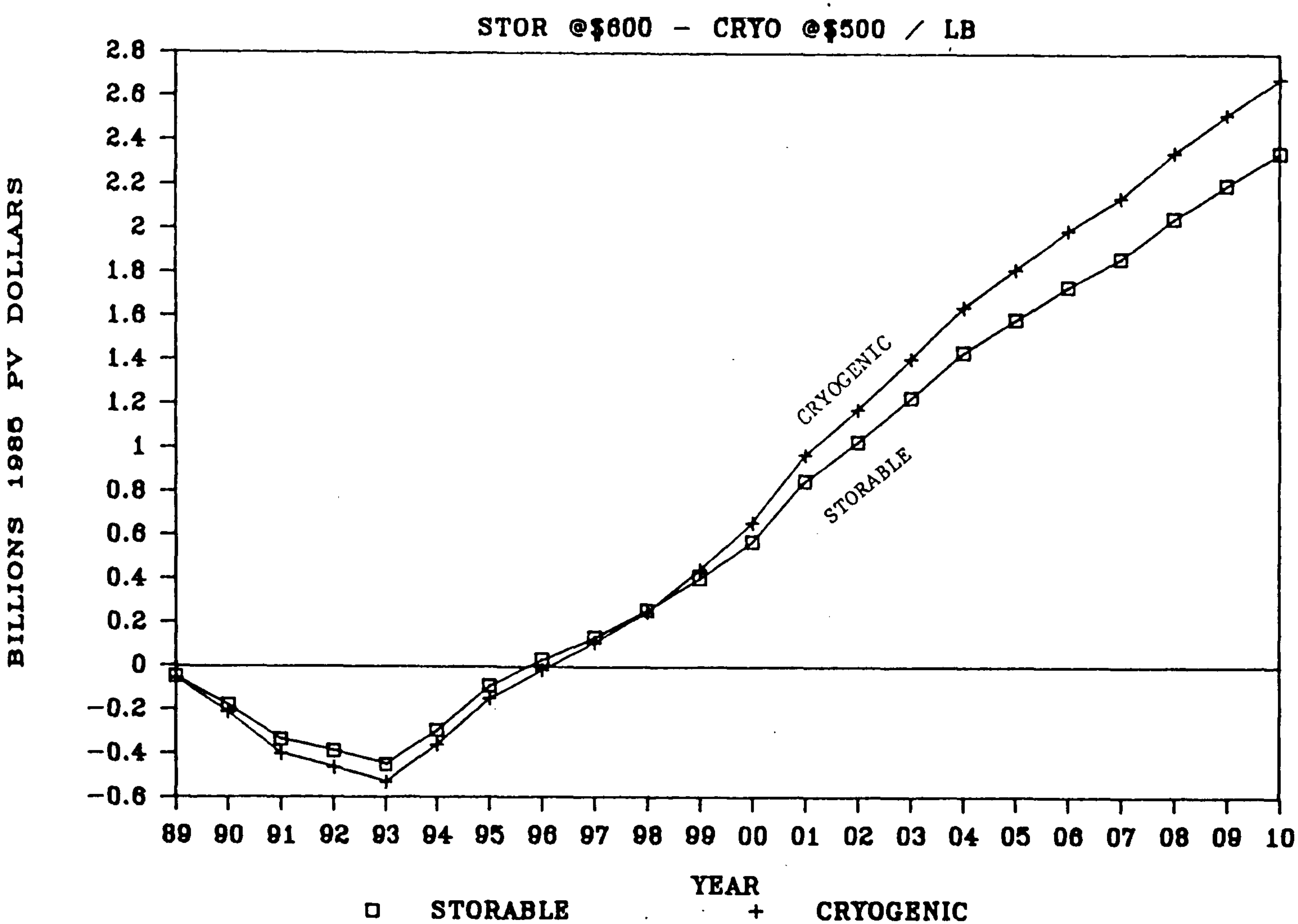


FIGURE 2.6-1 STORABLE VS CRYOGENIC PAYBACK COMPARISON

2.6.5 Alternative Comparison

Table 2.6-6 provides a comparison of the principal economic factors. It also provides a score ranking the most favorable alternative 10 and the other alternative with a value relative to the better option.

Table 2.6-6 OTV Storable Versus Cryogenic Propellant Trade Results

Economic Factor	Storable	Cryogenic
Return on Investment	3.01	3.02
Benefits	2356.0	2696.0
Investment	586.9	670.4
SCORE		
Return on Investment	9.9	10
Benefits	8.7	10
Investment	10	8.8

2.6.6 Conclusion

The cryogenic alternative is recommended as the preferred OTV propellants. The return on investment between the two options is essentially the same, however the cryogenic alternative advantage becomes greater as propellant requirements increase. This option therefore provides greater flexibility for growth.

The benefit analysis places the advantage on the side of the cryogenic propellant. The main disadvantage for cryogenic when comparing the two options lies in DDT&E costs. This difference, however, is not significant and both options can be considered to be affordable.

It should also be noted that, if OTV requirements change to include extended dwell time on orbit, the use of storable propellants should be revisited.

TABLE 2.6-7 STORABLE/COMPETITION LCC COMPARISON

YEAR	1989.00	1990.00	1991.00	1992.00	1993.00	1994.00	1995.00	1996.00	1997.00	1998.00	1999.00	2000.00	2001.00	2002.00	2003.00	2004.00	2005.00	2006.00	2007.00	2008.00	2009.00	2010.00	TOTAL
MISSIONS EXP																							
MISSION OTV						7.00	7.00	7.00	7.00	7.00	7.00	8.00	9.00	7.00	9.00	9.00	8.00	10.00	9.00	11.00	12.00	11.00	145.00
OTV DDT&E																							
37K GB	69.63	208.90	278.53	104.45	103.32																		764.82
53K SB						16.09	48.27	64.36	24.14	8.04													160.91
25&81K SB							9.12	27.35	36.46	13.67	4.56				3.04	9.12	12.15	4.56	1.52				121.54
TANK FARM									95.48	95.48													190.96
TOTAL	69.63	208.90	278.53	104.45	103.32	16.09	57.39	91.71	156.08	117.20	4.56	0.00	0.00	0.00	3.04	9.12	12.15	4.56	1.52	0.00	0.00	0.00	1238.23
PROD																							
37K GB					28.64																		28.64
53K SB										42.15	42.15												84.30
25&81K SB											42.96	42.96							48.03	48.03			181.98
TANK FARM											19.36												19.36
TOTAL	0.00	0.00	0.00	0.00	28.64	0.00	0.00	0.00	0.00	42.15	104.47	42.96	0.00	0.00	0.00	0.00	0.00	0.00	48.03	48.03	0.00	0.00	314.28
OPS	0.00	0.00	0.00	0.00	0.00	570.29	570.29	570.29	570.29	570.29	383.60	438.40	493.20	383.60	493.20	493.20	438.40	548.00	493.20	602.80	657.60	602.80	8879.45
TOTAL LCC	69.63	208.90	278.53	104.45	131.96	586.38	627.68	662.00	726.37	729.64	492.63	481.36	493.20	383.60	496.24	502.32	450.55	552.56	542.75	650.83	657.60	602.80	10431.96
CUM LCC	69.63	278.53	557.06	661.50	793.46	1379.84	2007.52	2669.52	3395.89	4125.53	4618.16	5099.52	5592.72	5976.32	6472.55	6974.87	7425.42	7977.98	8520.73	9171.56	9829.16	10431.96	
DISCOUNTED	47.56	129.71	157.22	53.60	61.56	248.68	242.00	232.03	231.44	211.35	129.72	115.23	107.33	75.89	89.25	82.13	66.97	74.67	66.67	72.68	66.76	55.64	2618.12
CUM DISC	47.56	177.27	334.49	388.09	449.65	698.33	940.33	1172.35	1403.80	1615.15	1744.87	1860.10	1967.44	2043.33	2132.58	2214.72	2281.69	2356.36	2423.03	2495.72	2562.48	2618.12	
COMPET. LCC	0.00	0.00	0.00	0.00	0.00	956.00	1158.00	1010.00	1062.00	1158.00	1055.00	1191.00	1757.00	1290.00	1625.00	1782.00	1451.00	1675.00	1583.00	2276.00	2147.00	2188.00	25364.00
CUM LCC	0.00	0.00	0.00	0.00	0.00	956.00	2114.00	3124.00	4186.00	5344.00	6399.00	7590.00	9347.00	10637.00	12262.00	14044.00	15495.00	17170.00	18753.00	21029.00	23176.00	25364.00	
COMPET. DISC						406.00	446.00	354.00	333.00	335.00	278.00	285.00	382.00	255.00	292.00	291.00	216.00	226.00	194.00	254.00	218.00	202.00	4967.00
COMP CUM	0.00	0.00	0.00	0.00	0.00	406.00	852.00	1206.00	1539.00	1874.00	2152.00	2437.00	2819.00	3074.00	3366.00	3657.00	3873.00	4099.00	4293.00	4547.00	4765.00	4967.00	
MISS CUM	0.00	0.00	0.00	0.00	0.00	7.00	14.00	21.00	28.00	35.00	42.00	50.00	59.00	66.00	75.00	84.00	92.00	102.00	111.00	122.00	134.00	145.00	

TABLE 2.6-8 CRYOGENIC/COMPETITION LCC COMPARISON

YEAR	1989.00	1990.00	1991.00	1992.00	1993.00	1994.00	1995.00	1996.00	1997.00	1998.00	1999.00	2000.00	2001.00	2002.00	2003.00	2004.00	2005.00	2006.00	2007.00	2008.00	2009.00	2010.00	TOTAL
MISSIONS EXP																							
MISSION OTV						7.00	7.00	7.00	7.00	7.00	7.00	8.00	9.00	7.00	9.00	9.00	8.00	10.00	9.00	11.00	12.00	11.00	145.00
OTV DDT&E																							
45K GB	83.48	250.45	333.93	125.22	110.24																		903.33
55K SB						27.66	82.97	110.63	41.49	13.83													276.58
81K SB															1.48	4.45	5.93	2.22	.74				14.82
TANK FARM									85.00	85.00													170.00
TOTAL	83.48	250.45	333.93	125.22	110.24	27.66	82.97	110.63	126.49	98.83	0.00	0.00	0.00	0.00	1.48	4.45	5.93	2.22	.74	0.00	0.00	0.00	1364.73
PROD																							
45K GB					32.62																		32.62
55K SB										48.13	48.13												96.26
81K SB																			48.48	48.48			96.96
TANK FARM											12.00												12.00
TOTAL	0.00	0.00	0.00	0.00	32.62	0.00	0.00	0.00	0.00	48.13	60.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.48	48.48	0.00	0.00	237.84
OPS	0.00	0.00	0.00	0.00	0.00	523.67	523.67	523.67	523.67	523.67	253.26	289.44	325.62	253.26	325.62	325.62	289.44	361.80	325.62	397.98	434.16	397.98	6598.15
TOTAL LCC	83.48	250.45	333.93	125.22	142.86	551.33	606.64	634.30	650.16	670.63	313.39	289.44	325.62	253.26	327.10	330.07	295.37	364.02	374.84	446.46	434.16	397.98	8200.72
CUM LCC	83.48	333.93	667.86	793.09	935.95	1487.28	2093.92	2728.22	3378.38	4049.01	4362.40	4651.84	4977.46	5230.72	5557.82	5887.89	6183.26	6547.28	6922.12	7368.58	7802.74	8200.72	
DISCOUNTED	57.02	155.51	188.50	64.26	66.64	233.82	233.89	222.32	207.16	194.26	82.52	69.29	70.86	50.11	58.83	53.97	43.90	49.19	46.05	49.86	44.08	36.73	2278.77
CUM DISC	57.02	212.53	401.02	465.28	531.93	765.75	999.64	1221.95	1429.11	1623.37	1705.90	1775.19	1846.05	1896.16	1954.99	2008.96	2052.86	2102.05	2148.10	2197.96	2242.04	2278.77	
COMPET. LCC	0.00	0.00	0.00	0.00	0.00	956.00	1158.00	1010.00	1062.00	1158.00	1055.00	1191.00	1757.00	1290.00	1625.00	1782.00	1451.00	1675.00	1583.00	2276.00	2147.00	2188.00	25364.00
CUM LCC	0.00	0.00	0.00	0.00	0.00	956.00	2114.00	3124.00	4186.00	5344.00	6399.00	7590.00	9347.00	10637.00	12262.00	14044.00	15495.00	17170.00	18753.00	21029.00	23176.00	25364.00	
COMPET. DISC						406.00	446.00	354.00	333.00	335.00	278.00	285.00	382.00	255.00	292.00	291.00	216.00	226.00	194.00	254.00	218.00	202.00	4967.00
COMP CUM	0.00	0.00	0.00	0.00	0.00	406.00	852.00	1206.00	1539.00	1874.00	2152.00	2437.00	2819.00	3074.00	3366.00	3657.00	3873.00	4099.00	4293.00	4547.00	4765.00	4967.00	
MISS CUM	0.00	0.00	0.00	0.00	0.00	7.00	14.00	21.00	28.00	35.00	42.00	50.00	59.00	66.00	75.00	84.00	92.00	102.00	111.00	122.00	134.00	145.00	

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TABLE 2.6-9 COMPETITION MISSION MODEL CAPTURE

REV. 7 NOMINAL

MISSION NUMBER	P/L WEIGHT (POUNDS)	P/L LENGTH (FEET)	COMPETITION	STAGE WEIGHT (POUNDS)	STAGE LENGTH (FEET)	STAGE COST (M$)	STS DEL TO LEO (M$)	TOTAL CPF (M$)	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	MISSION TOTAL	REMARKS
									COST PER YEAR (MILLION 1985 DOLLARS)																		
GEOSTATIONARY PLATFORMS																											
13006 EXPERIMENTAL GEO PLATFORM	12017	31.17	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0	128	SINGLE STS DELIVERY MAX GEO P/L 13200
13700 COMMERCIAL GEO PLATFORM	20000	35	STS/CENTAUR G'	63336	29.1	55.4	130	185.4	0	0	0	0	0	0	0	0	0	0	185	0	0	185	185	185	185	927	2 STS FLTS REQ ON-ORBIT: TOP OFF PROPELLANT MATE STAGE & P/L MAX GEO P/L 19500
INDIVIDUAL SATELLITES																											
18073 MRS-C	12000	35	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0	0	128	SINGLE STS DELIVERY MAX GEO P/L 13200
18040 GEO EARTH OBSERVATION SYSTEM	20000	20	STS/CENTAUR G'	63336	29.1	55.4	105.1	160.5	0	0	0	0	0	0	0	161	0	0	0	0	0	0	0	0	0	161	SAME AS MSN 13700
18722 INDIVIDUAL PLATFORM	20000	35	STS/CENTAUR G'	63336	29.1	55.4	130	185.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	185	185	SAME AS MSN 13700
PLANETARY SCENARIO																											
17081 S/C P/L UP P/L DN NEAR	4079 TBD 0	5 TBD 0	STS/TOS-AMS	37402	16.5	48	56.2	104.2	104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104	MAX GEO P/L 5935 lbs DIA 10.0
17084 S/C P/L UP P/L DN MSP	4410 4410 0	35 35 0	STS/TOS-AMS	37402	16.5	48	73	121	0	0	0	0	0	121	0	0	0	0	0	0	0	0	0	0	0	121	MAX GEO P/L 5935 lbs DIA 10.0
17075 S/C P/L UP P/L DN OBSERVER X	5000 TBD 0	5 TBD 0	STS/CENTAUR G	46390	19.5	55.4	69.5	124.9	0	0	125	0	0	0	0	0	0	125	0	0	0	0	0	0	0	250	MAX GEO P/L 10000
17074 S/C P/L UP P/L DN MF/P	3497 TBD 0	10 TBD 0	STS/CENTAUR G'	63336	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0	0	128	SAME AS MSN 13700

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TABLE 2.6-9 COMPETITION MISSION MODEL CAPTURE (CONTINUED)

MISSION NUMBER	P/L WEIGHT (POUNDS)	P/L LENGTH (FEET)	COMPETITION	STAGE WEIGHT (POUNDS)	STAGE LENGTH (FEET)	STAGE COST (M$)	STS DEL TO LEO (M$)	TOTAL CPF (M$)	COST PER YEAR (MILLION 1985 DOLLARS) 94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	MISSION TOTAL	REMARKS
17078 S/C	2205	10	STS/TOS-AMS	37402	16.5	48	53.3	101.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	101	0	101	MAX GEO P/L 5935 lbs
P/L UP	2205	10																									DIA 10.0
P/L DN	0	0																									
MD/L																											
MULTIPLE PAYLOAD DELIVERY SCENARIO																											
18912 A UP	12000	25	STS/PAM-D2	11215	6.5	11.37	20.7	32.07	128	128	0	128	128	0	128	0	0	128	0	0	128	0	0	128	0	1026	MAX GEO P/L 2030 lbs
DN	2000	5																									DIA 5.3'
4/1 MULTIPLING (0-2030 lb)																											
18912 B UP	12000	25	STS/TOS-AMS	37402	16.5	48	53.9	101.9	0	306	0	0	306	0	0	306	0	0	306	0	0	0	306	0	0	1529	MAX GEO P/L 5935 lbs
DN	2000	5																									DIA 10.0
3/1 MULTIPLING (2031-2500 lb)																											
18912 C UP	12000	25	STS/TOS-AMS	37402	16.5	48	57.1	105.1	210	210	210	420	210	420	420	420	420	631	420	420	420	420	631	420	631	6937	MAX GEO P/L 5935 lbs
DN	2000	5																									DIA 10.0
2/1 MULTIPLING (2501-4800 lb)																											
GEO SERVICING																											
13002 S/C UP	1690	15	STS/CENTAUR G	46390	19.5	55.4	73	128.4	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	128	MAX GEO P/L 10000
S/C DN	200	15																									
P/L UP	7000	15																									
P/L DN	4510	15																									
EXPERIMENTAL GEO PLATFORM SERVICING DEMO																											
15700 UP	7500	10	STS/CENTAUR (MAN-RATED)			138.5	146	284.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	285	285	285	854	MR VEHICLE COST EQUIVALENT OF 2.5 CENTAUR G's DDT&E: $200M OVER 2 YEARS 2 STS FLIGHTS PER MISSION MODEL FLT
DOWN	7500	10																									
MANNED SERVICING SORTIE																											
GEO SERVICE STATION LOGISTICS SCENARIO																											
15008	13159	15	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	128	SINGLE STS DELIVERY MAX GEO P/L 13200
MOBILE GEO SERVICE STATION																											
15009	13310	20	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0	128	SINGLE STS DELIVERY MAX GEO P/L 13200
GEO HABITAT/WORK STATION																											
15701 UP	12000	15	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	0	0	128	128	128	0	128	128	0	642	SINGLE STS DELIVERY MAX GEO P/L 13200
DOWN	2000	15																									
MOBILE GEO SERVICE STATION LOGISTICS																											

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TABLE 2.6-9 COMPETITION MISSION MODEL CAPTURE (CONTINUED)

MISSION NUMBER	P/L WEIGHT (POUNDS)	P/L LENGTH (FEET)	COMPETITION	STAGE WEIGHT (POUNDS)	STAGE LENGTH (FEET)	STAGE COST (M$)	STS DEL TO LEO (M$)	TOTAL CPF (M$)
LUNAR BASE PROGRAM SCENARIO								
17200 S/C	5000	20	STS/TOS-AMS	37402	16.5	48	59.2	107.2
P/L UP	5000	20						
P/L DN	0	0						
LUNAR COMMUNICATIONS RELAY								
17202 UP	20000	18	STS/CENTAUR G'	63336	29.1	55.4	102.2	157.6
DOWN	0	0						
LUNAR SURFACE EXPLORER								
DOD								
19031 GENERIC 1	12000	30	STS/CENTAUR G'	51800	29.1	55.4	73	128.4
19035 GENERIC 2	20000	35	STS/CENTAUR G'	63336	29.1	55.4	130	185.4
REFLIGHTS								
10100 REFLIGHTS (1/16)	20000	20	STS/CENTAUR G'	63336	29.1	55.4	105.4	160.8

COST PER YEAR (MILLION 1985 DOLLARS)

MISSION NUMBER	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	MISSION TOTAL	REMARKS
17200 S/C	0	0	0	0	0	0	0	0	0	0	0	0	0	107	0	0	0	107	MAX GEO P/L 5935 lbs DIA 10.0
17202 UP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	158	0	158	SAME AS MSN 13700
19031 GENERIC 1	514	514	514	514	514	514	514	0	0	0	0	0	0	0	0	0	0	3595	SINGLE STS DELIVERY MAX GEO P/L 13200
19035 GENERIC 2	0	0	0	0	0	0	0	742	742	742	742	742	742	742	742	742	742	7416	SAME AS MSN 13700
10100 REFLIGHTS (1/16)	0	0	161	0	0	0	0	0	0	0	0	161	0	0	0	0	161	482	SAME AS MSN 13700
TOTALS: CONSTANT 1985 DOLLARS	956	1158	1010	1062	1158	1055	1191	1757	1290	1625	1782	1451	1675	1583	2276	2147	2188	25365	
PV FACTOR (0% INFLATION, 10% DISCOUNT)	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15	0.14	0.12	0.11	0.10	0.09		
PRESENT VALUE 1985 DOLLARS	406	446	354	338	335	278	285	382	255	292	291	216	226	194	254	218	202	4974	

AVERAGE COST PER FLIGHT: (210 FLIGHTS WITH MULTIPLE P/L MISSIONS)
CONSTANT DOLLARS $120.8
PRESENT VALUE DOLLARS $23.7

2.7 Evolutionary Strategy Trade Study

The purpose of the evolutionary trade study is to select an Orbital Transfer Vehicle (OTV) development path that will accommodate all missions set forth in Revision 8 of the Marshall Space Flight Center (MSFC) Low Mission Model. The options cover both ground based and space based operations as well as unmanned and manned missions. Six options which provide the strategies studied are illustrated in Figure 2.7-1. These same options are shown with time phasing in Figure 2.7-2.

Options 2 and 6 are identical except that during ground based operations Option 2 employs an Aft Cargo Carrier (ACC) to deliver the OTV to Low Earth Orbit (LEO) and Option 6 uses the cargo bay. Selecting between these two options becomes more complex in that the investment cost for developing the ACC should be shared with the scavenging operation if scavenging is to also use the ACC.

Due to the similarities and complexities associated with Options 2 and 6, they are addressed first in a subtrade study to eliminate one or the other from contention. This subtrade is designated as Step 1. Step 2 of the trade study evaluates the surviving option from Step 1 along with the other remaining trade study options. From this group, the option representing the preferred overall evolutionary strategy is selected.

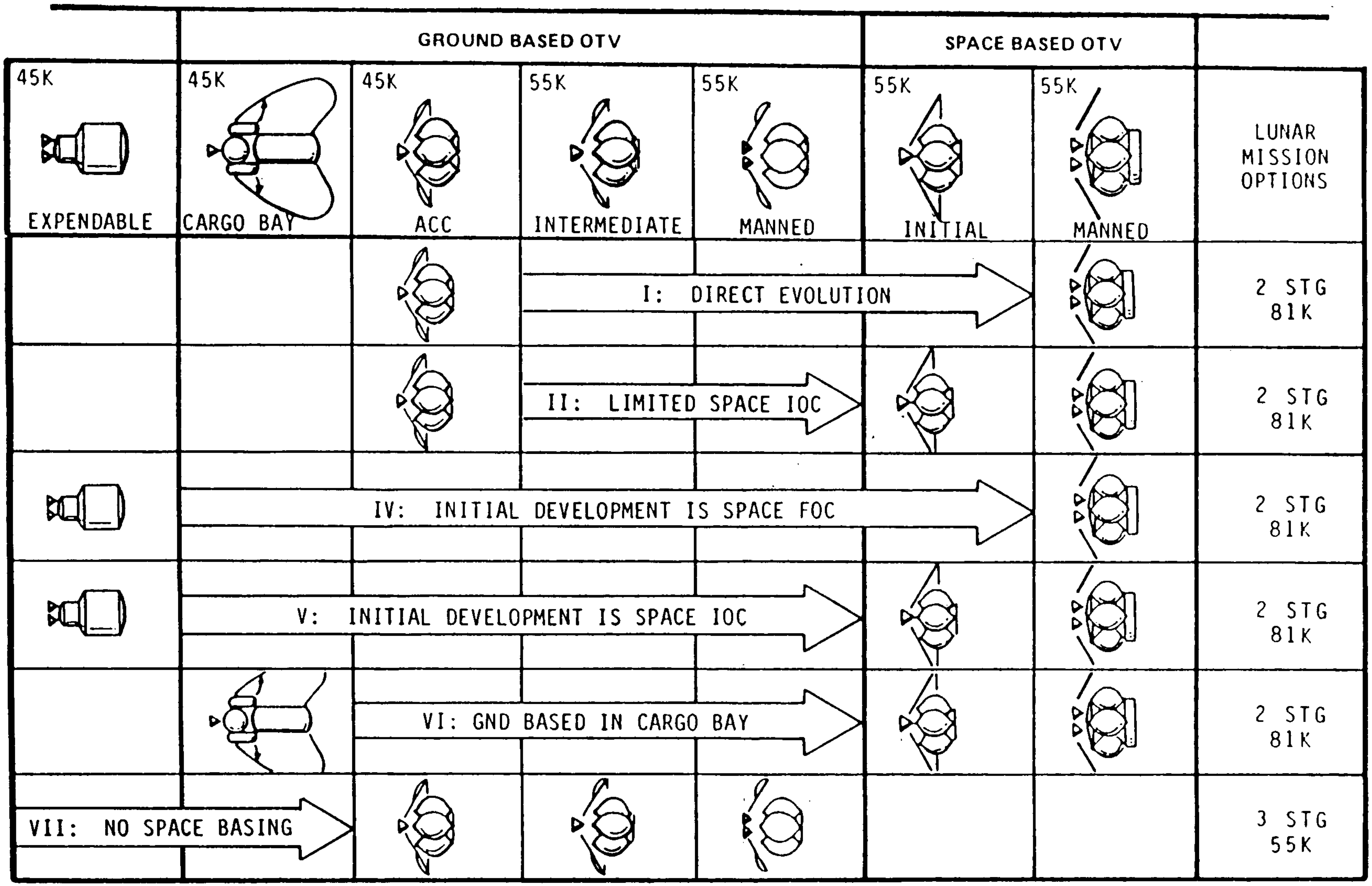


FIGURE 2.7-1 ALTERNATIVE OTV GROWTH PATHS

OPTION	GB IOC 94 95 96 97 98	SB IOC 99 00 01 02 03 04 05 06 07	MAN-RATED 08 09 10
1	----- GBU ------	--------------- SBM -----------	--------
2	----- GBU ------	--------------- SBU -----------	--SBM---
3	DELETED		
4	----- EXU ------	--------------- SBM -----------	--------
5	----- EXU ------	--------------- SBU -----------	--SBM---
6	--- GBU (CB) ---	--------------- SBU -----------	--SBM---
7	---- GBU ------	--------------- GBU (55K)-------	--GBM---

LEGEND:

GBU	45 klb Ground Based Nonman-rated
SBU	55 klb Space Based Nonman-rated
SBM	55 klb Space Based Man-rated
GBM	55 klb Ground Based Man-rated
EXU	Expendable Nonman-rated
CB	STS Cargo Bay
ACC	Aft Cargo Carrier

NOTE:
1. All space based OTVs are delivered in the STS cargo bay.
2. All ground based OTVs are delivered in the ACC except as noted in Option 6.

FIGURE 2.7-2 OTV CONFIGURATION EVOLUTION

2.7.1 Ground Rules and Assumptions

Ground rules and assumptions which apply to the trade study are shown below. They are consistent with the OTV ground rules provided by the MSFC.

- o GENERAL
  - Constant fiscal year 1985 dollars excluding fee and contingency
  - Discount rate of 10% per year

- o Research and Technology (R&T)
  - Assumed $100M for Aeroassist Flight Experiment (AFE) flight and $59M for advanced engine technology base for both candidates

- o Design Development Test and Evaluation (DDT&E)
  - Ground test hardware includes Static Test Article (STA), Ground Vibration Test Article (GVTA), Main Propulsion Test Article (MPTA), and functional test article: Follow-on stages include ground test hardware as required.
  - Dedicated flight test required for initial stage: includes Space Transportation System (STS) delivery and propellants.
  - Flight test article and GVTA of initial stage refurbished to meet operational requirements.
  - Ground Based (GB) ACC version includes ACC DDT&E ($163M); CB version includes $27M impact for orbiter bay modifications
  - All options include DDT&E for payload (P/L) clustering structure
  - Maximum sharing of engineering and tooling effort between stages assumed where applicable (evolutionary approach).
  - Supporting program DDT&E included per ground rules where applicable (e.g., Space Station accommodations and tank for ACC and propellant scavenging).

- o PROVISIONS
  - Each evolutionary stage requires two stages at Initial Operational Capability (IOC) (1 operations unit, 1 spare)
    - -- Refurbished DDT&E hardware credited to initial option stage
    - -- No learning on stages assumed due to small production run
    - -- Each evolutionary option stage requires 2 P/L clustering structures (1 operations unit, 1 spare)
    - -- Transportation charges of production hardware allocated to operations

- o OPERATIONS
  - P/L transportation costs included for all options according to STS program user charge guidelines
    - -- 1994-1998 P/L's and GB OTV stages were considered an integral P/L unit and charged accordingly
    - -- Space Based Payloads (1999-2010) were charged according to user charge guidelines.
    - -- Option 7 (GB evolutionary option) P/L's were charged in the same manner as 1999-2010 Space Based (SB) payloads (less than 6% of the missions may potentially be manifested with the stage hardware on a single shuttle)

- o OPERATIONS (Continued)
  - STS user charge of $73M per flight, ACC charge of $2.3M where applicable.
  - Low Mission Model (145 flights)
  - Ground based Mission operations at 35 Man-yrs/yr throughout operations period
  - Expendable stages (Options 4 & 5, 1994-1998)
    - -- Operations (OPS) cost includes stage Cost per Flight (CPF) and STS delivery of stage hardware and mission payload
  - Ground Based OTV
    - -- Operations costs consistent with ACC - CB GB OTV Trade Study
    - -- GB OTV stages for Option 7 (1999-1010) assume 1 shuttle flight per mission for hardware delivery
  - Space Based OTV
    - -- Space Station Intra Vehicular Activity (IVA) calculated on a per mission basis at $15K/hr
    - -- 2 Orbital Maneuvering Vehicle (OMV) uses per mission cost according to study ground rules at 2 hrs out, 1.5 hrs back and average of 500 lb propellant per mission
    - -- No Space Based Mission OPS or Extra Vehicular Activity (EVA) required
    - -- STS costs include delivery of initial operational unit and spares as required
    - -- On-orbit propellant costs are composite average of scavenged and STS tanker costs, determined by option usage ($330 to $360/lb)
  - Operations Spares
    - -- STS transportation applicable only to SB stages
    - -- Aerobrake Life = 5 flights; 0.34 STS flts/brake
    - -- Engine Life = 10 flights; 0.1 STS flt/engine
    - -- Avionics, EPS, STR Life = 40 flights; 1 STS flt/replacement

- o PRODUCTION
  - Production for both options includes 2 P/L clustering structures (1 operations, 1 spare)
  - No stage production is required due to refurbishment of DDT&E hardware and low flight rates.

- o FACILITIES
  - Facilities costs include
    - -- Provisions for manufacturing facility for initial stage and refurbishment hardware
    - -- Dedicated OTV Launch Processing Facility [Kennedy Space Center (KSC)]
    - -- Mission operations area at existing KSC facility

- o BENEFITS
  - STS benefits are based on 50% of the calculated weight and volume potential after the ground based OTV and STS payloads are manifested. Each of the P/Ls were manifested with stage for both an ACC and a cargo bay OTV concept. The amount of total volume and weight performance remaining represented potential STS P/L capability that could be utilized for other non-OTV P/Ls. The 50% factor represents a rough probability of how much of this additional potential might be used.

2.7.2 Step 1: ACC versus Cargo Bay for OTV Delivery/Scavenging.

As discussed in the introduction to this trade study the purpose of this subtrade analysis is two fold. One is to select either Option 2 (OTV in ACC) or Option 6 (OTV in STS Cargo Bay) as the preferred evolutionary OTV development strategy (Figure 2.7-2). The other is to select between the ACC and the STS cargo bay the most economic way to deliver the OTV to LEO during ground based operations and to deliver scavenged propellant to LEO during space based operations. OTV delivery and scavenging are correlated and the preferred delivery mode depends on the combined economics of the two systems. This selection, in turn, will provide the answer to the first part of the analysis and thus select either the ACC (Option 2) or the STS cargo bay (Option 6) as the preferred OTV evolutionary developmental strategy. The following therefore addresses the economy of OTV delivery and scavenging.

2.7.2.1 OTV Delivery/Scavenging Alternatives

Four possible combinations exist for delivering the OTV or scavenged propellant to LEO. The matrix in Figure 2.7.2-1 shows how the alternatives listed below were derived. The first designation listed represents the OTV delivery mode and the second represents scavenging.

- o Alternative 1 CB/ACC
- o Alternative 2 CB/CB
- o Alternative 3 ACC/ACC
- o Alternative 4 ACC/CB

		SCAVENGING SYSTEM	
		ACC	CARGO BAY
OTV DELIVERY	CARGO BAY	1	2
	ACC	3	4

FIGURE 2.7.2-1 CARGO BAY VS ACC SCAVENGING

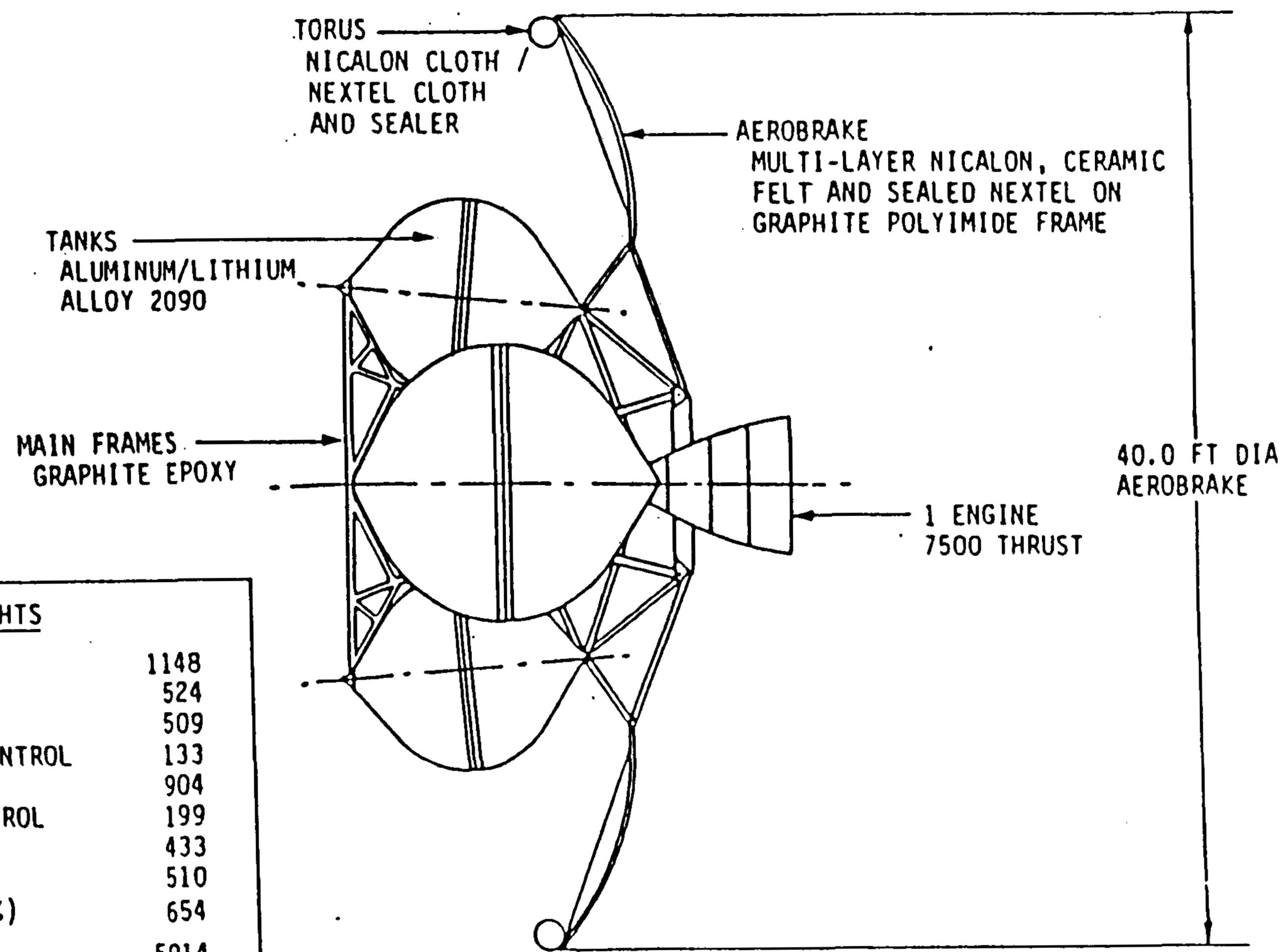
2.7.2.2 Cost of OTV Delivery/Scavenging Alternatives

The cost of the OTV delivery/scavenging alternatives is done in four parts. First is the OTV delivery computations for both the ACC and CB modes, next is the scavaging computations in both the ACC and CB modes, third is the computations for the OTV delivery and scavaging competition, and finally the computation for the STS benefit factor.

2.7.2.2.1 OTV Delivery Computations

Computations for OTV delivery to LEO are based upon the configurations for the ACC and CB as shown in Figures 2.7.2-2 and 2.7.2-3 respectively. A synopsis of a typical Geostationary Earth Orbit (GEO) payload delivery mission using these configurations is shown in Figure 2.7.2-4 for the ACC and Figure 2.7.2-5 for the CB. As can be seen, the cargo bay scenario is significantly less complex both in terms of OTV operations and on-orbit integration. This issue is traded against the increased benefits derived from freeing additional STS cargo bay space by placing the OTV in the ACC.

The Martin Marietta Life Cycle Cost (LCC) Model was used to derive the OTV delivery cost data for the ACC and CB configurations shown in Tables 2.7.2-1 through 2.7.2-4. These data are used to form the basis for the OTV economic analysis described in paragraph 2.7.2.3 below. Tables 2.7.2-1 and 2.7.2-2 show the LCC associated with each configuration in constant dollars and present value (PV) dollars respectively.



WEIGHTS	
AEROBRAKE	1148
TANKS	524
STRUCTURE	509
ENVIRONMENTAL CONTROL	133
MAIN PROPULSION	904
ORIENTATION CONTROL	199
ELECTRIC POWER	433
AVIONICS	510
CONTINGENCY (15%)	654
DRY WEIGHT	5014
PROPELLANTS, ETC	45349
LOADED WEIGHT	50363

FIGURE 2.7.2-2 GROUND BASED ACC OTV (NONMAN-RATED)

GROUND BASED CARGO BAY OTV

VEHICLE DATA

CRYOGENIC PROPELLANT	
TANK SIZE	48434 lbs
DRY WEIGHT	8642 lbs
LOADED WEIGHT	57076 lbs
ASE	5000 lbs
PAD WEIGHT	62076 lbs
SINGLE ENGINE	
THRUST	7500 lbs
ISP	475 sec
AVIONICS: SINGLE FAULT TOLERANT	

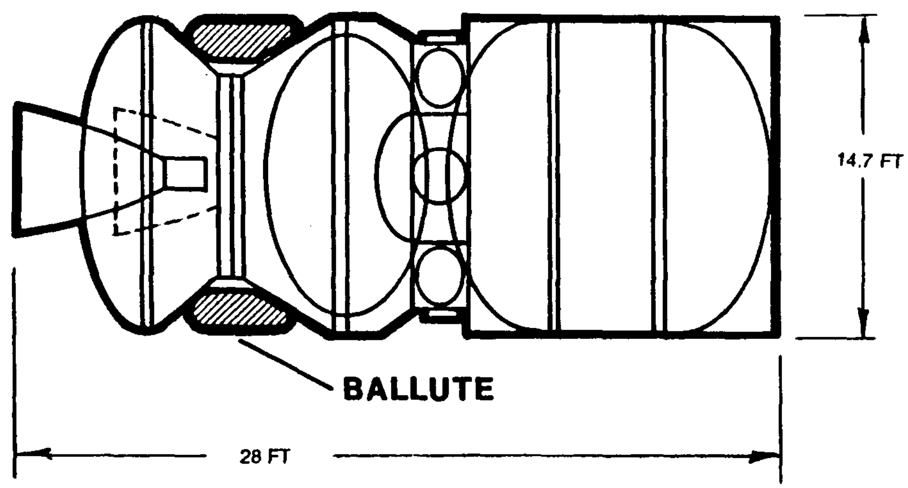


FIGURE 2.7.2-3 GROUND BASED CARGO BAY OTV

TIME (H:M:S)	EVENT
00:00:00	LAUNCH
00:08:2	MECO
00:08:350	OTV SEPARATION
00:09:35	DEPLOY AEROBRAKE
00:12:20	ORBITER OMS-1
00:33:290	OTV BOOST-1
00:44:20	ORBITER OMS-2
01:25:140	OTV BOOST-2
21:30:00	ORBITER RENDEZVOUS WITH OTV
22:00:00	GRAPPLE OTV
23:05:00	MATE PAYLOAD TO OTV
24:20:00	RELEASE OTV/PAYLOAD
24:35:00	ORBITER SEPARATION TO SAFE DIS.
25:43:000	OTV BOOST-3
26:15:000	OTV/PAYLOAD SEPARATION
27:50:000	OTV DEBOOST BURN
36:18:00	ATMOSPHERIC ENTRY
36:22:00	ATMOSPHERIC EXIT
36:25:00	JETTISON AEROBRAKE
36:49:00	OTV LEO REBOOST - 1
38:18:00	OTV LEO REBOOST - 2
43:17:00	ORBITER RENDEZVOUS
43:47:00	GRAPPLE OTV
44:02:00	OTV STORAGE
TBD	ORBITER DEORBIT

FIGURE 2.7.2-4 ACC GB GEO DELIVERY OPERATIONAL SCENARIO

TIME (H:M:S)	EVENT
00:00:00	LAUNCH
00:08:20	MECO
00:12:20	ORBITER OMS-1 (130 NM)
00:44:20	ORBITER OMS-2 (140 NM)
04:15:00	RELEASE OTV/PAYLOAD
04:20:00	DEPLOY AEROBRAKE
04:30:00	ORBITER SEPARATION TO A SAFE DISTANCE
05:37:00	OTV BOOST
06:15:00	OTV/PAYLOAD SEPARATION
07:44:00	OTV DEBOOST BURN
16:13:00	ATMPSPHERIC ENTRY
16:17:00	ATMOSPHERIC EXIT
16:20:00	JETTISON AEROBRAKE
16:44:00	OTV LEO REBOOST - 1
18:13:00	OTV LEO REBOOST - 2
23:12:00	ORBITER RENDEZVOUS
23:42:00	GRAPPLE OTV
23:57:00	OTV STOWAGE
TBD	ORBITER DEBOOST

FIGURE 2.7.2-5 CARGO BAY GB GEO DELIVERY OPERATIONAL SCENARIO

TABLE 2.7.2-1 OTV DELIVERY SUMMARY COST DATA (CONSTANT $M)

	ACC OTV	CARGO BAY	DELTA
R&T	153.00	153.00	0.00
DDT&E	1033.40	1056.40	-23.00
PRODUCTION	29.90	29.90	0.00
OPERATIONS	2998.30	2886.50	111.80
	------	------	-----
TOTAL	4214.60	4125.80	88.80
	CB % REDUCTION = 2.1		
ACC-ORB MODS	163.00	27.00	136.00
TOTAL LCC	4377.60	4152.80	224.80
TOTAL INVESTMENT (Total LCC minus operations)	1379.30	1266.30	113.00

TABLE 2.7.2-2 OTV DELIVERY SUMMARY COST DATA (PV $M)

	ACC OTV	CARGO BAY	DELTA
R&T	117.20	117.20	0.00
DDT&E	592.80	606.80	-14.00
PRODUCTION	12.70	12.70	0.00
OPERATIONS	1060.30	1020.70	39.60
	------	------	-----
TOTAL	1783.00	1757.40	25.60
	CB % REDUCTION = 1.4		
ACC-ORB MODS	92.70	13.20	79.50
TOTAL LCC $	1875.70	1770.60	105.10
TOTAL INVESTMENT (Total LCC minus operations)	815.40	749.90	65.50

TABLE 2.7.2-3 DELIVERY OPERATIONS COMPARISON (CONSTANT $M)

	ACC OTV	CARGO BAY	DELTA
GB MISSION OPS	10.50	10.50	0.00
GB LAUNCH OPS	2806.70	2726.20	80.50
PRP OPS	1.10	0.60	0.50
PROGRAM SUPPORT	42.40	41.20	1.20
P/L CLUST STR	7.60	6.20	1.40
PROPELLANTS	0.40	0.50	-0.10
AIRFRAME SPARES	0.00	0.00	0.00
AIRFRAME IVA	0.60	0.30	0.30
ENGINE SPARES	5.00	5.00	0.00
ENGINE IVA	0.10	0.10	0.00
BRAKE SPARES	70.00	42.70	27.30
BRAKE IVA	0.10	0.10	0.00
GROUND REFURB	11.80	12.80	-1.00
EXPECTED LOSS	38.60	38.60	0.00
P/L IVA	3.40	1.70	1.70
TOTAL OPS	2998.30	2886.50	111.80
CPF	85.7	82.5	3.19

TABLE 2.7.2-4 CARGO BAY VS ACC DDT&E COMPARISON (CONSTANT $M)

	ACC OTV	CARGO BAY	DELTA
D&D	372.30	378.30	-6.00
SOFTWARE	61.10	59.30	1.80
TOOLING *	24.40	31.50	-7.10
SE&I	87.20	88.10	-0.90
TEST HARDWARE *	145.10	152.40	-7.30
TEST OPS	20.70	21.30	-0.60
TEST FIXTURES	3.60	3.70	-0.10
PROG. MANAGE.	42.80	44.10	-1.30
STAGE DDT&E (INC P/L STR)	757.20	778.70	-21.50
LEVEL II			
PM,SE&I,TEST	176.00	179.80	-3.80
TEST FLTS	80.20	77.90	2.30
FACILITIES	20.00	20.00	0.00
DDT&E TOTAL	1033.40	1056.40	-23.00
ACC	163.00	0.00	163.00
CB MODS	0.00	27.00	-27.00
TOTAL	1196.40	1083.40	113.00

*The main cost discriminators include the tradeoff of the heavier tankage/structure of the cargo bay concept vs the more sophisticated ACC option aerobraking concept.

Operations cost and the Design, Development, Test, and Engineering (DDT&E) costs shown in Table 2.7.2-1 are further detailed in Tables 2.7.2-3 and 2.7.2-4. In each of these figures, the cost of acquiring the ACC and cargo bay capabilities are shown separately.

2.7.2.2.2 Scavenging Computations

2.7.2.2.2.1 Requirements and Assumptions

Costs of scavenging were also computed for both the ACC and CB modes. Additional requirements and assumptions used as a basis for arriving at the scavenging costs are shown below.

o REQUIREMENT

- 5.5M lb propellant required
- Delivery 1999 - 2010 (12 years)
- Investment 1995 - 1998 (4 years)
- 110 missions

o ASSUMPTIONS

- Constant flight rate (9 missions/yr)
- Constant investment distribution
- Constant 1985 dollars
- Cargo bay scavenging
  -- 181 scavengable flights
  -- 2.53M lb propellant scavenged
  -- Development, Production & Operations Cost $151M (Investment $40M + Production & Operations $111M)
- ACC Scavenging
  -- 328 scavengable flights
  -- 4.59M lb propellant scavenged
  -- Development, Production & Operations Cost $1250M (Investment $83M + Production & Operations $1167M)
- Composite Discount Factor
  -- Investment = 1.34
  -- Operating = 1.97
  -- STS Delivery Cost = $1014/lb

In this trade, the discount factor is treated as a constant to simplify computations. This can be done since we use a constant number of flights per year and a constant cost per flight. This same procedure is applied to the DDT&E costs by assuming costs are distributed equally over a five year period.

The amount of propellant required, 5.5 mlb, was derived from a performance simulation using the ground mission profile contained in Revision 8 of the MSFC OTV Mission Model.

We believe the investment (DDT&E) cost shown in the MSFC ground rules was high and consequently reduced the figure to $83M from $212M. A revision of the ACC study final report and the ACC scavenging study final report showed a discrepancy in charging. Table 2.7.2-5 shows where the discrepancies occurred in the original scavenging DDT&E costing.

TABLE 2.7.2-5 PROPELLANT SCAVENGING DDT&E COST REVISION

GROUND RULE ELEMENT	COST	REVISED COST	COMMENT
PROPELLANT SCAVENGING DDT&E	$65M	$65M	---
DDT&E for STS MODS and Integration	$101M	$12M	
o ACC DDT&E	60.9M	12M	Assumed 20% MOD to DACC
o Facility	34.9M	-	Existing with DACC
o GSE	6.4M	-	Existing with DACC
STS DDT&E	$46M	$6M	
o Level II Integration	30.5M	6M	Assumed 20% DACC to MOD
o Orbiter MODS	9.5M	-	Existing with DACC
o ET MODS	6.3M	-	Existing with DACC
Total	$212M	$83M	Reductions due to DDT&E Expendable for OTV DACC

2.7.2.2.2.2 Propellant Delivery Costs

The amount of propellant recovered under the scavenging concept is dependent, in part, on the number of STS missions suitable for scavenging operations. A significantly greater number of flights for scavenging are available using the ACC concept, (328 ACC versus 181 CB missions) since the full cargo bay space remains available for mission payloads whereas this is not the case under the cargo bay concept.

Calculations used to compare the costs of providing propellant at LEO using the ACC and cargo bay methods are shown in Tables 2.7.2-6, 2.7.2-7, and 2.7.2-8. These calculations are made in constant dollars. The figures used to arrive at this cost are extracted from the OTV Concept Definition and System Analysis Studies ground rules issued by the MSFC in May 1985 with the exception of the total amount of propellant required (5.5 mlb) which is described above, and modifications to the ACC scavenging system DDT&E (Table 2.7.2-5).

The results of this constant dollar evaluation show nearly a billion dollar spread favoring the ACC over the cargo bay scavenging method.

TABLE 2.7.2-6 PROPELLANT SCAVENGED

	No. of Available Scavenging Flights		Average Propellant Scavenged (lb)		Propellant Scavenged (lb)
ACC Version	328	x	14,000	=	4.59M
Cargo Bay	181	x	14,000	=	2.53M

TABLE 2.7.2-7 STS PROPELLANT DELIVERY COST

	Total Propellant Required (lb)		Scavenged Propellant (lb)		STS Delivery to LEO ($ per lb)		Delivery Cost
ACC	(5.5M	–	4.59M)	x	$1014	=	$923M
Cargo Bay	(5.5M	–	2.53M)	x	$1014	=	$3012M

TABLE 2.7.2-8 TOTAL PROPELLANT COST AT LEO

	Development Production Operations Cost		STS Delivery to LEO Cost		Total Cost
ACC	$1250M	+	$923M	=	$2253M
Cargo Bay	$ 151M	+	$3012M	=	$3163M

Tables 2.7.2-9 and 2.7.2-10 provide a scavenging cost comparison between the ACC and cargo bay which show a significantly different picture. Because of the time value of money, the magnitude of the difference is reduced. It should be noted that an approximation method was used in that the yearly distribution of costs were assumed in order to simplify computations.

The investment (DDT&E) costs, shown in Table 2.7.2-9 represent the total constant dollar investment spread over four years and reduced by a discount factor.

The operations costs equation, shown in Table 2.7.2-10 contain three terms. The first term is the cost of production and operations per year. The second term is the cost of delivery by the STS and is the difference between the propellant required per year and the amount scavenged. The third term is the cost of transportation of the scavenging system.

The cost of the ACC scavenging system is considerably higher because it is a "smart stage" having propulsion and guidance and, as a consequence, is heavier. The weight of this system is estimated to be 8.6 klb. This weight, in turn, translates into a cost for delivery to LEO. The results of the present value dollar evaluation shows a $153M spread favoring the ACC over the cargo bay scavenging method.

TABLE 2.7.2-9 INVESTMENT COSTS (PV)

	Scavenged DDT&E Per Year	Discount Factor (10%/year)	Present Value Investment Cost
ACC	$\frac{83}{4}$	x 1.34	= 27.8M
Cargo Bay	$\frac{40}{4}$	x 1.34	= 13.4M

TABLE 2.7.2-10 OPERATIONS COST (PV)

	Cost of Scav. /year	Cost of STS Propellant Delivery/Year	Cost of Scavenging/Yr.	Composite Discount Factor	Present Value Ops. Cost
	$\left[\left[\frac{\text{Prod.\& Ops}}{\text{years}}\right]\right.$	+ $\left[\frac{\text{Total Prop. Reqd.} - \text{Scavenged Prop}}{\text{Years}} \times \text{STS Del Cost}\right]$ +	$\left.\left[\text{Wt. Pen. (ACC) or Vol. Pen. (CB)} \times \text{STS Cost per Flt.} \times \text{Ave. STS Flts. per Year}\right]\right]$	x 1.97	= Ops. Cost
ACC	$\left[\left[\frac{1167M}{12}\right]\right.$	+ $\left[\frac{(5.5 - 4.59)M}{12} \times 1014\right]$ +	$\left.\left[\frac{8600}{72000} \times 73M \times 8\right]\right]$	x 1.97	= $480M
Cargo Bay	$\left[\left[\frac{111M}{12}\right]\right.$	+ $\left[\frac{(5.5 - 2.5)M}{12} \times 1014\right]$ +	$\left.\left[0.1 \times 73M \times 8\right]\right]$	x 1.97	= $633M

(See Section 1.3 for an explanation of uniform discounting.)

2.7.2.2.3 Computation for OTV Delivery and Scavenging Competition

The competition for the OTV delivery/scavenging concept is to neither develop an ACC or cargo bay for delivery of OTV to LEO nor develop a scavenging system (expendables 1994-1994; SBOTV 1999-2010 without propellant scavenging). All missions would be accomplished with expendable vehicles and with a propellant tank located in the cargo bay of the STS. The trade assumes conservatively that no DDT&E cost will be expended by the competition for a propellant tank in the cargo bay. Since this trade was designed to include the impact of the type of reusable GBOTV (cargo bay or ACC) as well as the subsequent evolution of a space based propellant delivery system, the competition consisted of the following program components:

a) Use of existing expendables from 1994-1998
b) Subsequent propellant delivery of space based propellants via STS tanker (5.5 mlb over 12 years, 1999-2010, see Table 2.7.2-11).

The cost of the competition to the scavenging system, STS delivered propellant, is summarized in Table 2.7.2-11. The cost for ground based operations from 1994-1998 with expendable stages is computed to be $1874M (Table 2.7.3-23, 1994-1998). This amount was derived by the Martin Marietta LCC computer model. The total competition cost is the sum of the scavenging competition (STS tanker) ($916M) and the expendable stage delivery ($1874M) for a total competition cost of $2790M.

TABLE 2.7.2-11 COMPETITION PROPELLANT DELIVERY COST

Propellant per year		STS Delivery to LEO ($ per pound)		Composite Discount Factor		STS Propellant Delivery Cost ($M PV)
$\frac{5.5M}{12}$	x	1014	x	1.97	=	916

2.7.2.2.4 STS Cargo Bay Benefit Factor Computation

The difference in manifesting cargo under the ACC and cargo bay modes of operation shows that additional volume and weight is made available to the STS for other payloads when the ACC mode is used. In order to make a fair assessment of this benefit, credit is awarded to the ACC concept for the benefit the STS receives. This is justified to offset ACC development costs since cost is added to the OTV system when expenditures are made on collateral systems for OTV support. In order to compensate for anomalies that may exist, the benefit is reduced to 50 percent of the calculated amount.

The calculations involve examination of the 35 ground based missions in both the ACC and cargo bay modes. Due to differing payload weights and volumes, missions have payload weight and volume less than the 60 linear feet and 72 klb STS capacities. A large volume benefit is realized by moving the OTV out of the cargo bay into the ACC. Adjustments are made, accordingly, if either the weight or volume benefits exceeded the capacity of the STS, e.g., if the payload weight is the maximum 72 klb and the cargo bay linear volume is 50 feet, zero credit is given for the remaining 10 linear feet since adding additional payload will exceed the STS weight capacity.

Examination of the 35 ground based missions produced the ACC and cargo bay total weights and volumes cost benefit for OTV delivery shown below.

Available capacity in the cargo bay mode:

Volume: $50M
Weight: $130M

Available capacity in the ACC mode:

Volume: $500M
Weight: $170M

These figures are used in the algorithms shown in Table 2.7.2-12 to produce the STS derived benefit of $245M.

TABLE 2.7.2-12 STS DERIVED BENEFIT

Volume Benefit			Weight Benefit			
Benefit Reduction Factor	ACC Volume Benefit	CB Volume Benefit	Benefit Reduction Factor	ACC wt Ben.	CB wt Ben.	STS Derived Benefit
0.5	x (500M	- 50M) +	0.5	x (170M	- 130M)	= $245M

(See Section 2.7.1, pages 73-74, for an explanation of STS benefits.)

The cost components that comprise the trade alternatives and hypothesized competition are summarized in Table 2.7.2-13. These figures are grouped together in Table 2.7.2-14 to show the combined cost for OTV delivery and scavenging for investment and operations under each of the trade alternatives. The total shown on this table are used in the analyses of the alternatives contained in the next paragraph below.

TABLE 2.7.2-13 COST DATA SUMMARY

ITEM	COST (PV)
OTV Delivery Cost	
ACC	
Investment	$815.4M
Operations	$1060.3M
Cargo Bay	
Investment	$749.9M
Operations	$1020.7M
Scavenging Costs	
ACC	
Investment	$27.8M
Operations	$480.0M
Cargo Bay	
Investment	$13.4M
Operations	$633.0M
Competitive Costs	
GB Delivery	$1874M
STS Propellant Delivery	$916M
STS Derived Benefit for OTV Delivery	
ACC	($245.0M/OTV Credit)
Cargo Bay	0

TABLE 2.7.2-14 ALTERNATIVE COST SUMMARY

ALTERNATIVE	OTV DELIVERY		SCAVENGING		TOTAL
CB/ACC (Alternative 1)					
Investment	$ 749.9M	+	$ 27.8M	=	$ 777.7M
Operations	$1020.7M	+	$480.0M	=	$1500.7M
CB/CB (Alternative 2)					
Investment	$ 749.9M	+	$ 13.4M	=	$ 763.3M
Operations	$1020.7M	+	$633.0M	=	$1653.7M
ACC/ACC (Alternative 3)					
Investment	$ 815.4M	+	$ 27.8M	=	$ 843.2M
Operations	$1060.3M	+	$480.0M	=	$1540.3M
ACC/CB (Alternative 4)					
Investment	$ 815.4M	+	$ 13.4M	=	$ 828.8M
Operations	$1060.3M	+	$633.0M	=	$1693.3M

(To track numbers, see Tables 2.7.2-2, 2.7.2-9 and 2.7.2-10.)

2.7.2.3 Alternative Comparison.

The aggregate benefits for each of the delivery and scavenging combinations are shown in Tables 2.7.2-15 and 2.7.2-16. The data used in these tables have been brought forward from the Cost Data Summary (Table 2.7.2-13) and the Alternative Cost Summary (Table 2.7.2-14).

The benefit, shown in Table 2.7.2-15, indicates that all alternatives provide an advantage over not undertaking any development for STS delivery or scavenging.

The return on investment, shown in Table 2.7.2-16, factors in investment cost. This calculation supports the finding that all alternatives provide a viable solution.

A comparison of alternatives against the principal selection criteria is shown in Tables 2.7.2-17. This comparison shows the alternative of using the ACC for both the OTV delivery and the scavenging system provides the greatest advantage. This is largely due to the freeing of revenue bearing cargo bay space leaving additional weight and volume for other payloads. This is a significant advantage since the available capacity can be used for logistics cargo destined for the space station or for other payloads that may be orbited during the same time frame.

TABLE 2.7.2-15 BENEFITS (PV)

OTV DELIVERY/ SCAVENGING	COMPETITION COST	OTV DELIVERY & SCAVENGING COST	STS DELIVERED BENEFIT	TOTAL BENEFIT
CB/ACC	$2790.0M	- $1500.7M	+ 0.0	= $1289.3M
CB/CB	$2790.0M	- $1653.7M	+ 0.0	= $1136.3M
ACC/ACC	$2790.0M	- $1540.3M	+ $245.0M	= $1494.7M
ACC/CB	$2790.0M	- $1693.3M	+ $245.0M	= $1341.7M

(See Section 2.7.1, pages 73-74, for an explanation of STS benefits.)

TABLE 2.7.2-16 RETURN ON INVESTMENT
(1985 $M [PV])

OTV DELIVERY/ SCAVENGING	COMPETITION COST	OTV DELIVERY & SCAVENGING COST	STS DERIVED BENEFIT	INVESTMENT (DDT&E)	TOTAL ROI
CB/ACC	((2790.0	- 1500.7	+ 0.0) /	777.7) -1	= 65.8%
CB/CB	((2790.0	- 1653.7	+ 0.0) /	763.3) -1	= 48.9%
ACC/ACC	((2790.0	- 1540.3	+ 245.0) /	843.2) -1	= 77.3%
ACC/CB	((2790.0	- 1693.3	+ 245.0) /	828.8) -1	= 61.9%

TABLE 2.7.2-17 OTV DELIVERY/SCAVENGING TRADE RESULTS

ECONOMIC FACTOR	CB/ACC	CB/CB	ACC/ACC	ACC/CB
Return on Investment	65.8%	48.9%	77.3%	61.9%
Benefits	$1289.3M	$1136.3M	$1494.7M	$1341.7M
Investment	$ 777.7M	$ 763.3M	$ 843.2M	$ 828.8M
SCORE				
Return on Investment	8.5	6.3	10.0	8.0
Benefits	8.6	7.7	10.0	9.1
Investment	9.8	10.0	9.1	9.2

2.7.2.4 Conclusion

We conclude from this study that all alternatives considered provide a benefit worthy of acquisition. Of the alternatives considered, using an ACC for delivering the OTV to LEO during ground based operations and using the ACC for a scavenging system during space based operations provide the greatest economic advantage. This is clearly indicated as the best alternative through a comparison of return on investment with benefits and through a comparison of return on investment with investment (DDT&E).

A major element in providing the ACC advantage is the increase in available payload volume and weight by moving the OTV and scavenging system out of the revenue producing STS cargo bay and into the ACC.

It is important to note that this conclusion is based upon a relatively low STS flight rate. If a more optimistic rate is assumed, the benefits of the ACC scavenging concept would increase and thus make it even more attractive.

Finally, as noted at the beginning of this step of the trade report, the selection of the ground based OTV delivery mode in the first part of the analysis will eliminate one of two OTV evolutionary configuration options in the second part of the analysis. Selection of the ACC for OTV delivery thereby eliminates Option 6, OTV cargo bay delivery during ground basing, and retains Option 2, ACC delivery, for further consideration.

2.7.3 Step 2, Preferred Overall Evolution

The purpose of this subtrade study analysis is to select the most economical OTV evolution strategy from the remaining five trade study options shown in Figure 2.7.3-1. The remaining options include one ground based option (Option 7) and four space based options. The ground based option avoids the high investment cost for Space Station accommodations and for a scavenging system. The space based options have merit in avoiding a high delivery cost to LEO for all but the vehicles initial delivery to the Space Station. Space based configurations are also less constrained by the envelope dimension of the STS cargo bay/ACC.

Economics are a principal discriminator in the selection of the development strategy. Since there are no near term mission delivery requirements cited in the mission model which cannot be accomplished by existing upper stages, the selected OTV system must be able to improve the cost of delivering payloads over the current STS/expendable systems.

Economic data gathered for each option are derived from simulated missions flown against Revision 8 of the MSFC OTV Low Mission Model. Economic data for the competition, represented by existing upper stage payload delivery systems, is also gathered in the same way. Using these data, the options are compared with one another and the competition. Any costs associated with the development and operation of interfacing systems such as the ACC, scavenging, etc., are assigned to the option(s) that use them.

Figures 2.7.3-3 through 2.7.3-7, placed at the back of this section of the report, pictorially illustrate the configurations and evolutionary steps of each of the remaining options. Configuration alterations may take place at two basic block changes. One is from ground basing to space basing and the other is from nonman-rated to man-rated. Ground based configurations are designed for packaging within the ACC whereas space based configurations are not as restricted by a constraining envelope. Changes from ground to space basing include moving the avionics from an integral packaging within the structure to a ring design to facilitate on-orbit maintenance. Changes from a nonman-rated configuration to a manrated configuration involve added redundancy to preclude any single credible failure from preventing the safe return of the crew. A prime example is moving from a single engine to dual engines. The aerobrake is unique to each configuration.

OPTION	GB IOC 94 95 96 97 98	SB IOC 99 00 01 02 03 04 05 06 07	MAN-RATED 08 09 10
1	----- GBU ------	--------------- SBM -----------------	-----
2	----- GBU ------	--------------- SBU ------------	--SBM---
RE-SERVED			
4	----- EXU ------	--------------- SBM -----------------	-----
5	----- EXU ------	--------------- SBU ------------	--SBM---
RE-SERVED			
7	---- GBU ------	--------------- GBU (55K)-------	--GBM---

LEGEND:

GBU	45 klb Ground Based Nonman-rated
SBU	55 klb Space Based Nonman-rated
SBM	55 klb Space Based Man-rated
GBM	55 klb Ground Based Man-rated
EXU	Expendable Nonman-rated
CB	STS Cargo Bay
ACC	Aft Cargo Carrier

NOTE:

1. All space based OTVs are delivered in the STS cargo bay.
2. All ground based OTVs are delivered in the ACC except as noted in Option 6.

FIGURE 2.7.3-1 REMAINING OTV CONFIGURATION EVOLUTION OPTIONS

2.7.3.1 Cost of Remaining Alternatives

Aggregate program costs for each of the remaining options are summarized in Table 2.7.3-1 in constant dollars and in Table 2.7.3-2 in discounted dollars. These tables include collateral costs associated with each option's interface requirements, i.e option's interface cost for Space Station, ACC, propellant scavenging, and payload transportation. The tables also address research and technology, DDT&E, production, and operations costs. A more detailed breakdown for DDT&E, production and operations cost for each option is contained in Tables 2.7.3-8 through 2.7.3-22 located at the back of this section.

The life cycle cost totals between options are quite close. The difference between the highest and lowest option in discounted dollars is only 14% (Table 2.7.3-2). This indicates that other factors such as risk, flexibility, and growth play a greater role in discriminating between options.

Life cycle costs calculations for the competition represented by existing upper stage vehicles are shown in Table 2.7.3-23 located at the back of this section. Information extracted from the totals shown on this table is used in the discussions below.

The cost per flight to capture 145 missions of the Revision 8 Low Mission Model are shown in Table 2.7.3-3. Two values are shown for the competition cost per flight. When flown against the Revision 8 Low Mission Model, the expendable upper stages take more STS flights and more upper stages to deliver the payloads. The real cost per flight is determined by the total cost divided by the number of transportation actions, i.e. 220 flights. For comparative purposes the cost per flight is adjusted to 145 missions thereby raising the cost per flight to an equivalent of $155.0M. A comparison of this figure with the cost per flight of each option shows the options with a significant advantage.

TABLE 2.7.3-1 OPTION COST SUMMARY (CONSTANT $M)

	OPTIONS				
	1	2	4	5	7
INTERFACING SYSTEM	GBU/SBM/SBM	GBU/SBU/SBM	EXU/SBM/SBM	EXU/SBU/SBM	GBU/GBU/GBM
Space Station	936.00	936.00	936.00	936.00	0.00
ACC	163.20	163.20	163.20	163.20	163.20
Prop Scav	83.00	83.00	83.00	83.00	0.00
P/L Trans	4995.11	4995.11	4995.11	4995.11	4995.11
Subtotal	6177.31	6177.31	6177.31	6117.31	5158.31
OTV					
R&T	153.00	153.00	153.00	153.00	153.00
DDT&E	1351.49	1414.69	1218.70	1257.60	1223.79
Prod.	145.30	251.10	29.90	145.30	242.30
OPS	6408.21	6098.01	8754.00	8443.00	12332.21
Subtotal	8058.00	7916.80	10155.60	9998.90	13951.30
TOTAL	14235.41	14094.11	16332.91	16176.21	19109.61

TABLE 2.7.3-2 OPTION COST SUMMARY (DISCOUNTED $M)

	OPTIONS				
	1	2	4	5	7
INTERFACING SYSTEM	GBU/SBM/SBM	GBU/SBU/SBM	EXU/SBM/SBM	EXU/SBU/SBM	GBU/GBU/GBM
Space Station	315.50	315.50	315.50	315.50	0.00
ACC	92.60	92.60	57.53	57.53	92.66
Prop Scav	30.75	30.75	30.75	30.75	0.00
P/L Trans	790.00	790.00	790.00	790.00	790.00
Subtotal	1228.85	1228.85	1193.78	1193.78	882.66
OTV					
R&T	116.94	116.94	72.61	72.61	116.94
DDT&E	692.07	686.32	435.42	421.93	639.90
Prod.	47.28	59.07	8.66	23.33	57.23
OPS	1596.57	1543.63	2416.02	2363.09	2527.33
Subtotal	2452.86	2405.96	2932.71	2880.96	3341.40
TOTAL	3181.71	3634.81	4126.49	4076.74	4224.06

TABLE 2.7.3-3 COST PER FLIGHT (CONSTANT $M)

OPTION	Operations	+	P/L Trans	/	145 Flts	=	Cost/Flight
1 GBU/SBM/SBM	6408	+	4995	/	145	=	79
2 GBU/SBU/SBM	6098	+	4995	/	145	=	77
4 EXU/SBM/SBM	8754	+	4995	/	145	=	95
5 EXU/SBU/SBM	8443	+	4995	/	145	=	93
7 GBU/GBU/GBM	12332	+	4995	/	145	=	119

Competition Cost per Flight:
220 required missions cost: $120.8
145 equivalent mission cost: $155.0

The investment cost, shown in discounted dollars in Table 2.7.3-4, includes the cost of acquiring the OTV and the cost of interfacing systems. Ground based Option 7 shows the lowest investment cost largely because it does not use either space station or scavenging systems. Options 4 and 5 also show a low investment because they do not have a ground based OTV configuration and can defer development costs of space based OTV configurations to a later time where they are discounted more. Options 1 and 2 show the highest investment costs due to earlier expenditures for ACC accommodations, research and technology, and DDT&E.

TABLE 2.7.3-4 INVESTMENT (DISCOUNTED $M)

OPTION	Space Station	+ ACC	+ Scav.	+ R&T	+ DDT&E	+ Prod.	= Investment
1 GBU/SBM/SBM	315.5	+ 92.6	+ 30.8	+ 116.9	+ 692.1	+ 47.3	= 1295.2
2 GBU/SBU/SBM	315.5	+ 92.6	+ 30.8	+ 116.9	+ 686.3	+ 59.1	= 1301.2
4 EXU/SBM/SBM	315.5	+ 0.0	+ 78.6	+ 72.6	+ 435.4	+ 8.7	= 910.8
5 EXU/SBU/SBM	315.5	+ 0.0	+ 78.6	+ 72.6	+ 424.5	+ 23.3	= 914.5
7 GBU/GBU/GBM	0.0	+ 92.7	+ 0.0	+ 116.9	+ 639.9	+ 57.2	= 906.7

A benefit analysis is shown in Table 2.7.3-5 for each option. Benefit represents the difference between the cost of the competition and the OTV option to accomplish the mission model. Where applicable, the STS benefit (described in 2.7.2.2.4 above) is added to provide the total benefit the option holds over the competition to do the job.

TABLE 2.7.3-5 OTV OPTION BENEFITS (PV $M)

OPTION	Competition	- Option Cost (Ops + P/L Trans)	+ STS Benefits	= Benefit
1 GBU/SBM/SBM	4974	- (1596.6 + 790)	+ 245	= 2832.4
2 GBU/SBU/SBM	4974	- (1543.6 + 790)	+ 245	= 2885.4
4 EXU/SBM/SBM	4974	- (2416.0 + 790)	+ 0	= 1768.0
5 EXU/SBU/SBM	4974	- (2363.1 + 790)	+ 0	= 1820.9
7 GBU/GBU/GBM	4974	- (2527.3 + 790)	+ 332.7	= 1989.4

The investment cost is added into the equation in Table 2.7.3-6 to produce a return on investment (ROI) ratio. The ROI difference among options is small with Options 1, 2 and 7 virtually falling into a tie. Option 7 favorable value is principally due to its relatively low investment cost.

TABLE 2.7.3-6 OTV OPTION RETURN ON INVESTMENT (PV)

OPTION	(Benefit	/	Investment)	- 1	=	ROI
1 GBU/SBM/SBM	(2832.4	/	1295.2)	- 1	=	1.19
2 GBU/SBU/SBM	(2885.4	/	1301.2)	- 1	=	1.22
4 EXU/SBM/SBM	(1768.0	/	920.3)	- 1	=	0.92
5 EXU/SBU/SBM	(1820.9	/	921.4)	- 1	=	0.98
7 GBU/GBU/GBM	(1989.4	/	906.7)	- 1	=	1.19

Figure 2.7.3-2 shows the payback and accumulation of benefits the five remaining options hold over the competition. The all ground based option, Option 7, provides the earliest payback because of the lower investment cost. The rate of benefit accumulation for Option 7 decreases when the mission complexity increases and a greater number of STS flights are required to support mission operations.

Options 4 and 5, which use existing expendable vehicles for the ground portion of the model, effectively delay the large space based investment. This delay also reduces the time available for benefit accumulation thereby increasing the number of missions before payback is realized and lessening the net benefit accumulation vis-a-vis the other options. The number of missions required before payback of an option is realized as follows:

- Option 1 48 Missions
- Option 2 48 Missions
- Option 4 80 Missions
- Option 5 81 Missions
- Option 7 25 Missions

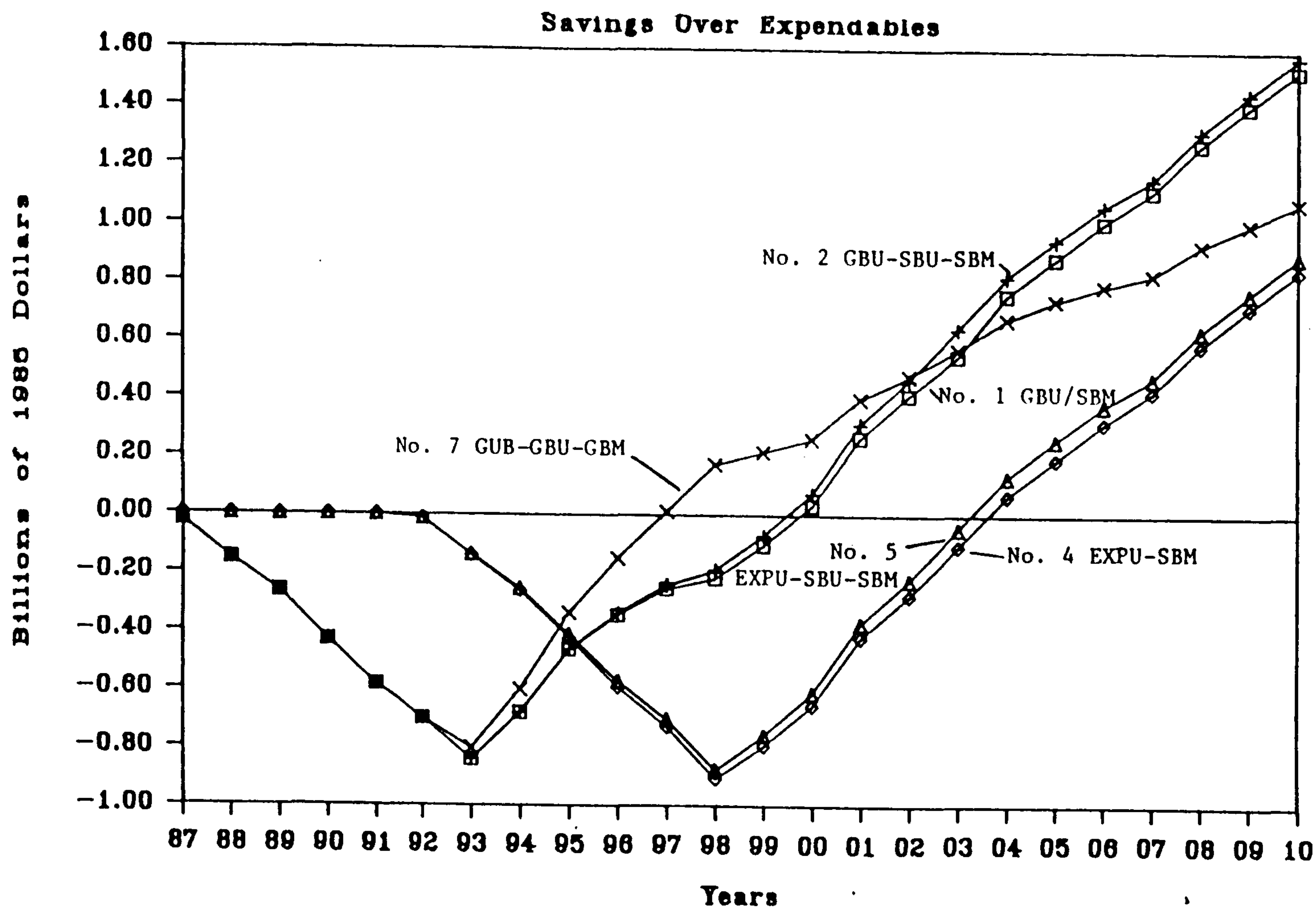


FIGURE 2.7.3-2 OTV EVOLUTIONARY STRATEGY COMPARISON

2.7.3.2 Alternative Comparison

Table 2.7.3-7 shows the principal economic factors for the candidate options along with scoring. As before, the best candidate is awarded a score of 10 and the other options a score relative to that awarded the best candidate. The table shows Options 1 and 2 rank high with virtually the same scores. Option 7 scores high an investment which also raises the score for ROI. Option 7 benefits are disproportionately low vis-a-vis Options 1 and 2. Options 4 and 5 score high on investment cost but low in the other two categories. The payback comparison, Figure 2.7.3-2, along with the ROI and benefits comparison place Options 4 and 5 below the other options considered.

TABLE 2.7.3-7 OTV OPTION RESULTS

Economic Factor	OPTION 1 GBU/SBM/SBM	2 GBU/SBU/SBM	4 EXU/SBM/SBM	5 EXU/SBU/SBM	7 GBU/GBU/GBM
ROI	1.19	1.22	0.92	0.98	1.19
Benefits	2832.4	2885.4	1768.0	1820.9	1989.4
Investment	1295.2	1301.2	920.3	921.4	906.7
Scores					
ROI	9.8	10	7.5	8.0	9.8
Benefits	9.8	10	6.1	6.3	6.9
Investment	7	7	9.8	9.8	10

Option 7 remains attractive only if the low investment costs are real. In order for the attractiveness of this option to be sustained, the STS user fee of $73M per flight or less must be achieved. For example, if the STS user charge were to increase to $100M, the Option 7 benefit would be reduced to $756M (discounted $) making it economically undesirable in that the investment would not be paid back in 145 mission. The STS lift capacity is another consideration. When using the groundruled 72 klb STS payload capacity, we find that 1.6 shuttle flights per OTV mission is required. If this capacity should be reduced to 65 klb, for example, the benefit would decrease to $1625M (discounted $) with a resulting ROI of 0.79. It also should be noted that Option 7 competes with revenue producing payloads for cargo space thereby reducing STS profitability.

Options 1 and 2 differ only in the space based unmanned phase of the mission model in that Option 2 specifies an intermediary space based nonman-rated vehicle whereas Option 1 moves initially to a space based man-rated vehicle. Costs for Option 2 are slightly higher principally due to the costs of acquiring a different vehicle for the space based nonman-rated phase.

There are four principal non-economic factors that favor Option 1 over Option 2. First, Option 1 maximizes early verification of man-rated reliability. Second, Option 1 reduces Space Station operational complexity in that it is only involved with one program cycle (space based man-rated). Third, Option 1 provides greater flexibility in that the earlier experience with the vehicle can promote confidence for accelerating the schedule for more advanced missions earlier, i.e. heavier payloads, manned missions, and lunar mission. Fourth, Option 1 has a lower cost risk than Option 2 because it has only two major program cycles rather than 3, involves no space based avionics repackaging, and remains with only one engine type rather than two engine types.

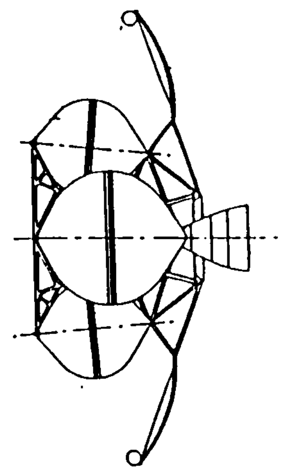
2.7.4 Conclusion

All OTV options provide an economic advantage over the continued use of existing expendable vehicles for accomplishing the missions postulated in Revision 8 of the MSFC Low OTV Mission Model.

Step 1 of the trade study shows that it is better during ground based operations to deliver the OTV via the STS Aft Cargo Carrier (Option 2) rather than in the cargo bay (Option 6). Step 2 of the trade study shows that Option 1 and 2 costs are essentially equal and both options hold an economic advantage over the remaining options. Option 1 provides several non economic advantages over Option 2. These include maximizing early verification of man-rated reliability, reducing space station operations complexity, providing greater flexibility by making it possible to do more advanced missions earlier, and reducing risk by eliminating the need to change vehicle configurations midway through the space based phase of the mission model.

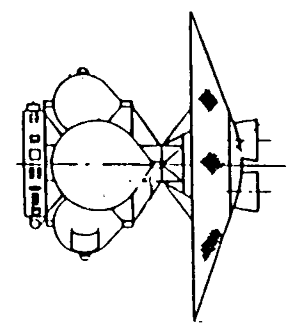
Based upon the ground rules and assumptions used in this study, Option 1 is recommended as the preferred evolutionary strategy for OTV development. This option progresses from a nonman-rated OTV carried in the ACC during ground based operations to a man-rated OTV based at the space station during space based operations.

The conclusions reached for the preferred overall evolution are largely based upon the postulated ground rules and assumptions and the results of other trade studies contained in this report. Any changes in the underlying ground rules and assumptions may have a bearing upon the conclusions reached in this study. Some key issues that may alter these results include: mission model length and activity level, utilization of scavenging for propellant recovery at LEO, operations risk of the ACC, STS cost per flight changes -- up or down, STS payload lift capability -- up or down, availability of the STS, accommodation of DOD requirements including no Space Station utilization and access to molniya orbits, and restrictions on Space Station utilization due to interference with other operations.



AVIONICS:	INTEGRAL
STRUCTURE:	GRAPHITE EPOXY
AEROBRAKE:	40 FT
REDUNDANCY:	NON-MAN RATED
PROP CAP:	45,000 Lb
LOADED WT:	50,363 Lb
ENGINE:	475 Isp/7500 Lb (1)

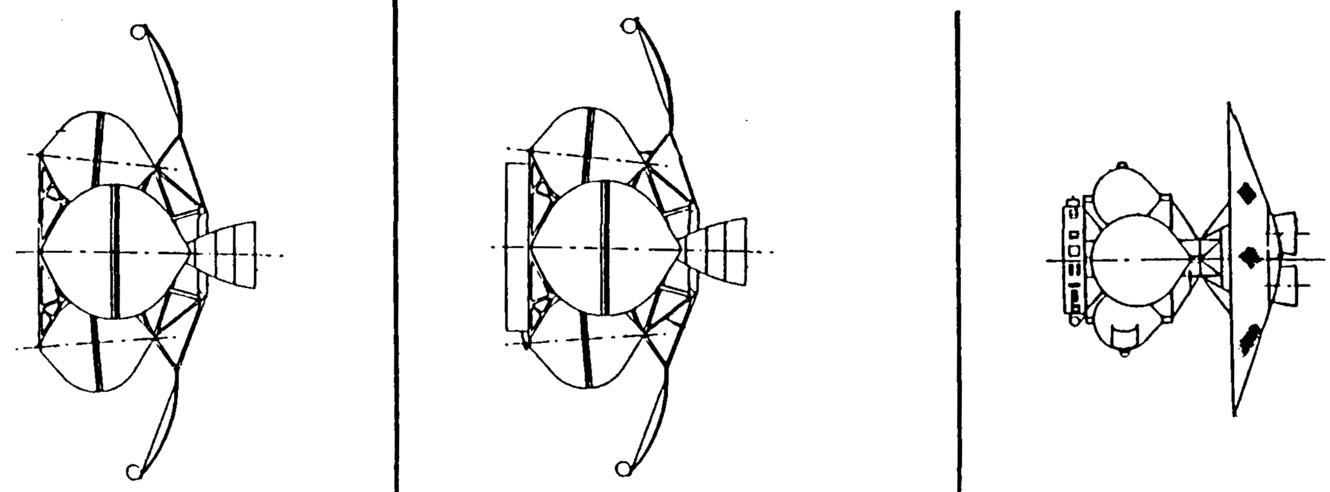
GROUND BASED
ACC DELIVERY



AVIONICS:	RING
STRUCTURE:	GRAPHITE EPOXY
AEROBRAKE:	44 FT
REDUNDANCY:	MAN RATED
PROP CAP:	55,000 Lb
LOADED WT:	62,169 Lb
ENGINES:	475 Isp/7500 Lb (2)

SPACE BASED
CB DELIVERY

FIGURE 2.7.3-3 OPTION 1 CONFIGURATION GBU/SBM



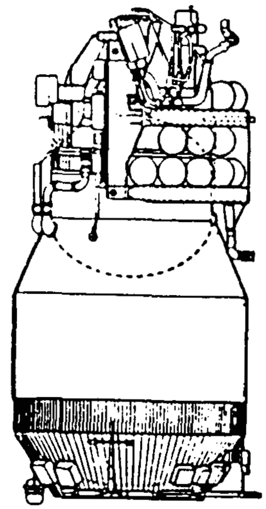
Ground Based ACC Delivery		Space Based ACC Delivery		Space Based CB Delivery	
AVIONICS:	INTEGRAL	AVIONICS:	RING	AVIONICS:	RING
STRUCTURE:	GRAPHITE EPOXY	STRUCTURE:	GRAPHITE EPOXY	STRUCTURE:	GRAPHITE EPOXY
AEROBRAKE:	40 FT	AEROBRAKE:	40 FT	AEROBRAKE:	44 FT
REDUNDANCY:	NON-MAN RATED	REDUNDANCY:	NON-MAN RATED	REDUNDANCY:	MAN RATED
PROP CAP:	45,000 Lb	PROP CAP:	52,500 Lb	PROP CAP:	55,000 Lb
LOADED WT:	50,363 Lb	LOADED WT:	58,282 Lb	LOADED WT:	62,169 Lb
ENGINE:	475 Isp/7500 Lb (1)	ENGINE:	475 Isp/7500 Lb (1)	ENGINES:	475 Isp/7500 Lb (2)

GROUND BASED
ACC DELIVERY

SPACE BASED
ACC DELIVERY

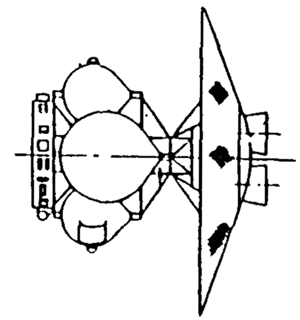
SPACE BASED
CB DELIVERY

FIGURE 2.7.3-4 OPTION 2 CONFIGURATION GBU/SBU/SBM



AVIONICS:	STAGE MOUNT
STRUCTURE:	AL & STAINLESS
REDUNDANCY:	UNMANNED
PROP CAP:	45941 Lb
LOADED WT:	52345 (+ ASE)
ENGINES:	444 Isp/15 KLb (2)

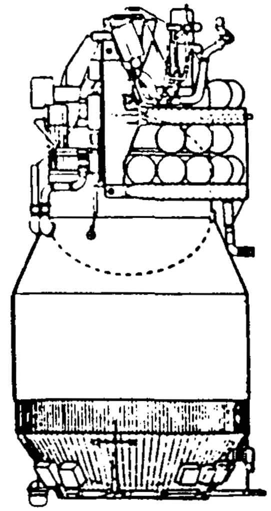
EXPENDABLE
CB DELIVERY



AVIONICS:	RING
STRUCTURE:	GRAPHITE EPOXY
AEROBRAKE:	44 FT
REDUNDANCY:	MAN RATED
PROP CAP:	55,000 Lb
LOADED WT:	62,169 Lb
ENGINES:	475 Isp/7500 Lb (2)

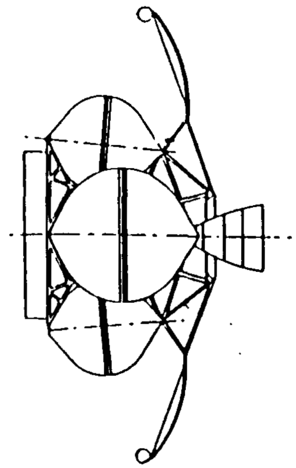
SPACE-BASED
CB DELIVERY

FIGURE 2.7.3-5 OPTION 4 CONFIGURATION EXU/SBM



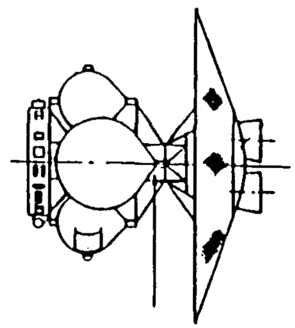
AVIONICS: STAGE MOUNT
STRUCTURE: AL & STAINLESS
REDUNDANCY: UNMANNED
PROP CAP: 45941 Lb
LOADED WT: 52345 (+ ASE)
ENGINES: 444 Isp/15 KLb (2)

EXPENDABLE
CB DELIVERY



AVIONICS: RING
STRUCTURE: GRAPHITE EPOXY
AEROBRAKE: 40 FT
REDUNDANCY: NON-MAN RATED
PROP CAP: 52,500 Lb
LOADED WT: 58,283 Lb
ENGINE: 475 Isp/7500 Lb (1)

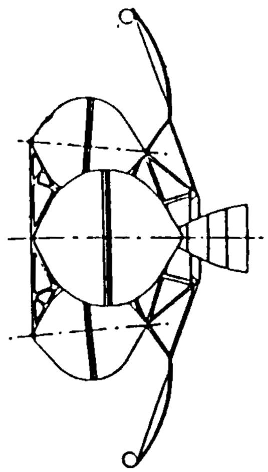
SPACE BASED
ACC DELIVERY



AVIONICS: RING
STRUCTURE: GRAPHITE EPOXY
AEROBRAKE: 44 FT
REDUNDANCY: MAN RATED
PROP CAP: 55,000 Lb
LOADED WT: 62,169 Lb
ENGINES: 475 Isp/7500 Lb (2)

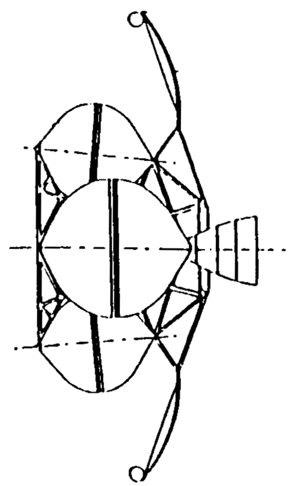
SPACE BASED
CB DELIVERY

FIGURE 2.7.3-6 OPTION 5 CONFIGURATION EXU/SBU/SBM



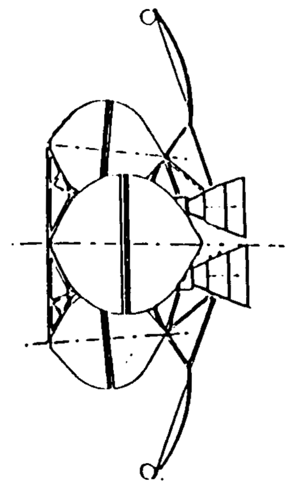
AVIONICS:	INTEGRAL
STRUCTURE:	GRAPHITE EPOXY
AEROBRAKE:	40 FT
REDUNDANCY:	NON-MAN RATED
PROP CAP:	45,000 Lb
LOADED WT:	50,363 Lb
ENGINE:	475 Isp/7500 Lb (1)

GROUND BASED
ACC DELIVERY



AVIONICS:	INTEGRAL
STRUCTURE:	GRAPHITE EPOXY
AEROBRAKE:	40 FT
REDUNDANCY:	NON-MAN RATED
PROP CAP:	54,000 Lb
LOADED WT:	59,472 Lb
ENGINE:	475 Isp/7500 Lb (1)

GROUND BASED
ACC DELIVERY



AVIONICS:	INTEGRAL
STRUCTURE:	GRAPHITE EPOXY
AEROBRAKE:	38 FT
REDUNDANCY:	MAN RATED
PROP CAP:	51,000 Lb
LOADED WT:	56,925 Lb
ENGINES:	475 Isp/7500 Lb (2)

GROUND BASED
ACC DELIVERY

FIGURE 2.7.3-7 OPTION 7 CONFIGURATION GBU/GBU(55 KLB)/GBM

TABLE 2.7.3-8 OPTION 1, DDT&E (CONSTANT 85 $M)

	GB ACC	SB MR	TOTAL
D&D	368.4	94.4	462.8
STRUCTURES	15.0	9.3	24.3
TANKS	6.8	5.4	12.2
PROPULSION	8.0	3.5	11.5
ENGINE	137.5	13.7	151.2
ACS	9.1	4.3	13.4
GN&C	81.5	8.6	90.1
C&DH	39.4	5.9	45.3
ELEC. PWR	16.6	1.9	18.5
ENV CNTRL	5.5	8.0	13.5
AEROBRAKE	33.2	10.3	43.5
GSE	5.2	.5	5.7
ASE	10.6	2.2	12.8
SSE		20.8	20.8
SE&I	85.9	57.3	143.2
SOFTWARE	61.2	10.1	71.3
TOOLING	19.3	4.3	23.6
TEST HARDWARE	125.2	50.5	175.7
TEST OPS & FIX	23.2	12.5	35.7
PROG MANAGE.	41.0	12.3	53.3
STAGE DDT&E	724.2	241.4	965.6
P/L CLUST. STR	30.1		30.1
LEVEL II			
PM,SE&I,TEST	179.0	77.2	256.2
TEST FLT	80.2		80.2
OTV TOTAL	1013.5	318.6	1332.1
FACILITIES	20.0		20.0
DDT&E TOTAL	1033.5	318.6	1352.1

TABLE 2.7.3-9 OPTION 2, DDT&E (CONSTANT 85 $M)

	GB ACC	SB	SB MR	TOTAL
D&D	368.4	80.1	40.2	488.7
STRUCTURES	15.0	9.1	4.6	28.7
TANKS	6.8	5.3	5.4	17.5
PROPULSION	8.0	2.5	1.3	11.8
ENGINE	137.5	13.5	6.9	157.9
ACS	9.1	4.3		13.4
GN&C	81.5	8.2	3.4	93.0
C&DH	39.4	5.4	1.6	46.4
ELEC. PWR	16.6	1.7	1.9	20.2
ENV CNTRL	5.5	7.8	1.0	14.3
AEROBRAKE	33.2	2.3	8.3	43.8
GSE	5.2	.5		5.7
ASE	10.6	2.2		12.8
SSE		17.4	5.9	23.3
SE&I	85.9	52.4	13.2	151.5
SOFTWARE	61.2	7.2	3.6	72.0
TOOLING	19.3	4.2	3.6	27.1
TEST HARDWARE	125.2	29.1	25.9	180.2
TEST OPS & FIX	23.2	11.3	5.7	40.2
PROG MANAGE.	41.0	11.1	5.5	57.6
STAGE DDT&E	724.2	195.4	97.7	1017.3
P/L CLUST. STR	30.1			30.1
LEVEL II				
PM,SE&I,TEST	179.0	44.6	44.1	267.7
TEST FLT	80.2			80.2
OTV TOTAL	1013.5	240.0	141.8	1395.3
FACILITIES	20.0			20.0
DDT&E TOTAL	1033.5	240.0	141.8	1415.3

TABLE 2.7.3-10 OPTION 4, DDT&E (CONSTANT 85 $M)

	SB MR	TOTAL
D&D	443.8	443.8
STRUCTURES	21.9	21.9
TANKS	9.3	9.3
PROPULSION	10.4	10.4
ENGINE	151.2	151.2
ACS	13.2	13.2
GN&C	86.2	86.2
C&DH	41.4	41.4
ELEC. PWR	18.4	18.4
ENV CNTRL	11.0	11.0
AEROBRAKE	41.3	41.3
GSE	5.7	5.7
ASE	11.1	11.1
SSE	22.7	22.7
SE&I	103.0	103.0
SOFTWARE	71.5	71.5
TOOLING	24.2	24.2
TEST HARDWARE	150.4	150.4
TEST OPS & FIX	35.0	35.0
PROG MANAGE.	49.7	49.7
STAGE DDT&E	877.6	877.6
P/L CLUST. STR	30.1	30.1
LEVEL II		
PM,SE&I,TEST	215.8	215.8
TEST FLT	80.2	80.2
OTV TOTAL	1203.7	1203.7
FACILITIES	15.0	15.0
DDT&E TOTAL	1218.7	1218.7

TABLE 2.7.3-11 OPTION 5, DDT&E (CONSTANT 85 $M)

	SB	SB MR	TOTAL
D&D	410.8	40.2	451.0
STRUCTURES	18.6	4.6	23.2
TANKS	7.7	5.4	13.1
PROPULSION	9.5	1.3	10.8
ENGINE	144.4	6.9	151.3
ACS	13.2		13.2
GN&C	83.5	3.4	86.9
C&DH	39.4	1.6	41.0
ELEC. PWR	17.3	1.9	19.2
ENV CNTRL	10.1	1.0	11.1
AEROBRAKE	33.2	8.3	41.5
GSE	5.7		5.7
ASE	10.9		10.9
SSE	17.4	5.9	23.3
SE&I	94.9	13.2	108.1
SOFTWARE	69.4	3.6	73.0
TOOLING	23.5	3.6	27.1
TEST HARDWARE	137.0	25.9	162.9
TEST OPS & FIX	33.3	5.7	39.0
PROG MANAGE.	48.0	5.5	53.5
STAGE DDT&E	816.9	97.7	914.6
P/L CLUST. STR	30.1		30.1
LEVEL II			
PM,SE&I,TEST	193.6	44.1	237.7
TEST FLT	80.2		80.2
OTV TOTAL	1120.8	141.8	1262.6
FACILITIES	15.0		15.0
DDT&E TOTAL	1135.8	141.8	1277.6

TABLE 2.7.3-12 OPTION 7, DDT&E (CONSTANT 85 $M)

	GB ACC	GB	GB MR	TOTAL
D&D	368.4	40.8	21.5	430.7
STRUCTURES	15.0	7.1	3.3	25.4
TANKS	6.8	4.4	2.0	13.2
PROPULSION	8.0	.7	1.3	10.0
ENGINE	137.5	6.9	6.9	151.3
ACS	9.1	2.1	-	11.2
GN&C	81.5	4.1	3.0	88.6
C&DH	39.4	2.0	1.4	42.8
ELEC. PWR	16.6	.8	.9	18.3
ENV CNTRL	5.5	7.8	.5	13.8
AEROBRAKE	33.2	2.3	2.2	37.7
GSE	5.2	.5	-	5.7
ASE	10.6	2.2	-	12.8
SSE	-	-	-	0.0
SE&I	85.9	17.1	6.4	109.4
SOFTWARE	61.2	3.6	1.0	65.8
TOOLING	19.3	4.2	2.9	26.4
TEST HARDWARE	125.2	25.7	20.6	171.5
TEST OPS & FIX	23.2	3.2	1.5	27.9
PROG MANAGE.	41.0	6.0	3.1	50.1
STAGE DDT&E	724.2	100.6	57.0	881.8
P/L CLUST. STR	30.1			30.1
LEVEL II				
PM,SE&I,TEST	179.0	21.4	11.9	212.3
TEST FLT	80.2			80.2
OTV TOTAL	1013.5	122.0	68.9	1204.4
FACILITIES	20.0			20.0
DDT&E TOTAL	1033.5	122.0	68.9	1224.4

TABLE 2.7.3-13 OPTION 1, INITIAL PRODUCTION (CONSTANT 85 $M)

	GB ACC		SB MR		TOTAL PRODUCTION
	UNIT	PROD	UNIT	(2 Units) PROD	
FLT HARDWARE	38.0		44.6	89.2	89.2
STRUCTURES	1.4	GVTA	2.3	4.6	4.6
TANKS	1.6	&	1.7	3.4	3.4
PROPULSION	1.8	FLT TEST	2.1	4.2	4.2
ENGINE	2.0	ARTICLES	4.0	8.0	8.0
ACS	1.3		1.8	3.6	3.6
GN&C	5.7	REFURBED	6.2	12.4	12.4
C&DH	12.0		12.0	24.0	24.0
ELEC. PWR	2.6		2.8	5.6	5.6
ENV CNTRL	.7		1.1	2.2	2.2
AEROBRAKE	2.5		3.0	6.0	6.0
A&CO	6.4		7.6	15.2	15.2
TOOLING & STE	3.6		4.3	8.6	8.6
SUSTAINING ENG	4.1		4.7	9.4	9.4
SE&I	.8		1.0	2.0	2.0
PROG MANAGEMENT	2.8		3.1	6.2	6.2
STAGE PROD.	49.3		57.7	115.4	115.4
P/L CLUST. STR	14.9	29.9		0.0	29.9
PROD TOTAL		29.9		115.4	145.3

TABLE 2.7.3-14 OPTION 2, INITIAL PRODUCTION (CONSTANT 85 $M)

	GB ACC		SB NMR		SB MR	
	UNIT	PROD	UNIT	(2 Units) PROD	UNIT	PROD
FLT HARDWARE	38.0		40.7	81.4	44.6	89.2
STRUCTURES	1.4	GVTA	2.3	4.6	2.3	4.6
TANKS	1.6	&	1.7	3.4	1.7	3.4
PROPULSION	1.8	FLT TEST	2.1	4.2	2.1	4.2
ENGINE	2.0	ARTICLES	2.0	4.0	4.0	8.0
ACS	1.3		1.8	3.6	1.8	3.6
GN&C	5.7	REFURBED	5.7	11.4	6.2	12.4
C&DH	12.0		12.0	24.0	12.0	24.0
ELEC. PWR	2.6		2.6	5.2	2.8	5.6
ENV CNTRL	.7		1.1	2.2	1.1	2.2
AEROBRAKE	2.5		2.5	5.0	3.0	6.0
A&CO	6.4		6.9	13.8	7.6	15.2
TOOLING & STE	3.6		3.9	7.8	4.3	8.6
SUSTAINING ENG	4.1		4.4	8.8	4.7	9.4
SE&I	.8		.9	1.8	1.0	2.0
PROG MANAGEMENT	2.8		3.0	6.0	3.1	6.2
STAGE PROD.	49.3		52.9	105.8	57.7	115.4
P/L CLUST. STR	14.9	29.9	14.9		14.9	
PROD TOTAL		29.9		105.8		115.4

TABLE 2.7.3-15 OPTION 4, INITIAL PRODUCTION (CONSTANT 85 $M)

	EXPENDABLE		SB MR		TOTAL PRODUCTION
	UNIT	PROD	UNIT	(2 Units) PROD	
FLT HARDWARE			44.6		0.0
STRUCTURES			2.3	GVTA	0.0
TANKS	UNIT COST		1.7	&	0.0
PROPULSION	PER		2.1	FLT TEST	0.0
ENGINE	STUDY		4.0	ARTICLES	0.0
ACS	GROUND		1.8		0.0
GN&C	RULES		6.2	REFURBED	0.0
C&DH		HARDWARE	12.0		0.0
ELEC. PWR		COST	2.8		0.0
ENV CNTRL		INCLUDED	1.1		0.0
AEROBRAKE		IN	3.0		0.0
A&CO		OPS	7.6		0.0
TOOLING & STE			4.3		0.0
SUSTAINING ENG			4.7		0.0
SE&I			1.0		0.0
PROG MANAGEMENT			3.1		0.0
STAGE PROD.			57.7		0.0
P/L CLUST. STR			14.9	29.9	29.9
PROD TOTAL				29.9	29.9

TABLE 2.7.3-16 OPTION 5, INITIAL PRODUCTION (CONSTANT 85 $M)

	EXPENDABLE		SB NMR		SB MR	
	UNIT	PROD	UNIT	(2 Units) PROD	UNIT	PROD
FLT HARDWARE			40.7		44.6	89.2
STRUCTURES			2.3	GVTA	2.3	4.6
TANKS	UNIT COST		1.7	&	1.7	3.4
PROPULSION	PER		2.1	FLT TEST	2.1	4.2
ENGINE	STUDY		2.0	ARTICLES	4.0	8.0
ACS	GROUND		1.8		1.8	3.6
GN&C	RULES		5.7	REFURBED	6.2	12.4
C&DH		HARDWARE	12.0		12.0	24.0
ELEC. PWR		COST	2.6		2.8	5.6
ENV CNTRL		INCLUDED	1.1		1.1	2.2
AEROBRAKE		IN	2.5		3.0	6.0
A&CO		OPS	6.9		7.6	15.2
TOOLING & STE			3.9		4.3	8.6
SUSTAINING ENG			4.4		4.7	9.4
SE&I			.9		1.0	2.0
PROG MANAGEMENT			3.0		3.1	6.2
STAGE PROD.			52.9		57.7	115.4
P/L CLUST. STR			14.9	29.9	14.9	
PROD TOTAL				29.9		115.4

TABLE 2.7.3-17 OPTION 7, INITIAL PRODUCTION (CONSTANT 85 $M)

	GB ACC		GB NMR		GB MR	
	UNIT	PROD	UNIT	(2 Units) PROD 2	UNIT	(2 Units) PROD
FLT HARDWARE	38.0		39.1	78.2	42.4	84.8
STRUCTURES	1.4	GVTA	1.8	3.6	1.8	3.6
TANKS	1.6	&	1.8	3.6	1.8	3.6
PROPULSION	1.8	FLT TEST	1.8	3.6	1.9	3.8
ENGINE	2.0	ARTICLES	2.0	4.0	4.0	8.0
ACS	1.3		1.8	3.6	1.8	3.6
GN&C	5.7	REFURBED	5.7	11.4	6.2	12.4
C&DH	12.0		12.0	24.0	12.0	24.0
ELEC. PWR	2.6		2.9	5.8	3.0	6.0
ENV CNTRL	.7		.8	1.6	1.1	2.2
AEROBRAKE	2.5		2.5	5.0	2.5	5.0
A&CO	6.4		6.0	12.0	6.3	12.6
TOOLING & STE	3.6		3.8	7.6	4.3	8.6
SUSTAINING ENG	4.1		4.2	8.4	4.6	9.2
SE&I	.8		.8	1.6	1.0	2.0
PROG MANAGEMENT	2.8		2.9	5.8	3.1	6.2
STAGE PROD.	49.3		50.8	101.6	55.4	110.8
P/L CLUST. STR	14.9	29.9	14.9		14.9	
PROD TOTAL		29.9		101.6		110.8

TABLE 2.7.3-18 OPTION 1, OPERATIONS COST SUMMARY (CONSTANT 85$M)

	OPTION 1		
OPS ELEMENT	GB ACC	SB MR	TOTAL
OTV FLIGHTS	35	110	145
MISS OPS, KSC	10.5	25.3	35.8
PROPELL. OPS	1.1	21.3	22.4
PROGRAM SUPP	42.4	69.7	112.1
AIRFRAME SPRS		85.5	85.5
AF IVA/EVA	.5	23.8	24.3
AEROBRAKE SPRS	70.0	48.4	118.4
AEROBRAKE IVA	.1	21.6	21.7
ENGINE SPARES	5.0	50.1	55.1
ENGINE IVA/EVA	.1	21.6	21.7
HDW RFB/MISC SPRS	11.8	11.6	23.4
EXPECT. MISS LOSS	38.5	148.9	187.4
OTV SUBTOTAL	180.0	527.8	707.8
PROPELLANT	.3	1879.3	1879.6
P/L CLUSTERING STR	7.6	22.7	30.3
SUBTOTAL	187.9	2429.8	2617.7
OMV SB LAUNCH OPS		59.0	59.0
STS LAUNCH COST	2806.7	926.5	3733.2
SUBTOTAL	2994.6	3415.3	6409.9
P/L TRANSPORTATION	3.4	4995.1	4998.5
TOTAL OPERATIONS	2998.0	8410.4	11408.4

TABLE 2.7.3-19 OPTION 2, OPERATIONS COST SUMMARY (CONSTANT 85$M)

	OPTION 2			
OPS ELEMENT	GB ACC	SB NMR	SB MR	TOTAL
OTV FLIGHTS	35	76	34	145
MISS OPS, KSC	10.5	19.0	6.3	35.8
PROPELL. OPS	1.1	14.9	6.7	22.7
PROGRAM SUPP	42.4	45.1	20.8	108.3
AIRFRAME SPRS		41.4		41.4
AF IVA/EVA	.5	16.4	7.3	24.2
AEROBRAKE SPRS	70.0	28.4	13.2	111.6
AEROBRAKE IVA	.1	14.9	6.7	21.7
ENGINE SPARES	5.0	16.0	14.4	35.4
ENGINE IVA/EVA	.1	14.9	6.7	21.7
HDW RFB/MISC SPRS	11.8	7.1	3.8	22.7
EXPECT. MISS LOSS	38.5	83.9	65.1	187.5
OTV SUBTOTAL	180.0	302.0	151.0	633.0
PROPELLANT	.3	1139.9	559.3	1699.5
P/L CLUSTERING STR	7.6	15.1	7.6	30.3
SUBTOTAL	187.9	1457.0	717.9	2362.8
OMV SB LAUNCH OPS		39.8	17.8	57.6
STS LAUNCH COST	2806.7	587.9	274.8	3669.4
SUBTOTAL	2994.6	2084.7	1010.5	6089.8
P/L TRANSPORTATION	3.4	3505.9	1489.0	4998.3
TOTAL OPERATIONS	2998.0	5590.6	2499.5	11088.1

TABLE 2.7.3-20 OPTION 4, OPERATIONS COST SUMMARY (CONSTANT 85$M)

	OPTION 4		
OPS ELEMENT	EXPEND.	SB MR	TOTAL
OTV FLIGHTS	35	110	145
MISS OPS, KSC		25.3	25.3
PROPELL. OPS		21.3	21.3
PROGRAM SUPP		69.7	69.7
AIRFRAME SPRS		85.5	85.5
AF IVA/EVA		23.8	23.8
AEROBRAKE SPRS		48.4	48.4
AEROBRAKE IVA		21.6	21.6
ENGINE SPARES		50.1	50.1
ENGINE IVA/EVA		21.6	21.6
HDW RFB/MISC SPRS		11.6	11.6
EXPECT. MISS LOSS		148.9	148.9
OTV SUBTOTAL	N/A	527.8	527.8
PROPELLANT		1879.3	1879.3
P/L CLUSTERING STR		22.7	22.7
SUBTOTAL	2312.7	2429.8	4742.5
OMV SB LAUNCH OPS		59.0	59.0
STS LAUNCH COST	3031.3	926.5	3957.8
SUBTOTAL	5344.0	3415.3	8759.3
P/L TRANSPORTATION		4995.1	4995.1
TOTAL OPERATIONS	5344.0	8410.4	11441.7

TABLE 2.7.3-21 OPTION 5, OPERATIONS COST SUMMARY (CONSTANT 85$M)

	OPTION 5			
OPS ELEMENT	EXPEND.	SB NMR	SB MR	TOTAL
OTV FLIGHTS	35	76	34	145
MISS OPS, KSC		19.0	6.3	25.3
PROPELL. OPS		14.9	6.7	21.6
PROGRAM SUPP		45.1	20.8	65.9
AIRFRAME SPRS		41.4		41.4
AF IVA/EVA		16.4	7.3	23.7
AEROBRAKE SPRS		28.4	13.2	41.6
AEROBRAKE IVA		14.9	6.7	21.6
ENGINE SPARES		16.0	14.4	30.4
ENGINE IVA/EVA		14.9	6.7	21.6
HDW RFB/MISC SPRS		7.1	3.8	10.9
EXPECT. MISS LOSS		83.9	65.1	149.0
OTV SUBTOTAL	N/A	302.0	151.0	453.0
PROPELLANT		1139.9	559.3	1699.2
P/L CLUSTERING STR		15.1	7.6	22.7
SUBTOTAL	2312.7	1457.0	717.9	4487.6
OMV SB LAUNCH OPS		39.8	17.8	57.6
STS LAUNCH COST	3031.3	587.9	274.8	3894.0
SUBTOTAL	5344.0	2084.7	1010.5	8439.2
P/L TRANSPORTATION		3505.9	1489.0	4994.9
TOTAL OPERATIONS	5344.0	5590.6	2499.5	13434.1

TABLE 2.7.3-22 OPTION 7, OPERATIONS COST SUMMARY (CONSTANT 85$M)

	OPTION 7			
OPS ELEMENT	GB ACC	GB NMR	GB MR	TOTAL
OTV FLIGHTS	35	76	34	145
MISS OPS, KSC	10.5	19.0	6.3	35.8
PROPELL. OPS	1.1	2.4	1.1	4.6
PROGRAM SUPP	42.4	86.0	38.5	166.9
AIRFRAME SPRS		37.1		37.1
AF IVA/EVA	.5	1.1	.5	2.1
AEROBRAKE SPRS	70.0	39.0	18.4	127.4
AEROBRAKE IVA	.1	.2	.1	.4
ENGINE SPARES	5.0	14.3	12.4	31.7
ENGINE IVA/EVA	.1	.2	.1	.4
HDW RFB/MISC SPRS	11.8	31.7	13.1	56.6
EXPECT. MISS LOSS	38.5	83.9	65.1	187.5
OTV SUBTOTAL	180.0	314.9	155.6	650.5
PROPELLANT	.3	1.1	.5	1.9
P/L CLUSTERING STR	7.6	15.6	7.6	30.8
SUBTOTAL	187.9	331.6	163.7	683.2
OMV SB LAUNCH OPS				
STS LAUNCH COST	2806.7	6106.5	2733.4	11646.6
SUBTOTAL	2994.6	6438.1	2897.1	12329.8
P/L TRANSPORTATION	3.4	3505.9	1489.0	4998.3
TOTAL OPERATIONS	2998.0	9944.0	4386.1	17328.1

TABLE 2.7.3-23 COMPETITION MISSION MODEL CAPTURE

MISSION NUMBER	P/L WEIGHT (POUNDS)	P/L LENGTH (FEET)	COMPETITION	STAGE WEIGHT (POUNDS)	STAGE LENGTH (FEET)	STAGE COST (M$)	STS DEL TO LEO (M$)	TOTAL CPF (M$)	COST PER YEAR (MILLION 1985 DOLLARS) 94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	MISSION TOTAL	REMARKS
GEO STATIONARY PLATFORMS																											
13006 EXPERIMENTAL GEO PLATFORM	12017	31.17	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0	128	SINGLE STS DELIVERY MAX GEO P/L 13200
13700 COMMERCIAL GEO PLATFORM	20000	35	STS/CENTAUR G'	63336	29.1	55.4	130	185.4	0	0	0	0	0	0	0	0	0	0	185	0	0	185	185	185	185	927	2 STS FLTS REQ ON-ORBIT: TOP OFF PROPELLANT MATE STAGE & P/L MAX GEO P/L 19500
INDIVIDUAL SATELLITES																											
18073 MRS-C	12000	35	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0	0	128	SINGLE STS DELIVERY MAX GEO P/L 13200
18040 GEO EARTH OBSERVATION SYSTEM	20000	20	STS/CENTAUR G'	63336	29.1	55.4	105.1	160.5	0	0	0	0	0	0	0	161	0	0	0	0	0	0	0	0	0	161	SAME AS MSN 13700
18722 INDIVIDUAL PLATFORM	20000	35	STS/CENTAUR G'	63336	29.1	55.4	130	185.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	185	185	SAME AS MSN 13700
PLANETARY SCENARIO																											
17081 S/C P/L UP P/L DN NEAR	4079 TBD 0	5 TBD 0	STS/TOS-AMS	37402	16.5	48	56.2	104.2	104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104	MAX GEO P/L 5935 lbs DIA 10.0
17084 S/C P/L UP P/L DN MSP	4410 4410 0	35 35 0	STS/TOS-AMS	37402	16.5	48	73	121	0	0	0	0	0	121	0	0	0	0	0	0	0	0	0	0	0	121	MAX GEO P/L 5935 lbs DIA 10.0
17075 S/C P/L UP P/L DN OBSERVER X	5000 TBD 0	5 TBD 0	STS/CENTAUR G	46390	19.5	55.4	69.5	124.9	0	0	125	0	0	0	0	0	0	125	0	0	0	0	0	0	0	250	MAX GEO P/L 10000
17074 S/C P/L UP P/L DN NF/P	3497 TBD 0	10 TBD 0	STS/CENTAUR G'	63336	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0	0	128	SAME AS MSN 13700

TABLE 2.7.3-23 COMPETITION MISSION MODEL CAPTURE (CONTINUED)

17078 S/C P/L UP P/L DN MO/L	2205 2205 0	10 10 0	STS/TOS-AMS	37402	16.5	48	53.3	101.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	101	0	101	MAX GEO P/L 5935 lbs DIA 10.0
MULTIPLE PAYLOAD DELIVERY SCENARIO																											
18912 A UP DN 4/1 MULTIPLING (0-2030 lb)	12000 2000	25 5	STS/PAM-D2	11215	6.5	11.37	20.7	32.07	128	128	0	128	128	0	128	0	0	128	0	0	128	0	0	128	0	1026	MAX GEO P/L 2030 lbs DIA 5.3'
18912 B UP DN 3/1 MULTIPLING (2031-2500 lb)	12000 2000	25 5	STS/TOS-AMS	37402	16.5	48	53.9	101.9	0	306	0	0	306	0	0	306	0	0	306	0	0	0	306	0	0	1529	MAX GEO P/L 5935 lbs DIA 10.0
18912 C UP DN 2/1 MULTIPLING (2501-4800 lb)	12000 2000	25 5	STS/TOS-AMS	37402	16.5	48	57.1	105.1	210	210	210	420	210	420	420	420	420	631	420	420	420	420	631	420	631	6937	MAX GEO P/L 5935 lbs DIA 10.0
GEO SERVICING																											
13002 S/C UP S/C DN P/L UP P/L DN EXPERIMENTAL GEO PLATFORM SERVICING DEMO	1690 200 7000 4510	15 15 15 15	STS/CENTAUR G	46390	19.5	55.4	73	128.4	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	128	MAX GEO P/L 10000
15700 UP DOWN MANNED SERVICING SORTIE	7500 7500	10 10	STS/CENTAUR (MAN-RATED)			138.5	146	284.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	285	285	285	854	MR VEHICLE COST EQUIVALENT OF 2.5 CENTAUR G's DDT&E: $200M OVER 2 YEARS 2 STS FLIGHTS PER MISSION MODEL FLT
GEO SERVICE STATION LOGISTICS SCENARIO																											
15008 MOBILE GEO SERVICE STATION	13159	15	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	128	SINGLE STS DELIVERY MAX GEO P/L 13200
15009 GEO HABITAT/WORK STATION	13310	20	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0	128	SINGLE STS DELIVERY MAX GEO P/L 13200
15701 UP DOWN MOBILE GEO SERVICE STATION LOGISTICS	12000 2000	15 15	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	0	0	0	0	0	0	0	0	0	0	128	128	128	0	128	128	0	642	SINGLE STS DELIVERY MAX GEO P/L 13200

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TABLE 2.7.3-23 COMPETITION MISSION MODEL CAPTURE (CONTINUED)

LUNAR BASE PROGRAM SCENARIO																										
17200 S/C	5000	20	STS/TOS-AMS	37402	16.5	48	59.2	107.2	0	0	0	0	0	0	0	0	0	0	0	0	0	107	0	0	0	107	MAX GEO P/L 5935 lbs DIA 10.0
P/L UP	5000	20																									
P/L DN	0	0																									
LUNAR COMMUNICATIONS RELAY																											
17202 UP	20000	18	STS/CENTAUR G'	63336	29.1	55.4	102.2	157.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	158	0	158	SAME AS MSN 13700
DOWN	0	0																									
LUNAR SURFACE EXPLORER																											
DOD																											
19031 GENERIC 1	12000	30	STS/CENTAUR G'	51800	29.1	55.4	73	128.4	514	514	514	514	514	514	514	0	0	0	0	0	0	0	0	0	0	3595	SINGLE STS DELIVERY MAX GEO P/L 13200
19035 GENERIC 2	20000	35	STS/CENTAUR G'	63336	29.1	55.4	130	185.4	0	0	0	0	0	0	0	742	742	742	742	742	742	742	742	742	742	7416	SAME AS MSN 13700
REFLIGHTS																											
10100 REFLIGHTS (1/16)	20000	20	STS/CENTAUR G'	63336	29.1	55.4	105.4	160.8	0	0	161	0	0	0	0	0	0	0	0	161	0	0	0	0	161	482	SAME AS MSN 13700
TOTALS: CONSTANT 1985 DOLLARS									956	1158	1010	1062	1158	1055	1191	1757	1290	1625	1782	1451	1675	1583	2276	2147	2188	25365	
PV FACTOR (0% INFLATION, 10% DISCOUNT)									0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15	0.14	0.12	0.11	0.10	0.09		
PRESENT VALUE 1985 DOLLARS									406	446	354	338	335	278	285	382	255	292	291	216	226	194	254	218	202	4974	

AVERAGE COST PER FLIGHT: (210 FLIGHTS WITH MULTIPLE P/L MISSIONS)
CONSTANT DOLLARS $120.8
PRESENT VALUE DOLLARS $23.7