General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

83NA2780

CR-170795

TELEOPERATOR MANEUVERING SYSTEM (TMS) BENEFITS ASSESSMENT STUDY

CONTRACT NAS8-34888

FINAL REPORT

VOLUME I

EXECUTIVE SUMMARY

PREPARED FOR NASA GEORGE C. MARSHALL SPACE FLIGHT CENTER

BY

ROCKWELL INTERNATIONAL CORPORATION

SPACE TRANSPORTATION AND SYSTEMS GROUP

12214 LAKEWOOD BOULEVARD

DOWNEY, CALIFORNIA 90241

(NASA-CR-170795) TELEOPERATOR MANEUVERING SYSTEM (TMS) BENEFITS ASSESSMENT STUDY. VOLUME 1: EXECUTIVE SUMMARY Final Report (Rockwell International Corp., Downey, Calif.) 42 p HC A03/MF A01 CSCL 05H G3/54

N83-30034

Unclas 28208

APRIL 1983

ORIGINAL PAGE IS
OF POOR QUALITY

FOREWORD

This Teleoperator Maneuvering System Benefits Assessment Study was performed by the Rockwell International Corporation under NASA Contract NAS8-34888 for the George C. Marshall Space Flight Center from April 1982 through October 1982. The study results are documented in two volumes:

Volume I: Executive Summary

Volume II: Technical Report

Study management and lead responsibility for each of the four major tasks were as follows:

Study Manager	W. T. Appleberry
Mission Models and Payload Requirements	W. A. McClure
Systems Integration	O. A. Nelson
Costing	H. Cameron
Benefits Analysis	R. M. Hayes

The study was directed from NASA/MSFC by Mr. J. R. Turner, Technical Manager for the Contracting Officer.

The Contract Administrator for Rockwell International Corporation was Mr. G. A. Beardslee.

Requests for further information will be welcomed by the following Rockwell personnel:

ORIGINAL PAGE IS
OF POOR QUALITY

W. T. (Tom) Appleberry, Program Manager

Telephone: (213) 922-5642, M.S.: AD38

D. L. (Doris) Tostensen

Telephone: (213) 922-1084, M.S.: AA77

Mail Address:

Rockwell International Corporation
12214 Lakewood Boulevard
Downey, California 90241

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE OF CONTENTS

		PAGE
1.0	SUMMARY	
	TMS Versus Integral Spacecraft Propulsion	1
	TMS Remote Maintenance of Spacecraft	1
	TMS Benefits Sensitivity to Investment Costs	1
	TMS Benefits Versus Increases In Transport Costs	1
	Launch Prices Use In Study Analysis	1
	Integral Propulsion Length Penalties	1
	TMS Remote Maintenance Versus EVA	1
	TMS Potential Benefits From Weight Reductions	1
	TMS Basing Mode Benefit Trades	2
	TMS Mission Models and Payload Requirements	2
	TMS Program Profitability	2
2.0	INTRODUCTION	3
2.1	Study Guidelines and Assumptions	4
2.2	Approach and Study Plan	6
2.3	Study Conclusions	8
3.0	SUMMARY DISCUSSION OF STUDY TASKS	9
3.1	Task 4.1 - Mission Models and Payload Requirements	9
3.2	Task 4.2 - TMS/Payload/Orbiter Systems Integration	10
3.3	Task 4.3 - Costing Analysis	12
3.4	Task 4.4 - TMS Benefits Analysis	16
4.0	SPECIAL INTEREST STUDY TASK RESULTS	21
4.1	TMS Remote Maintenance Versus EVA	21
4.2	TMS Benefits Sensitivity to Increases In Launch Charges	23
4.3	TMS Versus Integral Propulsion - Additional Savings for TMS	25
4.4	Space Basing the TMS Increases Benefits	31

ORIGINAL PAGE IS
OF POOR QUALITY

LIST OF ILLUSTRATIONS

FIGURE	
2.0-1	Rockwell's Strategy for Assisting TMS Development
2.0-2	TMS Benefits Study Organization
2.1-1	Study Guidelines and Assumptions
2.1-2	Baseline TMS Configuration
2.1.1-1	New Issues Emerging After Study Initiation
2.2-1	Approach and Study Plan
2.2-2	TMS Benefits Study Logic Flow
2.3-1	Seven Good Reasons for a TMS New Start
3.1-1	Task 4.1 - Mission Models, Ground Based TMS
3.2-1	Task 4.2 - TMS Ground Operations/Documentation
3.2-2	TMS/STS Ground Turnaround Timeline
3.3-1	Task 4.3 - Costing Analysis
3.3-2	TMS Versus Integral Propulsion - Comparison of Single and Multiple Engagement Missions
3.3.1-1	TMS Versus OMS Kits
3.4.1-1	TMS Shows Benefits Over Integral Propulsion
3.4.2-1	Remote Maintenance - The Maximum Potential Benefit for TMS - $3.4B
3.4.2-2	Potential Annual Loss Avoidance By Satellite Servicing, LEO/Polar/GEO
3.4.3-1	TMS Benefits Assessment: Bottomline
4.1-1	TMS Versus EVA - Cost Analysis
4.1-2	Cost Elements of EVA Missions
4.2-1	TMS Servicing Benefits Increase as Launch Charges Increase
4.2-2	TMS Deployment Benefits Diminish at Expected STS Costs

LIST OF ILLUSTRATIONS (Cont'd)

ORIGINAL PAGE IS
OF POOR QUALITY

FIGURE

4.3-1 TMS Versus Integral Propulsion - Potential for Further TMS Savings

4.3-2 Potential TMS Weight Reduction Benefits

4.3-3 Potential TMS Effective Length Reduction: The Annular TMS Concept

4.3-4 Integral Propulsion Length Penalties - A TMS Benefit

4.3.1-1 TMS Versus Integral Propulsion - Summary

4.3.2-1 The Optimal "Integral Propulsion Dilemma"

4.4-1 Early Space Basing Scenario for TMS

4.4.1-1 Mission Models for the Space Based TMS

4.4.1-2 TMS Basing Modes Analysis

ORIGINAL PAGE IS
OF POOR QUALITY

LIST OF ABBREVIATIONS AND ACRONYMS

AFD	Aft Flight Deck
ASE	Airborne Support Equipment
DDT&E	Design, Development, Testing, and Evaluation
DoD	Department of Defense
D_I	Inside Diameter
D_O	Outside Diameter
DMSP	Defense Meteorological Satellite Program
ETR	Eastern Test Range
EVA	Extravehicular Activity
FSS	Flight Support Station
GEO	Geostationary Orbit
GPS	Global Positioning System
GSE	Ground Support Equipment
GTAT	Ground Turnaround Time
IOC	Initial Operational Capability
I_{sp}	Specific Impulse
LEO	Low Earth Orbit
L	Length
MMS	Multimission Modular Spacecraft
NOM	Nominal
MPG	Miles Per Gallon
OMS	Orbital Maneuvering System
OPS	Operations
OTV	Orbital Transfer Vehicle
PM	Propulsion Module

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

q	Number of Satellites Per Program
R&D	Research and Development
RMS	Remote Manipulator System
STS	Space Transportation System
ST	Space Telescope
TMS	Teleoperator Maneuvering System
V	Velocity
WTR	Western Test Range
WT	Weight
W_P	Weight of Propellant

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

1.0 SUMMARY

- TMS Versus Integral Space Propulsion.
  - Program savings of $170M over integral propulsion through mission sharing.
  - Savings increase to $240M when minimum integral propulsion length penalties of about $70M are included.
  - TMS savings further increase to $600M when potential weight savings from use of bipropellant fuel and elimination of ASE cradle, reducing launch costs by $360M, are included.
  - Key cost driver: high transport charges for ground based TMS account for 85% of program costs. TMS generally larger, heavier than most missions require. Without TMS weight reduction, integral propulsion remains cost effective for small payloads, resulting in reduction of TMS flight base which increases TMS cost per engagement. This circular effect erodes TMS savings.
  - Key solution to TMS propulsion benefits: space basing. In lieu of this, reduce weight of ground based TMS.
- TMS Remote Maintenance of Spacecraft.
  - Program savings of $3.4B.
  - Conservative: Based on low user acceptance.
  - Largest potential TMS economic benefit.
- TMS Remote Maintenance Versus EVA
  - TMS savings of over $11M, first mission.
  - Added savings of over $10M for each successive maintenance mission.
- TMS Benefits Sensitivity to Investment Costs.
  - Relatively insensitive.
  - Costs driven by STS transport charges of 84% versus only 16% for acquisition.
- TMS Benefits Versus Increases in Transport Costs.
  - Servicing benefits increase: TMS is 5 feet shorter and 5700 pounds lighter than Orbiter/EVA servicing ASE.
  - Propulsion benefits decrease: TMS is typically 2.8 feet longer and 3782 pounds heavier than integral propulsion.
  - Assumes average length penalty for fully buried integral propulsion of 0.75 foot.

ORIGINAL PAGE IS
OF POOR QUALITY

- Launch Prices Used in Study Analyses.
  - $70.8M, dedicated launch; Effective in late 1985 through 1988.
  - Special study task evaluating actual launch cost effects on TMS benefits used NASA estimates of $92M (ETR) and $122M (WTR).
- TMS Basing Mode Benefit Trades.
  - Maximum benefits: A space based TMS, refueled on orbit from the Orbiter OMS pod tanks, saves $7.6M/mission over ground basing.
  - No space station required.
  - Refueling a space based TMS from a free flying tanker saves $3.9M/mission.
  - A space based, ground refueled TMS saves $3.4M/mission.
- TMS Mission Models and Payload Requirements.
  - Nominal, optimistic, and pessimistic models were developed for a ground based TMS. Nominal used for analysis.
  - Initial nominal model identified 218 missions in all, and 413 engagements (deploy, retrieve, or maintain, defines an engagement), with 109 of the missions shared, spanning the years 1988 to 2000.
  - Mission sharing was later found to enhance TMS propulsion benefits. The 210 non-GEO missions became 194, resulting in a $270M reduction in program cost.
  - TMS ground turnaround time is an estimated 40 days.
  - TMS fleet size is 10 vehicles for a 25-flight life, 8 vehicles at 30 flights each, 6 at 50 flights, and 4 vehicles at a 100-flight life.
- TMS Program Profitability.
  - 28% per year, internal rate of return on investment.
  - Payback in three years from initial operational capability.
  - A highly profitable addition to the national space program.

ORIGINAL PAGE IS
OF POOR QUALITY

2.0 INTRODUCTION

Rockwell's interest in the TMS goes back to its origins when it was called the Teleoperator Retrieval System. We proposed its use in our approach to Skylab reboost. We have closely monitored its progress and have been gratified to see it move forward to its present position of prominence. Rockwell sees in the TMS concept the potential for a major enhancement of the Space Transportation System. Our strategy, as noted in Figure 2.0-1, is to exert every effort to encourage and support development of the TMS by working closely with the Marshall Space Flight Center and its contractors.

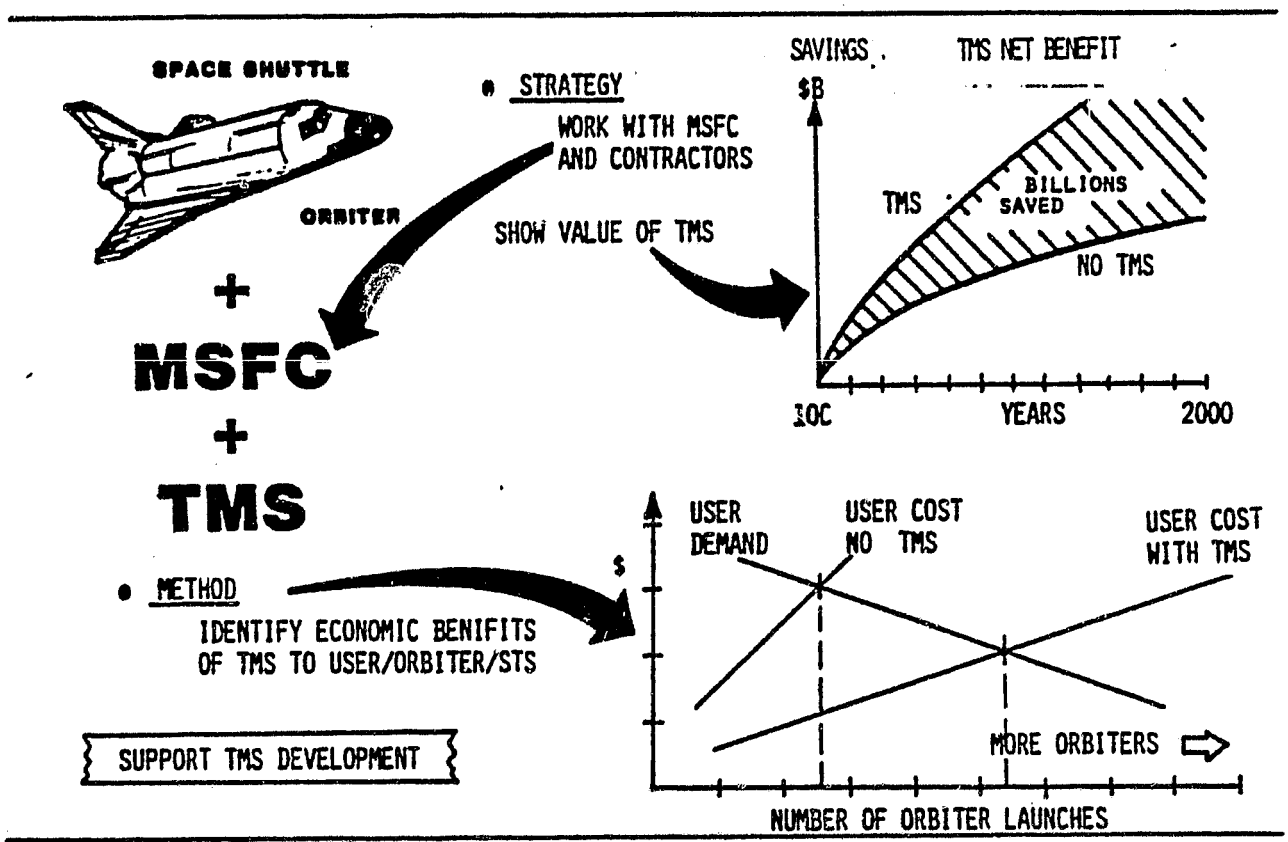


FIGURE 2.0-1 ROCKWELL'S STRATEGY FOR ASSISTING TMS DEVELOPMENT

After an evaluation of the status of TMS program definition, it was determined that a need existed for an economic benefits analysis which would cover the significant cost elements of TMS development, fleet acquisition, STS transport and operations, and compare them with alternative means for satisfying mission requirements. An unsolicited proposal was made to MSFC, and Rockwell was awarded a six month contract valued at $78,400.

The study organization and its position within the Rockwell Space Transportation and Systems Group is shown in Figure 2.0-2.

ORIGINAL PAGE IS
OF POOR QUALITY

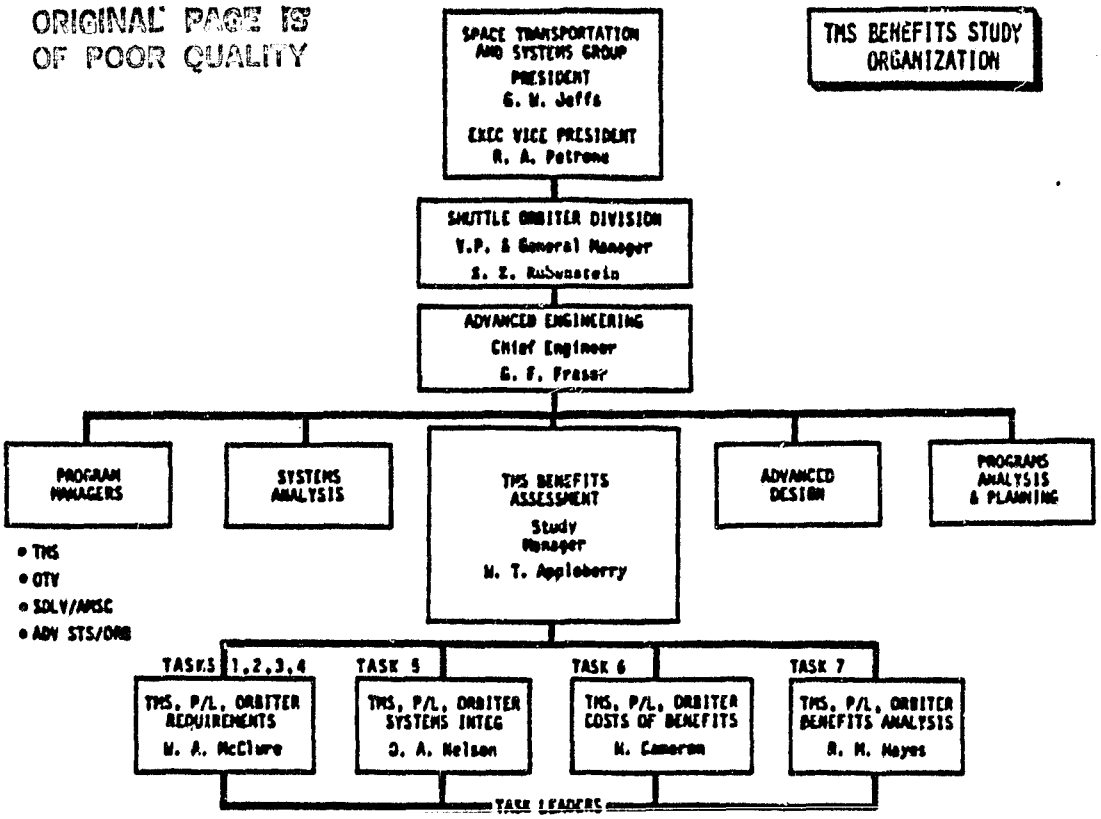


FIGURE 2.0-2 TMS BENEFITS STUDY ORGANIZATION

2.1 Study Guidelines and Assumptions

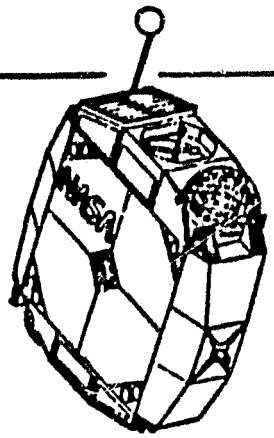
Rockwell proposed an unbiased evaluation of potential benefits of the Vought Corporation's Phase "A" study TMS configuration, using Vought's acquisition costs as baseline. No new configurations were to be proposed. We did, however, also propose to conduct sensitivity studies of benefits versus an assumed change in acquisition costs, and versus changes in propellant capacity. Figure 2.1-1 summarizes the study guidelines. The baseline TMS is illustrated in Figure 2.1-2.

2.1.1 New Issues Introduced After Study Initiation

During the course of the study, three new developments emerged which affected the TMS. A high altitude Orbiter ascent trajectory, without an OMS kit, was proposed for the Solar Maximum spacecraft repair mission. OMS kit development, initiated by NASA/JSC and active at Rockwell, was consequently cancelled in early 1982. The most important factor affecting TMS was the announced doubling of STS launch prices, to take effect in late 1985. These issues are summarized in Figure 2.1.1-1.

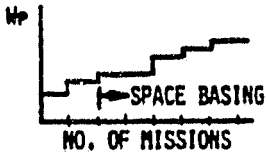
ORIGINAL PAGE IS
OF POOR QUALITY

- PROVIDE UNBIASED EVALUATION OF VOUGHT PHASE "A" TMS CONFIGURATION
  - ✓USE PHASE "A" CAPABILITIES AND ACQUISITION COSTS
  - ✓PROPOSE NO NEW CONFIGURATIONS
- FOUR STUDY TASKS
  - MISSION MODELS/REQUIREMENTS
  - SYSTEMS INTEGRATION
  - COSTING
  - BENEFITS ANALYSIS



LENGTH/DIAMETER
37/156"
TOTAL WEIGHT
7545 LB
PROPELLANT
[illegible] LB
Isp = 230 SEC.

✓ SUBTASK 4.1.4
EVALUATE PROPELLANT LOAD SIZING



✓ SUBTASK 4.3.2
ASSESS EFFECTS ON BENEFITS OF VARIATIONS IN ASSUMED COSTS/ SCHEDULES

FIGURE 2.1-1 STUDY GUIDELINES AND ASSUMPTIONS

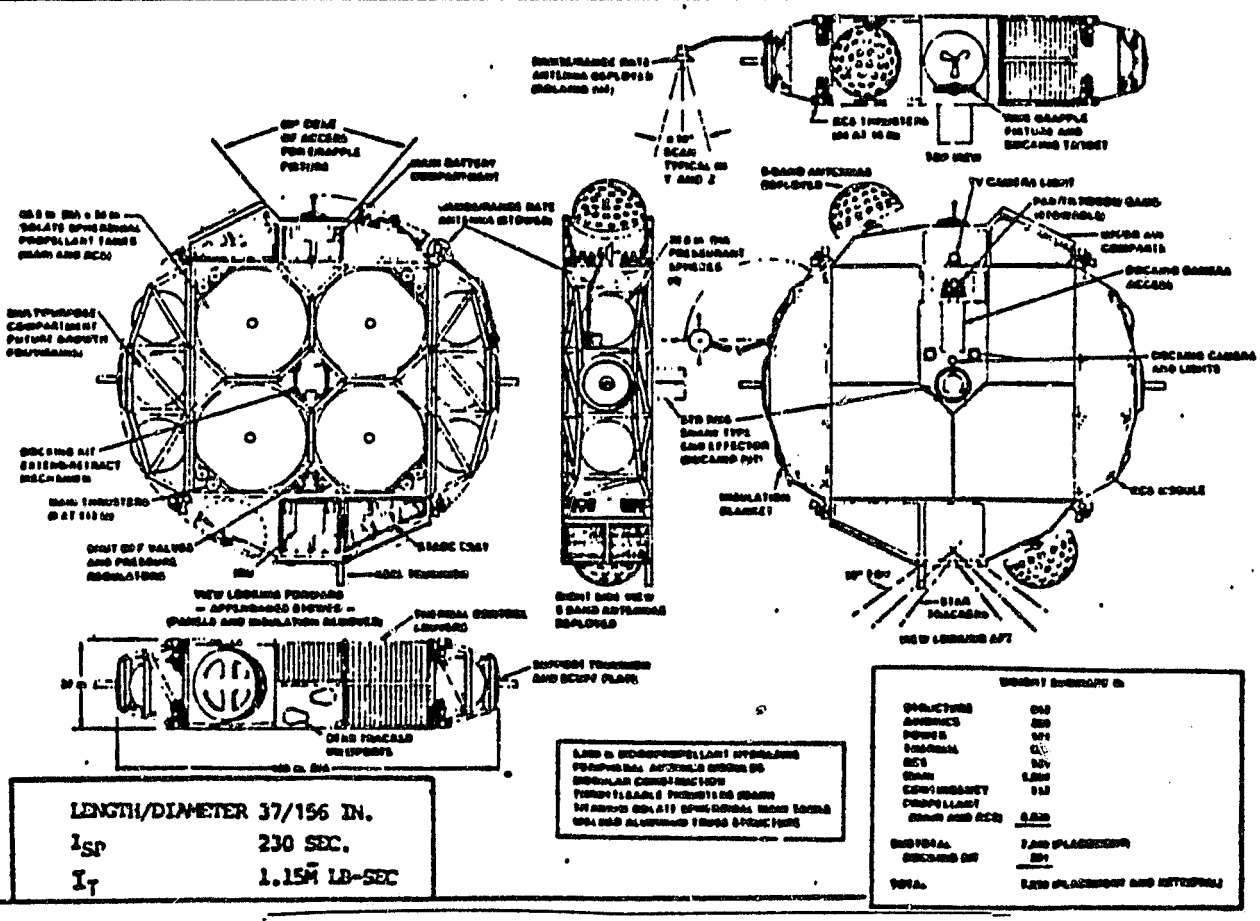


FIGURE 2.1-2 BASELINE TMS CONFIGURATION

ORIGINAL PAGE IS
OF POOR QUALITY

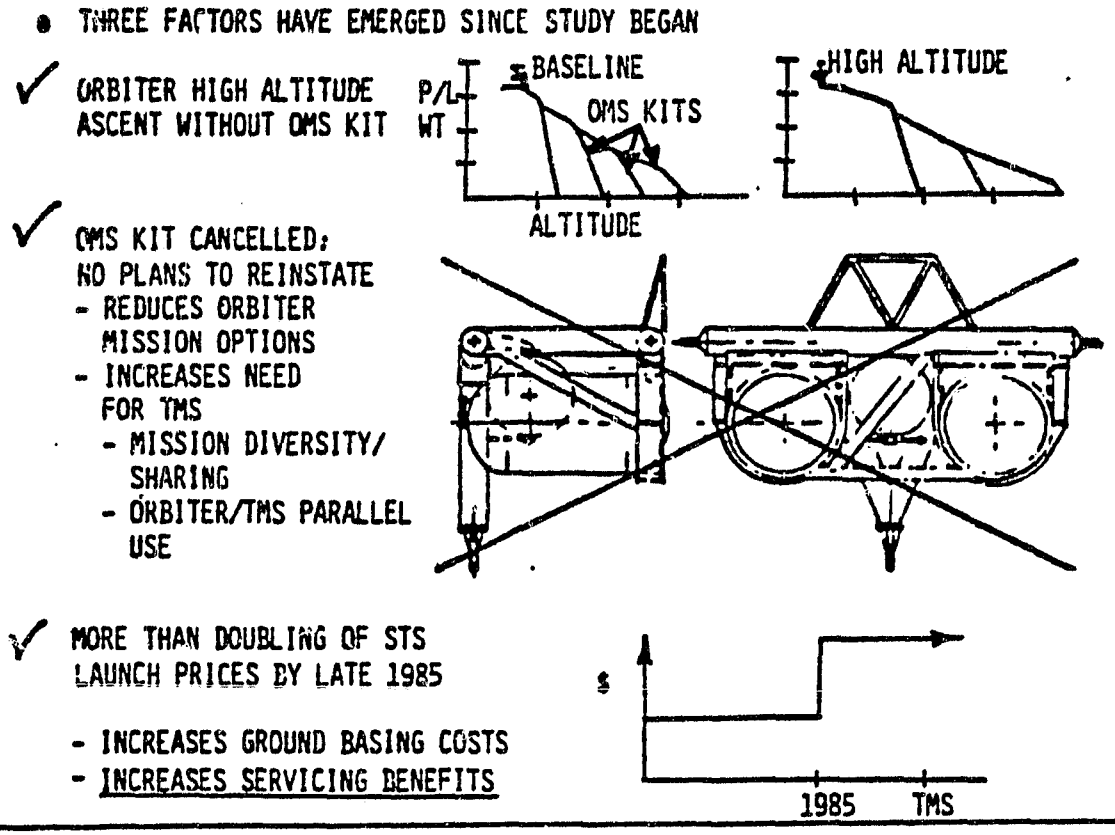


FIGURE 2.1.1-1 NEW ISSUES EMERGING AFTER STUDY INITIATION

2.2 Approach and Study Plan

An economic analysis was selected as the approach to the study, as shown in Figure 2.2-1. This meant that certain uses for the TMS which were difficult to quantify would not be included in the analysis, such as inspection, debris removal, and assembly operations, though the use of TMS for such tasks could become significant. It was determined most TMS functions amenable to costing could be classed as deployment, retrieval, or maintenance. The study plan consisted of the four major tasks shown in the Figure.

The study logic flow is shown in Figure 2.2-2. In progressive order, the first three tasks developed the data base used to support the benefits analysis in the fourth task. To reduce the losses associated with iterations due to incorrectly anticipating the requirements of successive tasks, the early practice in the study was to discuss task input/output requirements in reverse order, beginning with the fourth task. This was found productive, with transition to the normal sequence occurring later.

ORIGINAL PAGE IS
OF POOR QUALITY

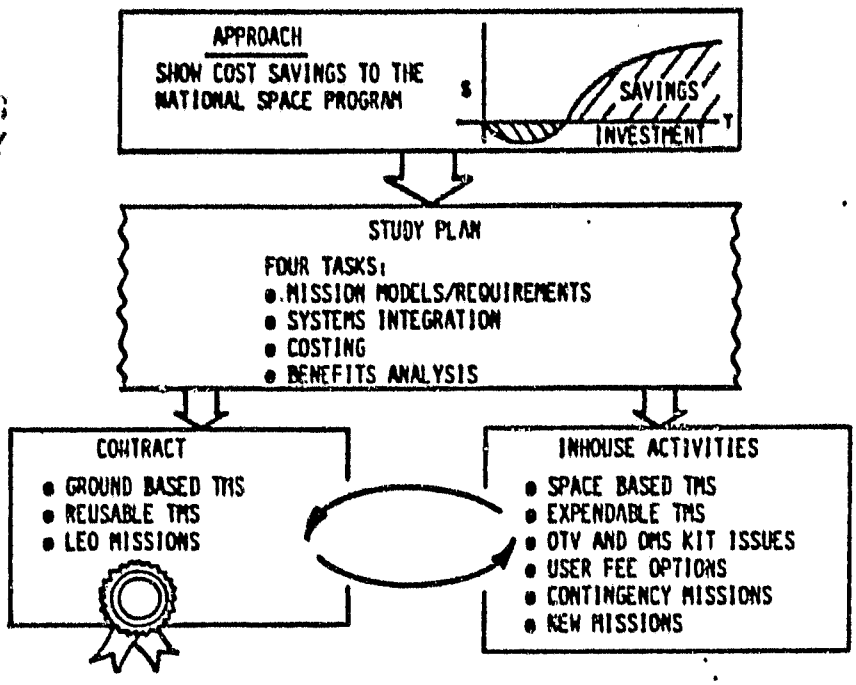


FIGURE 2.2-1 APPROACH AND STUDY PLAN

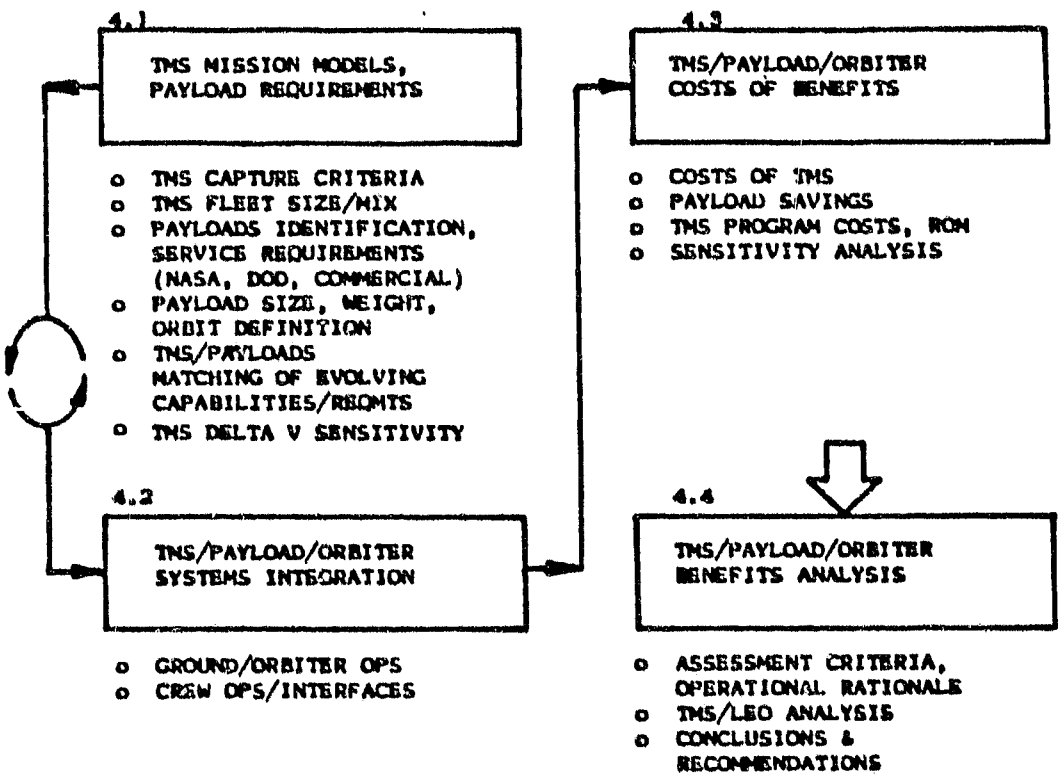


FIGURE 2.2-2 TMS BENEFITS STUDY LOGIC FLOW

ORIGINAL PAGE IS
OF POOR QUALITY

2.3 Study Conclusions

A TMS NEW START IS JUSTIFIED

- See Figure 2.3-1 for seven reasons.

- TMS Major Services: Propulsion and Maintenance.
  - Key to propulsion benefits: Mission sharing.
- Benefits not easily costed could be major: Inspection, assembly, debris removal, rapid or evasive maneuvering, LEO cargo transfer (logistics).
- Because of staging benefits, TMS provides significant savings over the OMS kit, and adds new mission flexibility.
- DoD showing interest in TMS for deployment, retrieval, and maintenance.
  - DMSP, GPS, and an R&D spacecraft.
  - Rockwell is pursuing this market.

- TMS BENEFITS: SIGNIFICANT AND RELATIVELY INSENSITIVE TO INVESTMENT
- ROCKWELL'S VIEW: THE IMPORTANT SHUTTLE ENHANCEMENT
- PROVIDES EARLY COST SAVINGS FOR MULTIPLE PAYLOAD DEPLOYMENT COMPARED TO INTEGRAL PROPULSION
- ADDED COST BENEFITS THROUGH PAYLOAD SERVICING
- OUT PERFORMS ORBITER OMS KIT
- COST EFFECTIVENESS IMPROVED BY SPACE BASING
- EXPANDED POTENTIAL FOR DOD

JUSTIFIES EARLY TMS PROGRAM START

FIGURE 2.3-1 SEVEN GOOD REASONS FOR A TMS NEW START

ORIGINAL PAGE IS
OF POOR QUALITY

3.0 SUMMARY DISCUSSION OF STUDY TASKS

3.1 Task 4.1 - Mission Models and Payload Requirements

- Nominal, low (pessimistic), and high (optimistic) models developed for ground based TMS, shown in Figure 3.1-1. Analyses based on nominal model.
- Engagement defined as one deployment, retrieval, or maintenance.
- TMS life: 25 flights for nominal model, 50 for the low, 30 for the high.
- TMS fleet size driven by flight life. For nominal mission model, fleet size is 10 vehicles at 25 flights each, 8 at 30 flights, 6 at 50, and 4 vehicles at 100 flights each.

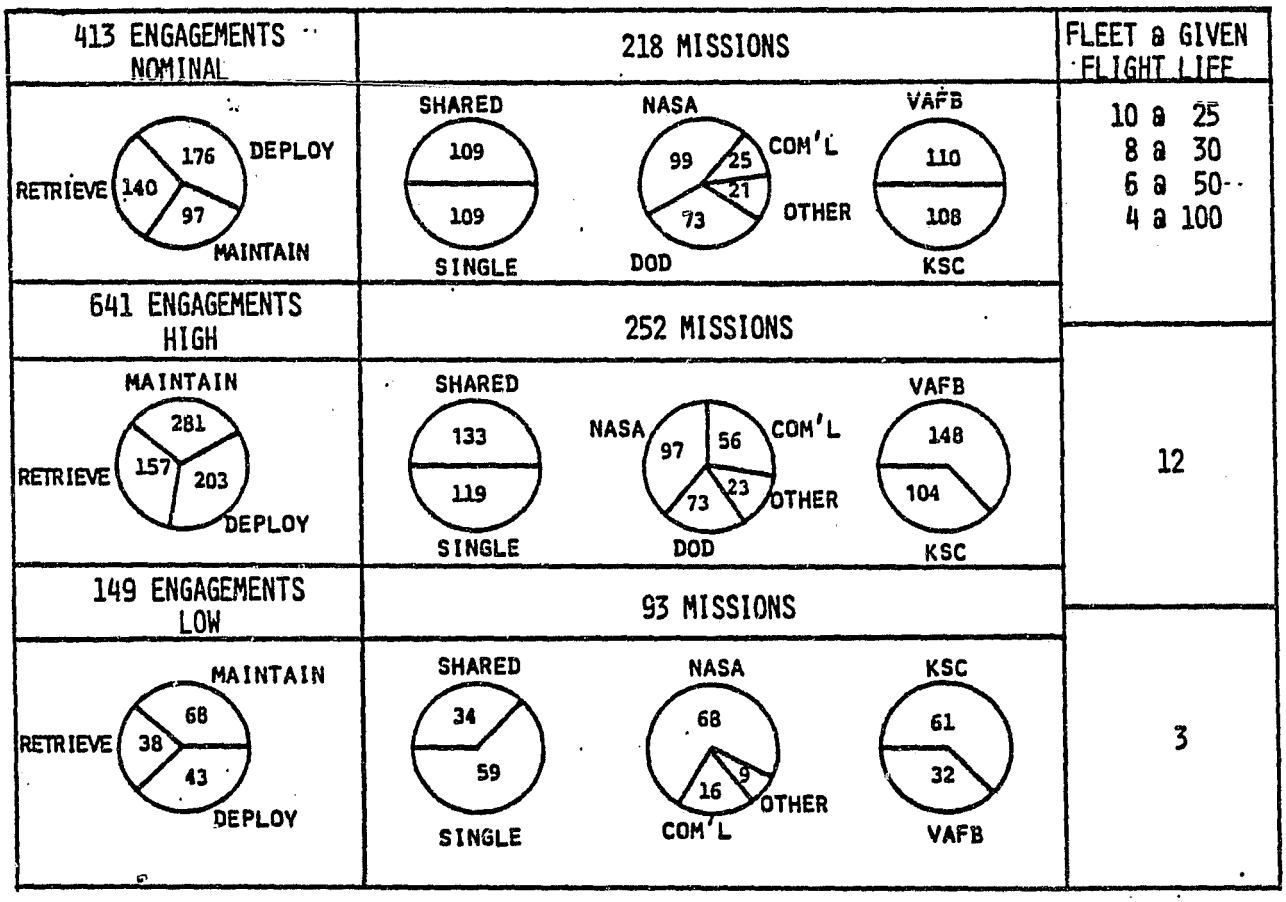


FIGURE 3.1-1 TASK 4.1 - MISSION MODELS, GROUND BASED TMS

ORIGINAL PAGE IS
OF POOR QUALITY

3.2 Task 4.2 - TMS/Payload/Orbiter Systems Integration

40 Days for TMS Ground Turnaround.

- Includes projected improvements and learning curve effects. Weekends only for emergencies.
- 28 month payload integration cycle may be shortened to 18 or 10 months, depending on studies now active.
- Ground operations/documentation summarized in Figure 3.2-1.

- TMS GROUND OPERATIONS

40 DAYS MINIMUM GTAT

TURNAROUND	40 DAYS
REFURBISHMENT	37 DAYS
CONTINGENCY MISSION INTEGRATION	62 DAYS
NORMAL PAYLOAD INTEGRATION	28 MONTHS

- RECURRING INTEGRATION AND DOCUMENTATION CONTRIBUTE TO GROUND BASING COSTS

	RECURRING	NON-RECURRING
DOCUMENTS	39	95
PAGES	617	2633
DRAWINGS	20	114

FIGURE 3.2-1 TASK 4.2 - TMS GROUND OPERATIONS/DOCUMENTATION

ORIGINAL PAGE IS
OF POOR QUALITY

- TMS/STS Ground Turnaround Timeline.
  - Figure 3.2-2 shows ground flow for TMS and STS.
  - Orbiter turnaround time not penalized.

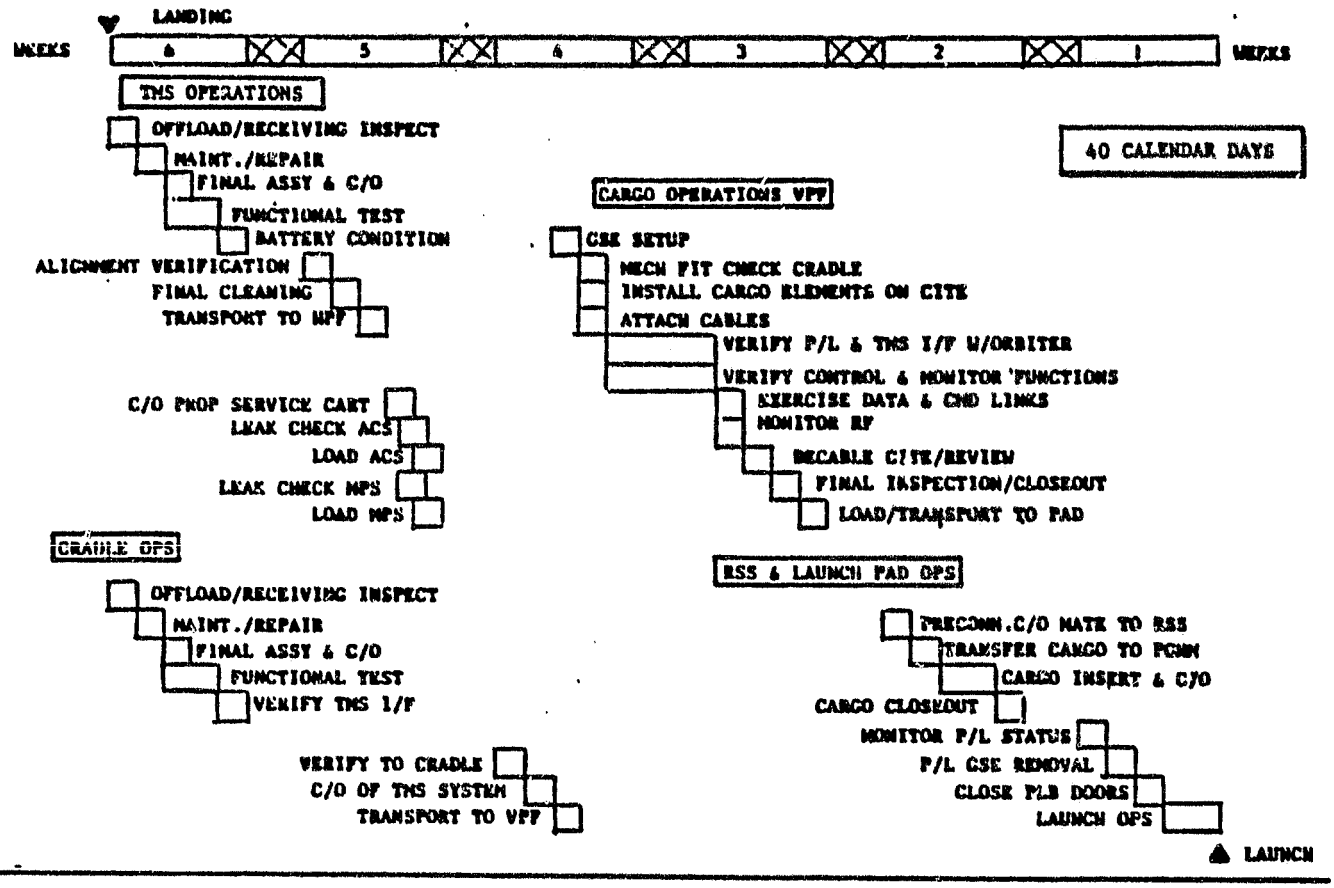


FIGURE 3.2-2 TMS/STS GROUND TURNAROUND TIMELINE

ORIGINAL PAGE IS
OF POOR QUALITY

3.3 Task 4.3 - Costing Analysis

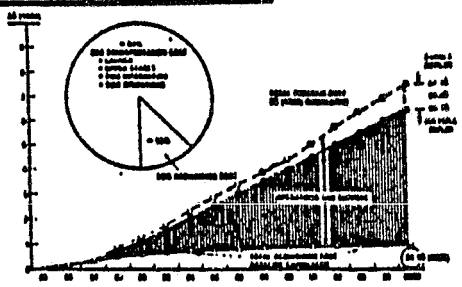
- Sensitivity of TMS Benefits to Changes In Investment Costs, Figure 3.3-1.

TMS BENEFITS RELATIVELY INSENSITIVE TO INVESTMENT COSTS

- Benefits driven by STS transport costs of $6.4B or 85% of $7.5B program.
- Investment of $1.1B or 15%, includes servicer for each of 12 TMS vehicles.
- Doubling of Vought DDT&E would increase program costs less than 3%.

$280M TMS PROGRAM SAVING BY MISSION SHARING IS ACHIEVABLE

- BENEFIT/COST OF TMS IS NOT SENSITIVE TO TMS ACQUISITION COSTS
- STS TRANSPORT COSTS DRIVE TOTAL TMS PROGRAM COSTS
- WITH 50% MISSION SHARING AND NO MULTIPLE MANIFESTING: (218 LAUNCHES) TOTAL TMS PROGRAM COST $7.5B 82, 1988-2000



✓ TMS ACQUISITION (12 UNITS)	$1.1B
✓ STS TRANSPORT AND TMS FLT OPS	$6.4B
	$7.5B

- WITH ACHIEVABLE MISSION SHARING (202 LAUNCHES):

PROGRAM COST	$7.2B
TRANSPORTATION, FLT OPS	$6.1B

- WITH MAXIMUM MULTIPLE MANIFESTING (GOAL):

PROGRAM COST	$6.7B
TRANSPORT & FLT OPS	$5.6B

*BASED ON 82 DAYS GTAT AND 25-FLIGHT LIFE; LATER REDUCED TO 10 UNITS AT 40 DAYS GTAT.

FIGURE 3.3-1 TASK 4.3 - COSTING ANALYSIS

- Multiple Versus Single TMS Engagement.

MULTIPLE MANIFESTING - KEY TO TMS PROPULSION PROFITS

- Single Engagements; no mission sharing: Program costs for integral propulsion given in left hand graph of Figure 3.3-2. The three solid lines show costs amortized over 2, 3, and 4 satellites. Two dashed lines show TMS costs, one for Vought DDT&E, and the other independently derived from Air Force Space Division Unmanned Spacecraft Cost Model.

ORIGINAL PAGE IS
OF POOR QUALITY

Results: TMS and integral propulsion costs essentially an even trade with 50% mission sharing using multiple engagements, but without multiple manifesting. In substantial agreement with three major studies by other contractors, when transport and investment costs are included.

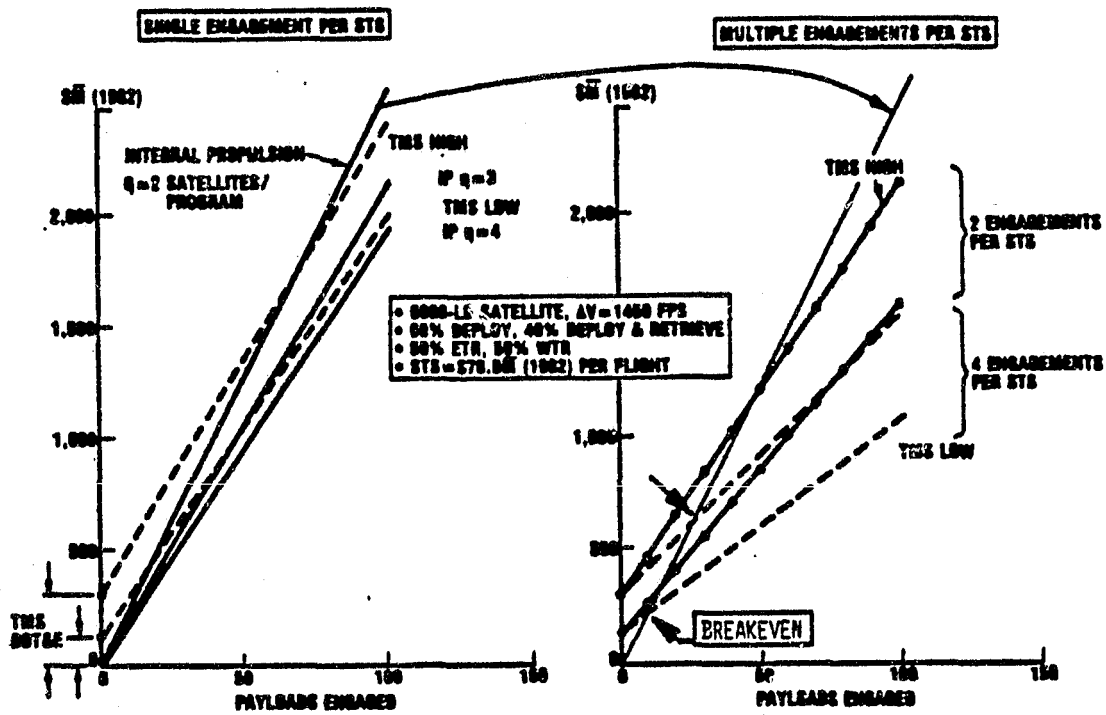


FIGURE 3.3-2 TMS VERSUS INTEGRAL PROPULSION - COMPARISON OF SINGLE AND MULTIPLE ENGAGEMENT MISSIONS

- Mission sharing; multiple engagements:

INCREASED MISSION SHARING - A $170M TMS PROPULSION BENEFIT

Mission sharing benefits are shown in right hand graph of Figure 3.3-2: Multiple TMS engagements are performed on the same mission. Transportation/ investment costs included.

The integral propulsion curve for the two-satellite case is repeated for ease of comparison and to show breakeven points. Two pairs of TMS lines, one solid, the other dashed, show effect of approximately doubling

ORIGINAL PAGE IS
OF POOR QUALITY

TMS DDT&E cost. Solid line in either case is for two engagements per launch, and dashed line for four engagements. For latter case, TMS savings over integral propulsion can begin after less than 10 engagements.

In addition to locating the breakeven point at 50% mission sharing (ratio of shared to single engagement missions), two additional levels of mission sharing were identified: (1) An achievable level in which 16 launches were eliminated, reducing the total to 202, producing a TMS saving over integral propulsion of $170M, and (2) A maximum or 100% mission sharing goal which included several multiple deployments, resulting in a TMS saving of $700M.

- Expected Frequency of Mission Sharing.
  - Multiple cargo manifesting played essential role in STS Phase "B" analyses. TMS has same manifesting goals. Present emphasis on STS mission sharing also expected for TMS.
  - A planned approach to the promotion and analysis of shared propulsion missions by the TMS program office is suggested.

ORIGINAL PAGE IS
OF POOR QUALITY

3.3.1 TMS Versus OMS Kits

- Background

  Though Rockwell was under contract to build a two-kit OMS package in early 1982, it was known that TMS would provide a large launch cost saving over the kits and that their use would generally be justified only for contingency missions requiring man's presence (even here, a manned TMS was seen as an eventuality). This, coupled with its subsequent cancellation, relegated TMS/kit trade studies to lower priority, especially since there are no current plans for further kit development.

- TMS and OMS Kit Launch Cost Comparisons.

  The price shown in Figure 3.3.1-1 for the flight unit included profit. Since WTR had scheduled several OMS kit missions, a composite Orbiter payload capacity of 48,500 pounds was used in estimating launch costs. A dedicated launch price of $71M in 1982 dollars was assumed.

- FULL PERFORMANCE TMS: AN STS BENEFITS/COST BARGAIN

  ✓ ADDED BENEFITS - REMOTE SERVICING; OUTPERFORMS OMS KIT

  ✓ REDUCED COSTS - FEWER ORBITER BASED OPERATIONS

  - TMS LAUNCH COST @ 8770 LB: $17.1M
    (ETR/WTR COMPOSITE 48,500 LB CAPACITY)

  - 2 OMS KITS DDT&E, ONE FLIGHT UNIT: $23.75M

  - OMS KIT LAUNCH COST (ETR/WTR COMPOSITE):

    1 KIT @ 19493 LB: $38M; 2 KITS @ 32738 LB: $64M

FIGURE 3.3.1-1 TMS VERSUS OMS KITS

ORIGINAL PAGE IS
OF POOR QUALITY

3.4 Task 4.4 - TMS Benefits Analysis

The TMS benefits study emplasized three area of economic analysis: Comparisons with integral spacecraft propulsion, remote maintenance of satellites, and program profitability.

3.4.1 TMS Versus Integral Spacecraft Propulsion

TMS SAVES $170M OVER INTEGRAL PROPULSION

TMS Propulsion Services: A Near Term Benefit.

- Use of the TMS as propulsion stage given top priority because of near term utilization potential. Payload changes to accommodate TMS propulsion: zero to minor. Though TMS remote maintenance has the highest benefit potential, user acceptance could take many years to mature.
- Mission sharing found to be the key to profitability for a ground based TMS. Three studies by other contractors concluded that, when transportation and TMS DDT&E costs were included, TMS and integral propulsion were an even trade -- without mission sharing. As one study put it, "No dual missions were performed (placement and retrieval on the same STS flight)". Rockwell confirmed these results, then proceeded to assess the benefits of mission sharing. This was a turning point in the study.

Results of Mission Sharing Analysis.

- Figure 3.4.1-1 shows program costs for integral propulsion (left hand graph) and TMS (right hand). The lower line for both is acquisition; the upper adds STS transportation. Dashed line (TMS) is approximate breakeven with integral propulsion at 50% mission sharing. Acquisition cost for integral propulsion is high ($3.9B), for a total of $5.6B. For TMS, acquisition is lower ($1.1B) but transportation is higher for the heavier vehicle, at $4.3B with achievable mission sharing, for total of $5.4B. The results:

TMS SAVES $170M OVER INTEGRAL PROPULSION; SHARED MISSIONS REDUCE PROGRAM COSTS BY $270M

Data based on TMS fleet of 12, each with servicer. Not included: savings from later fleet reduction to as few as 4 vehicles at a 100-flight life.

ORIGINAL PAGE IS
OF POOR QUALITY

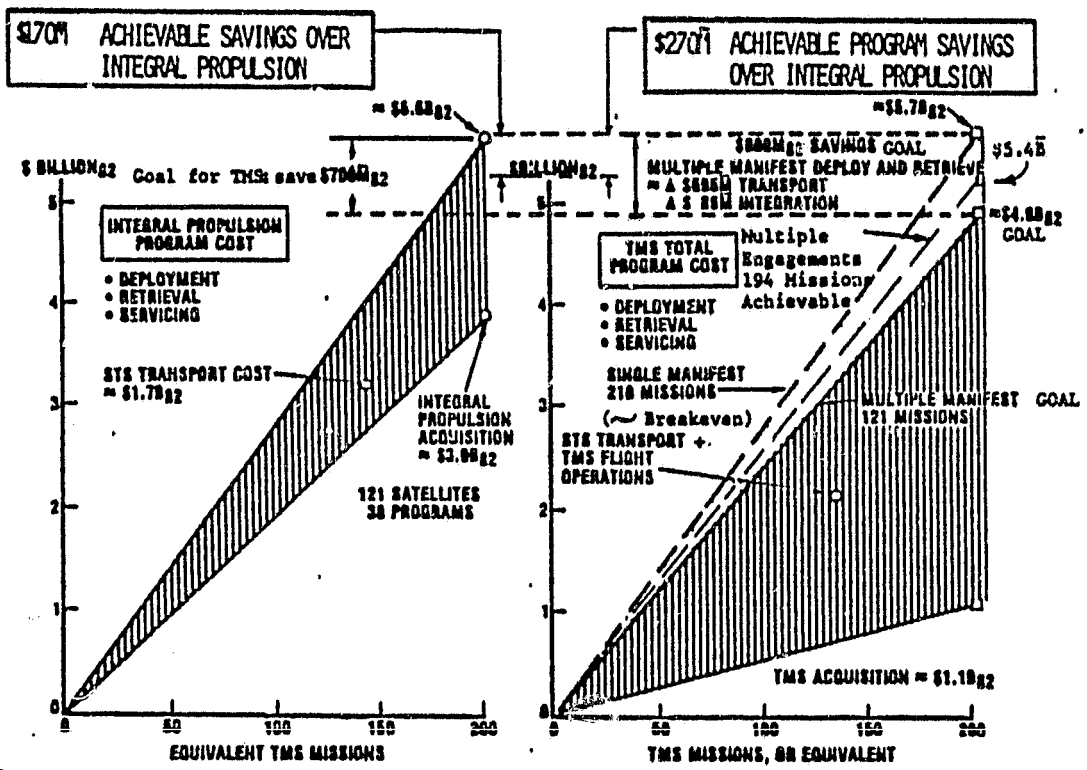


FIGURE 3.4.1-1 TMS SHOWS BENEFITS OVER INTEGRAL PROPULSION

3.4.2 TMS Remote Maintenance of Spacecraft

- Single Largest TMS Economic Benefit.

TMS REMOTE MAINTENANCE SAVES $3.4B̄

LEO/Polar Orbits Only

- Only TMS Can Perform Remote Maintenance.
  - Allows insitu servicing of satellites.
  - Reduces downtime.
  - Speeds contingency repairs and troubleshooting.
- TMS Servicing Is Long Term Benefit.
  - Servicing must be demonstrated to users.
  - User acceptance will be evolutionary, beginning with critical subsystems most apt to fail early.
- Figure 3.4.2-1 shows potential benefits for LEO/Polar servicing.
  - Conservatively assumes low acceptance of remote servicing.
  - Assuming more frequent (annual) maintenance, potential savings rise to $10.7B̄ for same low acceptance group.

ORIGINAL PAGE IS
OF POOR QUALITY

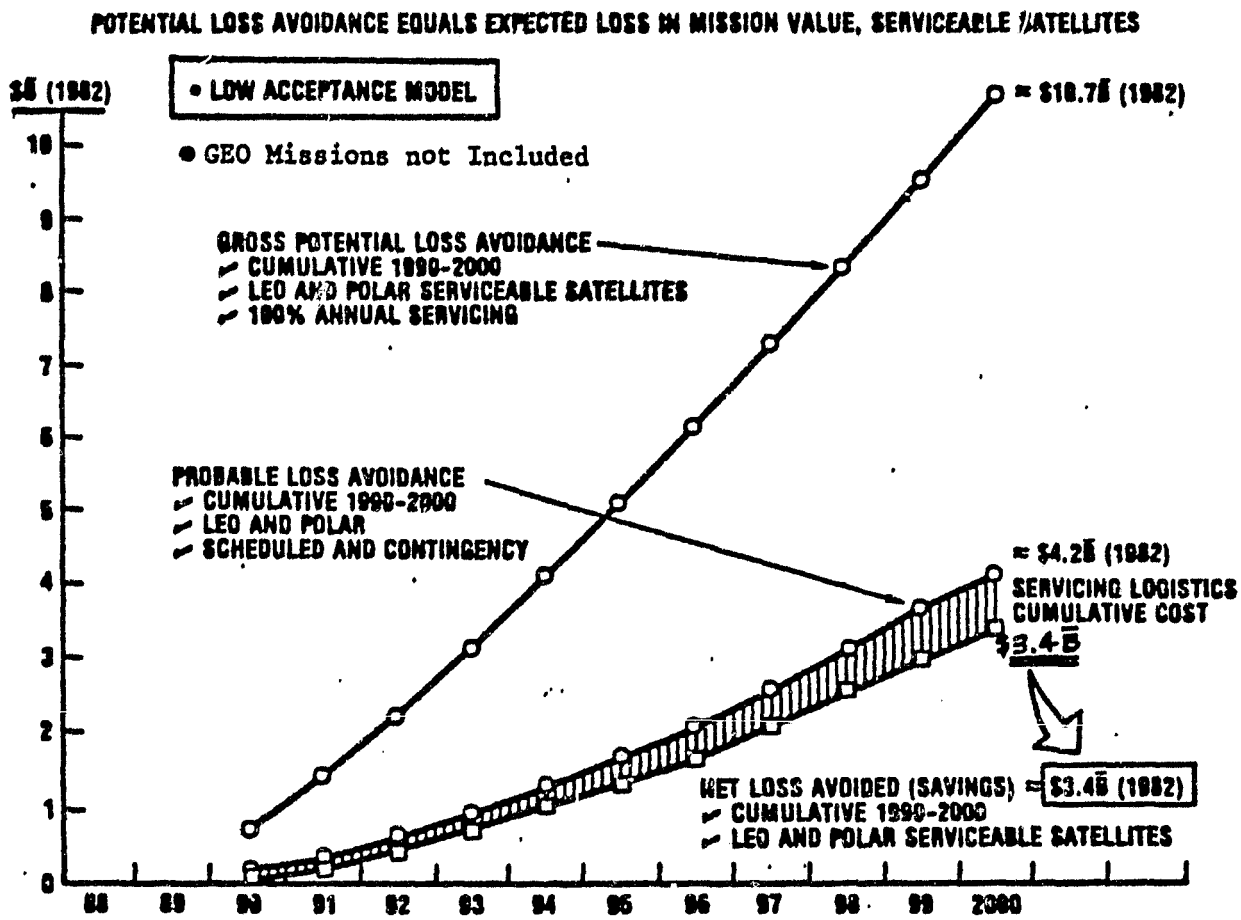


FIGURE 3.4.2-1 REMOTE MAINTENANCE - THE MAXIMUM POTENTIAL BENEFIT FOR TMS - $3.4B

- Growth In Satellite Maintenance.
  - First use: High value satellites, such as NASA astronomy observatories at 28.5° orbit inclination.
  - Will spread to polar and GEO orbits where higher launch costs provide servicing incentive. GEO servicing expected to encourage use of multipurpose platforms.
- Satellite Loss Avoidance Potential, Including GEO Servicing.

TMS REMOTE MAINTENANCE SAVES $16B

LEO/Polar/GEO Orbits

  - Figure 3.4.2-2 shows cumulative satellite loss avoidance projected for 1988 through 2000.
  - The two curves represent high and low user acceptance of satellite servicing, with annual savings reaching $2B to $4B.

ORIGINAL PAGE IS
OF POOR QUALITY

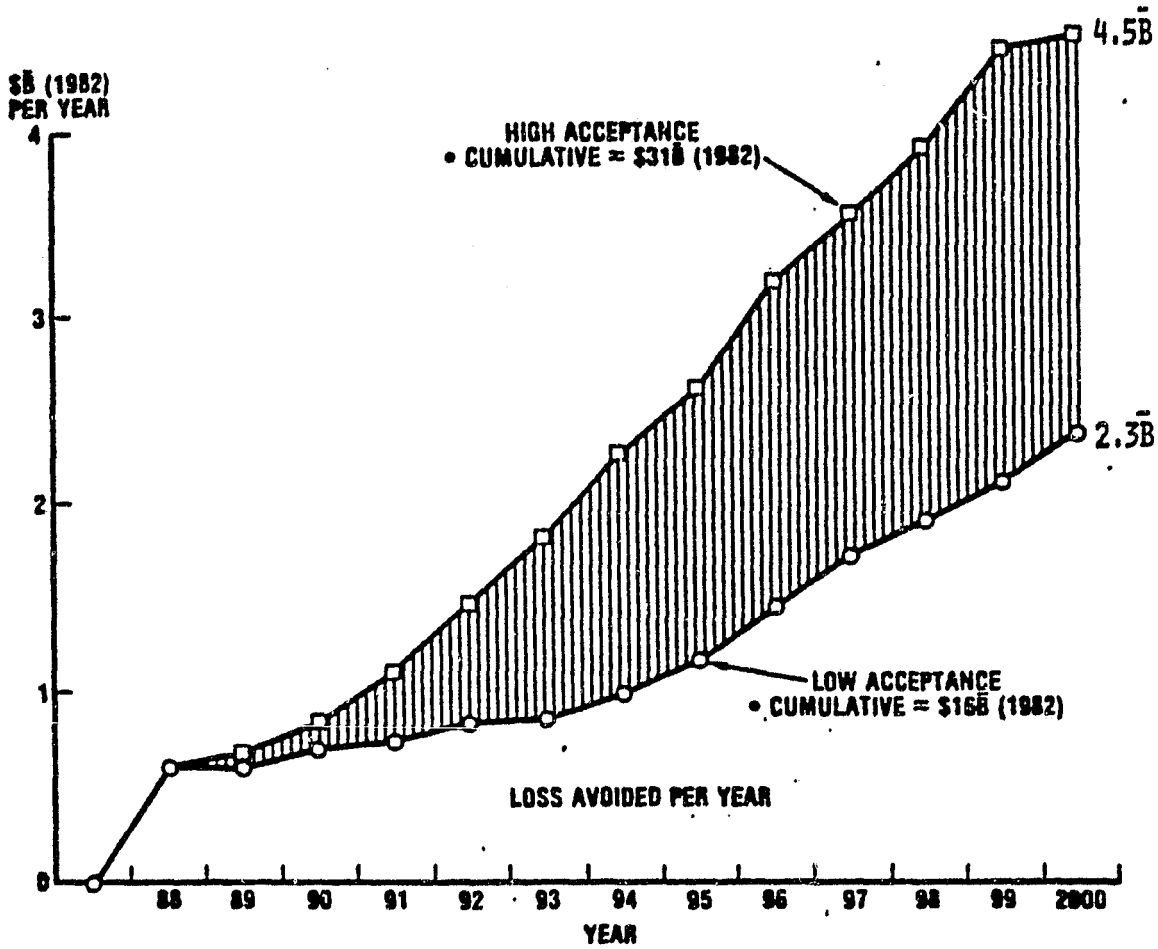


FIGURE 3.4.2-2 POTENTIAL ANNUAL LOSS AVOIDANCE BY SATELLITE SERVICING, LEO/POLAR/GEO

3.4.3 TMS Program Profitability

TMS INTERNAL RATE OF RETURN ON INVESTMENT: 28% PER YEAR; TMS PAYBACK PERIOD: ABOUT 3 YEARS

- TMS An Exceptionally Profitable Program.
  - Figure 3.4.3-1 shows the cumulative investment position for the TMS program — the bottom line. The solid line assumes single deploy or retrieve missions; the dashed line estimates the benefits of multiple manifesting, adding the attendant profitability of TMS propulsion services over integral propulsion. Both include servicing.
  - TMS payoff accelerates in mid to late 1990's when satellite maintenance begins to mature.

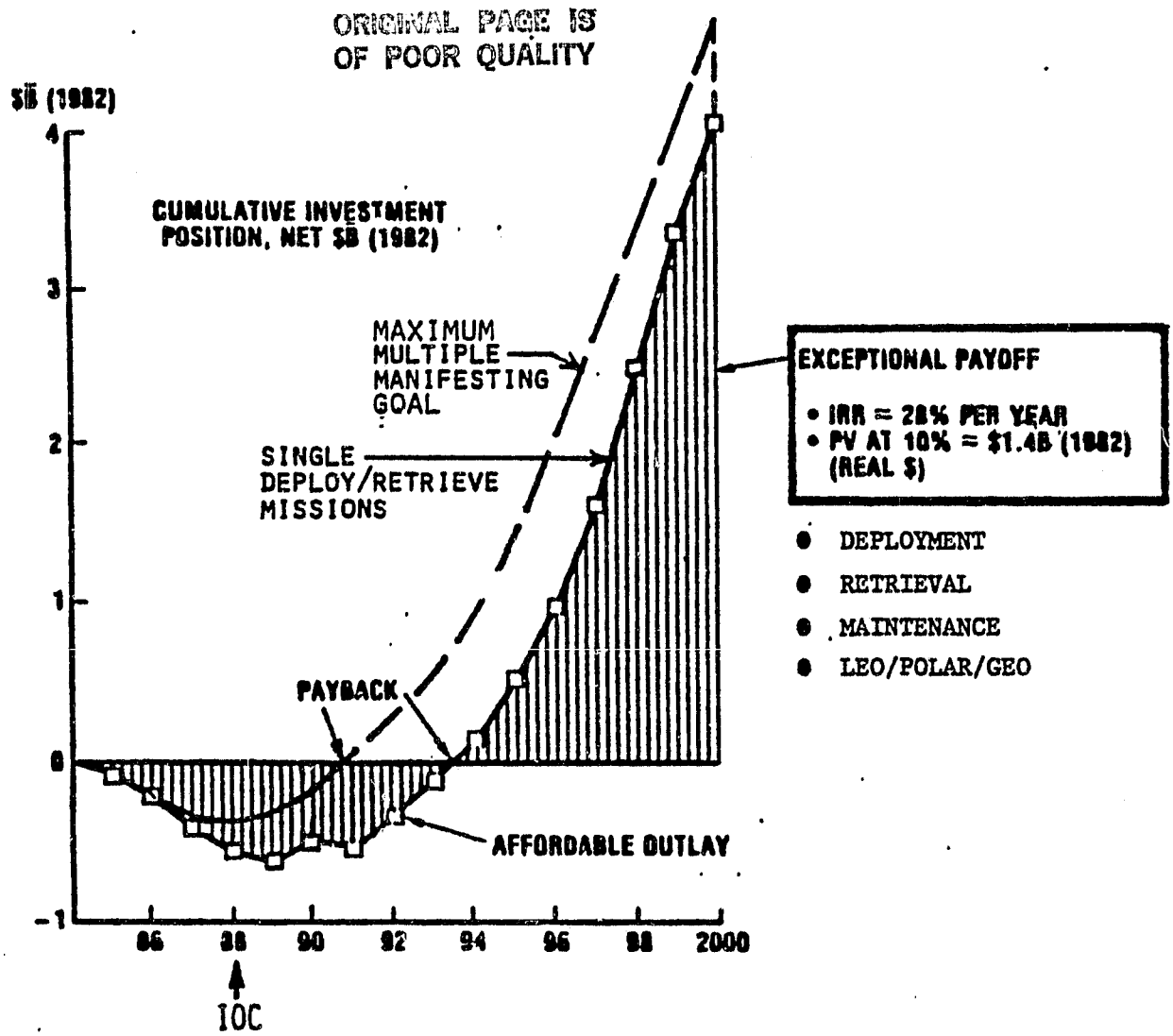


FIGURE 3.4.3-1 TMS BENEFITS ASSESSMENT: BOTTOMLINE

ORIGINAL PAGE IS
OF POOR QUALITY

4.0 SPECIAL INTEREST STUDY TASK RESULTS

4.1 TMS Remote Maintenance Versus EVA

TMS SAVES $10M/MISSION OVER EVA

- Three scenarios evaluated, Figure 4.1-1.
  - Integral propulsion with EVA servicing.
  - TMS retrieval for EVA servicing.
  - TMS remote servicing.
- Spacecraft delivery cost affected by servicing mode.
- Only delta costs affecting benefits were considered.
  - Spacecraft launch cost not included, except integral propulsion weight charge.
  - Integral propulsion length penalties not included.
- Assumes full performance Orbiter at 28.5°.
  - Delivery is length driven; Maintenance weight driven.
  - PMII module used for integral propulsion, $16M DDT&E escalated from Battelle/Vought value to 1982 $, conservatively spread over four satellites.
- TMS dry cargo weight: 3770 pounds (112, 281, 832 and 2545 for AFD equipment, docking kit, cradle, and TMS, respectively), plus 1301 pounds of fuel for remote maintenance mission. Servicer and replacement modules: 600 and 2900 pounds, respectively. Total TMS remote maintenance cargo weight: 8571 pounds. For TMS payload retrieval/deployment required in TMS/EVA scenario, TMS cargo weight is 6196 pounds (TMS: 3770; fuel: 2426), plus 10,800 pounds for the Flight Support System and module carrier, plus 2900 pounds of modules, for a total of 19,896 pounds.
- EVA and Related Costs, Figure 4.1-2.
  - EVA and related costs based on NASA "Payload Integration Plan" for Multimission Modular Spacecraft (JSC 14082) and Space Telescope (JSC 14009). Only typical costs used; no mission peculiar costs; no cost recovery of abandoned automated Flight Support System servicer; backup EVA costs not included.
  - Result: EVA mission costs are conservatively low.
  - EVA defined as two crewmen for six hours.

ORIGINAL PAGE IS
OF POOR QUALITY

COST ELEMENT	INTEGRAL PROPULSION	TMS - GROUND BASED	
	RETURN FOR EVA	RETRIEVE FOR EVA	REMOTE SERVICE
1st MISSION - DELIVERY, LENGTH DRIVEN, 28.5°	($11.4M)	($10.4M)	($10.4M)
• TMS LAUNCH	-	5.7	5.7
DDT&E + HARDWARE	-	2.3	2.3
• PMII MODULE + SPACECRAFT INTEG.	6.2 16/4 = 4.0	-	-
• ORBITER INTEGRATION	1.2	2.4	2.4
2nd MISSION - MAINTENANCE, WEIGHT DRIVEN, 28.5°	($27.6M) FSS + MODULES	($43.1M) TMS/FSS/MODULES	($17.2M) TMS/SERVICER/MOD
• LAUNCH	18.5	29.0	12.5
DDT&E +	1.0	4.6	2.3
HARDWARE	1.0	2 TMS TRIPS	413 ENGAGEMENTS
• EVA + EQUIPMENT	0.8 + 0.2 = 1.0	1.0	
RENDEZ/PROXIM OPS	0.4	0.4	TMS FLEET SIZE: 10
ORBITER/RMS SIMULAT.	0.3 = 1.3	0.3	
ORBITER EXTRA DAY	0.6	0.6	
• ORBITER INTEGRATION	4.8	7.2	2.4
• TOTALS: 1 DELIVERY, 1 MAINT. 1 DELIVERY, 2 MAINT.	 $39.0M 66.6	 $53.5M 96.6	 $27.6M 44.8

FIGURE 4.1-1 TMS VERSUS EVA - COST ANALYSIS

- ORBITER BASELINE EVA PROVISIONS (2 MEN PER 6 HOUR EVA)
  - ✓ 3 EVA'S: 2 FOR PAYLOAD SUPPORT; 1 FOR ORBITER CONTINGENCY
  - ✓ EVA PRICING GUIDELINE FLOOR ('82 $): $0.116M TO $0.194M
- EVA COSTS, INCLUDING TRAINING: (MAINTENANCE SHOWN; REPAIR HIGHER)

✓ SPACE TELESCOPE (PARTIAL SUMMARY)		✓ MULTIMISSION MODULAR SPACECRAFT	
- DELIVERY (2 BACKUP EVA'S)	$0.767M	- RETRIEVAL (2 BACKUP EVA'S)	$0.767M
EVA EQUIPMENT	0.219	EVA EQUIPMENT	0.219
	$0.986M		$0.986M
- MAINTENANCE (3 EVA'S)	1.151	- MAINTENANCE (2 EVA'S)	0.767
EVA EQUIPMENT	>4.000	EVA EQUIPMENT	> 1.219
EXTRA DAY ON ORBIT	0.581	EXTRA DAY ON ORBIT	0.581
	$5.732M		$2.567M
BACKUP EVA	$0.384M	BACKUP EVA'S	$0.767M
- RETURN (2 BACKUP EVA'S)	0.767	- RETURN (2 BACKUP EVA'S)	0.767
EVA EQUIPMENT	~0.219	EVA EQUIPMENT	0.219
	$0.986M		$0.986M
TOTAL: $5.732M TO $8.088M		TOTAL: $2.567M TO $5.306M	

FIGURE 4.1-2 COST ELEMENTS OF EVA MISSIONS

ORIGINAL PAGE IS
OF POOR QUALITY

4.2 TMS Benefits Sensitivity to Increases In Launch Charges

- TMS Servicing Benefits Increase, Figure 4.2-1.
  - TMS/Servicer/ASE lighter than Orbiter/EVA ASE which is based on Multimission Modular Spacecraft support equipment.
  - TMS/Servicer/ASE weight driven.

- DATA
  - TMS 5700 LB LIGHTER THAN ASE FOR ORBITER/EVA SERVICING
  - LAUNCH CHARGE FOR 1985 - 1988: $70.8M, ETR AND WTR
  - POTENTIAL CHARGES IN 1988: $92M AT ETR, $122M AT WTR
  - APPROXIMATELY 45 MISSIONS EACH AT ETR AND WTR
  - DELTA LAUNCH CHARGE: $21.2M AT ETR, $51.2M AT WTR

- ANALYSIS

  ETR: [5700/(65000 X 0.75)] 21.2 X 45 = $112M

  WTR: [5700/(32000 X 0.75)] 51.2 X 45 = $547M

- TOTAL TMS BENEFIT **$659M**

FIGURE 4.2-1 TMS SERVICING BENEFITS INCREASE AS LAUNCH CHARGES INCREASE

ORIGINAL PAGE IS
OF POOR QUALITY

- TMS Deployment Sensitivity, Figure 4.2-2.
  - TMS program savings of $270M̄ come through mission sharing of TMS engagements, but only single manifesting of deployment payloads, based on 1985-1988 launch charges.
  - At increased launch charges shown in Figure, reflecting estimated costs rather than price, delta launch charge penalty is $872M̄, based on single TMS deployment payload manifesting.
  - With minimum co-manifesting of only two deployment payloads per launch, penalty drops by half to $436M̄, still producing net loss of $166M̄.
  - Assumes weight driven launches.
  - Inclusion of length driven launches in analysis has negligible effect, since weight charge, based on 3782 pounds delta TMS weight over integral propulsion, is about the same as length charge.

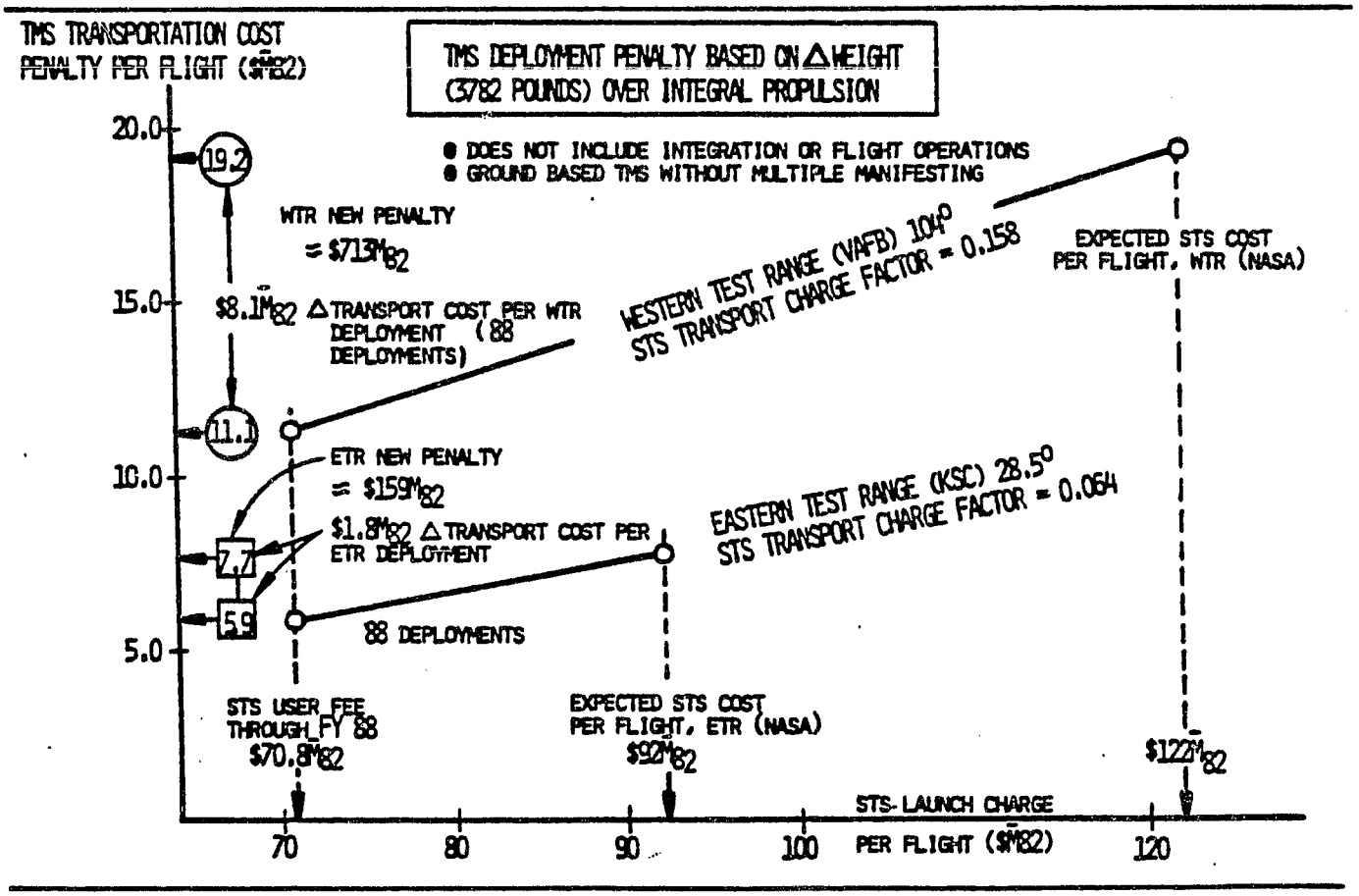


FIGURE 4.2-2 TMS DEPLOYMENT BENEFITS DIMINISH AT EXPECTED STS COSTS

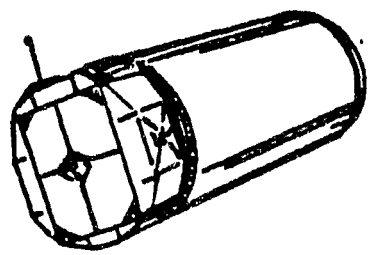
ORIGINAL PAGE IS
OF POOR QUALITY

4.3 TMS Versus Integral Propulsion - Additional Potential Savings For TMS

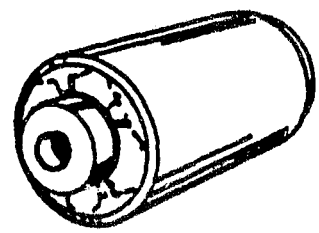
- Three potential added benefits:
  - TMS weight reductions.
  - TMS length penalty reductions.
  - Space basing.
- Figure 4.3-1 summarizes major cost factors and potential cost reduction measures.

FACTORS:
- MISSION SHARING
- PROPULSION COST
- TRANSPORTATION COST
- OPERATING MODE

TMS



INTEGRAL PROPULSION



SOLUTION:
- MULTIPLE MANIFESTING
- REDUCE WEIGHT/LENGTH OF TMS
- IDENTIFY INTEGRAL PROPULSION LENGTH PENALTIES
- SPACE BASING

FIGURE 4.3-1 TMS VERSUS INTEGRAL PROPULSION - POTENTIAL FOR FURTHER TMS SAVINGS

ORIGINAL PAGE IS
OF POOR QUALITY

- TMS potential weight reductions, Figure 4.3-2.

POTENTIAL PROGRAM SAVINGS OF $359M

- Switch from monopropellant to bipropellant fuel.
- Delete TMS cradle (present weight: about 600 pounds, plus 230 pounds of black boxes).

EFFECT OF POTENTIAL WEIGHT REDUCTIONS ON GROUND BASED TMS TRANSPORT COST

POTENTIAL WEIGHT REDUCTIONS	SAVINGS (LBS)	WEIGHT DRIVEN LAUNCHES	COST SAVINGS ($)
USE BIPROPELLANT FUEL	>1300	44 AT WESTERN TEST RANGE @ $5.92M/LAUNCH	260.5M
DELETE CRADLE	550	34 AT EASTERN TEST RANGE @ $2.91M/LAUNCH	98.9M
RESULTING LIGHTER STRUCTURE	150		
TOTAL WEIGHT SAVINGS	2000	TOTAL POTENTIAL TRANSPORT COST SAVINGS	359.4M

FIGURE 4.3-2 POTENTIAL TMS WEIGHT REDUCTION BENEFITS

ORIGINAL PAGE IS
OF POOR QUALITY

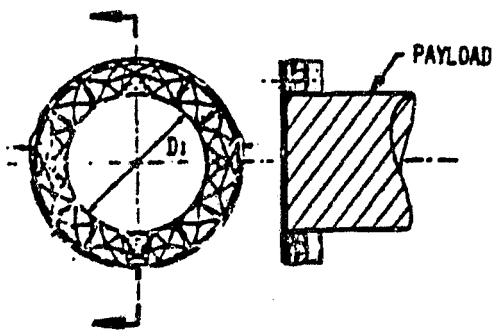
TMS Potential Length Penalty Reductions.

POTENTIAL PROGRAM SAVINGS OF $181M

- The Annular TMS Concept, Figure 4.3-3:: Ring shaped vehicle with central cavity for payloads.
- For modified full diameter payload, annular TMS adds 1.5 feet or half its length, to spacecraft length.
- Annular TMS encourages ground mating, preferred by users.
- Additional uses for central cavity, shown in Figure, may be more important than length benefits.

THE ANNULAR TMS CONCEPT REDUCES LENGTH DRIVEN TRANSPORT COSTS

- CENTRAL CAVITY : 9.83 FT. DIAMETER
  - ✓ USES:
    - ADD FUEL TANKS
    - MISSION KITS (SERVICER, ETC)
    - ACCESS BOTH ENDS OF P/L
    - MANNED MODULE
    - NEW STRUCTURES ASSEMBLY OPTIONS
- 63 LENGTH DRIVEN DELIVERY MISSIONS
  32 WITH PAYLOADS LESS THAN 9.83 FT. DIAMETER
  NO DoD, GEO, MAINTENANCE, OR RETRIEVAL
- ZERO TMS TRANSPORT COST FOR 32 MISSIONS
  ✓ SAVINGS: $5.65M X 32 = $180.8M
- SAVINGS DIMINISH FOR SHUTTLE OPTIMIZED (FULL DIAMETER) PAYLOADS: TMS ADDS 1.5 FEET TO PAYLOAD LENGTH
  FAR TERM SAVINGS: $2.37 X 63 = $149.3M



ANNULAR TMS CONCEPT
L = 36" TO 42"
Do = 14.5'
D1 = 9.8'
Wp = 3700 LB

FIGURE 4.3-3 POTENTIAL TMS EFFECTIVE LENGTH REDUCTION: THE ANNULAR TMS CONCEPT

ORIGINAL PAGE IS
OF POOR QUALITY

- Integral Propulsion Length Penalties.

LENGTH PENALTIES OF $69M TO $171M = TMS BENEFITS

- Battelle/Vought studies assumed integral propulsion added no length when buried in spacecraft.
- For given spacecraft diameter, average length added by integral propulsion is 0.75 feet. Figure 4.3-4 shows analysis, using propulsion systems specified by Battelle. Cases shown for both buried and add-on systems. WTR costs based on ETR launch charges, and 1.5 X ETR.
- Integral propulsion length penalties treated as TMS benefit.

SPACECRAFT	NO. MISSION	PM NO.	PAYLOAD Δ L_{MIN} FT.	TOTAL LAUNCH COST (MIN.)	PAYLOAD Δ L_{MAX} FT.	TOTAL LAUNCH COST (MAX.)
ETR						
XTE	1	I	0.5	0.9	1.3	2.1
SCE	1	I	1.0	1.5	5	7.9
XSE	1	II	2.2	3.5	5	7.9
MLSE	1	II	0.7	1.1	5	7.9
EUVSE	1	II	1.0	1.5	5	7.9
UARS	2	II	1.1	3.5	5	15.8
TOPEX	4	I	0.2	1.5	1.3	8.4
ERBS	1	II	2.0	3.1	5	7.9
SSM	2	II	0.4	14.1	5	15.8
LARS	3	I-B	0.4	1.8	2.7	12.6
WTR						
GP - B	1	II	0.5	.8, 1.2	5	7.9, 11.9
LANDSAT	4	II	5	31.6, 47.3	5	31.6, 47.3
MFS	2	I	0.3	1.1, 1.6	1.3	4.2, 6.3
ATM	1	II	2.2	3.4, 5.2	5	7.9, 11.9
	25	71 M/LAUNCH, ETR/WTR:		69.4		145.7
		106.5 M/LAUNCH, WTR:		87.9		171.4

FIGURE 4.3-4 INTEGRAL PROPULSION LENGTH PENALTIES - A TMS BENEFIT

ORIGINAL PAGE IS
OF POOR QUALITY

4.3.1 TMS Versus Integral Propulsion - Total Savings (5.6\bar{B}$ Integral Propulsion Program)

TMS PROVIDES 3 TO 14% SAVINGS

- Mission Sharing: 3% @ 170\bar{M}$.
  - Weight/Length Reduction: 11% @ 610\bar{M}$.
- Total Savings: 170\bar{M}$ to 780\bar{M}$, shown in Figure 4.3.1-1.
  - Excluding annular TMS, savings range from 3 to 12%.
- These savings do not include the servicing benefit potential of 3.4\bar{B}$.

SUMMARY COMPARISONS: **GROUND BASED TMS**

- BASELINE CONFIGURATION REDUCES PROPULSION COSTS FROM 5.6\bar{B}_{82}$ (USING INTEGRAL PROPULSION) TO 5.4\bar{B}_{82}$ FOR TMS ($170M SAVING)=3%
- ADDITIONAL TMS COST SAVINGS COMPARED TO INTEGRAL PROPULSION

WEIGHT REDUCTION	359.4\bar{M}_{82}$
ANNULAR TMS	180.8
INTEGRAL PROPULSION (LENGTH EFFECT)	69.4
	609.6\bar{M}_{82}$ = 11%

- NET RESULT: TMS SHOWS 3 To 14% COST ADVANTAGE OVER INTEGRAL PROPULSION.

FIGURE 4.3.1-1 TMS VERSUS INTEGRAL PROPULSION - SUMMARY

OF POOR QUALITY

4.3.2 TMS Versus Integral Propulsion Versus Spacecraft Size.

- Question: Would use of integral propulsion for small payloads avoid unfairly penalizing TMS?
- Answer: No. See Figure 4.3.2-1.
- Reason: Dimishing the TMS flight base by converting from TMS to integral propulsion raises TMS cost per flight and erodes the $170M TMS advantage.
- Analysis: Three vertical TMS lines in Figure are baseline flights and two successive reductions. Curve intersects are projected to integral propulsion curve, where baseline defines region "A" flights as favoring integral propulsion; these flights, when dropped from TMS, define intersect "A" and new enlarged zone A+C. The cycle is thus diverging. A second reduction, "B", in TMS results in favoring integral propulsion for all flights.
- Conclusions:
  - TMS reuse over large flight base is key to benefits.
  - Shift to integral propulsion for small payloads in the nominal mission model appears cost effective for payload user, but could increase TMS cost per flight by reducing flight base, producing an open ended cascading effect.
  - Remedial solutions:
    Reduce size/weight of the ground based TMS, or alter the basing mode. Potential approaches to both solutions are suggested in this benefits study. Purpose of either is to lower TMS curve in Figure, eliminating region "A".

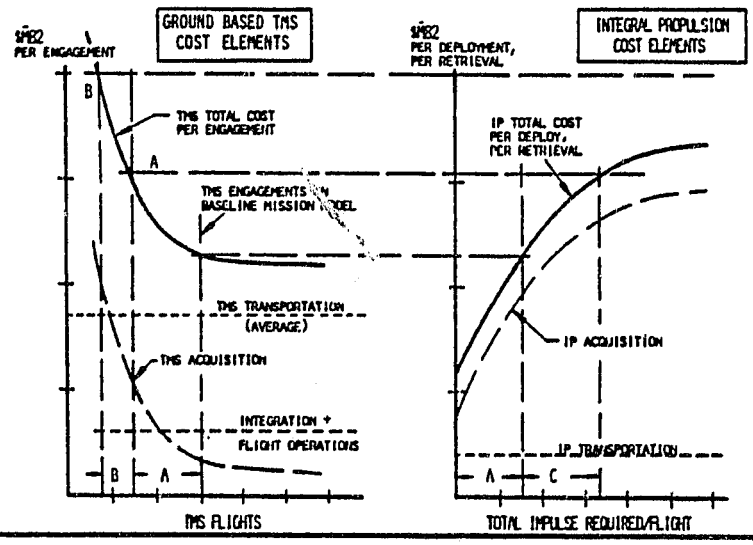


FIGURE 4.3.2-1 THE OPTIMAL "INTEGRAL PROPULSION DILEMMA"

ORIGINAL PAGE IS
OF POOR QUALITY

4.4 Space Basing the TMS Increases Benefits

- Three Scenarios For Basing Modes Analysis.
  - A ground based TMS as reference baseline.
  - Space based TMS, ground refueling.
  - Space based TMS, on-orbit refueling.
- Initial Space Based, Ground Refueling Scenario, Figure 4.4-1.
  - Assumed use of add-on tank module to reduce STS/TMS launch frequency. This was found to be unnecessary with ground refueling. However, other uses for the tank module were identified:

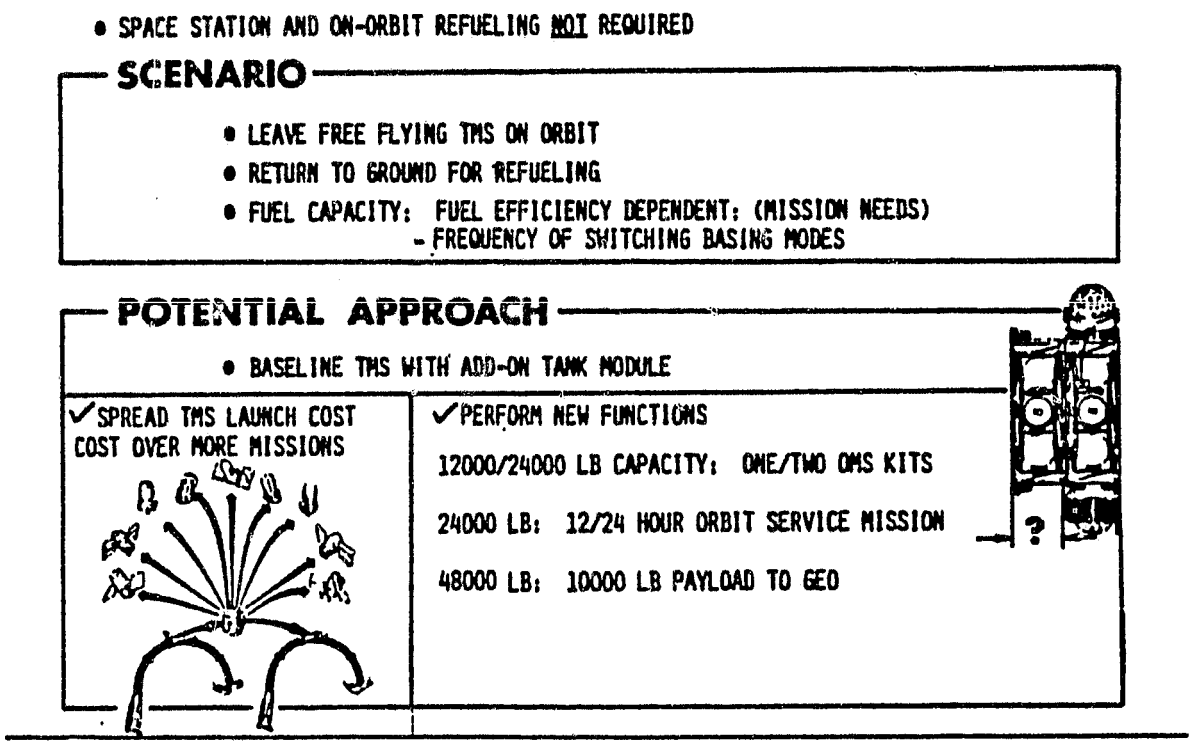


FIGURE 4:4-1 EARLY SPACE BASING SCENARIO FOR TMS

  - A two/four tank module, using OMS tanks, could serve as one/two OMS kits.
  - A four/eight tank module containing 24000/48000 pounds of bipropellant fuel, plus 5000 pounds in the TMS, could deliver 7300/14900 pounds of payload (brought to LEO on a separate STS launch) to the 12-hour orbit, or 4970/10600 pounds to GEO. These missions expend the TMS, but may be cost effective in that all prior TMS uses will help amortize its acquisition investment, thus reducing the expendable mission cost. This is denied the OTV user.

ORIGINAL PAGE IS
OF POOR QUALITY

4.4.1 Basing Modes Analysis

Mission Models for Space Based TMS

- Low, nominal, high mission models created, 28.5° orbit inclination, shown in Figure 4.4.1-1. Contingency missions were excluded, reducing nominal model to 51. Bipropellant fuel assumed.

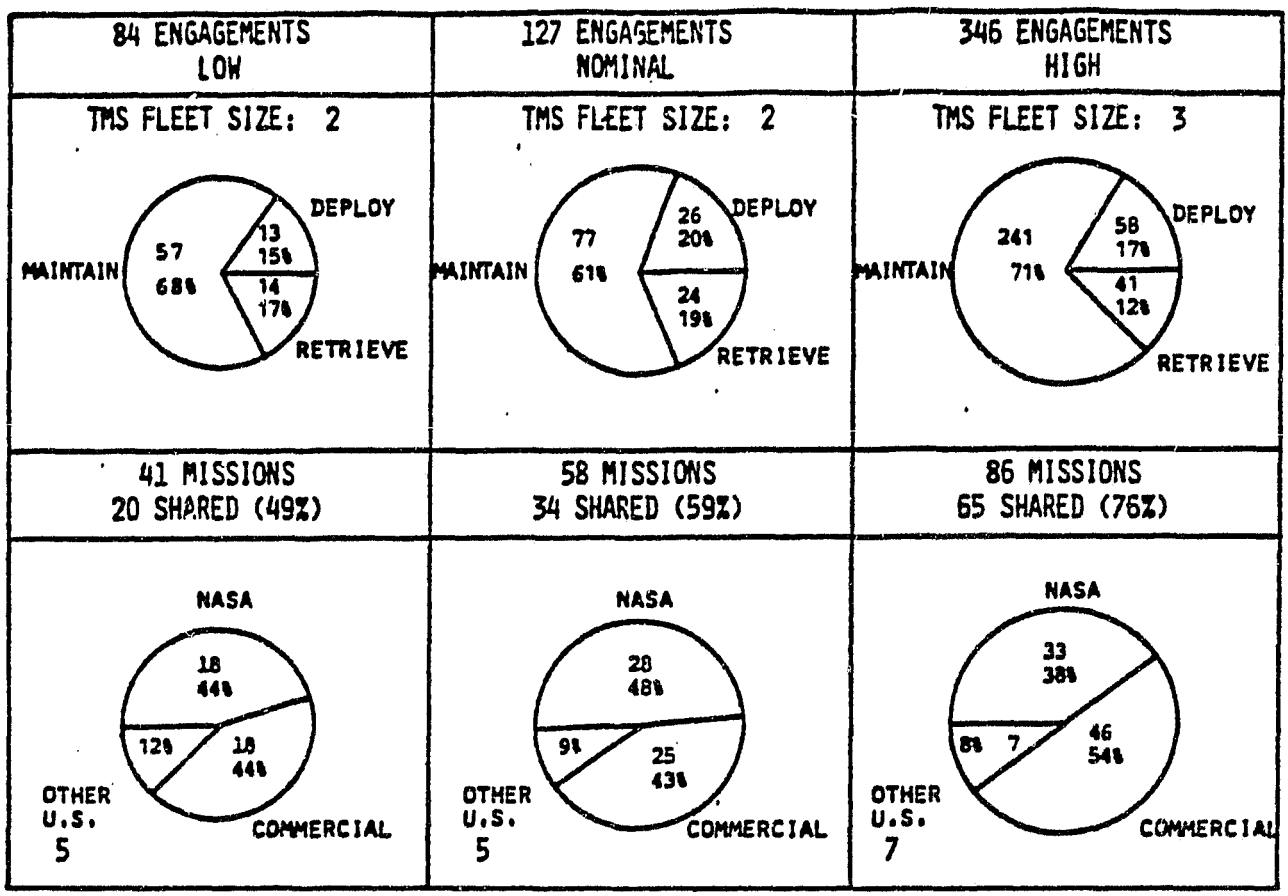


FIGURE 4.4.1-1 MISSION MODELS FOR THE SPACE BASED TMS

- Data Base Used In Analysis
  - TMS cargo weight: 3770 pounds (TMS @ 2545, docking kit @ 281, cradle @ 832, and AFD equipment @ 112), plus fuel.
  - For purposes of comparison, total costs for each case were averaged over 51 missions, i.e., for space basing, the number of missions is not the same as number of STS launches.

ORIGINAL PAGE IS
OF POOR QUALITY

- Results of Basing Modes Analysis, Figure 4.4.1-2

SPACE BASING PROVIDES MAXIMUM TMS BENEFITS

- Ground Based TMS, Reference Baseline.

	REFUEL MODE	Wp TMS/TANK TOTAL	ORBITER CARGO WEIGHT	NO. STS LAUNCHES	COST PER LAUNCH $ M	PROGRAM LAUNCH COST	LAUNCH COST PER TMS MISS.	TANK DDT&E PER MISS.	INTEG. COST PER MISSION	TOTAL COST PER TMS MISS.
							PRORATED OVER 51 MISSIONS			
1	GROUND BASED	2157 AVG NA	5927 NA	17 WEIGHT 34 LENGTH	8.63 5.654	338.9	6.646	—	2.5	1.146
2	SPACE BASED, GROUND REFUEL	50014 AVG	60014	5	71	355	6.96	1.3	0.25	8.51
3		26969 AVG	33729	7	49.12	343.9	6.74	0.9	0.34	7.98
4		7574 AVG	13244	7 WEIGHT 11 LENGTH	19.289 10.519	250.7	4.916	0.6	0.88	6.396
5		3945 AVG	7715	10 WEIGHT 19 LENGTH	11.236 5.654	219.8	4.31	—	1.42	5.73
										7.154 AVG.
6	TANKER REFUEL	55000	65000	2	71	142	2.78	2.3	0.10	5.18
7	OMS POD REFUEL	4314 FOR 2 MISSIONS	4314 FUEL 300 ASE	9 OF 26 LENGTH DRIVEN	5.03 FUEL 20% DISC. 0.44 ASE	49.23	0.96	0.40 OMS DDT&E	0.15* CREW TIME	1.51

*$0.30M PER REFUELING

FIGURE 4.4.1-2 TMS BASING MODES ANALYSIS

- Space Basing, Ground Refueling.

THE BASELINE TMS, ALONE, IS BEST

Four cases examined, three using progressively smaller add-on tank modules with baseline TMS. The TMS alone, without add-on module, was most economical, due mainly to better fuel efficiency, but also benefits from lower cost of length driven missions, an advantage that will diminish as more payloads become Shuttle optimized at higher linear densities.

ORIGINAL PAGE IS
OF POOR QUALITY

- Space Basing, on Orbit Refueling.

TMS REFUELING FROM OMS POD TANKS - A DRAMATIC BENEFIT

Two cases evaluated: Refueling from free flying tanker, and from the Orbiter OMS pod tanks. Refueling from the OMS tanks is, by far, the preferred approach at only 17% of the cost for ground basing, 25% of the minimum for a space based, ground refueled TMS, and 28% of alternative on orbit refueling from the tank module.