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Space Shuttle/Payload Interface Analysis (Study 2.4) Final Report

Volume II

Space Shuttle Traffic Analysis

Prepared by
ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

31 August 1973

Prepared for OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-2472

Systems Engineering Operations

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FOREWORD

The Space Shuttle/Payload Interface Analysis (Study 2.4) Final Report is comprised of five volumes, which are titled as follows.

Volume I	-	Executive Summary
Volume II	-	Space Shuttle Traffic Analysis
Volume III	-	New Expendable Vehicle with Reusable Solid Rocket Motors
Volume IV	-	Business Risk and Value of Operations in Space (BRAVO)
		Part 1 - Summary
		Part 2 - User's Manual
		Part 3 - Workbook
		Part 4 - Computer Programs and Data Look-Up
Volume V	-	Payload Community Analysis

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1. INTRODUCTION

The primary objective of this study was to furnish tools and guidance to a NASA/MSFC team headed by Mr. W. Huff so that MSFC can perform capture/cost analyses on mission models in a manner which provides traceability to the analyses performed by Aerospace for NASA in 1971 (see Ref. 1-8) and 1972 (see Ref. 9 and 10). This capability transfer was accomplished through the use of frequent technical interchange and working group meetings, data transfer by telephone and letters, and transfer of computer programs with sample case inputs and outputs. Subsequent to the transmission of the various computer programs there were numerous telephone conversations between NASA/MSFC and Aerospace computer personnel, followed by meetings at NASA/MSFC to answer questions and provide assistance. The procedures currently in use for carrying out capture and cost analyses were described in working groups and examples provided. Working sessions were held at both locations to discuss payload analysis and launch vehicle data.

A second objective was to perform a parallel capture/cost analysis with NASA/MSFC on an example mission model. This was accomplished for the case of current expendable payloads on the current expendable launch vehicles. Independent captures were performed manually and the results compared and costed. The additional capture/cost analysis cases were performed by Aerospace and inputs, listings, and results sent to NASA/MSFC. These cases were run on their computer and the results were compared. Shuttle traffic in the form of payload manifests for deployment and retrieval was prepared by Aerospace and supplied to NASA/MSFC.

This report briefly describes the effort accomplished in each area and records basic study inputs, assumptions, and results. Working copies and records of the activities and analyses were transmitted to MSFC and are on file at Aerospace.

2. CAPABILITY TRANSFER

One of the primary objectives of this study was to transfer to NASA/MSFC the capability to perform capture/cost analyses. This required liaison and guidance, as well as the transfer of tools and data such as computer programs, booster performance data, payload descriptions, and traffic.

A. DATA FLOW

The Space Shuttle performance and direct costs, Tug characteristics, reliability, and cost data were provided by NASA to Aerospace for this study. Upper stage performance and cost data were supplied by Aerospace and approved by MSFC for use in the parallel capture/cost analysis effort. Expendable launch vehicle data were extracted from Study A mid-term and final reports (Ref. 6 and 11) and transmitted to NASA/MSFC along with guidance for their use. The mission model and basic payload data were provided by NASA Headquarters. NASA payload descriptions and orbital characteristics were obtained from the Study 2.2 Payload Data Book (Ref. 12). Non-NASA payload data were obtained from the Study A Payload Data Book (Ref. 13). The large, low-cost payloads were defined by Aerospace using factors from Study A (Ref. 3) and the LMSC Follow-on Payload Effects Study (Ref. 14) applied by subsystem and then transmitted to NASA/MSFC. The current reusable payloads were defined using the formula in the Payloads section of this report and stored in the Payload Data Bank.

The working rules for this study were established jointly by NASA Headquarters, NASA/MSFC, and The Aerospace Corporation in July 1972 and are documented here in Table 2-1.

Table 2-1. Capture/Cost Analysis Ground Rules[a]

CAPTURE/COST ANALYSIS

1. Current expendable launch vehicles capture of current design expendable spacecraft payloads.

2. Current Shuttle capture of payloads with refurbishment/retrieval and payload effects applied to spacecraft designs.

3. Current Shuttle capture of payloads with refurbishment/retrieval with payload and standardized subsystem effects applied to spacecraft designs.

4. First two analyses to be conducted by MSFC and Aerospace in parallel and fully coordinated. The third to be conducted with Aerospace in backup mode.[b]

MISSION MODEL

1. NASA mission model dated June 1972.

    a. Lunar mission supplement excluded.

    b. "First ten missions" only to extent included in model.

2. 1971 non-NASA mission model.

3. DoD mission model of August 1971 (updated) - Option B.

4. Launch schedules are in calendar years.

    a. Shift DoD fiscal year launch schedule six months to calendar year schedule.

PAYLOADS

1. Data source for current NASA/non-NASA designs is NASA discipline office material.[c]

[a] Taken from Ref. 15, 16.

[b] The standardized subsystem effects effort was redirected and special studies substituted in the second quarter of FY 73.

[c] These data are included in Ref. 12, 13.

Table 2-1. Capture/Cost Analysis Ground Rules (Cont'd)

PAYLOADS (Cont'd)

2. Payload effects are Lockheed, TRW, and others.

3. Payload effects will be applied to each payload as appropriate from a cost effective viewpoint down to the subsystem level.

   a. Apply, where applicable, to the entire mission model, including NASA, non-NASA, and DoD.

4. Redesign for Shuttle utilization will neither degrade nor upgrade mission objectives.

5. Data source for costing payloads is the Aerospace Payload Cost Model.

SHUTTLE

1. Governing data sources are the RFP, Level 1 Requirements, and MSC Payload Accommodation document.

2. Weight and volume ΔV penalties (OMS tanks) and other required supplemental data to be mutually agreed upon by NASA/Aerospace.

3. Shuttle availability and buildup rate as specified in RFP for 1979 through 1983. For 1984 and on, assume Shuttle available as needed at both launch sites.

   a. Launch rate buildup at WTR similar to ETR.

4. ABES required only for personnel transport to and from Space Station.

5. Operations cost is $10.5 million/flight.

6. RDT&E and orbiters unit cost will not be amortized.

Table 2-1. Capture/Cost Analysis Ground Rules (Cont'd)

LAUNCH SITES 1. KSC available for entire time period as needed. 2. WTR available in 1981 and on as needed. 3. Assume launch azimuth capability as currently practiced at KSC and WTR. a. No change from current practice on dog legs. CAPTURE CONSTRAINTS 1. Time span is 1979-1990 inclusive. a. Extend to 1997 for cost only, not to identify meaningful missions. 2. On-orbit docking of Tug and payload may be used only when physically necessary to accommodate a spacecraft. 3. No expendable upper stages will be used in lieu of the Tug after Tug IOC. 4. Maximum number of payloads simultaneously carried by a Shuttle is five. 5. Maximum number of payloads simultaneously carried by a Tug or injection stage is three. 6. Average number of payloads simultaneously carried by expendable vehicles will not exceed historical average. 7. DoD payloads will not be carried with those of other users. 8. Payloads once assigned to Shuttle during buildup period will not revert to expendable vehicle launches. 9. Keep Space Station date and science content same as 1972 NASA mission model for the expendable launch vehicle capture.

Table 2-1. Capture/Cost Analysis Ground Rules (Cont'd)

CAPTURE CONSTRAINTS (Cont'd)

10. Omit any attempt to include Sortie Lab missions in the expendable launch vehicle capture, since Shuttle is required for these.

    a. Run trade studies on alternatives to replace Sortie Science later.

11. Payload effects will be applied in Shuttle launches when they are cost effective.

12. On-orbit service/maintenance/repair will be utilized as applicable and economically justified in contrast to retrieval/return.

13. Standard spacecraft and cluster spacecraft are excluded.

COSTING CONSTRAINTS

1. Costs will reflect reliability effects of vehicles/carriers and payloads.

2. All costs in 1971 dollars.

3. Only direct costs are included.

SUBSEQUENT ADDITIONAL ANALYSES

1. Include lunar supplement.

2. Mix Tug and expendable stages through 1990 when cost effective.

3. Include standard spacecraft.

4. Include standard and cluster spacecraft.

5. Include analysis of 1979 Tug IOC.

Table 2-1. Capture/Cost Analysis Ground Rules (Cont'd)

TUG

1. Governing data source is advanced missions program - Ref: letter of June 16, 1972 (to be updated).

2. Tug IOC is 1983, available to meet requirements from then on.

3. Tug unit costs (but not RDT&E) will be amortized.

STANDARD INJECTION STAGES

1. Basic stages

   a. D1-T Centaur

   b. "Standard" Agena

   c. Burner-II

2. Possible options

   a. Transtage

   b. Delta

3. Governing technical data to be as mutually agreed upon by NASA/ Aerospace.

4. Operating cost will include unit cost and will reflect rate effects.

5. RDT&E (for adaptation to Shuttle) will not be amortized.

Table 2-1. Capture/Cost Analysis Ground Rules (Cont'd)

<u>EXPENDABLE VEHICLES</u>

1. For automated missions:

   a. Scout

   b. Thor-Delta

   c. Atlas-Centaur

   d. Titan Derivatives

2. For space station missions use Titan III M, Big G

3. Governing technical data to be as mutually agreed upon by NASA and Aerospace.

4. Operations costs will reflect rate effects.

B. DATA TRANSFER

1. LAUNCH VEHICLE - EXPENDABLE BOOSTER, UPPER STAGE AND STS DATA

The Shuttle and Tug data were supplied to Aerospace for this study; however, effort was expended reviewing NASA documents (Ref. 17 and 18) and in discussing the data with NASA/MSFC personnel. It was agreed that the Shuttle performance data in Ref. 18 would be used for the capture analyses. Other accomplishments of the launch vehicle working group were to establish Shuttle launch azimuth constraints and a Shuttle flight buildup rate to be used in this study. These are shown in Tables 2-2 and 2-3, respectively.

Expendable launch vehicle data, vehicle descriptions, and performance capability for the current expendable payload capture analyses (Cases 500, 501) were obtained from Study A, Volume IV, of the mid-term and final reports (Ref. 6 and 11).

The candidate upper stage characteristics, including performance parameters, were provided by Aerospace to NASA/MSFC for review. The performance data used in this study for accommodation and capture analyses are presented in Figures 2-1 through 2-10 for the following listed upper stages:

(1) MSFC Tug

(2) Centaur - Modified D1-T

(3) Agena (I_{sp} = 290.8)

(4) Transtage

(5) Delta

(6) Burner-II.

Table 2-2. Space Shuttle Launch Azimuth Constraints

	Azimuth	Inclination
WTR Launches	140° 313°	56° 126°
ETR Launches	120° 35°	39° 57°

Table 2-3. Space Shuttle Flight Buildup Rate
1978 - 1983

Year	1978	1979	1980	1981	1982	1983
Shuttle Flights	6	15	24	32	40	60

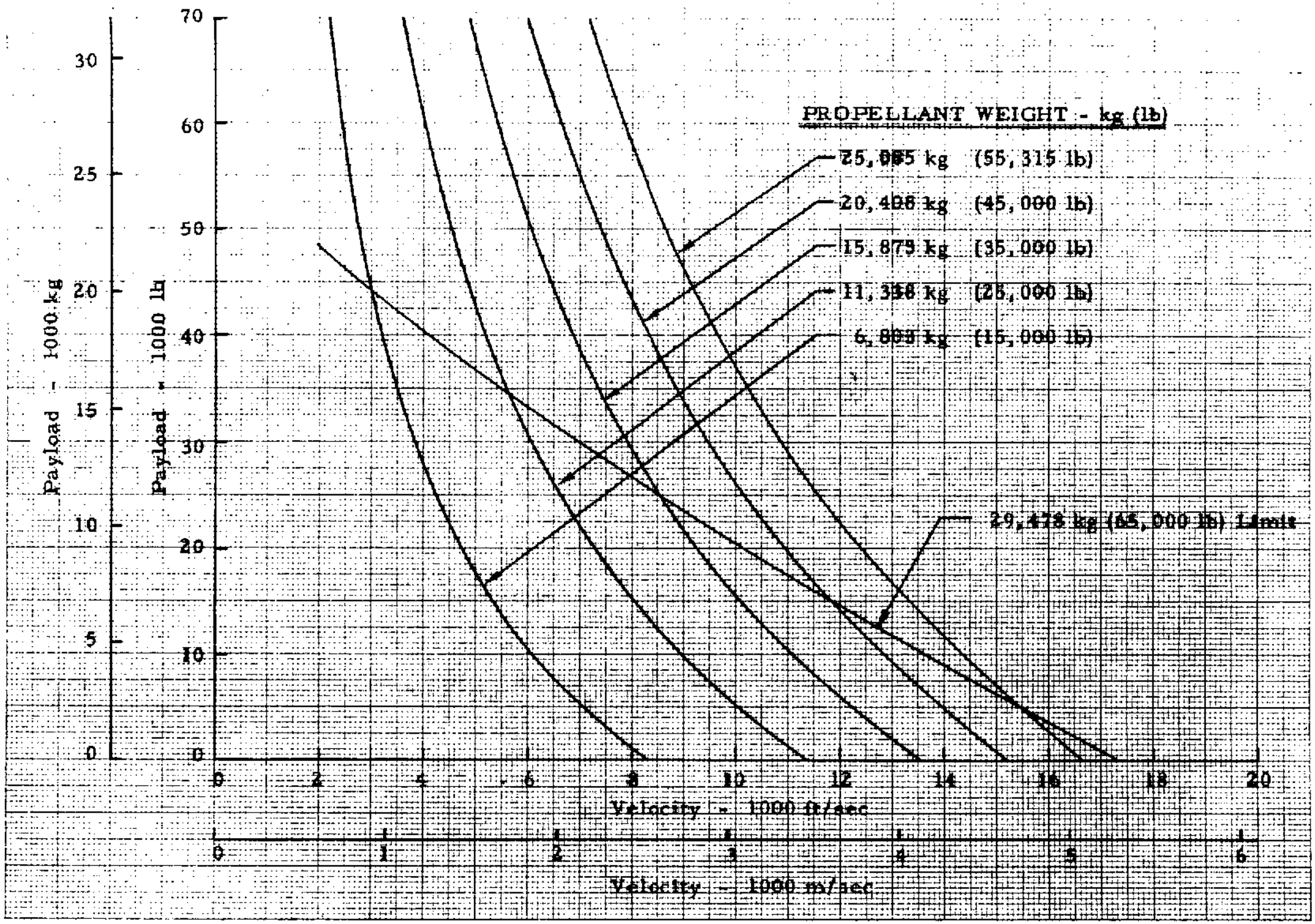

Figure 2-1. MSFC Tug Deployment Performance

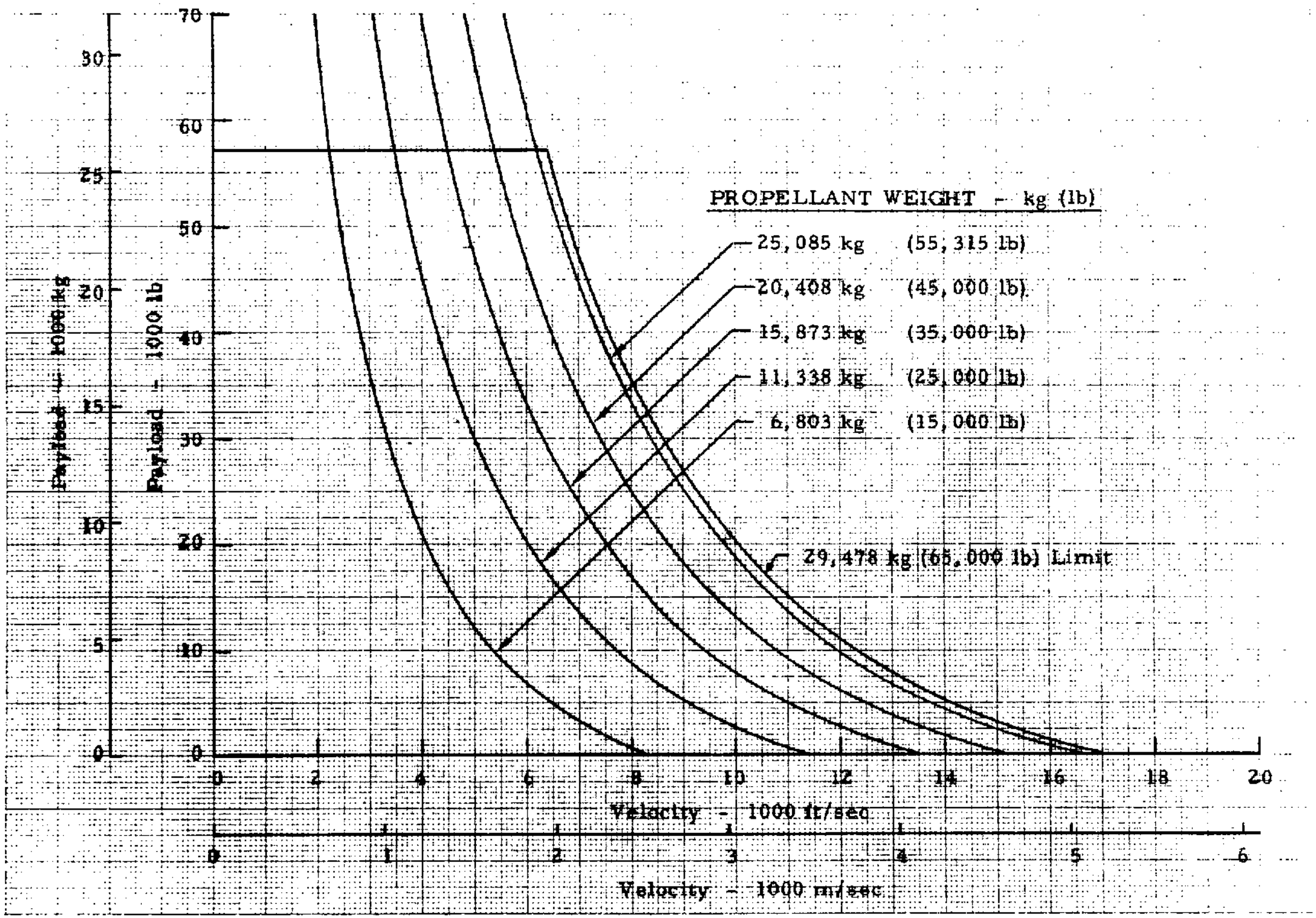

Figure 2-2. MSFC Tug Retrieval Performance

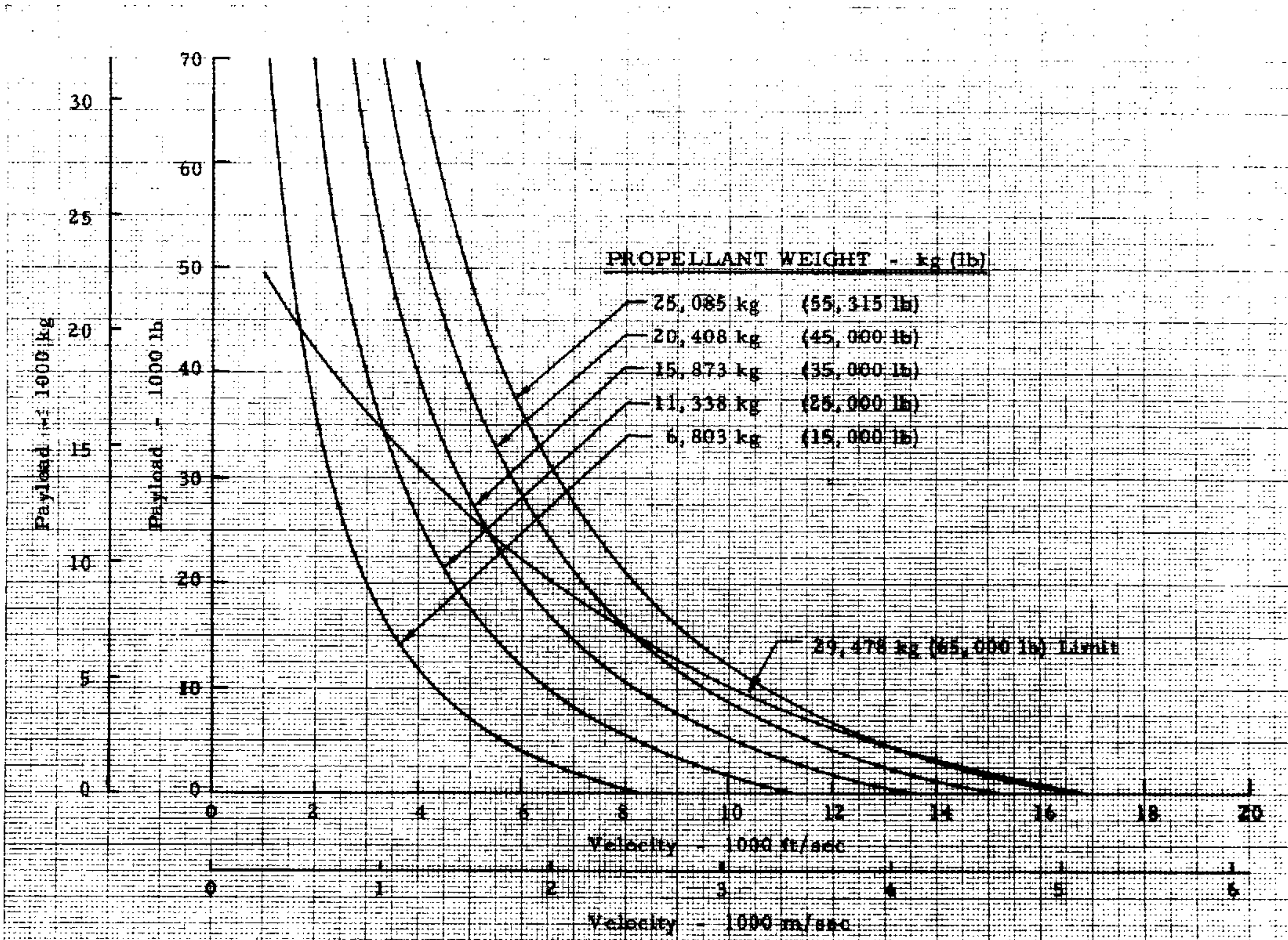

Figure 2-3. MSFC Tug Deploy and Retrieve Performance

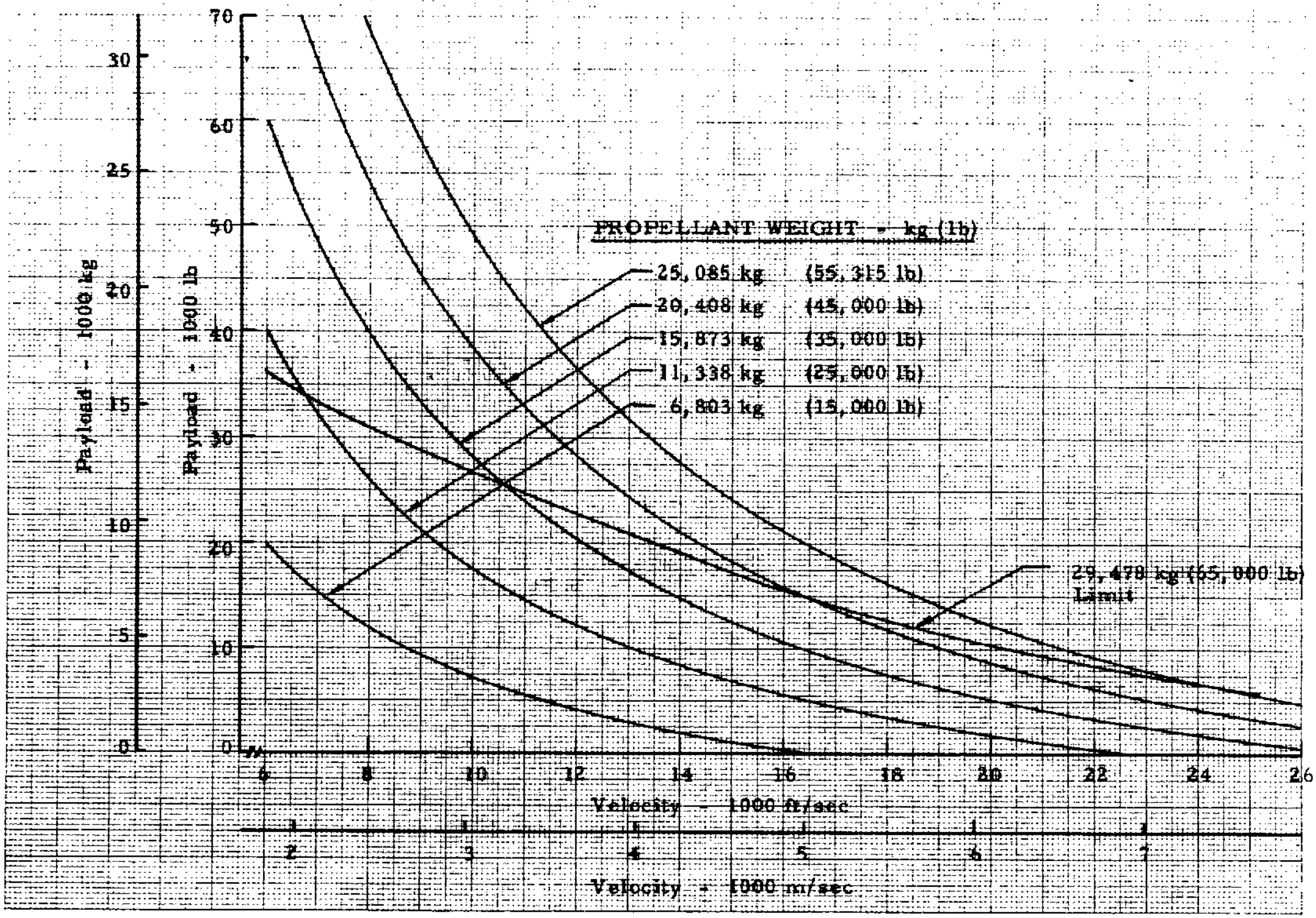

Figure 2-4. MSFC Expendable Tug Performance

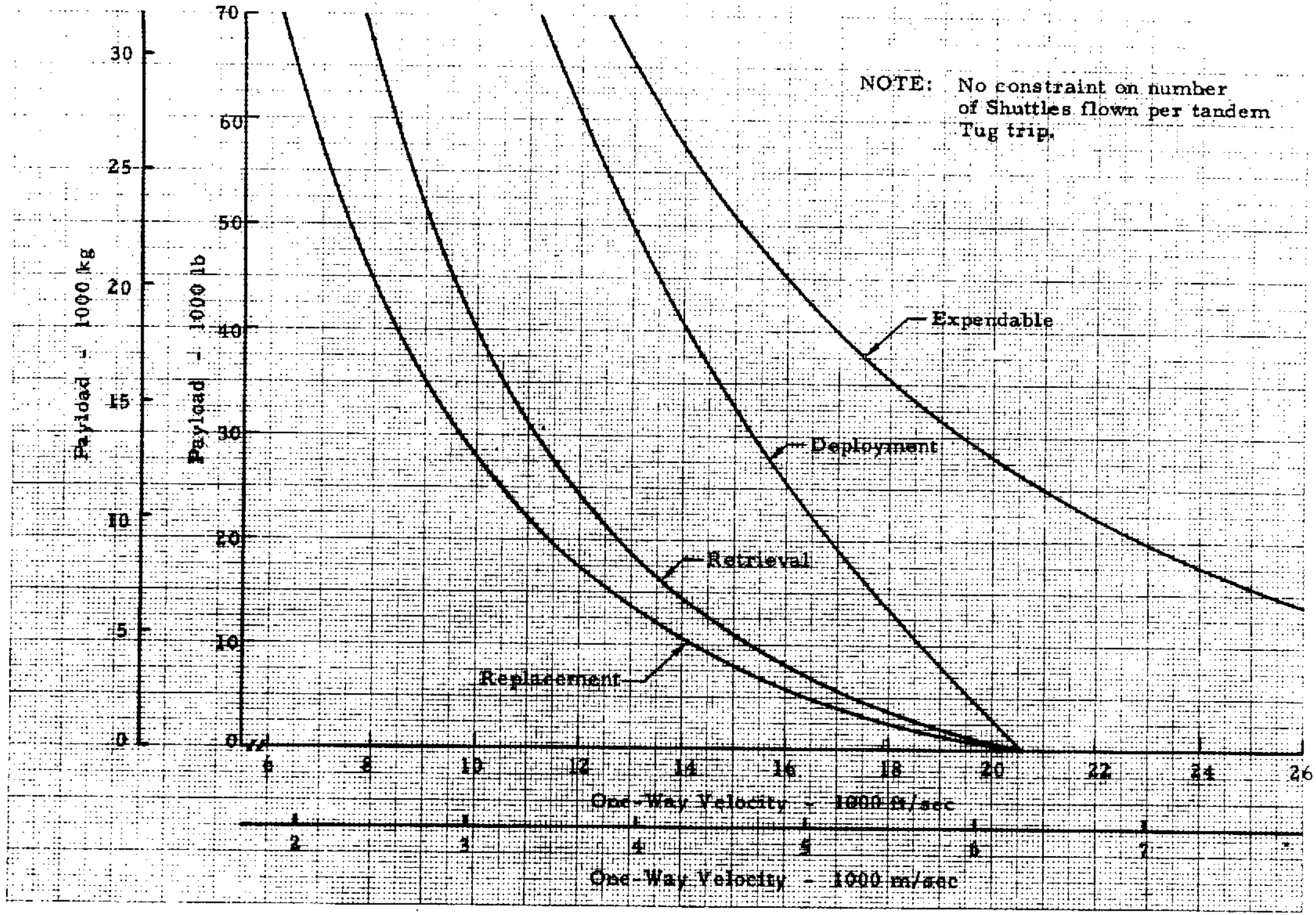

Figure 2-5. Tandem Tug Performance

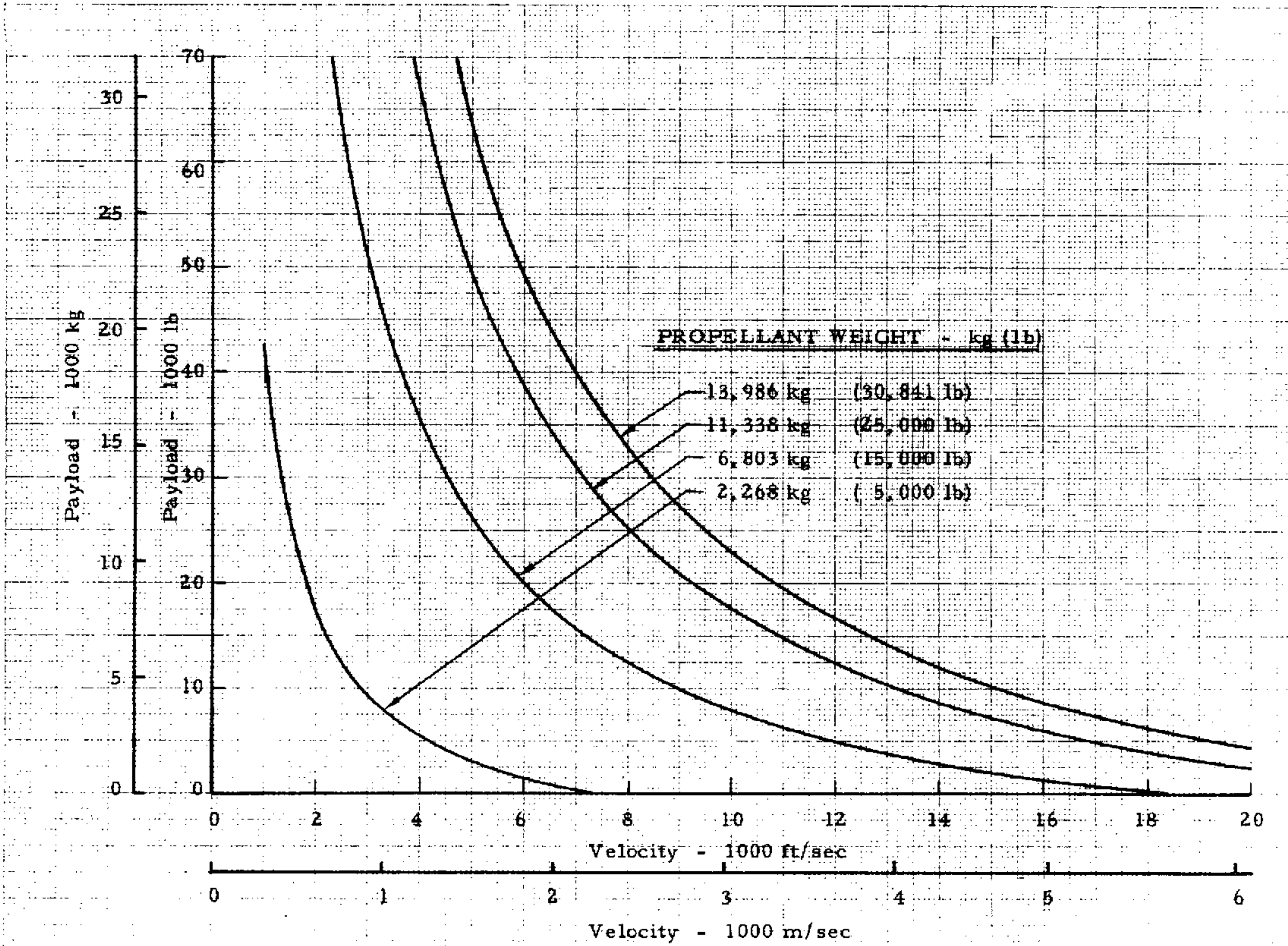

Figure 2-6. Centaur D1-T

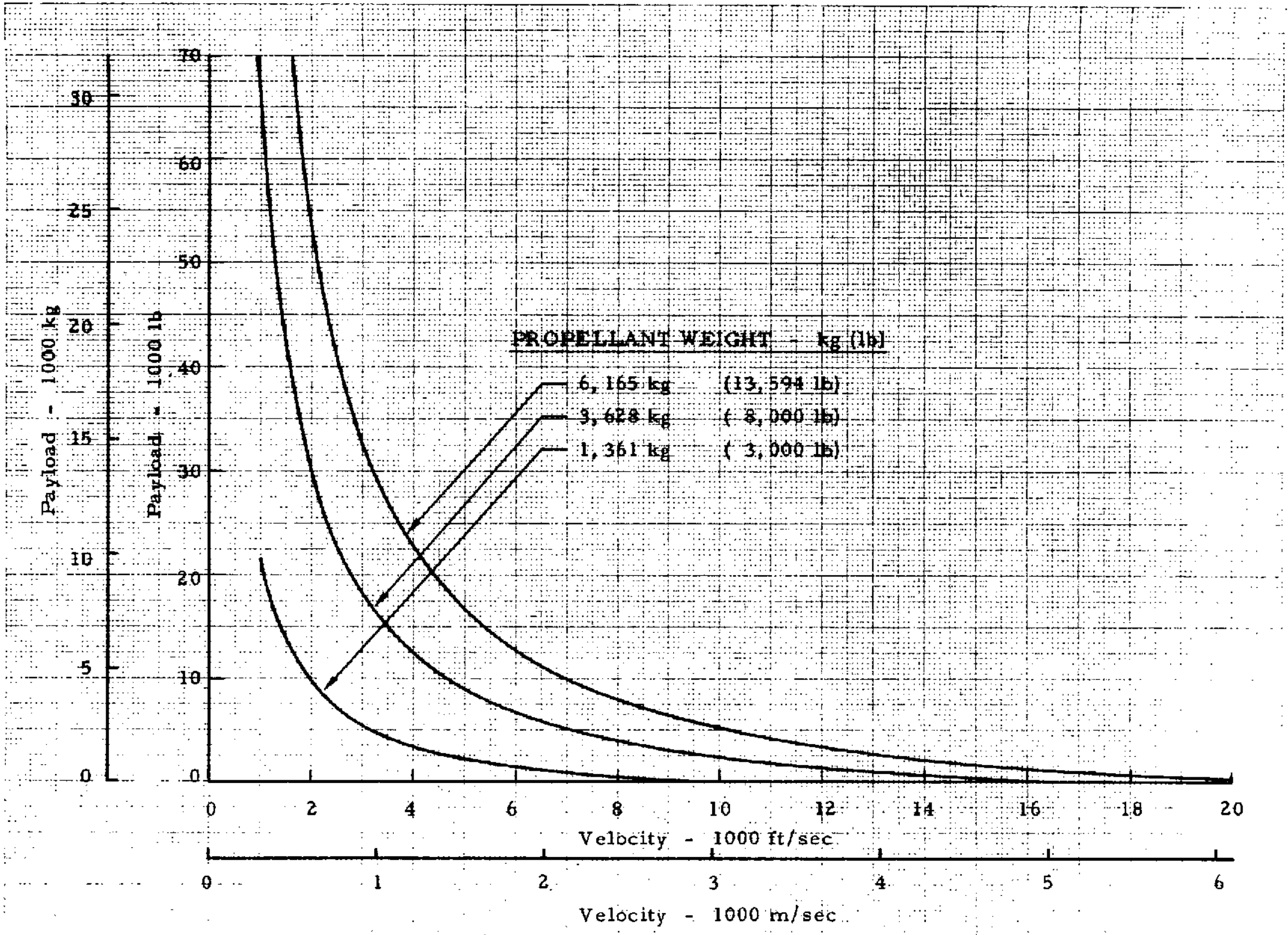

Figure 2-7. Agena (IRFNA)

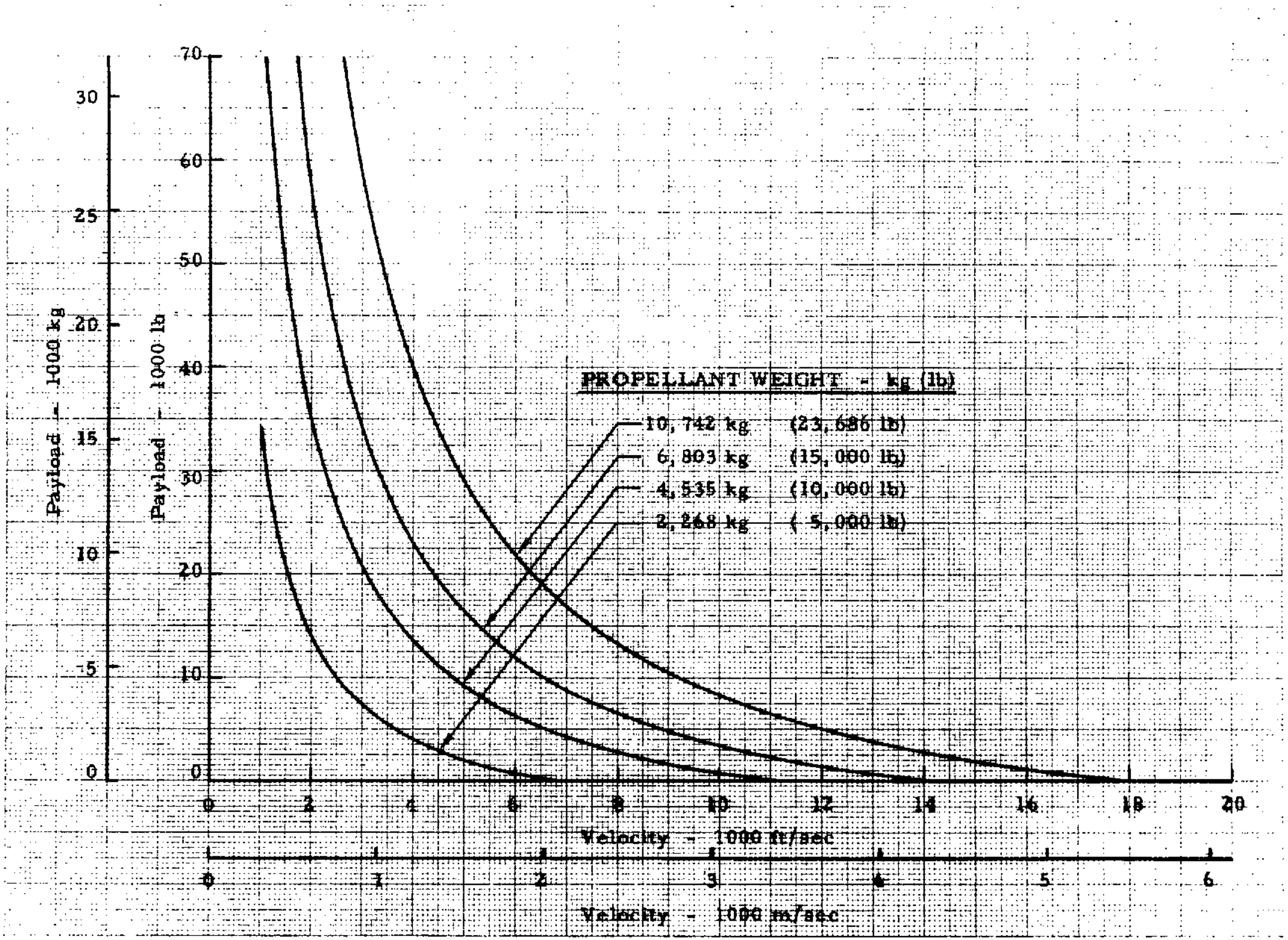

Figure 2-8. Transtage

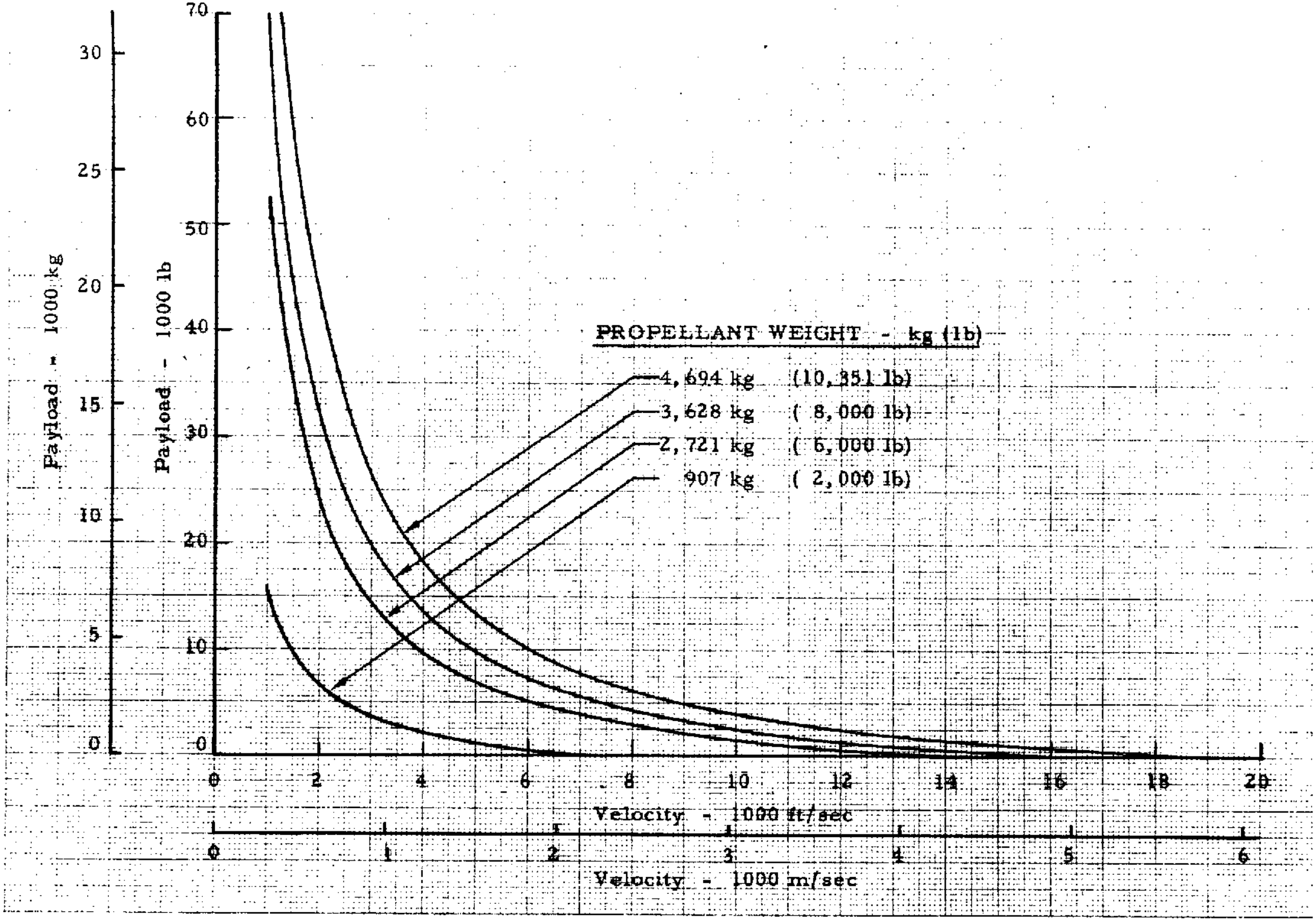

Figure 2-9. Delta

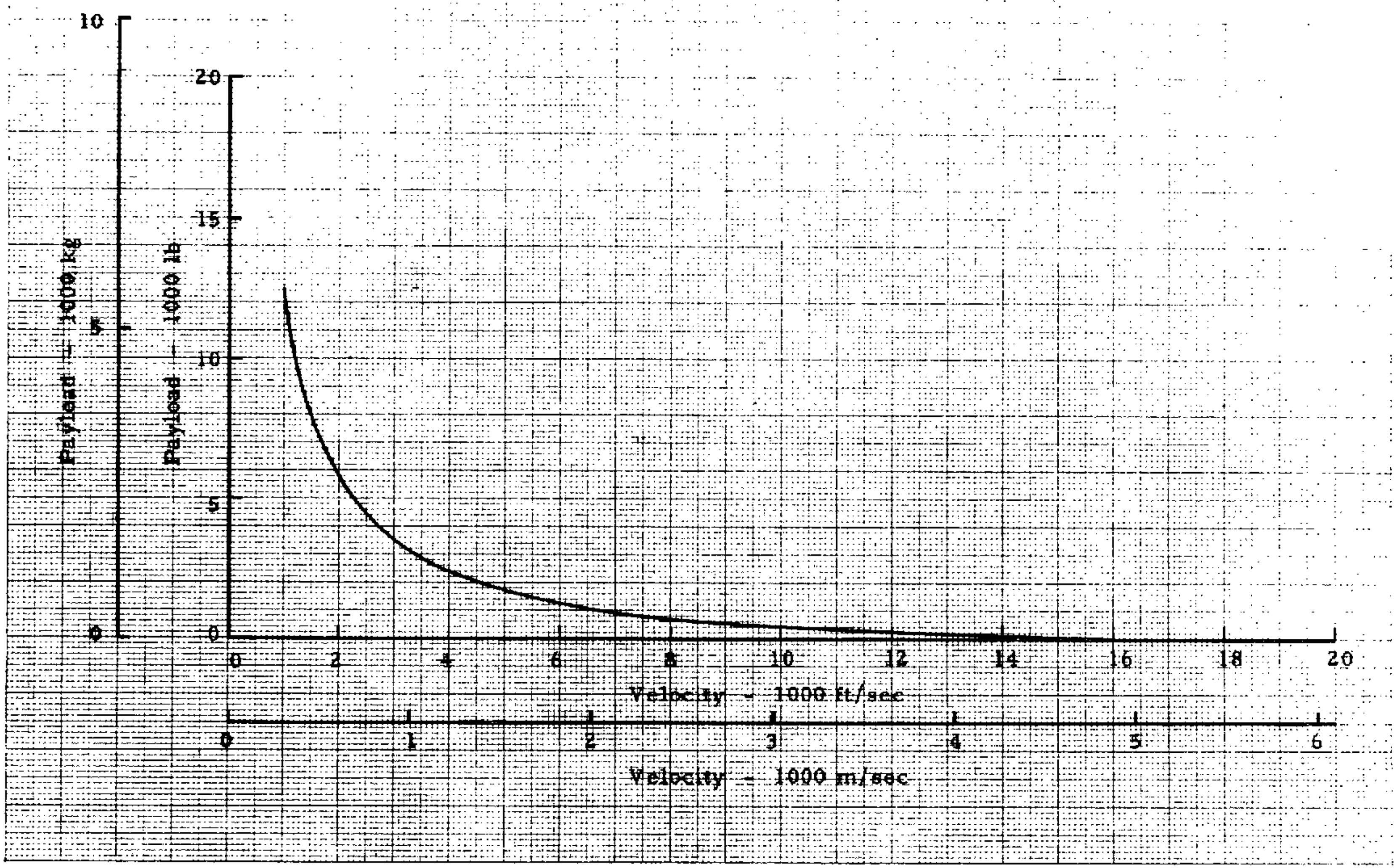

Figure 2-10. Burner-II (1440)

To maintain traceability and consistency, the methodology used to generate the performance data for this study is consistent with the methods used in the FY 1971 Study A (Integrated Operations/Payloads/Fleet Analysis).

The upper stages considered herein are, generically, those stages that have been considered in Study A. The latest available stage data, however, have been used to update their performance capabilities.

All performance data are presented as a function of payload vs velocity. This velocity is that outbound velocity requirement of the mission allocable to the third stage. In this analysis the inbound velocity (where applicable) is assumed equal to the outbound velocity.

The algorithms and definitions used to compute the performance are as follows:

$$\mathrm{WFI} = \mathrm{WSD} + \mathrm{WP}$$

$$\mathrm{WBO} = \mathrm{WSD} + \mathrm{WNUP}$$

$$\mathrm{WIMP} = \mathrm{WP} - \mathrm{WNUP} - \mathrm{WNIE}$$

$$\mathrm{SF} = \mathrm{WBO}/\mathrm{WFI}$$

$$\mathrm{WPEF} = \mathrm{WFI} - \mathrm{WBO}$$

$$\mathrm{IEF} = I_{sp} \times \mathrm{WIMP}/\mathrm{WPEF}$$

$$R = \mathrm{EXP}\ (V \times 1.02/32.174/\mathrm{IEF})$$

$$\text{Expendable P/L} = (R \times \mathrm{SF} - 1)/(1 - R) \times \mathrm{WFI}$$

$$\text{Deployment P/L} = (R^2 \times \mathrm{SF} - 1)/(1 - R) \times \mathrm{WFI}$$

$$\text{Retrieval P/L} = (R^2 \times \mathrm{SF} - 1)/(R - R^2) \times \mathrm{WFI}$$

$$\text{Replacement P/L} = (R^2 \times \mathrm{SF} - 1)/(1 - R^2) \times \mathrm{WFI}$$

where:

WFI	=	Stage weight at first ignition
WBO	=	Stage weight at burnout
WIMP	=	Weight of impulse propellant
SF	=	Structure factor
WPEF	=	Total expendables
IEF	=	Effective specific impulse
R	=	Mass ratio
WSD	=	Stage dry weight

WP	=	Weight of propellant, total difference between stage first ignition weight (WFI), not including payload, and the stage dry weight
WNUP	=	Total residuals
WNIE	=	Total non-impulsive expendables including APS propellants
V	=	Velocity of interest
P/L	=	Payload.

MSFC Tug

The following information was derived from Revision A of the "Baseline Tug Definition Document." (Ref. 20)

WSD	=	2369 kg (5223 lb)
WNUP	=	431 kg (950 lb)
WNIE	=	354 kg (780 lb)
WP max	=	25085 kg (55315 lb)
I_{sp}	=	470 sec

Centaur Dl-T

The Centaur weight data were obtained from General Dynamics Report GDCA-BNZ71-020-7, "Compatibility of a Cryogenic Upper Stage with Space Shuttle - Final Report."

WSD	=	1887 kg (4160 lb)
WNUP	=	214 kg (472 lb)
WNIE	=	458 kg (1009 lb)
WP max	=	13986 kg (30841 lb)
I_{sp}	=	444 sec

Agena

The Agena data used in this performance assessment were obtained from Lockheed Report LMSC-D152635, "Shuttle/Agena Study Final Report."

Agena (IRFNA)

WSD	=	621 kg (1369 lb)
WNUP	=	33 kg (73 lb)
WNIE		104 kg (230 lb)
WP max	=	6165 kg (13594 lb)
I_{sp}	=	290.8 sec

Transtage

The Transtage vehicle has not yet undergone modification studies for Shuttle use (current study contract at NASA Lewis), but the following data are the latest available to Aerospace through the Titan program office.

WSD	=	1601 kg (3530 lb)
WNUP	=	245 kg (541 lb)
WNIE	=	89 kg (196 lb)
WP max	=	10742 kg (23686 lb)
I_{sp}	=	302 sec

Delta

The following Delta data were obtained from McDonnell Douglas (personal communications), Huntington Beach. The Delta vehicle is also currently being studied by MDAC for NASA Lewis.

WSD	=	755 kg (1665 lb)
WNUP	=	18 kg (40 lb)
WNIE	=	5.2 kg (11.5 lb)
WP max	=	4694 kg (10351 lb)
I_{sp}	=	304 sec

Burner-II (1440)

The Burner-II (1440 data were supplied by NASA/MSFC Letter PD-SA-L-72-24 dated 22 August 1972 from T. H. Sharpe to L. L. Schilb.

WSD	=	137 kg (301 lb)
WNUP	=	0 kg (0 lb)
WNIE	=	0 kg (0 lb)
WP max	=	669 kg (1475 lb)
I_{sp}	=	290 sec

2. MISSION MODELS

The baseline integrated NASA-DoD mission model which was used for this Space Shuttle cost/capture analysis is defined by the NASA mission model dated June 1972, the March 1971 non-NASA mission model, and the August 1971 DoD Option B mission model. The baseline mission model developed for this study is an extension of the expendable payload approach now in use. It has been developed in a fashion similar to the one used in the Integrated Operations/Payloads/Fleet Analysis, Study A, in FY 1971. In addition to the baseline model, other mission models used in this study utilize current expendable payloads modified for reuse, and large, low-cost reusable payloads where reusable payloads may be expended, serviced on orbit, or returned to earth and refurbished for reuse. These additional models are based upon the baseline integrated model, but they require adjustment of the payload traffic rate to meet the objectives of the baseline. Most of the missions in the integrated model involve the placing of a satellite in orbit either singly or as a part of a "constellation" of satellites. Also projected are logistic flights in support of the space station, research application module, pallet experiment sortie flights, and low altitude satellite service flights. The lunar exploration supplement was not included in this analysis.

In previous capture/cost analyses the "sortie type" missions in the mission model were considered to be additional benefits of the Shuttle and were not included in the expendable launch vehicle mission model. For this analysis an "equivalent sortie" capability is included in one of the expendable mission model cases by launching a "minimum" modular space station in 1979 and conducting "sortie type" experiments from the space station. This "equivalent sortie" expendable mission model capture/cost analysis can then be compared with analysis of the Shuttle mission model which includes Shuttle sortie flights.

The given mission models cover the time period 1979-1990. Previous analyses using similar models have shown a cost tailoff which results from the model ending in 1990. The model was extended to 1997 to eliminate this cost tailoff. The ground rules used in extending the model are listed in Table 2-4. The R&D ground rules for establishing spacecraft model changes and mission equipment changeouts are listed in Table 2-5.

The NASA and non-NASA mission models for the various cases captured showing the extension through 1997 and the R&D schedules are presented in Tables 2-6 through 2-8. The current expendable Case 500 without sortie science is shown in Table 2-6; the current expendable Case 501 including sortie science equivalent in Table 2-7; and the reusable model for Case 506 including sorties in Table 2-8. In order for this report to remain unclassified, the DoD mission model is not presented.

Table 2-4. Ground Rules for Reusable Payload Mission Model Extension, 1991-1997

1. Repeat the 1981-1987 payloads in the 1991-1997 time period.

2. Payloads in operation in 1990 to continue into 1991 time period.

3. Payload programs in operation prior to 1981 will continue with the same R&D schedule for the 1991-1997 time period.

4. Planetary schedule will be determined by mission windows.

5. Sorties will phase down as space station laboratories become operational.

Table 2-5. Ground Rules for R&D Schedule

1. Programs which have first flight in 1979-1990 time period - show satellite R&D in first year.
2. Repeat satellite R&D on ten-year centers for programs other than R&D.
3. When satellite is a part of a family or type, show satellite R&D on first program and mission equipment R&D on others (i. e., Pioneer, Mariner).
4. When satellite program has more than one destination (i. e., synchronous, polar), show satellite R&D on first and mission equipment R&D on second.
5. When description in Data Book infers many different missions (i. e., ATS, SATS, Explorers, Sorties) under a single program name, show mission equipment R&D every other year or every other flight depending on flight schedule.
6. Mission equipment R&D on five-year centers maximum - may be more frequent.
7. Integrate sortie R&D schedule with applicable satellite programs.
8. Integrate NASA R&D schedule with non-NASA programs.
9. Programs which have first flight and several others prior to 1979 (i. e., early 1970s), show satellite R&D in 1977 or 1978 (to spread R&D peak) and show mission equipment R&D early in 1979-1990 period.
10. One sortie lab R&D to be spread over the various disciplines. Sortie experiment R&D will be applied to all disciplines.
11. Non-NASA R&D schedule is the same as used in Study A.

Table 2-6. NASA and Non-NASA Expendable Payload Traffic Without Sortie Science (Case 500)

NASA ASTRONOMY
AGENCY: OSS
NO SORTIES

CODE NO.(1)	PAYLOAD							NASA MODEL												MODEL EXTENSION							TOTAL
		73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	
	AUTOMATED SPACECRAFT																										
NA2-1	Explorers - LEO	□1	2	△1	1	△1	2	△1	1	△1	1	□1	1	△1	1	△1	1	△1	1	△1	1	□1	1	△1	1	△1	19
NA2-2	Explorers - Sync.								△1				1				△1		1				△1				5
	Orbiting Solar Observatory		1		1		1																				
	MAN-TENDED OBSERVATORIES																										
NA2-3	HEAO			1		1		△1		1		△1	□1	1	1	1	1	△1		1		△1	□1	1	1	1	15
NA2-5	Large Space Telescope							□1		1		△1		1		1		□1		1		△1		1		1	10
NA2-7	Large Solar Observatory														□1		1		1		△1		1		□1		6
NA2-9	Large Hi Energy Tele. (X-Ray)																	□1		1		1		△1		1	5
NA2-11	Radio Astronomy Observatory																		□1			1			△1		3
	TOTALS:	1	3	2	2	2	3	3	2	3	1	3	3	3	3	3	4	4	4	4	2	5	4	4	4	4	63

□ One Satellite R&D
△ One Mission Equipment R&D

(1) See Ref. 12

1

Table 2-6. NASA and Non-NASA Expendable Payload Traffic Without Sortie Science (Case 500) (Cont'd)

NASA SPACE PHYSICS
AGENCY: OSS

NO SORTIES

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	AUTOMATED SPACECRAFT																										
NP2-13	Explorers - Upper Atmosphere	$\boxed{3}$	2	$\triangle$2	1	$\triangle$2	1	$\triangle$1		1		$\boxed{1}$		1		$\triangle$1		1		$\triangle$1		$\boxed{1}$		1		$\triangle$1	10
NP2-14	Explorers - Medium Altitude							$\boxed{1}$		1		1		$\triangle$1		1		1		$\triangle$1		1		1		$\triangle$1	10
NP2-15	Explorers - High Altitude								1		$\triangle$1		1		1		$\boxed{1}$		1		1		$\triangle$1		1		9
NP2-16	Gravity & Relativity Sat. - LEO							$\boxed{1}$			1										$\boxed{1}$						3
NP2-17	Gravity & Relativity Sat. - Solar														$\boxed{1}$				1				$\triangle$1				3
NP2-18	Environ. Perturb. Sat - Mission A									$\boxed{1}$			1							$\boxed{1}$			1				4
NP2-19	Environ. Perturb. Sat - Mission B															$\boxed{1}$			1			$\triangle$1			1		4
NP2-20	Heliocentric & Interstellar S/C																$\triangle$1							$\triangle$1			2
	SPACE STATION - RAM																										
NP2-21	Physics Laboratory (10 Yr)															$\boxed{1}$										$\boxed{1}$	2
	TOTALS:	3	2	2	1	2	1	3	1	3	2	2	2	2	2	4	2	2	3	3	2	3	3	3	2	3	47

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

Table 2-6. NASA and Non-NASA Expendable Payload Traffic Without Sortie Science (Case 500) (Cont'd)

NASA PLANETARY
AGENCY: OSS
NO SORTIES

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
		NASA MODEL																		MODEL EXTENSION							
NU2-22	Mars Viking			2				2													□2						4
NU2-23	Mars Rover														□1											□1	2
	Venus Mercury Flyby	1																									
NU2-24	Venus Pioneer				□1	1	1		△1											□1							2
NU2-25	Venus Radar Mapper												□2									△2					4
NU2-26	Venus Large Lander																	□2							△2		4
	HELIOS		1	1																							
NU2-27	Mercury Orbiter															□2											2
	Pioneer-Jupiter Flyby	1																									
NU2-28	Pioneer-Jupiter Orbiter						△1	1														□1					2
	Mariner-Jupiter/Saturn Flyby					2																					
NU2-29	Mariner-Jupiter/Uranus Flyby							△2													□2						4
NU2-30	Pioneer-Jupiter Probe										△2												△2				4
NU2-31	Pioneer-Saturn Probe												△2											△2			4
NU2-32	Mariner-Jupiter Orbiter														△1	1										□1	3
NU2-33	Uranus Probe/Nepture Flyby														□2										□2		4
NU2-34	Mariner-Saturn Orbiter																	△1	1							△1	3
NU2-35	ENCKE Slow Flyby							△1												□1							2
NU2-36	ENCKE Rendezvous												□2										□2				4
NU2-37	Asteroid Rendezvous																	△2									2
	TOTALS:	2	1	3	1	3	2	6	1	0	2	0	6	0	4	3	0	5	1	2	4	3	4	2	4	3	50

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

Table 2-6. NASA and Non-NASA Expendable Payload Traffic Without Sortie Science (Case 500) (Cont'd)

NASA EARTH OBSERVATIONS AND EARTH AND OCEAN PHYSICS
AGENCY: OA
NO SORTIES

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	EARTH OBSERVATIONS																										
	AUTOMATED SPACECRAFT																										
	RESEARCH AND DEVELOPMENT																										
	Earth Resources Tech. Satellite	1			1																						
	NIMBUS		1			1																					
NE2-38	Earth Observatory Satellite						□1	1	△1	1		△1		1		□1		△1		△1		1		△1		□1	11
NE2-39	Sync. Earth Obs. Satellite								□1		1			△1		1			□1		1			△1		1	8
	SYSTEMS DEMONSTRATION																										
NE2-40	TIROS				1					△1																	1
NE2-41	Sync. Met. Satellite	□1				1				△1	1									□1	1						4
NE2-42	Earth Resources Satellite							2	2				1	1					2	2				1	1		12
NE2-43	Sync. Earth Obs. Sat/Proto.																		1		1		1		1		4
	EARTH AND OCEAN PHYSICS																										
	AUTOMATED SPACECRAFT																										
	GEOS	1																									
	LAGEOS				1																						
NE2-45	GEOPAUSE							□1	1											□1	1						4
	TOTALS:	3	1	0	3	2	1	4	5	3	2	1	1	3	0	2	0	1	4	5	4	1	1	3	2	2	44

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

Table 2-6. NASA and Non-NASA Expendable Payload Traffic Without Sortie Science (Case 500) (Cont'd)

NASA COMMUNICATIONS AND NAVIGATION
AGENCY: OA

NO SORTIES

CODE NO. (1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	AUTOMATED SPACECRAFT																										
	RESEARCH AND DEVELOPMENT																										
NC2-46	Applications Technology Satellite	□1		△1			□1	△1			□1	△1		□1		△1		□1			△1	□1		△1		□1	10
	Cooperative Appl. Satellite			1			1																				
NC2-47	Small Appl. Tech. Sat. - Sync.				□1	1	△1	1	△1	1	△1	1	△1	1	□1	1	△1	1	△1	1	△1	1	△1	1	□1	1	19
NC2-48	Small Appl. Tech. Sat. - Polar				△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	19
	SYSTEMS DEMONSTRATION																										
NC2-49	Tracking & Data Relay Satellite					□1	2					△3						□3				△3					9
NC2-50	Disaster Warning Satellite						□1	1																			1
NC2-51	System Test Satellites								□1	1	△1	1	△1	1		△1	1			□1	1	△1	1	△1		1	14
	SPACE STATION - RAM																										
NC2-54	Comm/Nav Lab														□1										□1		2
	TOTALS:	1	0	2	2	3	7	4	3	3	4	7	3	4	3	4	3	6	2	3	4	7	3	4	3	4	74

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

Table 2-6. NASA and Non-NASA Expendable Payload Traffic Without Sortie Science (Case 500) (Cont'd)

NASA LIFE SCIENCE, MATERIAL SCIENCE AND SPACE TECHNOLOGY
AGENCY: OMSF, OAST

NO SORTIES

CODE NO.(1)	PAYLOAD							NASA MODEL												MODEL EXTENSION							TOTAL
		73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	
	LIFE SCIENCE - OMSF																										
	AUTOMATED SPACECRAFT																										
NB2-55	Bio-Research Module			$\boxed{1}$	1	1	1	2																			2
NB2-56	Teleoperator							$\boxed{1}$																			1
	SPACE STATION - RAM																										
NB2-60	Station Lab Experiment															$\boxed{1}$										$\boxed{1}$	2
	SPACE TECHNOLOGY AND																										
	MATERIAL SCIENCE - OAST																										
	AUTOMATED SPACECRAFT																										
NT2-61	Meteoroid & Exposure Module						$\boxed{1}$		$\triangle$1			$\triangle$1															2
	SPACE STATION - RAM																										
NT2-64	Tech. & Material Science Lab.													$\boxed{1}$										$\boxed{1}$			2
	TOTALS:	0	0	1	1	1	2	3	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0	1	9

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

6

Table 2-6. NASA and Non-NASA Expendable Payload Traffic Without Sortie Science (Case 500) (Cont'd)

NASA SPACE STATION
AGENCY: OMSF

NO SORTIES

CODE NO.(1)	PAYLOAD							NASA MODEL												MODEL EXTENSION							TOTAL
		73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	
	Skylab																										
	Orbital Workshop	1																									
	Revisits	3																									
	International Rendezvous/			1																							
	Docking Mission																										
	SPACE STATION																										
NS2-65	Crew Operations												$\boxed{1}$						△1								2
NS2-66	Power Subsystems												$\boxed{1}$						△1								2
NS2-67	General Purpose Laboratory												$\boxed{1}$														1
NS2-68	Crew/Operations - Logistics												$\boxed{1}$	5	6	6	6	6	6	8	8	8	8	8	8	8	92
	TOTALS:	4	0	1	0	0	0	0	0	0	0	0	4	5	6	6	6	6	8	8	8	8	8	8	8	8	97

☐ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

7

Table 2-6. NASA and Non-NASA Expendable Payload Traffic Without Sortie Science (Case 500) (Concluded)

NON-NASA
AGENCY: OA
NO SORTIES

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	AUTOMATED SPACECRAFT																										
NCN-7	Comsat Satellite	2	1			1	2	2	1	1		2	1	1			2	1		1		2	1	1			16
NCN-8	U.S. Domestic Comm.		2	1	1		2	1	2	1	1	2	△2	2	2	2	2	2	2	1	1	2	△2	2	2	2	33
NCN-9	Foreign Domestic Comm.	1	1	2	5	2	2		△2	△6	△2	△2			△4	5	2	1	2	6	2	△2			4	△5	45
NCN-10A	Navigation/Traffic Control						1	3	1	2		1		1		1		1		2		1		1		1	15
NCN-10B	Navigation/Traffic Control						1		1	1		1		1		1		1		1		1		1		1	10
NEO-7	TOS Meteorological	1	1	1	1	1	1	1	1	1	△1	1	1	1	△1	1	1	1	1	1	△1	1	1	1	△1	1	19
NEO-15	Synchronous Met.		1	1	1	1	1	1	1	1	△1	1	1	1	△1	1	1	1	1	1	△1	1	1	1	△1	1	19
NEO-16	Polar Earth Resources							□4		4		△4		4				6		□4		4		4			34
NEO-11	Sync. Earth Resources													□4			4			4				□4			16
	TOTALS:	4	6	5	8	5	10	12	9	17	5	14	5	15	8	11	12	14	6	21	5	14	5	15	8	11	207

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 13

Table 2-7. NASA and Non-NASA Expendable Payload Traffic With Sortie Science (Case 501)

NASA ASTRONOMY

AGENCY: OSS

CODE NO.[1]	PAYLOAD							NASA MODEL												MODEL EXTENSION							TOTAL
		73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	
	AUTOMATED SPACECRAFT																										
NA2-1	Explorers - LEO	□1	2	△1	1	△1	2	△1	1	△1	1	□1	1	△1	1	△1	1	△1	1	△1	1	□1	1	△1	1	△1	19
NA2-2	Explorers - Sync.								△1				1				△1		1				△1				5
	Orbiting Solar Observatory		1		1		1																				
	MAN-TENDED OBSERVATORIES																										
NA2-3	HEAO			1		1		△1		1		△1	□1	1	1	1	1	△1		1		△1	□1	1	1	1	15
NA2-5	Large Space Telescope							□1		1		△1		1		1		□1		1		△1		1		1	10
NA2-7	Large Solar Observatory														□1		1		1		△1		1		□1		6
NA2-9	Large Hi Energy Tele. (X-Ray)																	□1		1		1		△1		1	5
NA2-11	Radio Astronomy Observatory																		□1			1			△1		3
	SORTIES (Space Station Physics Lab)																										
NA2-12	Astron. & Physics Obs.							△1	△1	△2	△1	△2	△3	2	2	3	△2	3	2	△2	△3	△2	△3	2	3	2	41
	TOTALS:	1	3	2	2	2	3	4	3	5	2	5	6	5	5	6	6	7	6	6	5	7	7	6	7	6	104

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

1

Table 2-7. NASA and Non-NASA Expendable Payload Traffic With Sortie Science (Case 501) (Cont'd)

NASA SPACE PHYSICS
AGENCY: OSS

CODE NO. (1)	PAYLOAD	73	74	75	76	77	78	NASA MODEL 79	80	81	82	83	84	85	86	87	88	89	90	MODEL EXTENSION 91	92	93	94	95	96	97	TOTAL
	AUTOMATED SPACECRAFT																										
NP2-13	Explorers - Upper Atmosphere	☐3	2	△2	1	△2	1	△1		1		☐1		1		△1		1		△1		☐1		1		△1	10
NP2-14	Explorers - Medium Altitude							☐1		1		1		△1		1		1		△1		1		1		△1	10
NP2-15	Explorers - High Altitude								1		△1		1		1		☐1		1		1		△1		1		9
NP2-16	Gravity & Relativity Sat. - LEO							☐1			1										☐1						3
NP2-17	Gravity & Relativity Sat. - Solar														☐1				1				△1				3
NP2-18	Environ. Perturb. Sat - Mission A									☐1			1							☐1			1				4
NP2-19	Environ. Perturb. Sat - Mission B															☐1			1			△1			1		4
NP2-20	Heliocentric & Interstellar S/C																△1							△1			2
	SPACE STATION - RAM																										
NP2-21	Physics Laboratory (10 Yr)															☐1										☐1	2
	TOTALS:	3	2	2	1	2	1	3	1	3	2	2	2	2	2	4	2	2	3	3	2	3	3	3	2	3	47

☐ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

Table 2-7. NASA and Non-NASA Expendable Payload Traffic With Sortie Science (Case 501) (Cont'd)

NASA PLANETARY
AGENCY: OSS

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
NU2-22	Mars Viking			2				2													□2						4
NU2-23	Mars Rover														□1											□1	2
	Venus Mercury Flyby	1																									
NU2-24	Venus Pioneer				□1	1	1		△1											□1							2
NU2-25	Venus Radar Mapper												□2									△2					4
NU2-26	Venus Large Lander																	□2							△2		4
	HELIOS		1	1																							
NU2-27	Mercury Orbiter															□2											2
	Pioneer-Jupiter Flyby	1																									
NU2-28	Pioneer-Jupiter Orbiter						△1	1														□1					2
	Mariner-Jupiter/Saturn Flyby					2																					
NU2-29	Mariner-Jupiter/Uranus Flyby							△2													□2						4
NU2-30	Pioneer-Jupiter Probe										△2												△2				4
NU2-31	Pioneer-Saturn Probe												△2											△2			4
NU2-32	Mariner-Jupiter Orbiter														△1	1										□1	3
NU2-33	Uranus Probe/Nepture Flyby														□2										□2		4
NU2-34	Mariner-Saturn Orbiter																	△1	1							△1	3
NU2-35	ENCKE Slow Flyby							△1												□1							2
NU2-36	ENCKE Rendezvous												□2										□2				4
NU2-37	Asteroid Rendezvous																	△2									2
	TOTALS:	2	1	3	1	3	2	6	1	0	2	0	6	0	4	3	0	5	1	2	4	3	4	2	4	3	50

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

Table 2-7. NASA and Non-NASA Expendable Payload Traffic With Sortie Science (Case 501) (Cont'd)

NASA EARTH OBSERVATIONS AND EARTH AND OCEAN PHYSICS
AGENCY: OA

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	EARTH OBSERVATIONS																										
	AUTOMATED SPACECRAFT																										
	RESEARCH AND DEVELOPMENT																										
	Earth Resources Tech. Sat.	1			1																						
	Nimbus		1			1																					
NE2-38	Earth Observatory Satellite						[1]	1	△1	1		△1		1		[1]		△1		△1		1		△1		[1]	11
NE2-39	Sync. Earth Obs. Satellite								[1]		1			△1		1			[1]		1			△1		1	8
	SYSTEMS DEMONSTRATION																										
NE2-40	Tiros				1					△1																	1
NE2-41	Sync. Met. Satellite	[1]				1				△1	1									[1]	1						4
NE2-42	Earth Resources Satellite							2	2				1	1					2	2				1	1		12
NE2-43	Sync. Earth Obs. Sat/Prototype																		1		1		1		1		4
	SPACE STATION - RAM																										
NE2-44	Earth Obs. Experiment								△1	1	1		△1	1	1		△1	1	1		△1	1	1		△1	1	14
	EARTH & OCEAN PHYSICS																										
	AUTOMATED SPACECRAFT																										
	GEOS	1																									
	LAGEOS				1																						
NE2-45	GEOPAUSE							[1]	1											[1]	1						4
	TOTALS:	3	1	0	3	2	1	4	6	4	3	1	2	4	1	2	1	2	5	5	5	2	2	3	3	3	58

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

Table 2-7. NASA and Non-NASA Expendable Payload Traffic With Sortie Science (Case 501) (Cont'd)

NASA COMMUNICATIONS AND NAVIGATION
AGENCY: OA

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	NASA MODEL 79	80	81	82	83	84	85	86	87	88	89	90	MODEL EXTENSION 91	92	93	94	95	96	97	TOTAL
	AUTOMATED SPACECRAFT																										
	RESEARCH AND DEVELOPMENT																										
NC2-46	Applications Tech. Satellite	[1]		△1			[1]	△1			[1]	△1		[1]		△1		[1]			△1	[1]		△1		[1]	10
	Cooperative Appl. Satellite			1			1																				
NC2-47	Small Appl. Tech. Sat. - Sync.				[1]	1	△1	1	△1	1	△1	1	△1	1	[1]	1	△1	1	△1	1	△1	1	△1	1	[1]	1	19
NC2-48	Small Appl. Tech. Sat. - Polar				△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	19
	SYSTEMS DEMONSTRATION																										
NC2-49	Tracking & Data Relay Satellite					[1]	2					△3						[3]				△3					9
NC2-50	Disaster Warning Satellite						[1]	1																			1
NC2-51	System Test Satellites								[1]	1	△1	1	△1	1		△1	1			[1]	1	△1	1	△1		1	14
	SPACE STATION - RAM																										
NC2-52	Comm/Nav. Experiments (Sorties)							△1	1			△1	1			△1			△1					△1			7
NC2-53	Comm/Nav. Lab (Exp) (Sorties)									△1	1			△1		1		△1				△1				△1	7
NC2-54	Comm/Nav. Lab														[1]										[1]		2
	TOTALS:	1	0	2	2	3	7	5	4	4	5	8	4	5	3	6	3	7	3	3	4	8	3	5	3	5	88

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

5

Table 2-7. NASA and Non-NASA Expendable Payload Traffic With Sortie Science (Case 501) (Cont'd)

NASA LIFE SCIENCE, MATERIAL SCIENCE & SPACE TECHNOLOGY
AGENCY: OMSF, OAST

CODE NO. (1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	LIFE SCIENCE - OMSF																										
	AUTOMATED SPACECRAFT																										
NB2-55	Bio-Research Module			$\boxed{1}$	1	1	1	2																			2
NB2-56	Teleoperator							$\boxed{1}$																			1
	SPACE STATION - RAM																										
NB2-57	Mini 7-Day Module (Sorties)								△1	1	1																3
NB2-58	Mini 30-Day Module (Sorties)											△1	2														3
NB2-59	Mini 30-Day Module (Sorties)													△2	3												5
NB2-60	Station Lab Exper.															$\boxed{1}$										$\boxed{1}$	2
	SPACE TECH & MAT'L SCIENCE - OAST																										
	AUTOMATED SPACECRAFT																										
NT2-61	Meteoroid & Exposure Module						$\boxed{1}$		△1			△1															2
	SPACE STATION - RAM																										
NT2-62	Mat'l Science Exp. (Sortie)							△1		1		△1	1							△1				△1			6
NT2-63	Adv. Technology Exp. (Sortie)								△1		△1		△1									△1				△1	5
NT2-64	Tech. & Mat'l Science Lab.													$\boxed{1}$										$\boxed{1}$			2
	TOTALS:	0	0	1	1	1	2	4	3	2	2	3	4	3	3	1	0	0	0	1	0	1	0	2	0	2	31

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

6

Table 2-7. NASA and Non-NASA Expendable Payload Traffic With Sortie Science (Case 501) (Cont'd)

NASA SPACE STATION
AGENCY: OMSF

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	SKYLAB																										
	Orbital Workshop	1																									
	Revisits	3																									
	International Rendezvous/ Docking Mission			1																							
	SPACE STATION																										
NS2-65	Crew Operations							$\boxed{1}$						△1													2
NS2-66	Power Subsystems							$\boxed{1}$						△1													2
NS2-67	General Purpose Laboratory							$\boxed{1}$						△1													2
NS2-68	Crew/Operations - Logistics							1	1	1	1	1	1	6	7	7	7	7	7	8	8	8	8	8	8	8	103
	TOTALS:	4	0	1	0	0	0	4	1	1	1	1	1	9	7	7	7	7	7	8	8	8	8	8	8	8	109

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

Table 2-7. NASA and Non-NASA Expendable Payload Traffic With Sortie Science (Case 501) (Concluded)

NON-NASA
AGENCY: OA

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	AUTOMATED SPACECRAFT																										
NCN-7	Comsat Satellite	2	1			1	2	2	1	1		2	1	1			2	1		1		2	1	1			15
NCN-8	U.S. Domestic Comm.		2	1	1		2	1	2	1	1	2	△2	2	2	2	2	2	2	1	1	2	△2	2	2	2	33
NCN-9	Foreign Domestic Comm.	1	1	2	5	2	2		△2	△6	△2	△2			△4	5	2	1	2	6	2	△2			4	△5	45
NCN-10A	Navigation/Traffic Control						1	3	1	2		1		1		1		1		2		1		1		1	15
NCN-10B	Navigation/Traffic Control						1		1	1		1		1		1		1		1		1		1		1	10
NEO-7	TOS Meteorological	1	1	1	1	1	1	1	1	1	△1	1	1	1	△1	1	1	1	1	1	△1	1	1	1	△1	1	19
NEO-15	Synchronous Met.		1	1	1	1	1	1	1	1	△1	1	1	1	△1	1	1	1	1	1	△1	1	1	1	△1	1	19
NEO-16	Polar Earth Resources							□4		4		△4		4				6		□4		4		4			34
NEO-11	Sync. Earth Resources													□4			4			4				□4			16
	TOTALS:	4	6	5	8	5	10	12	9	17	5	14	5	15	8	11	12	14	6	21	5	14	5	15	8	11	207

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 13

Table 2-8. NASA and Non-NASA Reusable Payload Traffic With Sortie Science (Case 506)

NASA ASTRONOMY

AGENCY: OSS

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	AUTOMATED SPACECRAFT																										
NA2-1	Explorers - LEO	1	2	1	1	□1	2	1	△1	1	△1	1	△1	1	△1	1	□1	1	△1	1	△1	1	△1	1	△1	1	19
NA2-2	Explorers - Sync.								△1				1				△1		1				□1				5
	Orbiting Solar Observatory		1		1		1																				
	MAN-TENDED OBSERVATORIES																										
NA2-3	HEAO			1		1		△				△	□					△				△	□				6
NA2-4	Revisits								1	1	1		1	2	2	2	1		1	1	1		1	2	2	2	21
NA2-5	Large Space Telescope							□				△					□					△					4
NA2-6	Revisits								1	1	1		1	1	1	1		1	1	1	1		1	1	1	1	15
NA2-7	Large Solar Observatory														□					△					□		3
NA2-8	Revisits															1	1	1	1		1	1	1	1		1	9
NA2-9	Large Hi Energy Tele. (X-Ray)																	□					△				2
NA2-10	Revisits																		1	1	1	1		1	1	1	7
NA2-11	Radio Astronomy Observatory																		□1			1			△1		3
	SORTIES																										
NA2-12	Astro. & Physics Observatory							△1	△1	△1	△1	△2	△2	2	2	2	△2	2	2	△2	△2	△2	△2	2	2	2	34
	TOTALS:	1	3	2	2	2	3	4	5	4	4	5	7	6	7	7	7	7	9	7	7	8	9	8	9	8	128

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

1

Table 2-8. NASA and Non-NASA Reusable Payload Traffic With Sortie Science (Case 506) (Cont'd)

NASA SPACE PHYSICS
AGENCY: OSS

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	AUTOMATED SPACECRAFT																										
NP2-13	Explorers - Upper Atmosphere	3	2	2	1	[2]	1	△1		1		△1		1		[1]		1		△1		1		△1		[1]	10
NP2-14	Explorers - Medium Altitude							[1]		1		1		△1		1		1		△1		1		1		△1	10
NP2-15	Explorers - High Altitude								1		△1		1		1		[1]		1		1		△1		1		9
NP2-16	Gravity & Relativity Sat - LEO							[1]			1										[1]						3
NP2-17	Gravity & Relativity Sat - Solar														[1]				1				△1				3
NP2-18	Environ. Perturb. Sat - Mission A									[1]			1							[1]			1				4
NP2-19	Environ. Perturb. Sat - Mission B															[1]			1			△1			1		4
NP2-20	Heliocentric & Interstellar S/C																△1							△1			2
	SPACE STATION																										
NP2-21	Physics Laboratories															[1]										[1]	4
	TOTALS:	3	2	2	1	2	1	3	1	3	2	2	2	2	2	4	2	3	3	3	2	4	3	3	2	3	49

☐ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

2

Table 2-8. NASA and Non-NASA Reusable Payload Traffic With Sortie Science (Case 506) (Cont'd)

NASA PLANETARY

AGENCY: OSS

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
NU2-22	Mars Viking			2				2													$\boxed{2}$						4
NU2-23	Mars Rover														$\boxed{1}$											$\boxed{1}$	2
	Venus Mercury Flyby	1																									
NU2-24	Venus Pioneer				$\boxed{1}$	1	1		△											$\boxed{1}$							2
NU2-25	Venus Radar Mapper												$\boxed{2}$									△2					4
NU2-26	Venus Large Lander																	$\boxed{2}$							△2		4
	HELIOS		1	1																							
NU2-27	Mercury Orbiter															$\boxed{2}$											2
	Pioneer-Jupiter Flyby	1																									
NU2-28	Pioneer-Jupiter Orbiter						△	1														$\boxed{1}$					2
	Mariner-Jupiter/Saturn Flyby					2																					
NU2-29	Mariner-Jupiter/Uranus Flyby							△2													$\boxed{2}$						4
NU2-30	Pioneer-Jupiter Probe										△2												△2				4
NU2-31	Pioneer-Saturn Probe												△2											△2			4
NU2-32	Mariner-Jupiter Orbiter														△	1										$\boxed{1}$	3
NU2-33	Uranus Probe/Neptune Flyby														$\boxed{2}$										$\boxed{2}$		4
NU2-34	Mariner-Saturn Orbiter																	△	1							△	3
NU2-35	ENCKE Slow Flyby							△												$\boxed{1}$							2
NU2-36	ENCKE Rendezvous												$\boxed{2}$										$\boxed{2}$				4
NU2-37	Asteroid Rendezvous																	△2									2
	TOTAL:	2	1	3	1	3	2	6	1	0	2	0	6	0	4	3	0	5	1	2	4	3	4	2	4	3	50

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

3

Table 2-8. NASA and Non-NASA Reusable Payload Traffic With Sortie Science (Case 506) (Cont'd)

NASA EARTH OBSERVATIONS AND EARTH AND OCEAN PHYSICS

AGENCY: OA

CODE NO.(1)	PAYLOAD							NASA MODEL												MODEL EXTENSION							TOTAL
		73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	
	EARTH OBSERVATIONS																										
	Automated Spacecraft																										
	Research and Development																										
	Earth Resources Tech. Satellite	1			1																						
	NIMBUS		1			1																					
NE2-38	Earth Observatory Satellite						□1	1	△1	1		△1		1		□1		△1		△1		1		△1		□1	11
NE2-39	Sync. Earth Obs. Satellite								□1		1			△1		1			□1		1			△1		1	8
	SYSTEMS DEMONSTRATION																										
NE2-40	TIROS				1					△1																	1
NE2-41	Sync. Met. Satellite	1				1				△1	1									□1	1						4
NE2-42	Earth Resources Satellite							2	2				1	1					2	2				1	1		12
NE2-43	Sync. Earth Obs. Sat. /Proto.																		1		1		1		1		4
	SORTIES																										
NE2-44	Earth Obs. Lab.								△1	1	1	△1	1	1	△1	1	1	△1	1	△1	1	1	△1	1	1	△1	18
	SUB TOTAL:	2	1	0	2	2	1	3	5	4	3	2	2	4	1	3	1	2	5	5	4	2	2	4	3	3	58
	EARTH AND OCEAN PHYSICS																										
	Automated Spacecraft																										
	GEOS	1																									
	LAGOES				1																						
NE2-45	Geopause							□1	1											□1	1						4
	SUB TOTAL	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	4
	TOTAL:	3	1	0	3	2	1	4	6	4	3	2	2	4	1	3	1	2	5	6	5	2	2	4	3	3	62

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

4

Table 2-8. NASA and Non-NASA Reusable Payload Traffic
With Sortie Science (Case 506) (Cont'd)

NASA COMMUNICATIONS AND NAVIGATION
AGENCY: OA

CODE NO.[1]	PAYLOAD	73	74	75	76	77	78	NASA MODEL 79	80	81	82	83	84	85	86	87	88	89	90	MODEL EXTENSION 91	92	93	94	95	96	97	TOTAL
	AUTOMATED SPACECRAFT																										
	RESEARCH AND DEVELOPMENT																										
NC2-46	Applications Technology Satellite	1		1			□1	△1			□1	△1		□1		△1		□1			□1	△1		□1		△1	10
	Cooperative Appl. Satellite			1			1																				
NC2-47	Small Appl. Tech. Sat - Sync.				1	1	□1	1	△1	1	△1	1	△1	1	△1	1	□1	1	△1	1	△1	1	△1	1	△1	1	19
NC2-48	Small Appl. Tech. Sat - Polar				1	1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	1	△1	19
	SYSTEMS DEMONSTRATION																										
NC2-49	Tracking & Data Relay Satellite					□1	2					△3						□3				△3					9
NC2-50	Disaster Warning Satellite						□1	1																			1
NC2-51	System Test Satellites								□1	1	△1	1	△1	1		△1	1			□1	1	△1	1	△1		1	14
	SORTIES																										
NC2-52	Comm/Nav Experiments							△1	1			△1	1			△1			△1					△1			7
NC2-53	Comm/Nav Laboratory									△1	1			△1				△1				△1				△1	6
	SPACE STATION - RAM																										
NC2-54	Comm/Nav Laboratory																										4
	TOTAL:	1	0	2	2	3	7	5	4	4	5	8	4	5	3	5	4	7	3	4	4	8	3	5	2	6	89

□ One Satellite R&D
△ One Mission Equipment R&D
(1) See Ref. 12

Table 2-8. NASA and Non-NASA Reusable Payload Traffic With Sortie Science (Case 506) (Cont'd)

NASA LIFE SCIENCE, MATERIAL SCIENCE, AND SPACE TECHNOLOGY
AGENCY: OMSF, OAST

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	LIFE SCIENCE - OMSF																										
	AUTOMATED SPACECRAFT																										
NB2-55	Bio-Research Module			□1	1	1	1	2																			2
NB2-56	Teleoperator							□1																			1
	SORTIES																										
NB2-57	Mini 7-Day Module								△1	1	1																3
NB2-58	Mini 30-Day Module											△1	1														2
	SPACE STATION - RAM																										
NB2-59	Mini 30-Day Module													□	□												2
NB2-60	Station Lab. Experiment															□										□	3
	SPACE TECHNOLOGY AND																										
	MATERIAL SCIENCE - OAST																										
	AUTOMATED SPACECRAFT																										
NT2-61	Meteoroid & Exposure Module						□		△			△															2
	SORTIES																										
NT2-62	Material Science Experiment							△	1	△	1	△	2							△				△			9
NT2-63	Advanced Technology Experiment								△		△		△									△				△	5
	SPACE STATION - RAM																										
NT2-64	Tech & Mat'l Science Lab.													□										□			3
	TOTAL:	0	0	1	1	1	2	4	4	2	3	3	4	2	1	1	0	0	0	2	1	1	0	2	0	2	32

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

6

Table 2-8. NASA and Non-NASA Reusable Payload Traffic With Sortie Science (Case 506) (Cont'd)

NASA SPACE STATIONS

AGENCY: OMSF

CODE NO.(1)	PAYLOAD	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	TOTAL
								NASA MODEL												MODEL EXTENSION							
	Skylab																										
	Orbital Workshop	1																									
	Revisits	3																									
	International Rend. & Dock. Miss.			1																							
	SPACE STATION																										
NS2-65	Crew Operations												$\boxed{1}$						$\triangle 1$								2
NS2-66	Power Subsystems												$\boxed{1}$						$\triangle 1$								2
NS2-67	General Purpose Laboratory												$\boxed{1}$														1
NS2-68	Crew/Operations - Logistics													$\boxed{5}$	6	6	6	6	6	8	8	8	8	8	8	8	91
	(EXPERIMENT MODULES)																										
	(Space Physics)																										
	(Life Science)																										
	(Comm/Nav)																										
	(Tech & Mat'l Science)																										
	TOTAL:	4	0	1	0	0	0	0	0	0	0	0	3	5	6	6	6	6	8	8	8	8	8	8	8	8	96

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 12

7

Table 2-8. NASA and Non-NASA Reusable Payload Traffic With Sortie Science (Case 506) (Concluded)

NON-NASA

AGENCY: OA

CODE NO.(1)	PAYLOAD							NASA MODEL												MODEL EXTENSION							TOTAL
		73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	
	AUTOMATED SPACECRAFT																										
NCN-7	Comsat Satellite	2	1			□1	2	2	1	1		2	1	1			2	1		1		2	1	1			16
NCN-8	U.S. Domestic Comm.		2	1	1		□2	1	2	1	1	2	△2	2	2	2	2	2	2	1	1	2	△2	2	2	2	33
NCN-9	Foreign Domestic Comm.	1	1	2	5	2	□2		△2	△6	△2	△2			△4	5	2	1	2	6	2	△2			4	△5	45
NCN-10A	Navigation/Traffic Control						□1	3	1	2		1		1		1		1		2		1		1		1	15
NCN-10B	Navigation/Traffic Control						△1		1	1		1		1		1		1		1		1		1		1	10
NEO-7	TOS Meteorological	1	1	1	1	□1	1	1	1	1	△1	1	1	1	△1	1	1	1	1	1	△1	1	1	1	△1	1	19
NEO-15	Synchronous Met.		1	1	1	1	□1	1	1	1	△1	1	1	1	△1	1	1	1	1	1	△1	1	1	1	△1	1	19
NEO-16	Polar Earth Resources							□4		4		△4		4				6		□4		4		4			34
NEO-11	Synchronous Earth Resources													□4			4			4				□4			16
	TOTALS:	4	6	5	8	5	10	12	9	17	5	14	5	15	8	11	12	14	6	21	5	14	5	15	8	11	207

□ One Satellite R&D

△ One Mission Equipment R&D

(1) See Ref. 13

8

3. PAYLOADS

The methodology documented in Volume II of the Integrated Operations/Payloads/Fleet Analysis Final Report (Ref. 3), updated and supplemented with the results of NASA and DoD studies, was used in this study. The types of payloads analyzed are:

(a) Current Expendable

A payload using the current design approach and intended for use with expendable launch vehicles.

(b) Current Reusable

A current expendable payload adapted to reuse.

(c) Large, Low-Cost Expendable

A payload using the low-cost (LMSC) expendable design approach and intended for use with expendable launch vehicles.

(d) Large, Low-Cost Reusable

A payload using the low-cost (LMSC) reusable design approach and intended for use with the Space Shuttle/Tug launch and retrieval system.

The Study 2.2 NASA Payload Data Book (Ref. 12) containing descriptions of NASA current expendable payloads; the Integrated Operations/Payloads/Fleet Analysis Phase II Second Interim Report, Volume II (Ref. 13) containing descriptions of the non-NASA current expendable payloads; and the Integrated Operations/Payloads/Fleet Analysis Final Report, Volume VI, (Ref. 8) containing descriptions of the DoD current expendable payloads, were used to provide payload subsystem weight estimates and dimensions. These payload data have been computerized to permit direct use in the accommodation and cost analyses in the DARES data bank.

Since both weight and cost factors are applied by subsystem, it is appropriate to include a list of subsystem definitions with typical hardware in each subsystem noted (Table 2-9).

A computerized methodology was applied to allocate the weight and estimate volume data for (1) current reusable payloads, (2) large, low-cost expendable payloads, and (3) large, low-cost reusable payloads. The current reusable payloads are baseline payloads adapted for Shuttle launch and for reuse. The low-cost payloads are developed by applying the LMSC "payload effects" to the payloads listed in the NASA, non-NASA, and DoD current expendable payloads.

The current expendable payload subsystem weight estimates are used to define the current reusable payloads by adding provisions for retrieval and refurbishment. The current reusable spacecraft subsystem design data used in Study A were reviewed and updated based upon a DSP satellite study performed by TRW (Ref. 19). Since reusability is achieved by orbital retrieval and return to the ground for maintenance, it should not significantly influence the basic design of the satellite. Using this as an assumption, a simplified method was derived to modify the current expendable payloads to have refurbishment capability. The following assumptions were made:

1. Velocity and position match for acquisition and rendezvous are to be determined by the Space Shuttle, Tug, or ground station.

2. Payloads are stable and provide passive support for terminal guidance. (Tumbling or unstable satellites are not normally retrieved.)

Table 2-9. Payload Subsystem Definition

Subsystem Element	Typical Hardware
Structures, Mechanisms (All structural and mechanical elements which are not part of the other functional subsystems. Also includes installation of subsystems into spacecraft, attachment of experiments and docking system for retrievable satellites.)	• Spacecraft structure • Equipment Supports • Sun Baffles • Balance Booms and Extns. Mech. • Antenna Deploy Mechanism • Solar Array Deployment Mech. • Retrieval Docking Ring
Environmental Control (All elements which alter and/or control the temperature of the payload and components thereof.)	• Thermal Louvers • Insulation • Thermal Paints and Coatings • Thermostats • Heaters • Radiators, Heat Pipes
Guidance, Navigation, and Stabilization (All elements which provide flight control, orbit positioning, and attitude hold, but excluding thruster system.)	• Position Sensors, (Solar, Earth, Star) • Momentum Wheels • Flight Control Electronics • Gyros • Inertial Ref. Units
Propulsion (All elements which are provided for major changes in velocity vectors.)	• Solid-Propellant Motors • Monopropellant or Bi-propellant Thrusters • Tankage for Propellant, Pressurants • Plumbing and Valves • Propellant, Pressurants
Attitude Control (Elements for control and/or maintenance of attitude which involve mass expulsion.)	• Cold Gas, Monopropellant, or Bi-propellant Thrusters • Tankage for Propellant, Cold Gas, Pressurants • Plumbing and Valves • Propellant, Pressurants

Table 2-9. Payload Subsystem Definition (Concluded)

Subsystem Element	Typical Hardware
Command, Data Processing, Instrumentation (All elements of data processing, instrumentation, telemetry, communications, and command.)	• Data Handling, Processing, Storage Equipment • Signal Conditioners • Transducers • Transmitters, Beacons, Transponders • RCVRS/Decoders • Multiplexers/Encoders • Antennas • RF Power Amplifiers • CMD, Data Storage, Timing
Electrical (All elements of electrical power generation, control, distribution. Also includes pyrotechnic hardware.)	• Batteries • Solar Arrays (Including Structural Panels, Solar Cell Diodes, Interconnects, Orientation Assembly) • Voltage Regulators, Inverters • Distrib., Primary and Inst. Cabling • Pyrotechnic Devices (Squibs, etc.)
Mission Equipment (All elements which are mission-peculiar and not part of the supporting spacecraft. Includes any data processing equipment which is integral with experiments.)	• Telescopes • Cameras • TV Cameras • Physics Experiments • Radiometers, Epectrometers, etc.
Payload Assembly, Integration (All elements which are part of the payload system but do not remain with the payload in orbit.)	• Payload Adapters and Interstages • Fairings • Umbilicals • Safety Devices • Separation Devices

3. Payloads provide electrical power and the command link for safing/deactivation commands.

4. Rendezvous and docking are automatic.

5. The docking/deployment interface is standardized.

6. The mechanism required to dock with and despin a spinning satellite is on the Space Tug side of the docking interface.

The velocity and position match between the Space Shuttle or Space Tug (chaser) and payload (target) can be achieved within the acquisition range of a laser radar. The laser can also be used for the terminal guidance with several corner reflectors located on the payload to provide data on the payload attitude in addition to range and range rate.

A TV camera located on the chaser will provide backup data assistance in the form of payload inspection and gross rendezvous operations.

The docking would use the same mechanism that is used in the payload deployment. The docking ring should be approximately two meters (six feet) in diameter, which appears to be the nominal diameter in other earlier studies. After docking is achieved, the payload should be deactivated and safed by commands from the Shuttle or Tug. The equipment involved in the command deactivation should be the same hardware that is used in the initial payload activation. Also, retraction of appendages such as the antenna and solar arrays may be required for the return flight or for storage in the cargo bay.

In summary, the equipments involved for deployment and retrieval are as follows:

Space Shuttle	Space Tug	Payload
Laser Radar	Laser Radar	Corner Reflectors
Docking and Despin Mechanism	Docking and Despin Mechanism	Adapter and Docking Mechanism
CDPI	CDPI	CDPI
TV Display	TV Camera	---

Some of the items are normal equipments used to deploy the payloads, but all of the items are needed for payload retrieval. It is reasonable to assume that the Space Shuttle will include all its required items, since these types of equipments will be required to deploy and retrieve the Space Tug. The retrieval-peculiar equipment for the Tug is the TV camera. The payload add-on kit includes the corner reflectors.

The weights of the items used for retrieval and refurbishment are:

	Space Tug		Payload	
	kg	(lb)	kg	(lb)
Corner Reflector	0	(0)	2.3	(5)
Rendezvous and Docking	33	(73)	0	(0)
Docking Mechanism	31.8	(70)	2% (wt) + 13.6	[2% (wt) + 30]
Refurbishability	0	(0)	5% (wt)	[5% (wt)]
Retraction of Appendages	0	(0)	3% (wt)	[3% (wt)]
Total	64.8	(143)	10% (wt) + 15.9	[10% (wt) + 35]

where (wt) is the total expendable payload weight. Weight penalties imposed on the Tug were extracted from Ref. 20. The weights for the corner reflectors, docking mechanism, and retraction mechanism are assigned to the structures subsystem. The weight allocation for refurbishability is considered to be those modifications necessary for accessibility and subsystem modularity, and 20 percent of this is arbitrarily assigned to the electrical subsystem and 80 percent to the structure/mechanisms subsystem. The resulting weights are used to determine the current reusable payload cost.

The payloads were assumed to have the same length to diameter ratio as the corresponding baseline payloads described in Ref. 12 but with the diameters limited to 3.8 meters (14.7 feet). The payload volumes were calculated from these dimensions.

The low-cost payload data were developed by examining the baseline payload's mission objective, satellite life, and subsystem characteristics to select the appropriate low-cost weight and volume factors at the subsystem level. These low-cost factors, which are presented in Tables 2-10 through 2-14[1], were not all applied directly. Those factors that are not directly applicable are the structures, environmental control, propulsion, and satellite volume items. The other low-cost factors (guidance and navigation, attitude control, CDPI, electrical, and mission equipment) were applied directly.

Studies were performed by LMSC in which they defined five reference satellites designed for launch by current expendable launch vehicles and then modified the designs to general low-cost expendable and low-cost reusable versions of the same payloads. The studies are documented in Ref. 14, 21, 22, and the information extracted from these documents is summarized in Tables 2-10 through 2-14. It will be noted that an Aerospace weight summary is listed alongside each LMSC weight summary. The difference shown in subsystem weights is due to the LMSC approach to tabulating low-cost design involving modularization. LMSC tabulates module structure weights as a part of each subsystem weight. It was decided to remove the module structural weight associated with each subsystem and allocate it to structure and mechanisms for this analysis in order to simplify cost estimation. The low-cost weight factors that are listed in Tables 2-10 through 2-14 are obtained by dividing the Aerospace low-cost weights by the baseline (current expendable) weights.

The original versions of Tables 2-10 through 2-12 were included in Ref. 3. Later work by LMSC led to the conclusion that there was little difference between the low-cost expendable and the low-cost reusable payloads, and therefore it will be noted in Tables 2-10 through 2-14 that the "LMSC estimate" subsystem weights are the same for expendable and

[1] Note that the tables are in pairs, metric units are shown in table (a) and English units in table (b).

Table 2-10(a). Preliminary Design Weight Factors - Small Research Satellite (SRS)

Item		LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (kg)		LMSC		Aerospace	
	Baseline Wt. (kg)	Cont. (%)	Weight (kg)	Cont. (%)	Weight (kg)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	18	15	94	15	94	120	120	5.18	5.18	6.62	6.62
Environmental Control	3	15	21	15	21	21	21	7.67	7.67	7.67	7.67
Guid, Nav & Stab	12	15	28	15	28	23	23	2.34	2.34	1.92	1.92
Dry Propulsion	--	--	--	--	--	--	--	--	--	--	--
Dry Attitude Control	6	15	14	15	14	14	14	2.21	2.21	2.21	2.21
CDPI	28	15	30	15	30	24	24	1.08	1.08	0.89	0.89
Electrical	45	15	76	15	76	70	70	1.67	1.67	1.55	1.55
Mission Equipment	25	15	43	15	43	33	33	1.70	1.70	1.29	1.29
Total Dry Weight	137		305		305	305	305				
Propulsion Propellant	--		--		--	--	--				
Att. Cont. Propellant	6	15	11	15	11	11	11				
Total Wet Weight	143		316		316	316	316				

NOTES:
1. Low-cost versions not modularized.
2. Satellite described in LMSC-A981647 (PE-47).
3. Docking ring included in structure weight.
4. Payload adapter weight not included in structure weight.

Table 2-10(b). Preliminary Design Weight Factors - Small Research Satellite (SRS)

Item	Baseline Wt. (lb)	LMSC Estimate: Low-Cost Expendable Cont. (%)	LMSC Estimate: Low-Cost Expendable Weight (lb)	LMSC Estimate: Low-Cost Reusable Cont. (%)	LMSC Estimate: Low-Cost Reusable Weight (lb)	Aerospace Estimate Weight (lb): Low-Cost Expendable	Aerospace Estimate Weight (lb): Low-Cost Reusable	Weight Factors LMSC: Low-Cost Expendable	Weight Factors LMSC: Low-Cost Reusable	Weight Factors Aerospace: Low-Cost Expendable	Weight Factors Aerospace: Low-Cost Reusable
Structure/Mechanisms	40	15	207	15	207	265	265	5.18	5.18	6.62	6.62
Environmental Control	6	15	46	15	46	46	46	7.67	7.67	7.67	7.67
Guid, Nav & Stab	26	15	61	15	61	50	50	2.34	2.34	1.92	1.92
Dry Propulsion	--	--	--	--	--	--	--	--	--	--	--
Dry Attitude Control	14	15	31	15	31	31	31	2.21	2.21	2.21	2.21
CDPI	61	15	66	15	66	54	54	1.08	1.08	0.89	0.89
Electrical	100	15	167	15	167	155	155	1.67	1.67	1.55	1.55
Mission Equipment	56	15	95	15	95	72	72	1.70	1.70	1.29	1.29
Total Dry Weight	303		673		673	673	673				
Propulsion Propellant	--		--		--		--				
Att. Cont. Propellant	13	15	24	15	24	24	24				
Total Wet Weight	316		697		697	697	697				

NOTES:
1. Low-cost versions not modularized.
2. Satellite described in LMSC-A981647 (PE-47).
3. Docking ring included in structure weight.
4. Payload adapter weight not included in structure weight.

Table 2-11(a). Preliminary Design Weight Factors - Orbiting Astronautical Observatory (OAO)

Item	Baseline Wt. (kg)	LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (kg)		LMSC		Aerospace	
		Cont. (%)	Weight (kg)	Cont. (%)	Weight (kg)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	517	15	799	15	799	1212	1212	1.54	1.54	2.34	2.34
Environmental Control	45	15	50	15	50	50	50	1.10	1.10	1.10	1.10
Guid, Nav & Stab	325	15	297	15	297	154	154	0.91	0.91	0.47	0.47
Dry Propulsion	--	--	--	--	--	--	--	--	--	--	--
Dry Attitude Control	60	15	400	15	400	286	286	6.65	6.65	4.75	4.75
CDPI	207	15	201	15	201	141	141	0.97	0.97	0.68	0.68
Electrical	559	15	805	15	805	758	758	1.44	1.44	1.36	1.36
Mission Equipment	439	15	893	15	893	844	844	2.04	2.04	1.93	1.93
Total Dry Weight	2152		3445		3445	3445	3445				
Propulsion Propellant	--		--		--	--	--				
Att. Cont. Propellant	30	15	145	15	145	145	145				
Total Wet Weight	2182		3590		3590	3590	3590				

NOTES:
1. Satellite described in LMSC-A973890 and LMSC A983808.
2. Docking ring included in structure weight.
3. Payload adapter weight not included in structure weight.

Table 2-11(b). Preliminary Design Weight Factors - Orbiting Astronautical Observatory (OAO)

Item		LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (lb)		LMSC		Aerospace	
	Baseline Wt. (lb)	Cont. (%)	Weight (lb)	Cont. (%)	Weight (lb)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	1141	15	1766	15	1762	2675	2675	1.54	1.54	2.34	2.34
Environmental Control	100	15	110	15	110	110	110	1.10	1.10	1.10	1.10
Guid, Nav & Stab	716	15	655	15	655	339	339	0.91	0.91	0.47	0.47
Dry Propulsion	--	--	--	--	--	--	--	--	--	--	--
Dry Attitude Control	133	15	883	15	883	631	631	6.65	6.65	4.75	4.75
CDPI	456	15	443	15	443	310	310	0.97	0.97	0.68	0.68
Electrical	1232	15	1775	15	1775	1671	1671	1.44	1.44	1.36	1.36
Mission Equipment	967	15	1970	15	1970	1862	1862	2.04	2.04	1.93	1.93
Total Dry Weight	4745		7598		7598	7598	7598				
Propulsion Propellant	--		--		--	--	--				
Att. Cont. Propellant	66	15	320	15	320	320	320				
Total Wet Weight	4811		7918		7918	7918	7918				

NOTES:
1. Satellite described in LMSC-A973890 and LMSC A983808.
2. Docking ring included in structure weight.
3. Payload adapter weight not included in structure weight.

Table 2-12(a). Preliminary Design Weight Factors – Synchronous Equatorial Orbiter (SEO)

Item		LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (kg)		LMSC		Aerospace	
	Baseline Wt. (kg)	Cont. (%)	Weight (kg)	Cont. (%)	Weight (kg)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	60	15	337	15	337	570	570	5.57	5.57	9.45	9.46
Environmental Control	5	15	33	15	33	33	33	6.64	6.64	6.64	6.64
Guid, Nav & Stab	62	15	101	15	101	66	66	1.64	1.64	1.07	1.07
Dry Propulsion	--	--	--	--	--	--	--	--	--	--	--
Dry Attitude Control	32	15	260	15	260	184	184	8.19	8.19	5.82	5.82
CDPI	67	15	115	15	115	77	77	1.73	1.73	1.16	1.16
Electrical	141	15	301	15	301	257	257	2.13	2.13	1.81	1.81
Mission Equipment	133	15	235	15	235	195	195	1.76	1.76	1.47	1.47
Total Dry Weight	500		1382		1382	1382	1382				
Propulsion Propellant	--		--		--	--	--				
Att. Cont. Propellant	27	15	74	15	74	74	74				
Total Wet Weight	527		1456		1456	1456	1456				

NOTES:
1. Satellite described in LMSC-A981600 (PE-27).
2. Docking ring included in structure weight.
3. Payload adapter weight not included in structure weight.

Table 2-12(b). Preliminary Design Weight Factors - Synchronous Equatorial Orbiter (SEO)

Item	Baseline Wt. (lb)	LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (lb)		LMSC		Aerospace	
		Cont. (%)	Weight (lb)	Cont. (%)	Weight (lb)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	133	15	742	15	742	1256	1256	5.57	5.57	9.45	9.45
Environmental Control	11	15	73	15	73	73	73	6.64	6.64	6.64	6.64
Guid, Nav & Stab	136	15	223	15	223	145	145	1.64	1.64	1.07	1.07
Dry Propulsion	--	--	--	--	--	--	--	--	--	--	--
Dry Attitude Control	70	15	573	15	573	407	407	8.19	8.19	5.82	5.82
CDPI	147	15	254	15	254	169	169	1.73	1.73	1.16	1.16
Electrical	312	15	664	15	664	566	566	2.13	2.13	1.81	1.81
Mission Equipment	294	15	518	15	518	431	431	1.76	1.76	1.47	1.47
Total Dry Weight	1103		3047		3047	3047	3047				
Propulsion Propellant	--		--		--	--	--				
Att. Cont. Propellant	60	15	164	15	164	164	164				
Total Wet Weight	1163		3211		3211	3211	3211				

NOTES:
1. Satellite described in LMSC-A981600 (PE-27).
2. Docking ring included in structure weight.
3. Payload adapter weight not included in structure weight.

Table 2-13(a). Preliminary Design Weight Factors - Earth Observation Satellite (EOS)

Item	Baseline Wt. (kg)	LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (kg)		LMSC		Aerospace	
		Cont. (%)	Weight (kg)	Cont. (%)	Weight (kg)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	392	15	753	15	753	1007	1007	1.92	1.92	2.55	2.55
Environmental Control	50	15	68	15	68	68	68	1.36	1.36	1.36	1.36
Guid, Nav & Stab	88	15	146	15	146	96	96	1.65	1.65	1.08	1.08
Dry Propulsion	73		--		--	--	--				
Dry Attitude Control	32	15	183	15	183	89	89	5.77	5.77	2.80	2.80
CDPI	163	15	149	15	149	104	104	0.91	0.91	0.64	0.64
Electrical	376	15	967	20	967	902	902	2.57	2.57	2.40	2.40
Mission Equipment	541	Basic	541	Basic	541	541	541	1.00	1.00	1.00	1.00
Total Dry Weight	1715		2807		2807	2807	2807				
Propulsion Propellant	54		--		--	--	--				
Att. Cont. Propellant	12		70	15	70	70	70				
Total Wet Weight	1781		2877		2877	2877	2877				

NOTES:
1. This payload utilizes standard subsystems.
2. Satellite described in LMSC-D154696 (PE-106).
3. Docking ring included in structure weight.
4. Payload adapter weight not included in structure weight.
5. Propulsion for low-cost versions supplied by Shuttle.

Table 2-13(b). Preliminary Design Weight Factors - Earth Observation Satellite (EOS)

Item		LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (lb)		LMSC		Aerospace	
	Baseline Wt. (lb)	Cont. (%)	Weight (lb)	Cont. (%)	Weight (lb)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	865	15	1660	15	1660	2220	2220	1.92	1.92	2.55	2.55
Environmental Control	110	15	150	15	150	150	150	1.36	1.36	1.36	1.36
Guid, Nav & Stab	195	15	322	15	322	211	211	1.65	1.65	1.08	1.08
Dry Propulsion	160		--		--	--	--	--	--	--	--
Dry Attitude Control	70	15	404	15	404	196	196	5.77	5.77	2.80	2.80
CDPI	360	15	329	15	329	230	230	0.91	0.91	0.64	0.64
Electrical	830	15	2132	20	2132	1990	1990	2.57	2.57	2.40	2.40
Mission Equipment	1192	Basic	1192	Basic	1192	1192	1192	1.00	1.00	1.00	1.00
Total Dry Weight	3782		6189		6189	6189	6189				
Propulsion Propellant	119		--		--	--	--				
Att. Cont. Propellant	26		154	15	154	154	154				
Total Wet Weight	3927		6343		6343	3643	6343				

NOTES:
1. This payload utilizes standard subsystems.
2. Satellite described in LMSC-D154696 (PE-106).
3. Docking ring included in structure weight.
4. Payload adapter weight not included in structure weight.
5. Propulsion for low-cost versions supplied by Shuttle.

Table 2-14(a). Preliminary Design Weight Factors - Domestic Communications Satellite (Hydrazine Version)

Item		LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (kg)		LMSC		Aerospace	
	Baseline Wt. (kg)	Cont. (%)	Weight (kg)	Cont. (%)	Weight (kg)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	204	15	410	15	410	669	669	2.01	2.01	3.28	3.28
Environmental Control	34	15	45	15	45	45	45	1.33	1.33	1.33	1.33
Guid, Nav & Stab	57	15	138	15	138	102	102	2.44	2.44	1.79	1.79
Dry Propulsion	--	--	--	--	--	--	--	--	--	--	--
Dry Attitude Control	91	15	176	15	176	116	116	1.94	1.94	1.28	1.28
CDPI	27	15	30	15	30	20	20	1.12	1.12	0.75	0.75
Electrical	328	15	565	15	565	508	508	1.72	1.72	1.45	1.45
Mission Equipment	313	15	438	15	438	342	342	1.40	1.40	1.09	1.09
Total Dry Weight	1054		1802		1802	1802	1802				
Propulsion Propellant	--		--		--	--	--				
Att. Cont. Propellant	184	15	314	15	314	314	314				
Total Wet Weight	1238		2116		2116	2116	2116				

NOTES:
1. This payload utilizes standard subsystems.
2. Satellite described in LMSC-D154696 (PE-126).
3. Docking ring included in structure weight.
4. Payload adapter weight not included in structure weight.
5. Power level = 1200 W.

Table 2-14(b). Preliminary Design Weight Factors - Domestic Communications Satellite (Hydrazine Version)

Item	Baseline Wt. (lb)	LMSC Estimate				Aerospace Estimate		Weight Factors			
		Low-Cost Expendable		Low-Cost Reusable		Weight (lb)		LMSC		Aerospace	
		Cont. (%)	Weight (lb)	Cont. (%)	Weight (lb)	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable	Low-Cost Expendable	Low-Cost Reusable
Structure/Mechanisms	450	15	904	15	904	1476	1476	2.01	2.01	3.28	3.28
Environmental Control	75	15	100	15	100	100	100	1.33	1.33	1.33	1.33
Guid, Nav & Stab	125	15	305	15	305	224	224	2.44	2.44	1.79	1.79
Dry Propulsion	---	--	---	---	---	---	---	---	---	---	---
Dry Attitude Control	200	15	388	15	388	256	256	1.94	1.94	1.28	1.28
CDPI	60	15	67	15	67	45	45	1.12	1.12	0.75	0.75
Electrical	724	15	1245	15	1245	1120	1120	1.72	1.72	1.45	1.45
Mission Equipment	690	15	966	15	966	754	754	1.40	1.40	1.09	1.09
Total Dry Weight	2324		3975		3975	3975	3975				
Propulsion Propellant	---		---		---	---	---				
Att. Cont. Propellant	405	15	692	15	692	692	692				
Total Wet Weight	2729		4667		4667	4667	4667				

NOTES:
1. This payload utilizes standard subsystems.
2. Satellite described in LMSC-D154696 (PE-126).
3. Docking ring included in structure weight.
4. Payload adapter weight not included in structure weight.
5. Power level = 1200 W.

reusable. Because LMSC applied different ground rules to the design of the final two reference satellites than those applied in the design of the first three vehicles utilized in the study documented in Ref. 3, true consistency is lacking in the data. Nevertheless, it was concluded in discussions with MSFC and LMSC that the five reference satellites could be considered part of the same set for the purposes of this study.

An important feature of this study is the visibility engendered by mechanizing the subsystem weight calculations. Orderly instructions were programmed for the computer and, even though a final set of computational rules was generated which can be applied to virtually every payload, some payload data were modified after review of the computer output.

The methodology does not claim to relieve the investigator of the responsibility for subjective judgment. Indeed, subjective judgment is used to determine subsystem similarity in selecting low-cost payload factors to apply to each satellite or probe. If time and manpower had permitted, a "delphi" approach could have been used more extensively to make the analogous subsystem selection.

Because of the limitations in the quality of the input data, very little can be gained by further refining the methodology, although it is fairly apparent where more complexity and further subroutines can be introduced. For instance, both specific impulse and mean mission duration were assumed constant to generate the results. Mean mission duration is, of course, an important characteristic and should be parameterized in future studies. At this time, however, parameterizing mean mission duration is not justified since, for most of the payloads, its true value is unknown and also any investigation of mean mission duration must include consideration of a further parameter, reliability, to have any meaning.

Used with a knowledge of its limitations, the payload information generated by this study gives a useful departure point for the allocation of space, weight allowance, and flight number to a particular experimenter.

C. COMPUTER PROGRAM TRANSFERS

Computer programs developed by Aerospace and used in capture/cost analyses were sent to MSFC with sample cases for use in checking out the program (after conversion of the programs to the UNIVAC 1108 computer by MSFC). The computer programs that are used in a capture/cost analysis include DARES, ACCOMDAP, COSTAN, STSCM, PALCM, PROGCM, SPAT, and DORCA-II.

The DARES (DAta REtrieval System) computer program is an automated program capable of documenting, cataloging, retrieving, and printing payload data. Operation of DARES with PALCM involves the retrieval of payload performance and physical characteristics data. The DARES payload data bank stores payload data for the three basic payload types, i.e., current expendable, current reusable, and large low-cost reusable. Payload data desired on any of these three types of payloads are input into PALCM through a direct linking routine.

The ACCOMDAP (ACCOMmodation Data Analysis Program) is used in conjunction with the DARES data bank to separate those Shuttle payloads accommodated by the Shuttle and upper stage, as required, from payloads not accommodated. The payload data bank contains descriptions of the three payload types and three upper stages (Agena, Centaur, and Tug). The outputs of the accommodation analyses are lists of payloads accommodated and not accommodated (together with reasons for non-accommodation such as length, diameter, or weight), accommodated payload weight to orbit by year, and accommodated payload weight to orbit by orbit class (destination).

The COSTAN (COST ANalysis) program is used to obtain expendable launch vehicles' costs. COSTAN accepts data concerning a family of vehicles with given launch schedules by year and site, production costs for their several components, launch costs, and other costs. From these data a smoothed production schedule for each component, together with the unit costs, may be computed. Printouts provide the recurring or nonrecurring costs per family, vehicle, and component by calendar year and fiscal year. These costs are used as inputs to PROGCM in determining program and mission model launch costs.

The STSCM (Space Transportation System Cost Model) is a predictive cost model that can be used to estimate the life-cycle costs of the various elements that comprise the Space Transportation System (STS). These STS elements are Earth-to-Orbit Shuttle[1] (EOS), and Orbit-to-Orbit Shuttle - Tug. The STSCM is based on a methodology and cost estimating relationships (CERs) developed by The Aerospace Corporation.

The output of the STSCM consists of two principal categories:

(1) The Basic Output Report

(2) The Time-Phased Output Report.

The basic report provides a static (non-time-phased) display of all costs in the STS life cycle. The time-phased report, which is an optional feature, provides an annual summary of major cost elements in the life cycle. These time-phased costs can be displayed in base year (current) dollars, in actual year (adjusted for inflation) dollars, or in present value dollars.

The life-cycle costs of each STS element are separated into three distinct phases, which are computed as separate blocks of cost. The phases are:

(1) RDT&E Phase

(2) Investment Phase

(3) Operations Phase.

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[1] Synonymous with Space Shuttle

In addition to these three program phases a fourth block identified as Vehicle First Unit Cost is utilized in the model. This block builds up the vehicle unit cost which is then used to compute costs of hardware utilized in the three life-cycle phases.

The STSCM is defined in such a manner as to allow costing of the following configurations in a single case:

(1) One EOS configuration

(2) Up to five Tug configurations.

The EOS costs are subdivided into orbiter, booster, and system categories, while the costs of each Tug configuration stand by themselves.

The calculation of actual costs for any configuration is in the order of (1) first unit cost, (2) RDT&E cost, (3) investment cost, (4) operations cost, and (5) summary of costs.

The PALCM (PAyLoad Cost Model) is an automated cost estimating and time-phased computer model capable of handling several hundred different payload programs simultaneously. Time-phased cost estimates are generated for each payload program in terms of RDT&E, investment, operations, and total payload costs.

The process of cost estimating for each payload program requires information concerning the payload performance and physical characteristics; identification of payload type; development status; launch schedules of new, refurbished, and orbitally maintained payloads; number of spacecraft; mission equipment redesigns; etc. These required inputs are provided to PALCM by card or tape inputs and by direct link with DARES. The DARES program prepares the payload data bank, which provides specific payload performance and physical characteristics data with the remaining required data provided by cards or tape. Initial operation of PALCM on a complete mission model involves extensive manual effort in organizing the input sheets for card punching. In addition to the above-described inputs to PALCM, the launch vehicles assigned to the individual payloads are read from PROGCM input tape or cards to enable PALCM to compute the payload reliability effects (i.e., payload losses associated with expendable launch vehicles).

Although PALCM can operate in the absence of PROGCM, and provide separate printed outputs, the normal operational mode is in conjunction with PROGCM, resulting in direct data input to SPAT for storage. The data from PALCM are processed by PROGCM to obtain both payload and launch vehicle combined data for input to SPAT for storage.

PROGCM (PROGram Cost Model) is an automated model which assigns launch vehicle direct operating costs (DOC) yearly to each payload program, combines the launch vehicle DOC with payload direct costs, applies reliability effects according to certain rules, and displays the results along with payload and launch vehicle traffic schedules for each separate payload program. Launch vehicle direct costs normally include the vehicle investment hardware costs and the launch operations costs. Direct costs for the Shuttle and Tug include only the launch operations, recovery operations, command and control, vehicle maintenance, and propellant support. The costs associated with amortization of reusable vehicle investment, RDT&E, range support, etc. are not included.

PROGCM is run in conjunction with PALCM. Program inputs are received from two sources, direct linkage with PALCM and card or tape input. All payload information, costs, and schedules are provided from PALCM, and launch vehicle schedules and costs are provided by card or tape.

Initial operation of PROGCM on a new mission model, like PALCM, involves an extensive manual effort in preparing the input sheets for card punching. The launch scheduling inputs are obtained from the capture analysis performed on the entire mission model. Expendable launch vehicle costs are obtained from the COSTAN computer program.

PROGCM, like PALCM, is designed to be compatible with the storage requirements and capabilities of SPAT. The output of PROGCM, providing summary payload and launch vehicle information, can be printed separately or provided by direct link into SPAT for storage.

SPAT (Shuttle/Payload Analysis and Tradeoffs) is a combined bulk storage, retrieval, and comparison/manipulator computer program developed as an aid in accomplishing system tradeoff studies. The program accomplishes four basic computerized functions:

(1) Bulk data storage
(2) Data selection and retrieval
(3) Data comparison
(4) Report.

Data stored include payload and launch vehicle direct operating cost (DOC) streams, payload and launch vehicle traffic schedules, and other pertinent program information for each alternative payload program investigated.

The data retrieval and comparison function provides the capability to automatically retrieve and print out any previously stored information. Also available is the capability to perform overall comparisons and selections between alternative approaches to an individual payload program or for the entire mission model (based on previously stored information).

SPAT operates in two modes. The first mode involves the input and storage of data in SPAT. The normal method of inputting data involves concurrently running PALCM and PROGCM to directly provide the individual payload program DOC and traffic scheduling data to SPAT, with a separate card input to provide other pertinent data for storage or override capability. Data can also be input directly by cards, without running PALCM and PROGCM.

The second mode involves retrieval of data from SPAT. In this mode of operation SPAT card inputs are used to identify the type of data required and the comparisons to be made. SPAT outputs the requested information in the form of printed reports (tables) for convenient inspection.

Data storage capability in SPAT covers a continuous period of 19 years, with payload and launch vehicle traffic stored in 12-month or 6-month intervals, and with costs stored on a fiscal yearly basis. All data are stored with appropriate coding so that specific alternative program data can be readily identified for comparison with other alternative approaches.

All individual payload program and mission model data permanently stored in SPAT are on a consistent basis. Therefore, the cost and traffic schedule data stored for a particular alternate payload program reflect a capture analysis of an entire mission model using a similar alternative approach schedule. SPAT has the capability of comparing and selecting from many specific alternative payload programs, in order to build a best-mix case. There are no provisions in the "frozen" SPAT, however, to ensure that this selected best mix of alternative payload programs is compatible with the launch vehicle schedule on an integrated basis, or that the Shuttle constraints are satisfied. While the launch vehicle data may be close enough for some analysis, and though the cost and schedule data for this mixed mission model would be a good first approximation, a manual inspection with the corrections re-inputted into PALCM and PROGCM is required for finer tuning of the results. SPAT temporarily stores corrected best mix data inputs from PALCM and PROGCM for printout or comparative purposes.

The DORCA-II (Dynamic Operational Requirements and Cost Analysis) computer program (see Ref. 23) is coded to load payloads aboard vehicles, in a consistent manner, for transport from one point to another within successive time frames. DORCA-II does not include any optimization capabilities, but, rather, relies on a man-machine interaction to optimize results based on external criteria. DORCA-II relies heavily on outside sources to provide cost information and vehicle parameters, as the program does not determine these quantities, but, rather, uses them.

Given data describing missions, vehicles, payloads, containers, space facilities, schedules, cost values, and costing procedures, the program computes flight schedules, cargo manifests, vehicle fleet requirements, acquisition schedules, and cost summaries. The program is designed to consider the Earth Orbit, Lunar, Interplanetary, and Automated Satellite Programs.

3. CAPTURE/COST ANALYSIS

A. APPROACH

The capture analyses of the cases listed in Table 3-1 performed in this study differ from those of Study A (Integrated Operations/Payloads/Fleet Analysis) in that a computer program, DORCA-II, was used to load the payload(s) onto the launch vehicle. DORCA-II is described in Ref. 23. In Study A the loading was performed manually. It should be noted here that the DORCA-II builds upon the logic developed from the manual capture and also that some manipulation of the DORCA-II loading results is necessary to satisfy mission model requirements. The DORCA-II payload manifest was then used to manually input the program cost model.

The various cases which were captured were Case 500 (equivalent to Case A in Study A), current expendable launch vehicle fleet with current expendable payloads (no sortie science); Case 501, current expendable launch vehicle fleet with current expendable payloads including sortie science; and Case 506 (equivalent to Case C-2 in Study A), Space Shuttle with 1983 Tug and best mix of payload types yielding the lowest system cost. The best-mix selection methodology is the same as that used in Study A.

Case 500, current expendable launch vehicles and current expendable payloads, was captured both manually and with DORCA-II and the results compared. Multiple payloads were allowed for Case 500 while Case A of Study A, by ground rule, had no multiple payloads. The number of multiple payloads allowed in Case 500 was established by a review of historical launch data. These data are tabulated in Table 3-2 for the years 1965 through 1970 and result in an average of about 1.4 payloads per launch. The capture was performed and the results checked against this average and adjustments made.

Table 3-1. Case Definitions for Capture/Cost Analyses

Case No.	Launch Vehicle - Payload Type
500	Current Design Expendable Payloads on Current Expendable Launch Vehicles, No Sortie Science
501	Current Design Expendable Payloads on Current Expendable Launch Vehicles, Sortie Science Included
506	Best Mix of Payloads Launched by the STS, Sortie Science Included

Table 3-2. Historical Data for Current Launch Fleet

Year	Launches	Payloads	Launches With Multiple Payloads	% Launches With Multiple Payloads	Average No. Of Payloads Per Launch
1965	70	98	14	20.0	1.4
1966	77	112	18	23.4	1.455
1967	61	92	11	18.0	1.508
1968	48	76	12	25.0	1.583
1969	41	55	9	22.0	1.342
1970	26	33	7	26.9	1.27

NOTES:

- MSFC indicated average number of payloads per launch ~ 1.4 for 1958-1971 time period.
- Launches include manned flights and vehicle tests.
- Manned flights counted as single payload.

Case 506 consists of a capture using the Shuttle system of the best-mix payloads selected from two separate capture/cost analyses. In the first, only current expendable and current reusable payloads were considered and in the second, large, low-cost reusable payloads (where defined) were captured.

B. CAPTURE ANALYSIS - TRAFFIC SUMMARIES

1. CURRENT DESIGN PAYLOADS ON CURRENT EXPENDABLE LAUNCH VEHICLES, NO SORTIE SCIENCE (CASE 500)

(a) Analysis

The capture analysis for Case 500 was performed both manually and using DORCA-II for loading the launch vehicles. It was noted in many instances over the twelve-year mission model that payloads were flown in various combinations on different launch vehicles. This would result in numerous expensive integration costs. The DORCA-II capture was then modified so that once a launch vehicle was selected for a payload program it was retained until there was a new payload development where integration costs could be included. This was accomplished by preselecting the launch-sharing payloads. Launches not selected as shared are accomplished with the lowest cost launch vehicle having the capability, on a one-payload-per-launch basis. As a result the average multiple payload was reduced from about 1.3 to 1.25 payloads per launch.

(b) Manual Capture Comparison with Computerized Capture Analysis

A comparison of the expendable launch vehicle utilization of DORCA-II and the manual capture for Case 500 is shown in Table 3-3. It should be noted that the main difference is the larger number of small (Thor Delta) vehicles in the computerized capture. This is the result of

Table 3-3. Comparison of Expendable Launch Vehicle Utilization - DORCA-II vs Manual Capture, Case 500

Launch Vehicle	Total Launches (1979-1990)		
	DORCA-II	DORCA-II (Revised)	Manual Capture
Thor Delta	86	61	33
Thor Delta/TE-364	4	18	11
Titan III B/Burner-II	--	--	1
Titan III B/Agena	39	49	60
Titan III B/Centaur/Burner-II	11	59	12
Titan III D	52	52	51
Titan III D/Burner-II	73	72	57
Titan III D/Centaur	52	46	71
Titan III C	82	72	90
Titan III D 7	36	36	--
Titan III D 7/Burner-II	1	1	1
Titan III D 7/Centaur	10	10	10
Titan III D 7/Centaur/Burner-II	5	5	5
Titan III M	36	36	36
	487	517	438

the program logic which matches a payload to the lowest cost (smallest) launch vehicle and then tries to multiply payloads within the launch vehicle capability. The manual capture resulted in multiple payloads in excess of the ground rules of this study. This was left unadjusted since the manual capture was accomplished for comparative purposes only. After the mechanized capture has been performed a review of the launch vehicle utilization should be made and modified prior to input into COSTAN for launch vehicle costs.

2. CURRENT DESIGN PAYLOADS ON CURRENT EXPENDABLE LAUNCH VEHICLES, SORTIE SCIENCE INCLUDED (CASE 501)

The mission model provided by NASA for this study has the sortie flights integrated into the payload traffic. In order that a reasonable economical comparison can be made between performing the space program expendably and on the Shuttle system, an equivalent sortie science methodology was developed to be added to Case 500. This new case was denoted Case 501. A minimum space station was launched in 1979 to provide a space laboratory. The min-mod Big G and propulsion module were used to transport the men and the experiments to be performed. The mission model sortie destinations were all changed to the space station. One space station maintenance and resupply mission per year is included. The min-mod Big G and propulsion module have a cargo capability of 3,000 kg (6,630 lb) per flight. The flight schedule is based upon equal pounds of mission equipment to orbit, both expendably and with the Shuttle.

The sortie flight mission equipment weight, divided by 3,000 kg (6,630 lb), provides a factor for determining a flight schedule to be added to Case 500. A new COSTAN run was made to obtain the launch vehicle costs and then Case 501 costs determined. Table 3-4 shows the sortie science programs and weight summaries.

The launch vehicle traffic is the same as Case 500 with the addition of 62 Titan III M flights through 1990 and 29 Titan III M flights from 1991-1997 for a total of 91.

Table 3-4. Sortie Science Equivalent Payloads for Expendable Launch, Case 501

SORTIE		WEIGHT													
		Structure		Electrical Power		TT&C		Stability Control		Spacecraft		Mission Equipment		Satellite	
		kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)
NA2-12	Physics	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	1,983	(4,373)	6,512	(14,359)
	Astronomy	2,256	(4,975)	91	(200)	27	(60)	184	(405)	2,558	(5,640)	1,619	(3,570)	4,177	(9,210)
NE2-44	Earth Obs. Lab.	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	2,217	(4,889)	6,746	(14,875)
NC2-52	Comm/Nav Exp.	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	3,087	(6,806)	7,615	(16,792)
NC2-53	Comm/Nav Lab.	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	3,268	(7,206)	7,797	(17,192)
NB2-57	Mini 7-Day Module	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	2,293	(5,056)	6,822	(15,042)
NB2-58	Mini 30-Day Module	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	4,492	(9,906)	9,021	(19,892)
NB2-59	Mini 30-Day Module	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	7,083	(15,618)	11,612	(25,604)
NT2-62	Material Sci. Exp.	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	1,234	(2,720)	5,763	(12,706)
NT2-63	Adv. Tech. Exp.	4,255	(9,382)	190	(418)	84	(186)	0	0	4,529	(9,986)	2,682	(5,914)	7,211	(15,900)

NOTES: 1. Structure weight includes structure, environmental control, crew equipment, and residuals.

2. Dimensions: Length 9.1 m (30 ft), Diameter 4.3 m (14 ft).

3. BEST MIX OF PAYLOADS LAUNCHED BY STS, SORTIE SCIENCE INCLUDED

a. Selection of Best-Mix Payloads

The selection of the best-mix payloads was accomplished by performing two separate capture/cost analyses. The first was a Shuttle capture of a mission model made up of only current expendable and reusable payloads. All the payloads were reusable except for those where retrieval/reuse was not feasible, such as planetary. The second capture/cost analysis was performed on a model consisting of only large, low-cost payloads. The exceptions here were those payloads where no large, low-cost definition was made, such as the large orbiting observatory. These were compared program-by-program and the lowest cost configuration selected. A third complete capture analysis was then performed on DORCA-II, capturing the lowest cost (best mix) of payloads.

The payload manifests were reviewed and modified to satisfy mission model constraints for (1) launch rate buildup, and (2) allowable flight sequencing when payloads had to be retrieved, refurbished, and then redeployed, thus requiring separate launches. Other modifications included checking the allowance for phasing ΔV for multiple payload deployments. Inputs were then made to PROGCM to obtain program costs and compared with the earlier captures to ensure that the lowest cost selection was not invalidated by the recapture.

b. Analysis of Selected Best-Mix Payloads (Case 506)

The traffic summaries for Case 506 are presented in Tables 3-5 through 3-7. Table 3-5 is a summary of the Shuttle-launched payload traffic. The 58 sorties for Case 506 are equivalent to the 62 sorties in Case 501 based upon equal mission equipment weight in orbit. This table also shows the number of revisits, retrievals, and the number of new and refurbished payloads.

Table 3-5. Summary, Shuttle-Launched Payload Traffic - Best Mix of Payloads, Case 506

Mode of Operation	Year												Total
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	
Sortie	3	6	5	6	6	8	5	4	4	3	4	4	58
Revisit	0	4	4	6	0	6	6	6	10	4	4	11	59
Launch New	12	19	25	24	35	22	20	17	16	15	22	16	243
Launch Refurbished	1	1	1	7	18	27	36	31	38	37	41	32	270
Retrieval	3	2	10	10	39	35	29	37	36	42	39	25	307

Table 3-6. Case 506 — Shuttle Flights

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Totals
ETR													
NASA	9	11	18	14	17	29	23	27	30	24	27	28	257
Abort Reflights	1	1	2	2[1]	1	2	2	2	2	2	2	2	21[1]
Total	10	12	20	16[1]	18	31	25	29	32	26	29	30	278[1]
DoD	4	11	4	8	12	15	6	9	11	11	5	13	109
Abort Reflights	--	1	--	1	1	1	--	1	1	1	--	1	8
Total	4	12	4	9	13	16	6	10	12	12	5	14	117
Total Reflights	1	2	2	3[1]	2	3	2	3	3	3	2	3	29[1]
ETR Total Flights	14	24	24	25[1]	31	47	31	39	44	38	34	44	395[1]
WTR													
NASA	--	--	2	3	8	4	8	3	6	3	9	4	50
Abort Reflights	--	--	--	--	1	--	1	--	--	--	1	--	3
Total	--	--	2	3	9	4	9	3	6	3	10	4	53
DoD	--	--	6	7	10	13	18	14	15	13	17	12	125
Abort Reflights	--	--	--	1	1	1	1	1	1	1	1	1	9
Total	--	--	6	8	11	14	19	15	16	14	18	13	134
Total Reflights	--	--	--	1	2	1	2	1	1	1	2	1	12
WTR Total Flights	--	--	8	11	20	18	28	18	22	17	28	17	187
TOTAL FLIGHTS	14	24	32	36	51	65	59	57	66	55	62	61	582

[1] Includes one Tug development flight.

Table 3-7. Case 506 — Tug Flights

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
ETR													
NASA					10	19	11	14	17	13	14	14	112
Abort Reflights				1[1]	1	1	1	1	1	1	1	1	9[1]
Total				1[1]	11	20	12	15	18	14	15	15	121[1]
DoD					12	15	6	9	11	11	5	13	82
Abort Reflights					1	1	--	1	1	1	--	1	6
Total					13	16	6	10	12	12	5	14	88
Total Reflights				1[1]	2	2	1	2	2	2	1	2	15[1]
ETR Total Flights				1[1]	24	36	18	25	30	26	20	29	209[1]
WTR													
NASA					7	3	7	2	5	2	8	3	37
Abort Reflights					1	--	1	--	--	--	1	--	3
Total					8	3	8	2	5	2	9	3	40
DoD					3	4	6	6	5	5	7	4	40
Abort Reflights					--	--	--	1	1	--	--	--	2
Total					3	4	6	7	6	5	7	4	42
Total Reflights					1	--	1	1	1	--	1	--	5
WTR Total Flights					11	7	14	9	11	7	16	7	82
TOTAL FLIGHTS				1[1]	35	43	32	34	41	33	36	36	291[1]

[1] Tug development flight included.

Tables 3-6 and 3-7 present the Shuttle and Tug flight schedules, respectively. The traffic is presented by year, launch site, DoD flights, NASA flights, and the abort reflights required to complete the programs in the mission model.

Figures 3-1 and 3-2 are presented to show time histories of Shuttle and Tug traffic including reliability effects for the various agencies in the mission model over the span of calendar years 1979 through 1990.

A representative sample of payload combinations and flights (payload manifests) is shown in Table 3-8. Similar payload combinations and flight data for all of the payloads in the mission model listed by year were prepared and transmitted to NASA/MSFC.

C. COST ESTIMATES

1. PAYLOAD COST ESTIMATING PROCEDURES

The procedures used and the assumptions made in preparing cost estimates for space plan Cases 500, 501, and 506 are presented in this section. In essence, the procedures are the same as those employed in preparing cost estimates for Study A (Ref. 4). The payload program cost model was used to provide estimates in terms of constant 1971 dollars. Briefly, the model uses payload physical and performance data from a computer-stored program (DARES) and applies cost-estimating relationships to these data to produce RDT&E and unit cost estimates by payload subsystems. Estimates are made for all satellite programs, more or less simultaneously, and the costs are accumulated by program, agency, and total space plan by fiscal year to produce direct program costs.

Estimates for current expendable payloads are the same, whether flown on expendable launch vehicles or the Shuttle. Reliability effects are the same as those used in Study A. Current payloads, designed for reuse or on-orbit servicing, are based on the weight data in DARES for reusable satellites. (In Study A, baseline current expendable weights

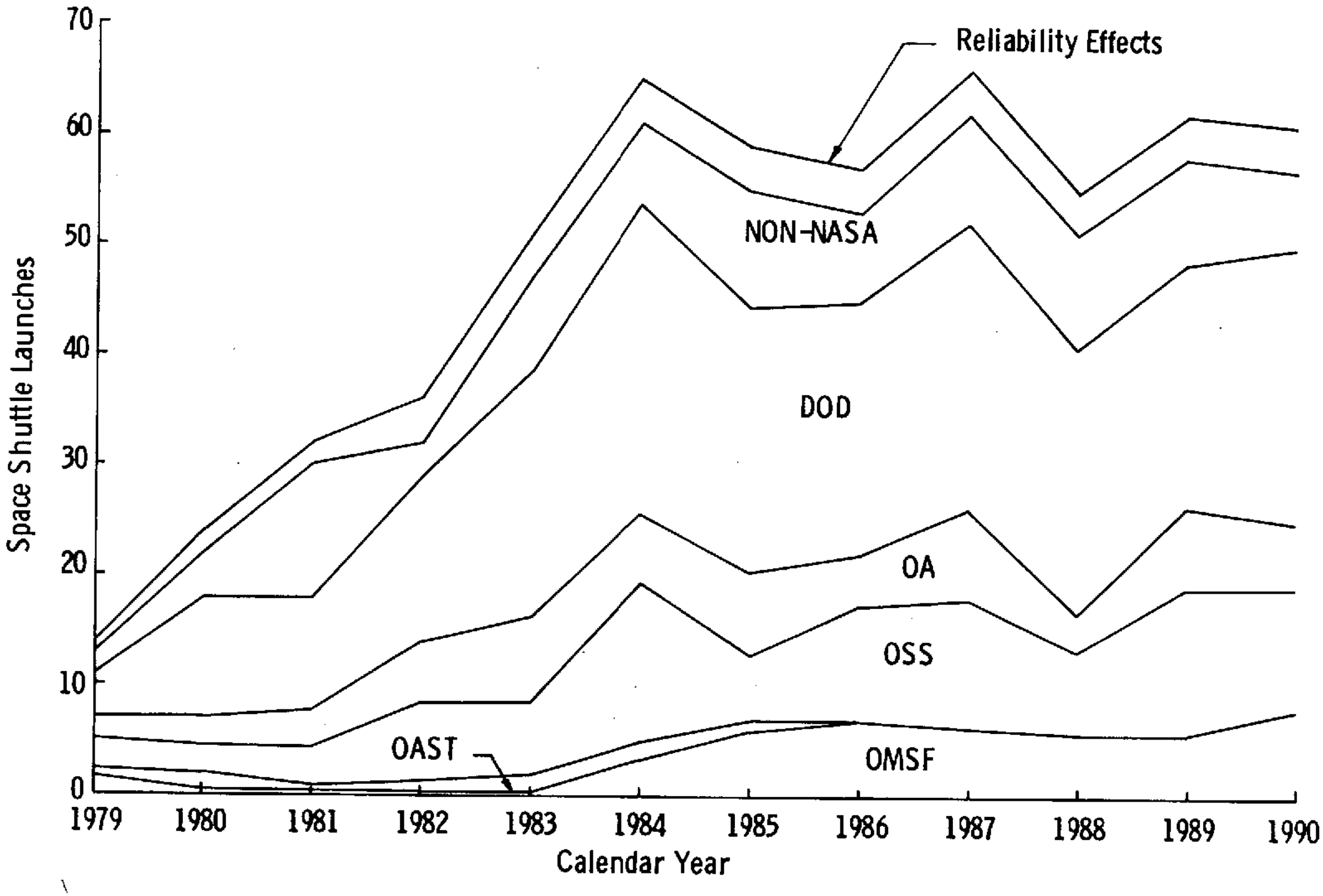

Figure 3-1. Space Shuttle Traffic

NOTE: (1) No OMSF and OAST Tug Flights
(2) OSS Flights Include 15 Expended Tugs

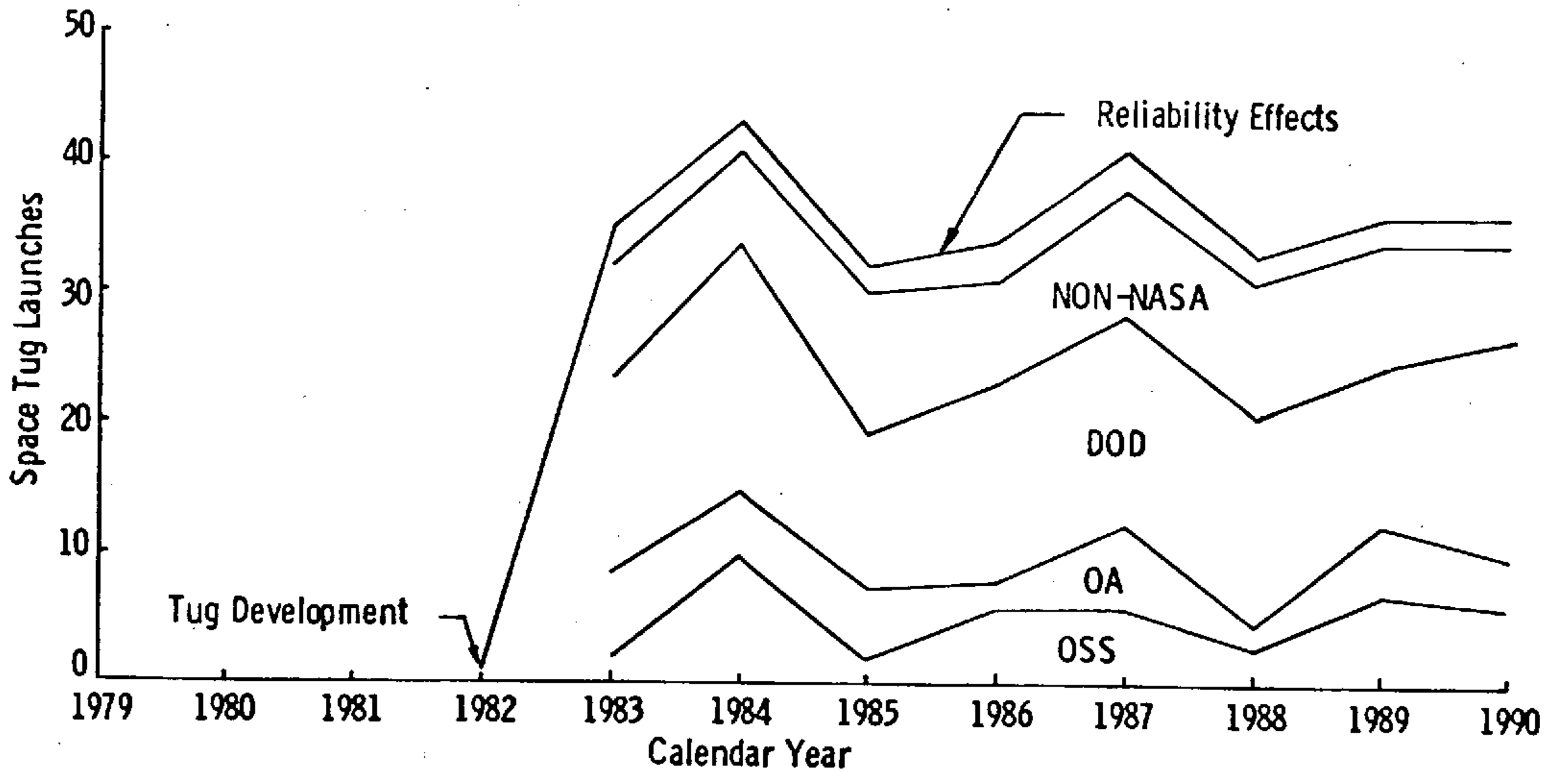

Figure 3-2. Space Tug Launches

Table 3-8. Payload Combinations and Flights, Example from Manifest, 1990 - Best Mix (Case 506)

Shuttle Flight No.	Payload Number		Earth to Orbit Trip Payload + Stage			Stage
			Length			
	Earth to Orbit	Return	m	ft	Load Factors[1]	
1	NA2-11 Tug	Tug	17.9	58.7	0.81	Tug
2	NE2-39 NC2-47 Tug	Tug	17.3	56.6	0.92	Tug
3	NE2-43 Tug	NEO-15 Tug	14.1	46.3	0.98	Tug
4	Tug	NCN-8 Tug	10.7	35.0	0.91	Tug
5	Tug	NCN-8 Tug	10.7	35.0	0.91	Tug
6	NCN-8 Tug	NC2-47 Tug	18.3	60.0	1.00	Tug
7	NCN-8 Tug	NCN-9 Tug	18.3	60.0	0.95	Tug

[1] $\text{Load Factor} = \dfrac{\text{Weight of Payload + Stage}}{\text{Orbiter Capability to Orbiter Destination}}$

were used and factors applied to account for reusability.) Ground refurbishment of current reusable satellites is assumed to require 39 percent of the cost of a new unit (as in Study A). On-orbit servicing is estimated to require 30 percent, based on data from the LMSC study.

Satellites designed for low cost are estimated by applying CERs (cost estimating relationships) to the baseline weights and adjusting each subsystem by the low-cost factor associated with a particular design. This method is the same as that used in Study A, except that the low-cost designs are identified by each subsystem in DARES and the factors are automatically applied by the computer program. In addition, the number of low-cost designs and their associated factors have been increased to cover the communications satellite and earth observation satellite designs from the LMSC Payload Effects Follow-on studies. These LMSC designs provide for longer MMDs for low-cost satellites (see Table 3-9 for factors). For low-cost designs, either ground refurbishment or on-orbit servicing is estimated to require 30 percent of the cost of a new unit. (LMSC mentioned various lower rates; however, the available data suggest an average figure close to 30 percent - Ref. 21.)

In addition to current and low-cost satellites the payloads also included RAMs, sorties, and a manned space station. RAMs were treated in the same manner as a current reusable satellite. The manned space station costs were handled as a throughput, i.e., the costs generated by the model were multiplied by factors so that the output reflected the costs provided by MSFC. Sorties were treated differently in each case estimated. Case 500 contained no sortie flights; Case 506 included sortie flights on the Shuttle. Case 501 was developed so that sortie "equivalent" flights were considered by using additional Titan III M launch vehicles and Big G entry and cargo modules (in lieu of a sortie laboratory) to transport scientific experiments. Table 3-10 contains data on Big G cost estimates. Big G quantities reflect space station crew rotation flights of 67 for Case 500 and 78 for Case 501 (plus 91 for sortie "equivalents").

Table 3-9. Low-Cost Factors

$$\left(\frac{\text{Low-Cost Satellite Cost Estimate}}{\text{Baseline Satellite Cost Estimate}}\right)$$

	Satellite					
	Baseline	SRS	OAO	EOS	SEO	Comsat [1]
RDT&E						
Structure	1.00	0.81	0.56	0.62	0.53	0.59
Electrical	1.00	0.54	0.65	0.65	0.73	0.76
Communications	1.00	0.57	1.00	0.72	0.70	0.79
Stability & Control	1.00	0.58	1.00	0.68	0.61	0.71
Propulsion	1.00	0.88	0.85	0.85	0.85	0.85
Mission Equipment	1.00	1.00	0.63	1.00	0.80	1.00
GSE	1.00	0.71	0.71	0.71	0.71	0.71
Launch Support	1.00	1.00	1.00	1.00	1.00	1.00
UNIT						
Structure	1.00	0.89	0.59	0.81	0.42	0.81
Electrical	1.00	0.59	0.79	0.95	0.85	0.80
Communications	1.00	0.78	1.00	0.66	0.85	0.85
Stability	1.00	0.63	1.00	0.82	0.83	0.87
Propulsion	1.00	1.14	0.75	0.75	0.75	0.75
Mission Equipment	1.00	1.00	0.83	1.00	0.65	1.00
GSE	1.00	1.00	1.00	1.00	1.00	1.00
LOPS	1.00	1.00	0.74	0.74	0.74	1.00

1 The LMSC Low-Cost Communications Satellite.

NOTE: Baseline represents current expendable, i.e., baseline design.

Table 3-10. Big G Cost Estimates (1979-1997)
(Millions of 1971 Dollars)

	Case 500	Case 501
Nonrecurring and Indirect		
RDT&E	846	846
Nonrecurring Investment	616	1245
Facilities	(53)	(53)
Entry Vehicles	(563)	(1192)
Operations (Indirect)	254	402
Total	1716	2493
Unit Operations (Direct)		
Recovery, Refurbishment, and Launch Support	18.8	18.8
Cargo Propulsion Module	12.2	10.2
Total Unit Operations	31.0	29.0

In Case 506 sortie laboratory RDT&E is spread over all disciplines; one sortie laboratory is bought for each program and is refurbished at a rate of three percent on subsequent flights (estimate based on Tug refurbishment studies, the best available data at the time of this analysis). Each program is charged for sortie mission equipment RDT&E; one set of new mission equipment is bought when new designs occur. Refurbishment of sortie mission equipment is also based on three percent per flight for Case 506. All mission equipment is replaced on each flight in the expendably-launched Case 501.

2. LAUNCH VEHICLE COST ESTIMATES

The costs of expendable launch vehicles were derived by using the same methods as Study A employed, i.e., the COSTAN computer program was used to calculate average launch vehicle costs based on the effect of yearly launch rate variations for the complete mission model through 1997. The costs of Shuttle and Tug operations were provided by NASA. The unit launch costs used in the three cases are summarized in Table 3-11. Big G direct operating cost is included in the Titan III M + G launch vehicle unit cost.

The payload program cost model uses the unit launch costs in conjunction with the mission model schedules to assign direct launch costs to each payload program. It also spreads launch costs by fiscal year for each program, for each agency, and for the total space plan. In addition the payload program cost model combines payload and launch costs to produce total direct cost by program and by fiscal year.

A total direct cost estimate comparison of Cases 501 and 506 with sortie science included is shown in Figure 3-3. The program direct costs are plotted versus year for the period 1975 through 1990 to show graphically the cost savings which result from using the Shuttle system and reusable payloads rather than an expendable launch vehicle fleet and expendable payloads.

Table 3-11. Launch Vehicle Unit Cost
(Millions of 1971 Dollars)

Launch Vehicle	Case 500				Case 501				Case 506			
	ETR		WTR		ETR		WTR		ETR		WTR	
	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
TAT 3/D	22	8.94	47	7.74	22	8.94	47	7.74			2	7.29
TAT 3/D/T	5	8.81	10	7.90	5	8.81	10	7.90				
TAT 6/D			14	7.34			14	7.34			5	7.55
TAT 9/D			10	7.86			10	7.86			7	7.75
TAT 9/D/T			13	8.69			13	8.69			6	7.94
T3B/A	34	11.00	43	10.43	34	10.92	43	10.39	1	9.58	18	9.61
T3B/B											4	6.64
T3B/C/B	88	12.51			88	12.44						
T3C	120	13.40			120	13.20			14	14.09		
T3D	2	9.83	81	9.87	2	9.61	81	9.73			6	10.20
T3D/B	55	10.50	63	10.62	56	10.32	63	10.48	2	13.32	20	13.41
T3D/C	80	16.50			80	16.34			3	17.22		
T3F	25	10.22	57	10.38	25	10.02	57	10.21			9	11.13
T3F/B	2	10.72			2	10.57						
T3F/C	20	10.82			20	16.63						
T3F/C/A									4	21.21		
T3F/C/B	9	17.64			9	17.42			2	17.70		
T3M + G	67	47.55			169	43.30						
Agena									18	4.15		
Centaur									33	6.80		
Delta									5	3.49		
Shuttle (Operations)									395	10.50	187	10.50
Tug (Operations)									209	1.95	82	1.95

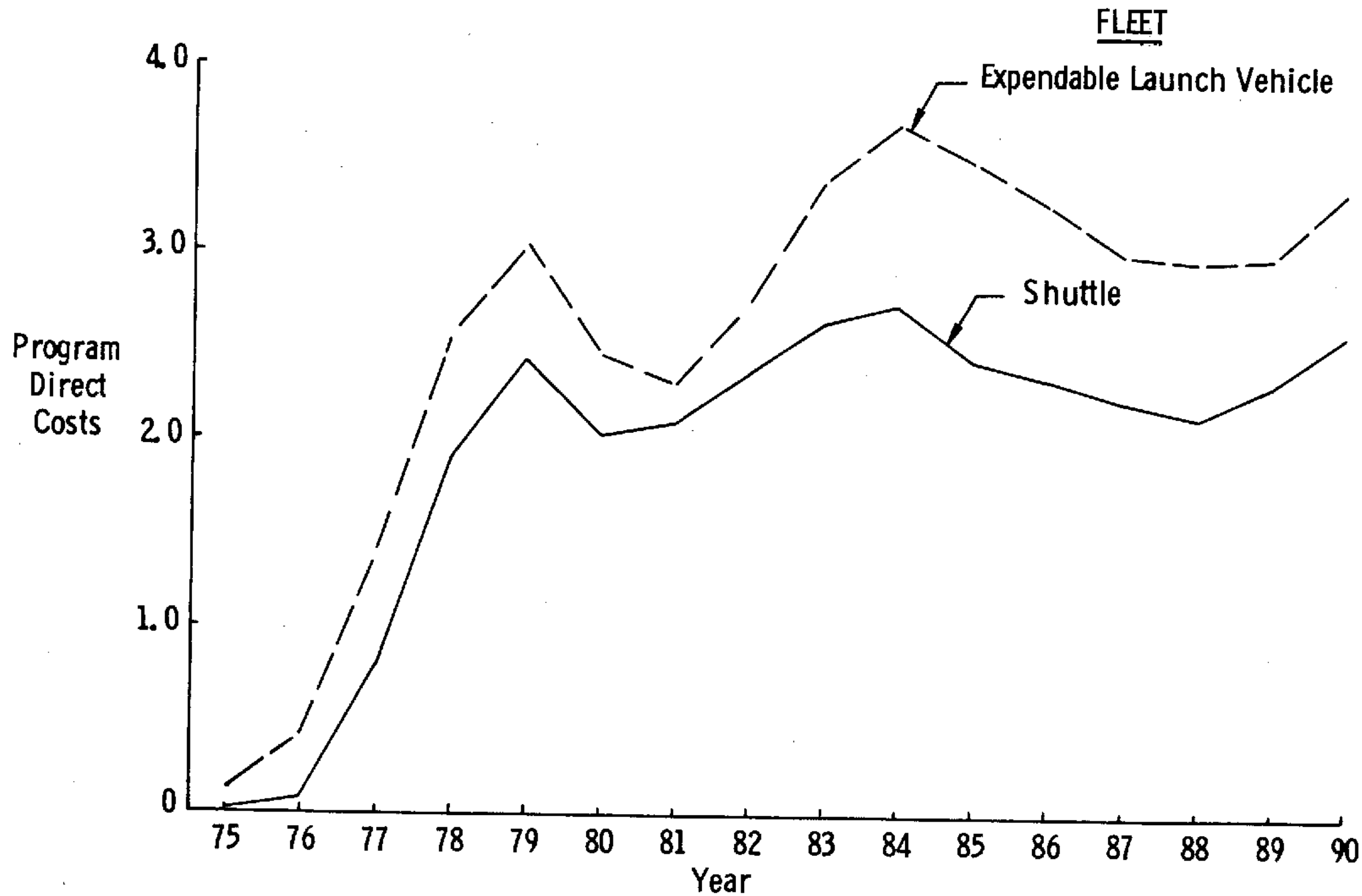

Figure 3-3. Total Direct Cost Estimate Comparison, Sortie Science Included

3. NONRECURRING AND INDIRECT COST ESTIMATES

The computer output for Cases 500, 501, and 506 covers (1) direct launch vehicle cost including expendable launch hardware and contractor launch site operations; (2) Shuttle operations cost; (3) Tug operations and investment cost; and (4) payload RDT&E, investment, and operations costs. The output, which is designed to cover direct cost primarily, does not include (1) expendable launch vehicle RDT&E, facilities, or indirect range and base support costs; (2) similar elements for Big G plus investment in reusable Big G reentry vehicles; or (3) Shuttle and Tug RDT&E, facilities, Shuttle investment, and indirect range and base support. (Note that a portion of such costs may be included in the unit operations cost of $10 million and $1.95 million, respectively, for the Shuttle and Tug.) Finally, no payload costs for DoD support missions are included in any case.

D. OBSERVATIONS

In Study A, sorties were handled as "benefit" payloads in an extra case (Case K). There was no attempt to include a sortie science equivalent in the expendable case so that sorties could be included in the economic comparison. In this study the sortie science is integrated into the automated spacecraft and space station program. A sortie science equivalent was developed in this study (Case 501) so that sorties could be included in the mission model capture/cost analyses. The cost savings with the Shuttle for sortie science are large. It is recommended that the sortie science be included in future analyses.

The logic in the automated capture program, DORCA-II, is such that it selects the lowest cost expendable launch vehicle or upper stage to launch a payload and then searches for multiples within its capability. This resulted in using many small (Thor-Delta) expendable launch vehicles and Deltas for upper stages during the pre-Tug years on the Shuttle The use of a Centaur with its capability for multiple payloads with the

Shuttle would decrease launch costs. A study ground rule which eliminated expendable upper stages after Tug IOC resulted in expending Tugs for planetary flights. Keeping expendable upper stage(s) in the inventory would lower launch costs by not expending Tugs.

Multiple payloads deployed by the Tug, especially at synchronous equatorial orbit where the traffic is large, reduce costs. Side-by-side and end-to-end stacking is recommended to increase the multiple payloads accommodated.

On-orbit revisit for maintenance, especially of large payloads, is an economical mode of operation when compared to retrieval, ground refurbishment, and redeployment or deploying additional payloads to provide the required availability. Improved definition of payload weights, sizes, and operations is needed.

Thirty-nine percent of the Tug flights are launched from WTR during the Shuttle era. This is a surprisingly large number. It is recommended that a shortened version of the Tug be considered for these lower energy missions to increase the payload volume capability of the STS.

The savings which result for automated (unmanned) payloads when comparing a reusable payload mission model launched on the Space Shuttle with an expendable payload model launched on expendable launch vehicles have been estimated to be 15-20 percent. The use of standardized subsystem modules in the spacecraft design has been estimated to save an additional 5-10 percent which would increase the total savings to about 25 percent. The economics of standardized subsystem module spacecraft need to be factored into the cost analysis.

Since the payload performance capability of tandem Tugs at synchronous equatorial orbit is about four times that of a single Tug at only a factor of two on cost, on-orbit docking (use of tandem Tugs) should be an acceptable mode of operation in future studies.

Multiple payloads are a major factor in reducing program costs. The requirement for "special" destinations which limit multiples and result in low load factors should be carefully reviewed and justified.

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