Advanced Space Power Requirements and Techniques

Task 1: Mission Projections and Requirements

Volume I: Technical Report

Prepared by
Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

1 March 1978

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-3078

Systems Engineering Operations
THE AEROSPACE CORPORATION

(NASA-CR-157344) ADVANCED SPACE POWER REQUIREMENTS AND TECHNIQUES. TASK 1: MISSION PROJECTIONS AND REQUIREMENTS. VOLUME 1: TECHNICAL REPORT (Aerospace Corp., El Segundo, Calif.) 207 p
N78-28597
Unclas
G3/44 15273

Aerospace Report No.
ATR-78(7667)-1, Vol. I

ADVANCED SPACE POWER REQUIREMENTS AND TECHNIQUES

TASK 1: MISSION PROJECTIONS AND REQUIREMENTS

Volume I: Technical Report

Prepared by

Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

1 March 1978

Systems Engineering Operations
THE AEROSPACE CORPORATION
El Segundo, California 90245

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C.

Contract No. NASW-3078

Aerospace Report No.
ATR-78(7667)-1, Vol. I

ADVANCED SPACE POWER REQUIREMENTS AND TECHNIQUES
TASK 1: MISSION PROJECTIONS AND REQUIREMENTS

Volume I: Technical Report

Prepared by:

Malcolm G. Wolfe
Assistant Director
Advanced Mission Analysis Directorate

Approved by:

Ivan Bekey
Assistant Group Director
Advanced Mission Analysis Directorate

Samuel M. Tennant
Vice President and General Manager
Advanced Orbital Systems Division

FOREWORD

This is Volume I of a three-volume report. The report documents the results of Task 1 of a study entitled, "Advanced Space Power Requirements and Techniques" performed under NASA Headquarters Contract No. NASW-3078 during fiscal years 1977 and 1978. Task 2 is documented separately.

The Task 1 effort was directed by Dr. Malcolm G. Wolfe of the Advanced Applications Analysis Office. Mr. Jerome P. Mullin (Code RP) of NASA Headquarters was the NASA study director. Technical direction was also provided by Mr. Lee Holcomb of NASA Headquarters, speaking for Mr. Mullin.

The report consists of the following three volumes:

Volume I: Technical Report
Volume II: Classified Addendum
Volume III: Appendices

Volume I is an unclassified volume which describes the results of the technical studies that were performed as part of the effort. The study encompassed DoD as well as NASA and civil missions and mission requirements. Volume II is a classified volume which includes data which could not be included in Volume I for national security reasons. Volume III is unclassified and contains ancillary information, such as computer printout, which was generated during the course of the study.

ACKNOWLEDGMENTS

The invaluable contributions of the following individuals to the successful completion of this study are gratefully acknowledged:

Edwin R. Berry	Power and Electrical Department
Vernelle C. Boykin	Radar and Microwave Department
Harry G. Campbell	Advanced Mission Analysis Directorate
Leopold J. Cantafio	Radar and Microwave Department
Harrison J. Killian	Power and Electrical Department
James A. Plough	Advanced Mission Analysis Directorate
Lawrence Raphael	Advanced Mission Analysis Directorate

CONTENTS

TABLES

FIGURES

FIGURES (cont'd)

FIGURES (cont'd)

1. INTRODUCTION

1.1 OBJECTIVES

The objectives of this study are to:

1. Develop projections of the NASA, DoD, and civil space power requirements for the 1980-1995 time period
2. Identify specific areas of application and space power subsystem type needs for each prospective user group
3. Document the supporting and historical base, including relevant cost-related measures of performance
4. Quantify the benefits of specific technology projection advancements.

1.2 SCOPE

The initial scope of this study included:

1. Construction of likely mission models for NASA, DoD, and civil space systems in the 1980-1995 time period
2. Generation of a number of future scenarios
3. Extraction of time-phased technology requirements based on the scenarios
4. Cost/benefit analyses of some of the technologies identified.

Major emphasis was to be placed on the development of technology projections.

During the study NASA directed the inclusion of a development of NASA, DoD, and civil traffic models, together with the corresponding life-cycle costs, within specified budgetary constraints. Two budgetary levels were to be studied, one conservative and one optimistic, for each of the three user groups; and to define the budgetary constraints in terms of average yearly cost expenditures during the 1980-1995 time period. Because of this reorientation, the planned effort in the areas of technology projections and cost/benefit analysis was de-emphasized.

1.3 APPROACH

Since the study emphasis was reoriented partway through the effort, the results of both the original and the modified approaches are documented herein. One of the approaches emphasizes a future in which large multipurpose, multi-user satellites will be the objective of early development and deployment; the other approach emphasizes a future in which many dedicated, single-user satellites will be deployed in the near and mid term, with large multipurpose satellites not being introduced until the far term.

The scenarios, mission models, and traffic models are, in general, synthesized from modified and amplified extractions from the prior efforts described in the documents listed in the bibliography to this report. They have no official NASA or DoD standing and very few can be traced to a single document source; however, the significant characteristics are articulated in such a way that they can be used as a base for determining the impact of changes in NASA or DoD policy or as a departure point for performing sensitivity analyses in future studies.

The first approach adopted in this study was to use the output of previous NASA studies (References 1 and 2), which themselves included the results of a number of other studies, to prepare a set of future mission scenarios. The power requirements to satisfy the needs of the missions included in these scenarios were then determined.

The second approach adopted in this study is illustrated in Figure 1-1. Individual low and high average yearly budget goals were selected for each of the three user groups (NASA, DoD, and civil). The budget levels

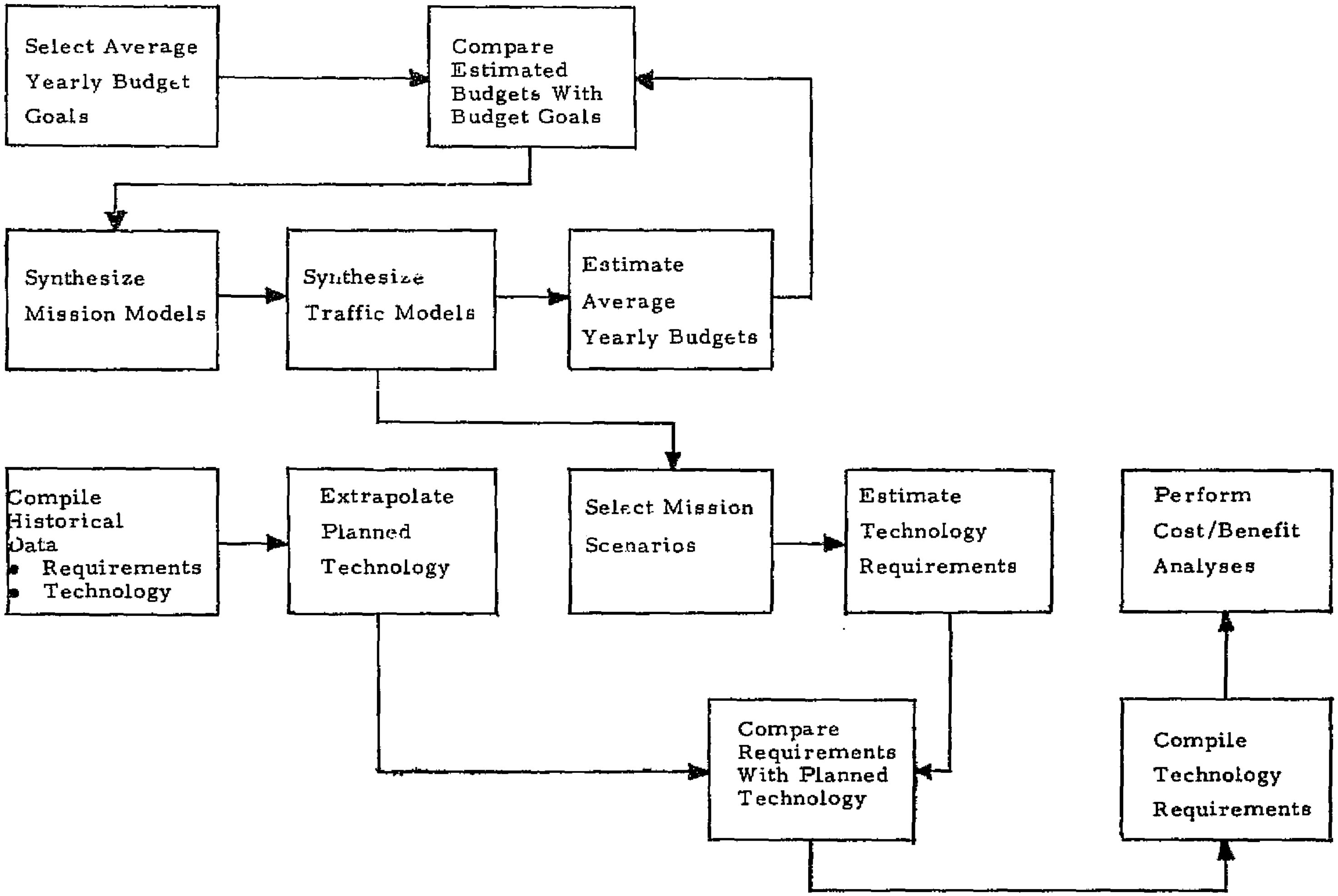


Figure 1-1. Study Plan

that were selected are listed in Table 1-1. Mission models and, from these, traffic models were synthesized and the corresponding average yearly cost expenditures estimated. An iterative process was used, modifying the mission/traffic models to meet the budgetary goals established by Table 1-1. The missions included in the mission/traffic models were extracted from prior efforts described in a number of documents, as described later in this report. Some of the ground rules and assumptions that were used during the course of the effort are delineated in Appendices I and II, Volume III to this report.

Historical space power requirements and technologies were compiled and anticipated capabilities extrapolated into the future. The technology requirements arising out of the scenario development effort then were compared with future anticipated capabilities. Finally, a simplified cost/benefit analysis was performed.

Table 1-1. Assumed Average Yearly Budget Goals for 1980-1995

ORGANIZATION	CONSERVATIVE BUDGET ($B)	OPTIMISTIC BUDGET ($B)
NASA		
Institutional	2.0	2.0
Transportation	1.0	2.0
Programs	1.0	2.0
Total	4.0	6.0
DoD Programs	0.7	1.5
Civil (Non-NASA, Non-DoD Programs)	0.5	1.0

Notes:

(1) Budgets are in 1977 dollars.
(2) Budgets are averages and therefore peak budgets will exceed these values in certain years.

2. HISTORICAL SPACE POWER TRENDS

2.1 HISTORICAL POWER LEVEL REQUIREMENTS

Using References 3 through 7, a survey was made of satellites launched or planned to be launched during the 1959-1979 time period, together with their user group, function, power system type and prime power requirements. The results are listed in Appendix III, Volume III to this report. Scatter diagrams of power versus launch date for the satellite programs listed in Appendix III were prepared for each user group and are shown in Figures 2-1 through 2-4. A trend line of 100 watts per year is shown for reference purposes. The single point which lies above this trend line is the OAO 2 launch of 7 December 1968, which is given in Reference 8 as 1400 W.

2.2 POWER LEVEL REGRESSION ANALYSIS

A general problem solving computer program (GYPSY) was used to perform a regression analysis on the historical prime power requirements data. A total of 175 launches were used, including 96 NASA, 44 DOD and 35 civil data points.

The computer program considers eight types of equations, viz:

1. $Y = A + BX + CX^2 + DX^3$
   $Y = A + BX + CX^2$
   $Y = A + BX$

2. $I/Y = A + BX + CX^2 + DX^3$
   $I/Y = A + BX + CX^2$
   $I/Y = A + BX$

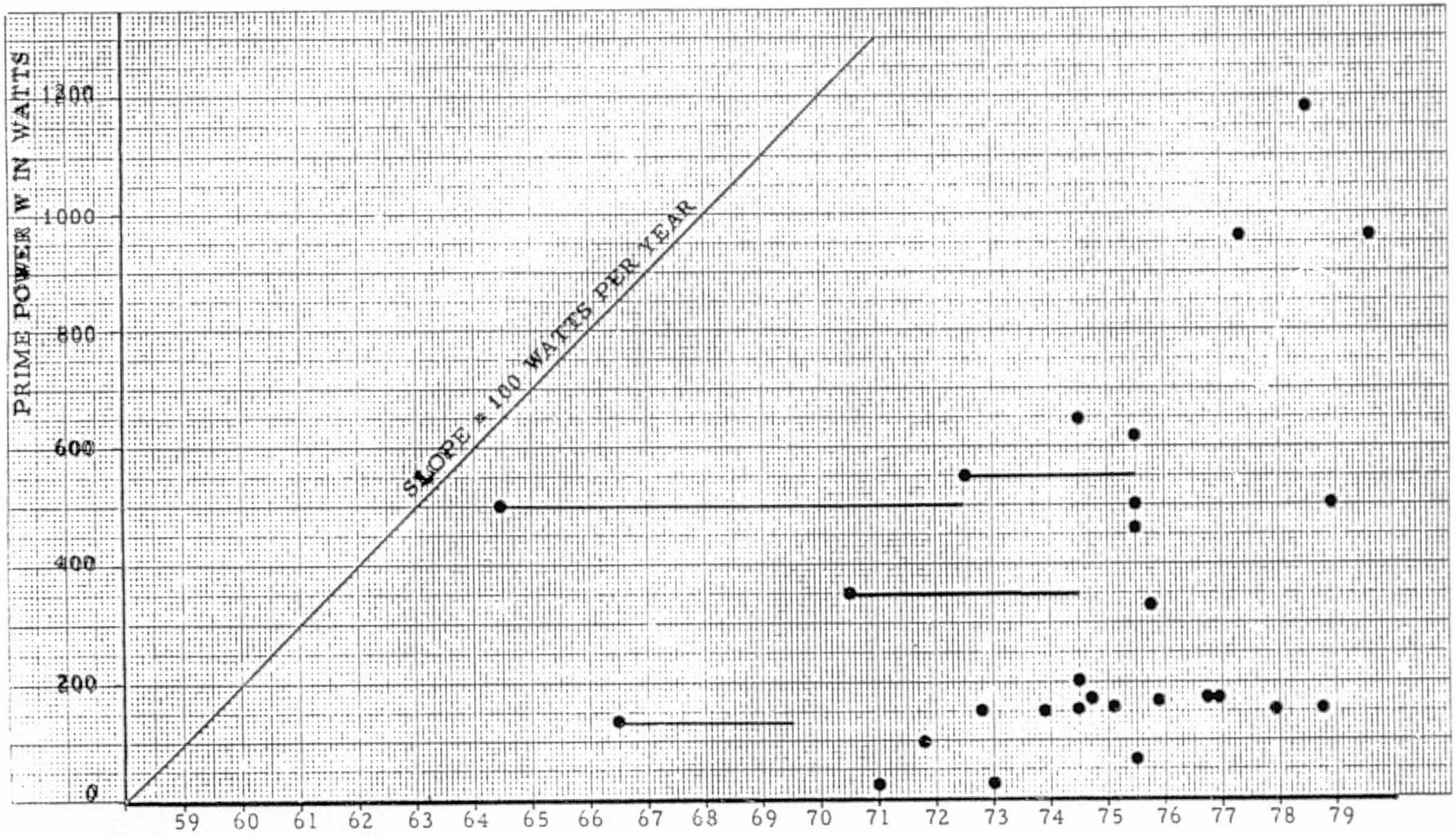


Figure 2-1. NASA Satellites Prime Power Trend, 1959-1979

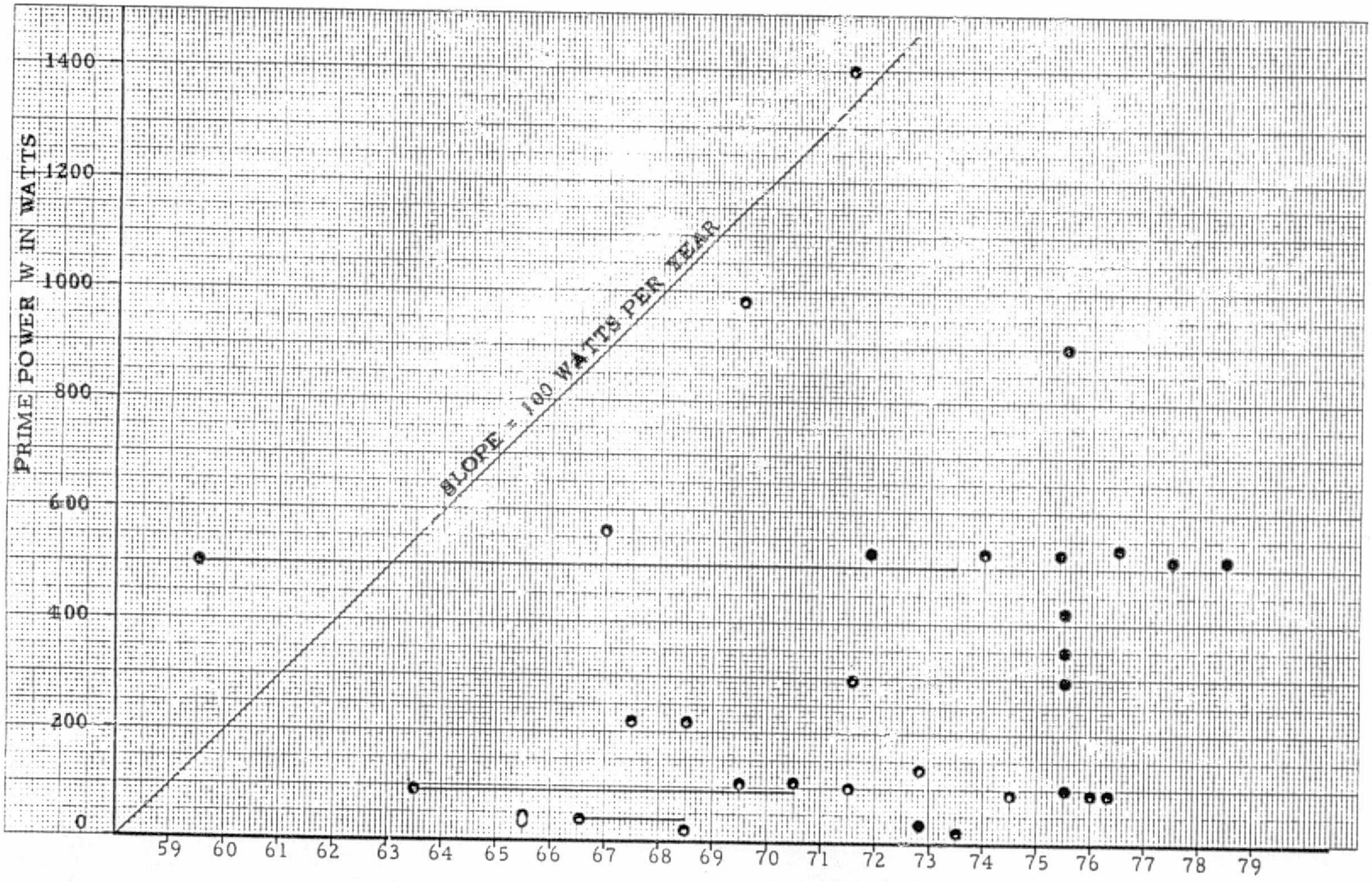


Figure 2-2. DoD Satellites Prime Power Trend, 1959-1979

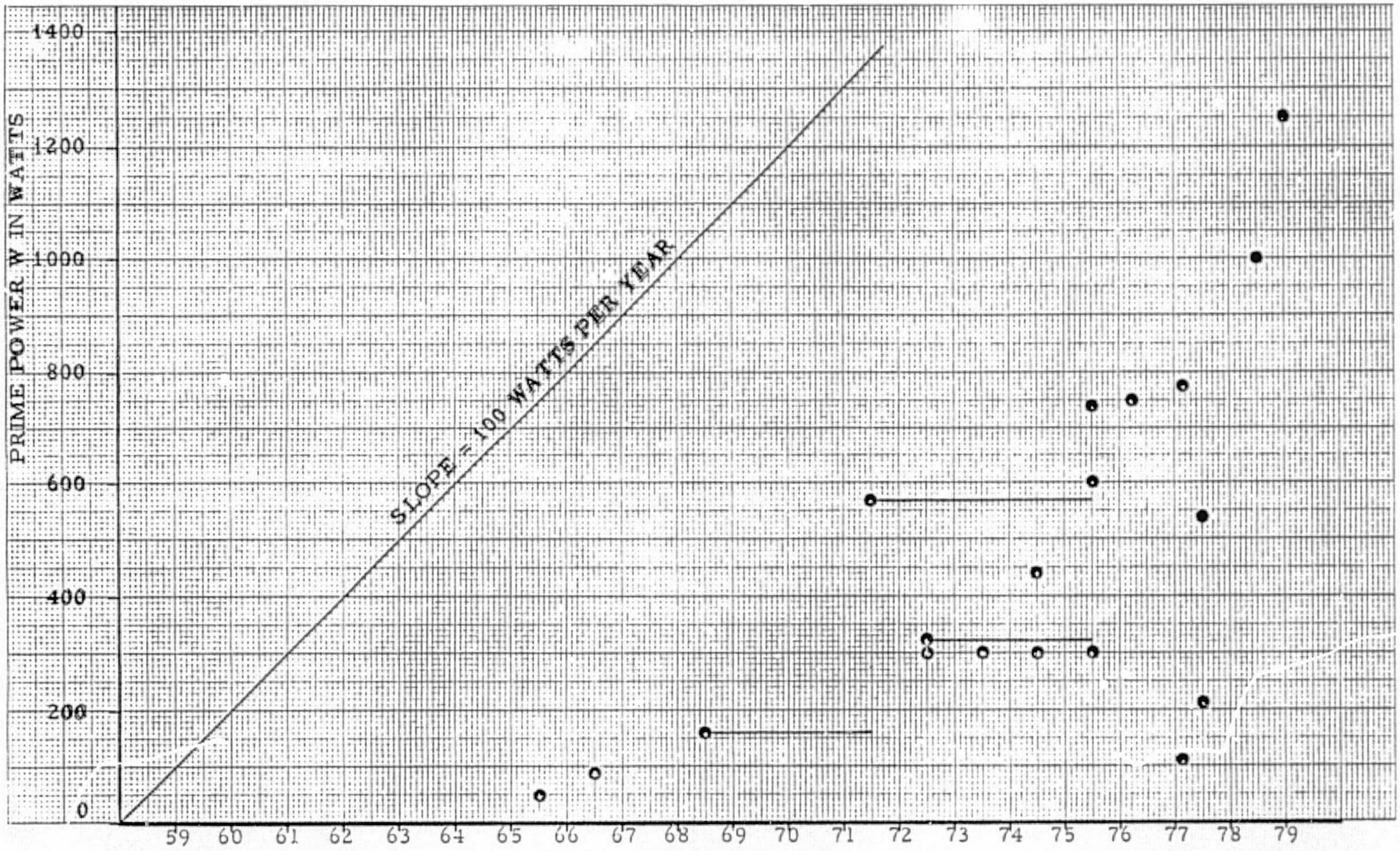


Figure 2-3. Civil Satellites Prime Power Trend, 1959-1979

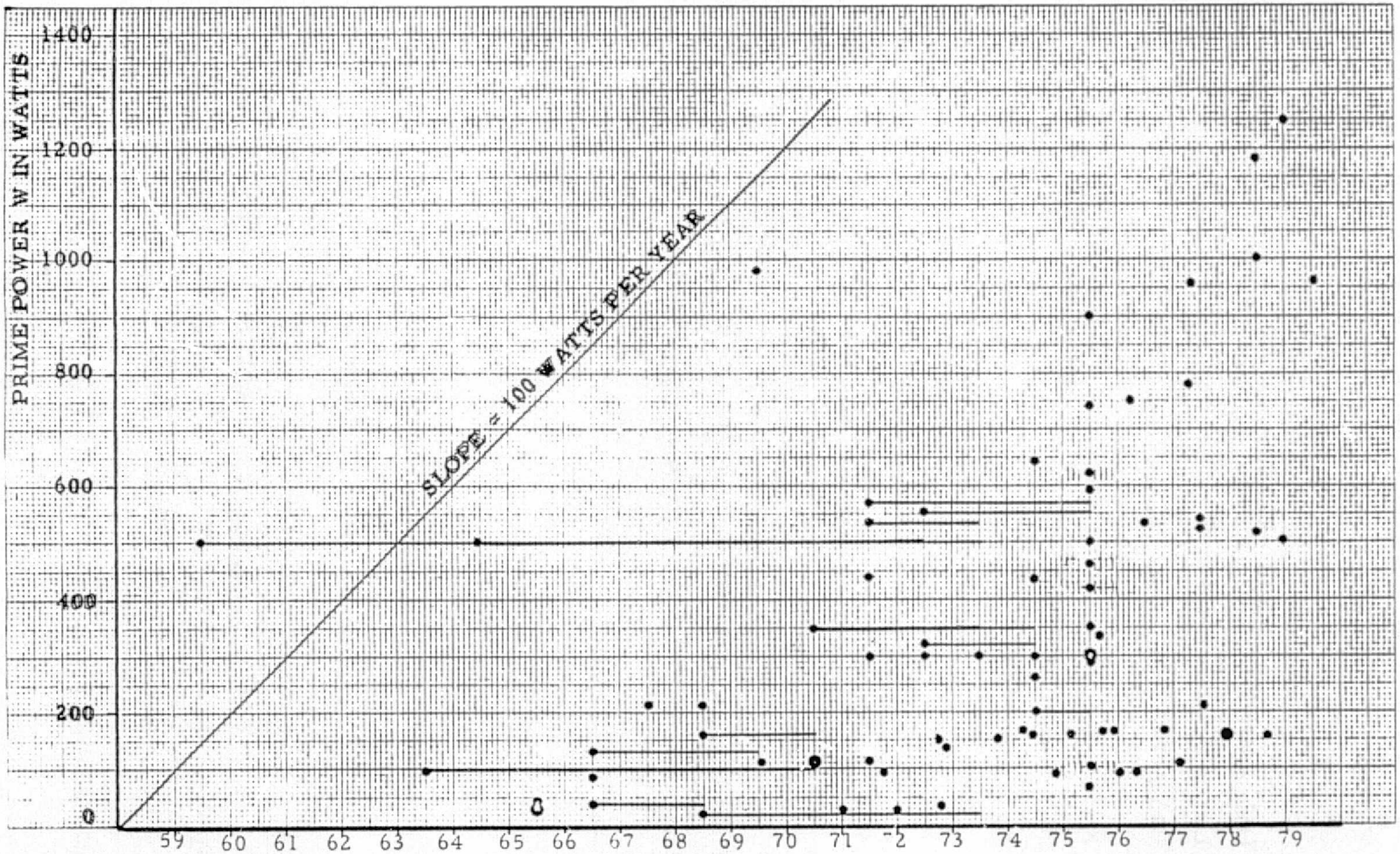


Figure 2-4. All Satellites Prime Power Trend, 1959-1979

3. $Y^2 = A + BX + CX^2 + DX^3$
   $Y^2 = A + BX + CX^2$
   $Y^2 = A + BX$

4. $LnY = A + BX + CX^2 + DX^3$
   $LnY = A + BX + CX^2$
   $LnY = A + BX$

5. $X/Y = A + BX + CX^2 + DX^3$
   $X/Y = A + BX + CX^2$
   $X/Y = A + BX$

6. $Y = AB^X$

7. $Y = Ae^{BX}$

8. $Y = AX^B$

and bases its selection on high correlation and low standard deviation of residuals. The best fit to all the data was found to be:

$$LnP = A + BM + CM^2 + DM^3$$

where: P = Prime power in watts
M = Number of months after June 1959

and the coefficients are as follows:

	A	B	C	D
NASA	6.41	-0.0186	6×10^{-5}	5×10^{-8}
DoD	6.9	-0.06	0.0005	-10×10^{-5}
Civil	5.4	-0.05	6×10^{-4}	-2×10^{-6}
All	6.5	-0.0377	-0.00029	-6×10^{-7}

Computer plots of the output are shown in Figures 2-5 through 2-8.

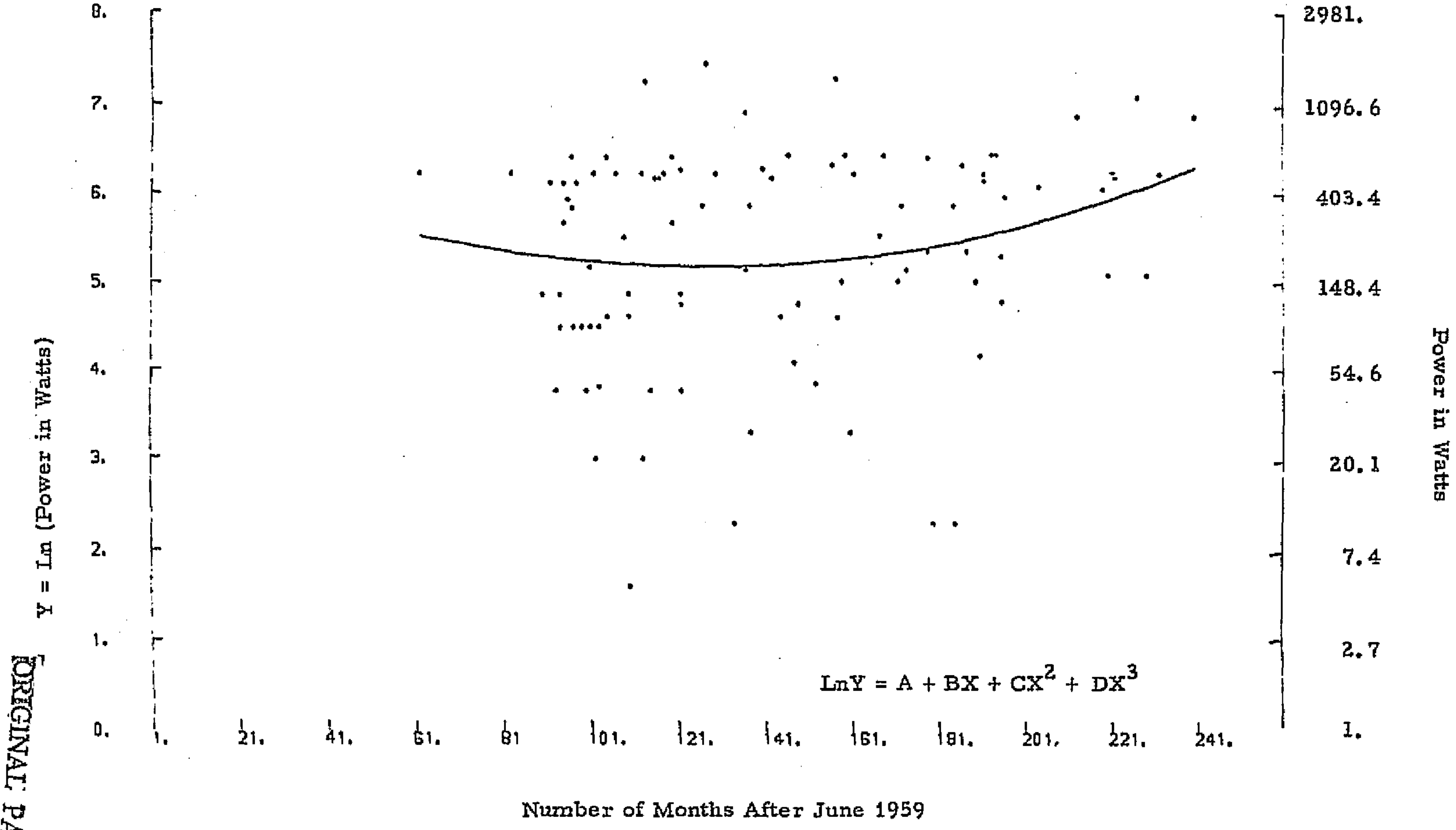


Figure 2-5. Satellite Prime Power Regression Analysis - NASA

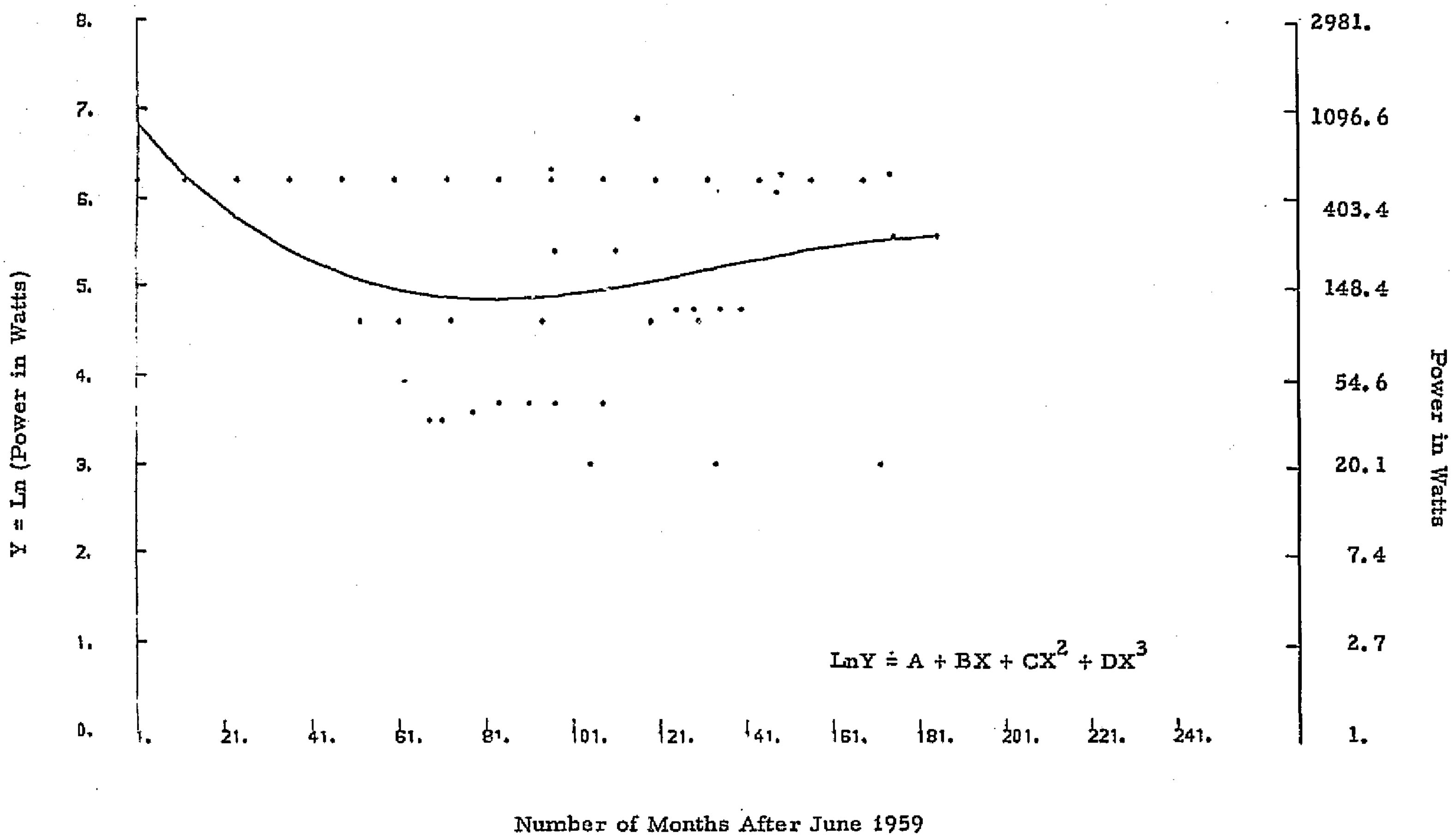


Figure 2-6. Satellite Prime Power Regression Analysis - DoD

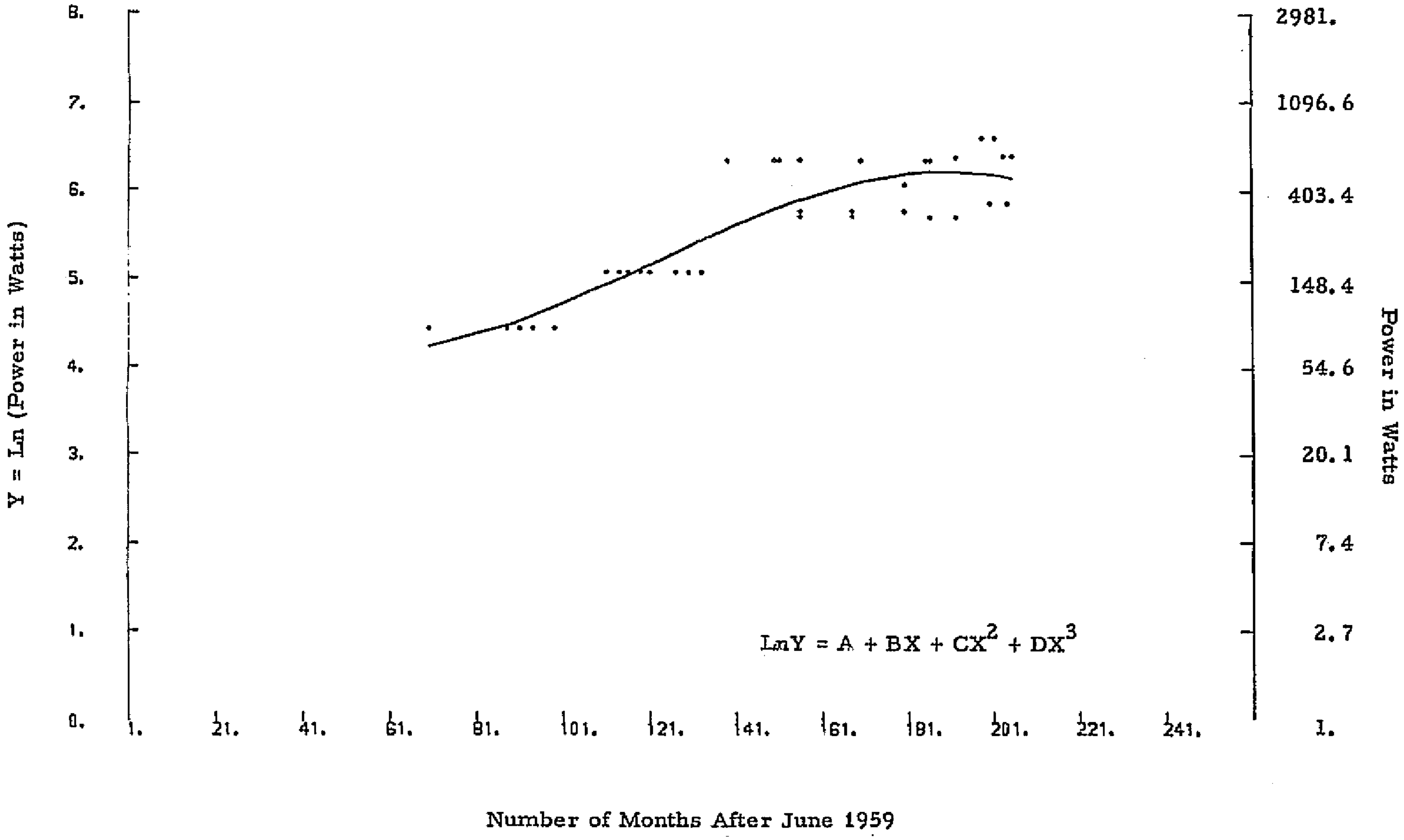


Figure 2-7. Satellite Prime Power Regression Analysis - Civil

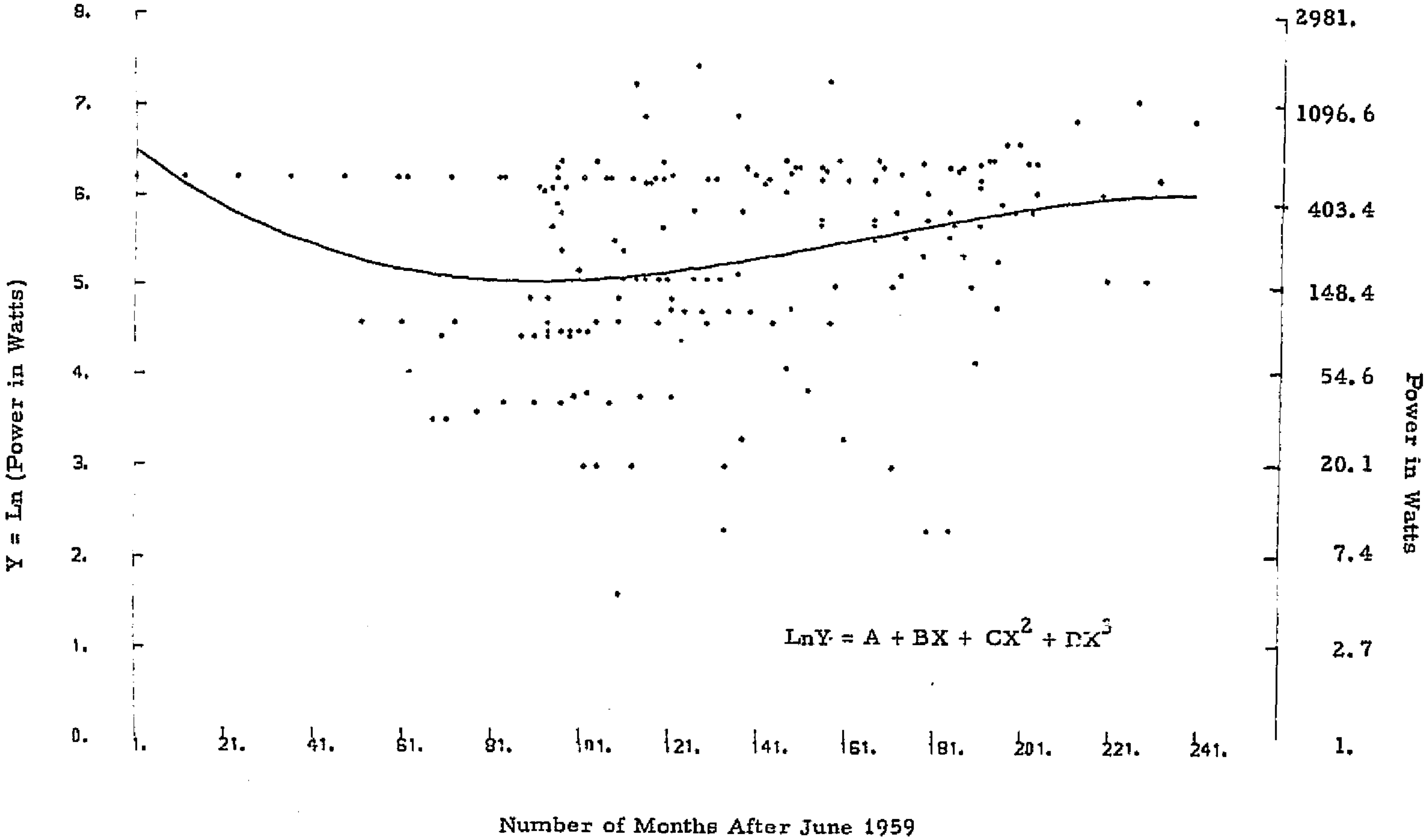


Figure 2-8. Satellite Prime Power Regression Analysis - All Launches

2.3 POWER SYSTEM COSTS

2.3.1 Background

For a number of years The Aerospace Corporation has collected satellite and launch vehicle hardware costs on ongoing programs from government and private industry sources and incorporated them into a computerized cost data bank. This data bank has a number of uses, including being used as a base for developing future subsystem nonrecurring and recurring costs and is being constantly expanded. It has been found expedient to organize the data to suit the accounting procedures of industry as much as possible and the format used for the satellite power system is illustrated in Table 2-1.

2.3.2 Ground Rules and Assumptions

In addition to the guidelines delineated in Appendices I and II, Volume III to this report, the following specific ground rules and assumptions were used to develop the costs reported below:

1. Only unmanned satellite data is included.
2. The programs utilized include: OGO A-C; OGO D-F; Tiros-M; Nimbus-D; SMS; ATS-F; OSO-I ; VELA; VASP; TACSAT; DSP; DSCS-II; STP 72-2; GPS.
3. All program quantities are adjusted to a quantity of 5 for comparability.
4. All dollar figures represent prime contractor cost (less fee) and are adjusted to constant 1977 dollars.
5. Costs include supplier and prime contractor effort plus allocated system related costs (i.e., system engineering and integration, assembly, test and checkout, quality control and program management).
6. The electrical power subsystem is composed of solar arrays, drives (if required), batteries, power control units, shunt elements, converters and wiring.

Table 2-1. Satellite Power System Cost Summary Format

SATELLITE _______

__ Mo., Des. Life, ____ W, BOL Pwr, ____ W, Avg Pwr,

First Launch 19__

Item Cost Category	Solar Array (_____ sq ft)	Battery (__A-H)	Power Control Unit	Converters	Wiring	Drive	Total
Non-recurring							
Design Engrg. Test & Eval.							
Recurring (5 Sat.)							
Syst. Engrg. Production							
Total (1977 $)							
Average (5 Sat.)							

Subsystem Weight/Satellite Weight

Cost/lb. (kg)

Cost/ft^2(m^2)

Cost/A-H

Cost/kW-H

2.3.3 Cost Analyses

Historical electric power subsystem costs were analyzed for the years 1963 through 1977 and the percentage distribution by major component is listed in Table 2-2. The electrical subsystem cost per kilowatt-hour as a function of year of first flight is given in Figure 2-9 and as a function of kilowatt hour in Figure 2-10. The data is scattered but, as shown, some trend lines can be postulated.

Table 2-2. Satellite Electrical Power Cost Percentage Distribution by Major Components

Year of 1st Launch	Solar Array	Batteries	PCU Plus Converters	Wiring	Array Drives
1963	43.3	16.7	37.0	2.9	-
1964	23.5	22.6	15.8	23.6	14.6
1967	34.2	9.6	45.8	10.3	-
1967	21.6	10.9	23.1	-	44.4
1969	62.5	9.0	15.9	12.6	-
1970	46.2	13.2	32.2	8.5	-
1970	9.3	11.1	9.2	22.4	48.0
1971	46.0	12.1	28.9	13.0	-
1971	21.4	19.3	32.1	27.1	-
1974	26.9	8.9	26.5	37.8	-
1974	34.2	15.9	33.6	16.3	-
1975	23.3	12.1	36.7	28.0	-
1975	18.4	14.7	43.3	23.6	-
1977	10.8	9.9	41.6	9.4	28.4

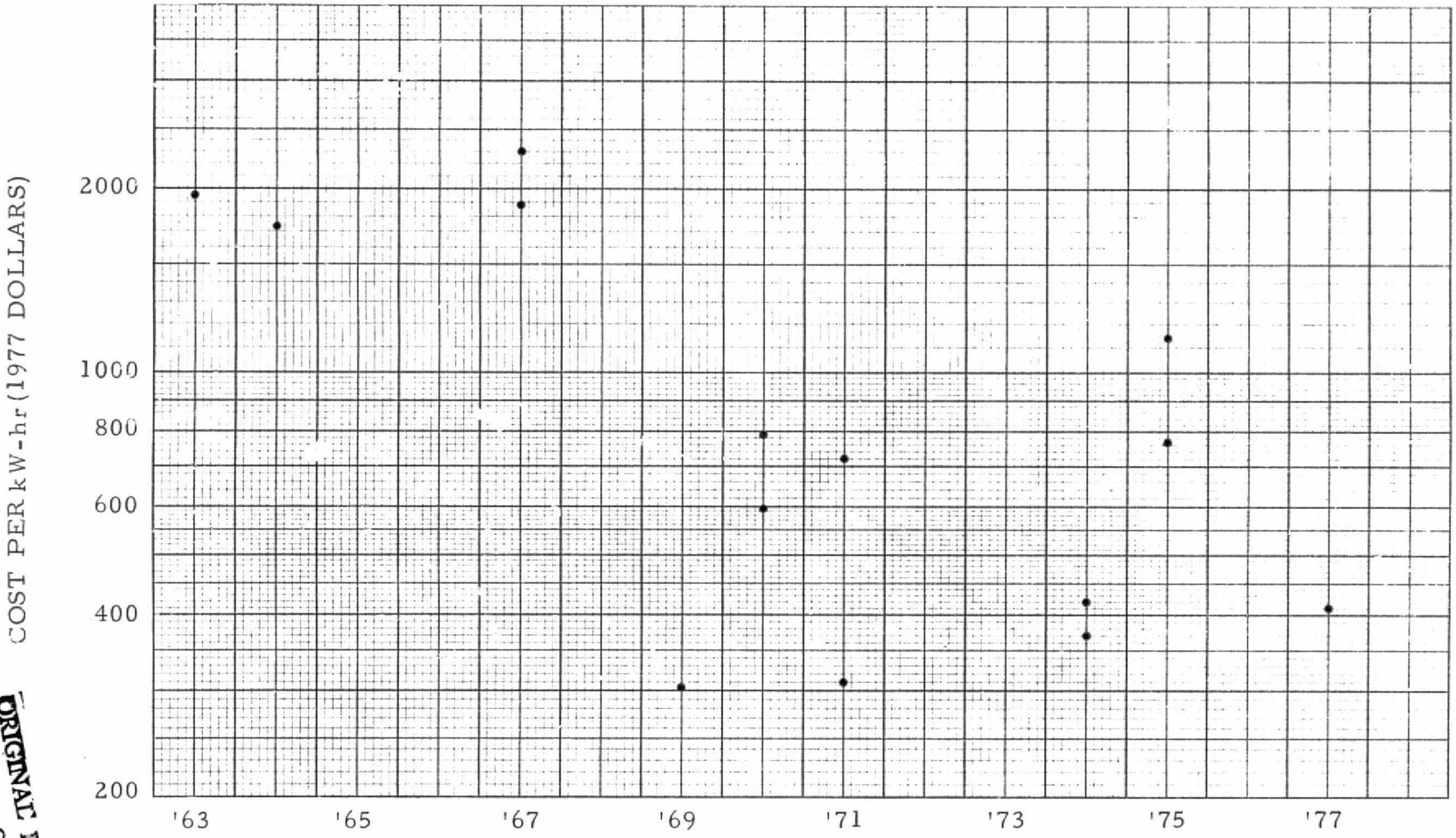


Figure 2-9. Electrical Subsystem Cost per kW-hr vs. Year of First Flight

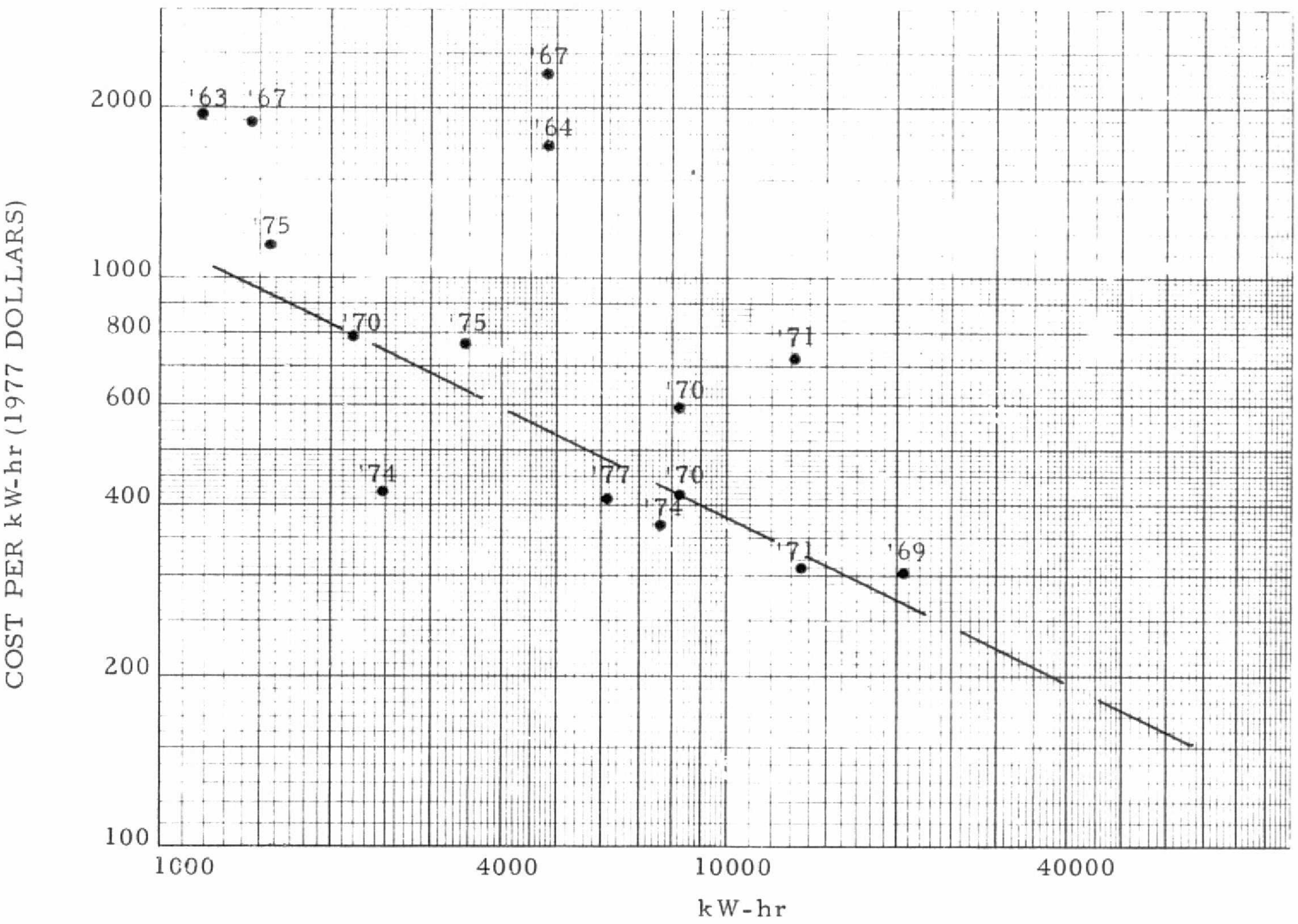


Figure 2-10. Electrical Subsystem Cost per kW-hr vs. kW-hr

3. FUTURE SPACE POWER REQUIREMENTS

3.1 INTRODUCTION

As stated earlier, two approaches were used to develop future space power requirements. One approach emphasizes a future in which large multipurpose, multi-user satellites will be the objective of early development and deployment; the other approach emphasizes a future in which many dedicated, single-user satellites will be deployed in the near and mid term, with large multipurpose satellites not being introduced until the far term. As far as total power requirements are concerned, the two approaches lead to more or less the same conclusions since, in general, the accumulation of several initiatives on one space platform results in a corresponding accumulation of total power. Where differences will occur, however, is in such areas as the need for supporting and folding large solar arrays and the establishment of policies for the design, development and deployment of remote space power modules. If remote space power modules are used to supply power to other satellites via laser or microwave links, consideration must be given to whether they have to supply a multitude of low-powered satellites or a small number of high-powered satellites.

3.2 MISSION/TRAFFIC MODELS

A number of sources (References 8 through 28) together with judgment was used to assemble information necessary to construct the traffic models shown in Figure 3-1 through 3-17. Some of the basic design and cost assumptions are delineated in Appendices I, II and IV, Volume III, to this report. Appendix IV lists the basic mission and design characteristics assigned to each initiative included in the traffic models and also the assumed launch vehicle combination; Appendix II lists the performance and cost characteristics of the launch vehicles which are assumed to develop the costs listed in Figures 3-1 through 3-17; Appendix I lists some general guidelines and assumptions. The methods used for developing costs are described in References 29 and 30.

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Earth Resource Monitoring	Automated	NO1-1-1	Landsat Follow-on	Low/Low	1.3
		-2	Earth Survey Satellite	Low/High	1.2
		-3	Geosync.	Geosync.	1.2
		-4	GRANSAT	Low/High	0.35
		-5	MAGSAT B	High/Low	0.18
		-6	SMIAS		1.1
		-7	HCMM Follow-on		1.1
		-8	STEREOSAT		0.84
	Spacelab	NO1-2-1	Spacelab Payloads	Low/Int.	7.5
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Environmental Monitoring	Automated	NO2-1-1	SEASAT -B	Low/High	3.5
		-2	Environ. Monitoring Sat.	Low/High	1.8
		-3	HALOE		1.3
		-4	STORMSAT	Geosync.	1.4
		-5	ERBSS		0.47
	Spacelab	NO2-2-1	ACPL	Low/Low	1.9
		-2	Spacelab Payloads	Low/High	3.0
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
		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					
			1	1	1	1	1	1	1	1	1	1	1	1	1	1				
		1	2		2	1	2	3		2	2	3	1	3	1	4				
		70	120		70	70	130	200	60	130	140	130	60	140	70	190				
					1			1		2					1	1				
1	2	1			2	4	2	2		1			2	3			8	12	20	1.2
3	9	6		3	7	8	8	9	3	5	3	2	4	3	4	3	30	50	80	4.7
82	176	163	63	76	136	157	136	123	94	86	77	73	72	73	93	52	566	1166	1732	102
		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	1	1	1	1	1	1	1	1	1	1	1	1	1				
	1	3		2			2	1			3			1	2					
	70	190		140			100	80			180			80	100					
	.2	.6		.5		.4	.5				.7			.5	.4					
2	2	1	1	2		1	2						2				7	6	13	0.8
7	6	4	4	4	1	5	2	2	1	3	2		2	2	1	2	23	25	28	1.6
116	107	74	72	35	27	69	61	26	24	45	23	17	35	36	23	26	344	472	216	48

Figure 3.1 Traffic Model - NASA Observation (Nominal Budget) 2

FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Intergovernment Links		NC1-1-1	Hotline	Geosync.	2.0
		-2	Intergovernment - I	"	2.0
		-3	" - II	"	3.5
		-4	" - III	"	5.0
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Gov't to People Links		NC2-1-1	Voting/Polling - I	Geosync.	1.0
		-2	" - II	"	50
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Intra Gov't Links	Routine	NC4-1-1	Electronic Mail - I	Geosync.	5.0
		-2	" - II	"	15
	Emergency	NC4-2-1	Emergency - I	Geosync.	2.0
		-2	" - II	"	5.0
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
		1		1	1		1	1	1	1		1	1	1	1 1					
		2		2	3		2	5	2	4		2	5	2	3					
		110		110	190		110	280	110	190		110	280	110	190					
		.5		.5	.7		.6	.8	.6	.7		.5	.8	.5	.7					
	3	2	3	1	1	2	3	2		1		2	1	2			9	14	23	1.4
3	7	7	7	5	6	6	6	4	3	2	3	5	4	3	1		29	43	72	4.2
84	222	218	208	180	152	192	186	146	98	54	95	137	126	91	24		841	1372	2213	130
							1				1			1	1					
							1				1			50	1					
							60				60			1380	60					
							.5				.5			2.2	.5					
					1				1	.1	3	6	5	3			12	8	20	1.2
				1	2	3	1			4	6	10	10	5			24	18	42	2.5
				17	52	54	16	6	12	60	127	201	210	95	7		474	383	857	50
	1		1		1		1	1	1	1	1		1	1	1	1				
	2		5		5		15	2	5	5	15		5	2	15	5				
	110		280		280		690	110	280	280	690		280	110	690	280				
	.5		.8		.8		1.3	.6	.8	.8	1.3		.8	.5	1.3	.8				
3	1	3	2	5	3	3	2	1	3	2	1	1	2	4		1	13	24	37	2.2
8	7	8	6	10	7	8	6	4	6	5	3	4	5	6	5	1	37	62	99	5.8
230	216	220	219	239	221	195	155	145	160	137	82	114	134	161	119	29	1017	1759	2776	16[illegible]

Figure 3.2 Traffic Model - NASA Communications (Nominal Budget)

2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Space Processing	Spacelab	NS1-1-1	Space Processing	Low/Low	5.0
		-2	Spacelab R&D Facility	Low/Low	10
	Space Station	NS1-2-1	Extended Mission Vehicle	Low/Low	5.5
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^5)		
Orbital Operations		NS3-1-1	Large Struc. Deployment	Low/Low	10
		-2	Skylab Revisit	Low/Low	1.0
		-3	Tethered Sat. Op.	Low/Low	0.5
		-4	Satellite Retrieval	Low/Low	1.0
		-5	Shuttle External Tank Usage	Low/Low	1.0
		-6	Launch Retrieval & Refueling of Upper Stages	Low/Low	1.0
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Satellite Power		NS4-1-1	25 kW Power Module	Low/Low	25
		-3	2 MW Power Module	Geosync.	2 X 10^3
		-5	1.2 GW Power Module	Geosync.	12 X 10^5
		-6	10 GW Power Station	Geosync.	10 X 10^6
		-2	250 kW Power Module	Low/Low	250
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

	NEAR-TERM							MID-TERM										COSTS ($M)			
r	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
																	1				
																	6				
																	310				
																	.9				
															2	3		3	2	5	0.3
														1	5	5	2	9	4	13	0.8
														24	113	127	40	200	104	304	18
			1		1		1					1		1	1						
			1			1			1												
		1																			
				1		1		1						1		1					
				1																	
				1						1						1					
		25	10		10		10					10		10	10						
		820	550		550		550					550		550	550						
		1.6	1.1		1.1		1.1					1.1		1.1	1.1						
	10	5	1	2	1	2	1			1	1	2	2	3				10	21	31	1.8
	19	10	4	4	2	4	1			2	3	3	5	5	1			23	40	63	3.7
	179	123	63	50	43	49	17	5	4	26	48	41	74	68	20	1	1	261	551	812	48
								1													
03																	1				
05																					
06																					
											1										
								25			250						2000				
								820			3100						22150				
								2			6						46				
						1	7	4	9	19	6		8	26	50	99	110	101	238	339	20.0
						2	12	10	17	40	15		19	57	101	181	193	231	416	647	38.1
						3	19	15	19	42	15		19	57	105	195	205	244	450	694	41

Figure 3.3 Traffic Model - NASA Support (Nominal Budget)

FOLDOUT FRAME

2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Astrophysics	Automated	NP1-1-1	Space Telescope	Low/Low	1.5
		-2	HEAO-D	Low/Low	2.7
		-3	HEAO-E	Low/Low	2.7
		-4	VLBI	(a) Escape (b) High/Low	(a) 0.21 (b) 0.38
		-5	Gravity Wave Detector	Low/Low	0.57
		-6	Gravity Probe B/C	Low/High	0.35
		-7	Adv. Relativity Exp.	Low/High	0.35
		-8	Explorer	Geosync.	0.18
	Spacelab	NP1-2-1	P.I. S/L Payloads	Low/Low	6.2
		-2	SIRTF	Low/Low	1.2
		-3	SUOT	Low/Low	0.72
		-4	IR Interferometer	Low/Low	1.8
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Solar Terrestrial	Automated	NP2-1-1	Solar Max. Missions	Low/Low	0.94
		-2	Out-of-eclip. Solar Obs.	Escape	0.22
		-3	Explorer (Delta Class)	Geosync.	0.31
		-4	Explorer (Scout Class)	Geosync.	0.22
		-5	Large Solar Observatory	Low/Low	2.7
	Spacelab	NP2-2-1	Solar Terr. S/L Payloads	Low/Low	3.0
		-2	Solar/Stellar IM Obs.	Low/Int.	2.9
		-3	Solar Physics S/L Block II	Low/Int.	2.7
		-4	AMPS	Low/Int.	3.9
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

FOLDOUT FRAME

	NEAR-TERM							MID-TERM										COSTS ($M)			
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
					1				1							1					
				1		1		1				1									
							1		1				1			1					
0.38								1 (a)			1 (b)			1 (a)			1 (b)				
								1		1		1									
					1				1												
													2								
		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	1	1	1	1	1				
				1	1	1	1	1	1	1	1	1	1	1	1	1	1				
									1												
				3	2	2	3	4	4			4	4			5	1				
		20		170	150	150	150	210	300	30	60	180	270	30		240	60				
		.1		1.2	1.3	1.0	1.1	1.5	2.3	.2	.3	1.1	1.5	.2		2.1	.2				
		2	2	3	3	3	2	1	1	2	2	1	1	2				10	15	25	1.5
	4	7	13	17	11	11	12	10	4	5	8	8	3	2	6	3	1	48	77	125	7.4
	27	57	119	168	126	104	140	112	56	56	94	107	52	40	65	35	10	494	874	1368	80
					1		1		1		1		1		1		1				
					1																
	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2				
	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2				
												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	1	1	1	1	1	1	1	1	1				
					1	2	2	2	2	2	2	2	2	2	2	2	2				
		1	1		1	1	2	1	1	2	1	5	2	1	2	1	2				
	80	80	80	80	160	80	130	160	210	160	210	310	210	160	210	160	210				
	.4	.4	.3	.3	.8	.4	.6	.6	1.0	.6	.9	2.4	.1	.1	.1	.7	.9				
	1	1		2	2	1	1	2		3	4		2	1	2	1	1	5	19	24	1.4
	4	4	3	8	5	5	5	5	9	12	16	7	5	7	5	7	2	57	82	109	6.4
	41	41	39	76	69	57	62	68	78	131	133	88	65	68	65	61	34	209	967	1176	69

2

Figure 3.4 Traffic Model - NASA Scientific (Nominal Budget)

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Life Sciences	Automated	NP3-1-1	BESS	Low/Low	1.1
		-2	Vestibular Func. Research	Low/Low	1.1
	Spacelab	NP3-2-1	Life Sciences Dedicated Lab	Low/Low	3.7
		-2	Mini-Lab (Multi-Mission)	Low/Low	1.1
		-3	Carry-on Lab (Multi-Mission)	Low/Low	1.1
		-4	KOSMOS	Low/Low	1.6
	Space Station	NP3-3-1	Research Module	Low/Low	5.2

Beginning of Life Power (kW)
Solar Array Weight (lb)
Power Subsystem Weight (lb X 10^3)
Solar Array Cost ($ X 10^6)
Power Subsystem Cost ($ X 10^6)
Total Program Cost ($ X 10^6)

1

FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
			1	1	2	1														
		1																		
		2	2	2	2	2														
		2	2	2	2	2														
		2	2	2	2	2														
	1																			
		1	1	1	2	2														
		60	60	60	120	60														
		.3	.3	.3	.6	.3														
1	1	1		1		1									2	3	5	5	10	0.6
2	4	3	3	3	2									1	4	5	14	13	27	1.6
99	173	138	102	104	65	12								24	113	127	431	426	957	56

Figure 3.4 Traffic Model - NASA Scientific (Nominal Budget) cont.

2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Planetary		NL1-1-1	JUP	Escape	0.57
		-2	VOIR	Escape	1.43
		-3	Mercury Orbiter/SEPS	Escape	0.74
		-4	Saturn-Uranus Probe	Escape	0.30
		-5	Dual Comet Flyby	Escape	1.07
		-6	Sat. Orb./Tit. Lander	Escape	1.27
		-7	Mars Polar Orbiter	Escape	0.89
		-8	Follow-on Jupiter (SEPS)	Escape	0.82
		-9	Encke Rendezvous (SEPS)	Escape	0.78
		-10	Multi-Asteroid (SEPS)	Escape	0.78
		-11	Jupiter Swing by	Escape	0.52
		-12	Mars Surf. Sample Return	Escape	1.59
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Lunar		NL2-1-1	Lunar Orbiter	Escape	0.59
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

1 FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
								1					1							
						1								1						
							1									1				
					1	1									1	1				
						2									1					
										1										
							1									1				
								1												
									1											
											1									
												1								
												1								
						4	2		1		1	3		2	1	1				
					30	230	90		40		40	120		80	90	120				
					.2	1.7	.6		.3		.3	1.0		.9	.5	.7				
				1	3			1	1	1	1	1					6	3	9	0.5
			2	10	16	8	2	3	4	8	6	4	5	4	4	1	41	36	77	4.5
		6	45	144	255	247	193	185	183	199	171	107	69	88	78	20	883	1107	1990	117
	1																			
	1																			
	30																			
	.2																			
3																	2	1	3	0.2
41	14																24	31	55	3

Figure 3.5 Traffic Model - NASA Planetary and Lunar (Nominal Budget)

FOLDOUT FRAME

2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Environmental Monitoring	U.S. Domestic	CO1-1-1 -2	Environ. Monitor. Sat. GOES	Low/High Geosync.	1.2 0.44
	Foreign	CO1-2-1	All Weather Microwave	Low/High	3.6
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost (\$ X 10^6)		
			Power Subsystem Cost (\$ X 10^6)		
			Total Program Cost (\$ X 10^6)		
Earth and Ocean Monitoring		CO2-1-1	Operational SEASAT	Low/High	4.1
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost (\$ X 10^6)		
			Power Subsystem Cost (\$ X 10^6)		
			Total Program Cost (\$ X 10^6)		
Earth Resources	U.S. Domestic	CO3-1-1	U.S. Government LEO	Low/High	1.6
	Foreign	CO3-2-1 -2 -3	SPOT SPOT Follow-on ETS-III	Low/High Low/High Low/High	1.5 1.6 0.98
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost (\$ X 10^6)		
			Power Subsystem Cost (\$ X 10^6)		
			Total Program Cost (\$ X 10^6)		
Weather Monitoring	Weather	CO4-1-1 -2 -3	TIROS TIROS Follow-on NOAA Follow-on	Low/High Low/High Low/High	-- 1.2 1.5
	Foreign Meteorology	CO4-2-1 -2 -3	METEOSAT METEOSAT Follow-on GEO Meteorol. Sat (GMS)	Geosync. Geosync. Geosync.	-- 0.46 --
			Beginning of Life Power (kW0		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost (\$ X 10^6)		
			Power Subsystem Cost (\$ X 10^6)		
			Total Program Cost (\$ X 10^6)		

FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
										1		1		1						
	2	1																		
						1						1								
	1					4				1		4		2						
	.6	.3				1						1								
7	3		1	4	5	2		3	3	1	4	1	2				16	20	36	2.1
71	41	7	13	60	68	21	10	45	51	40	52	28	22	8			228	309	537	32
											2	1			2	1				
											8	4			8	5				
											1.4	.8			1.4	.8				
								1	6	9	4	1	2	6	4	1	8	26	34	2.0
								16	94	137	75	12	34	89	61	13	137	364	531	31
				1	1	1	1	2	2	2	2	3	3	3						
				1			1													
										1			1							
				1																
				5	1	2	2	4	3	5	3	5	6	5						
				.8	.3	.3	1	1	1		1	1	2	1						
		4	12	3	2	4	4	6	7	5	6	7	5	1			17	49	66	3.9
		60	134	63	32	48	48	71	99	71	72	85	55	13			229	622	851	50
1	1	1	1	1	1	1														
							1	1	1	1	1	1	1	1	1	1				
			1				1				1				1					
1	2	1	1	1	1	2	3	1	2	1	2	1	2	1	1					
.3	.2			.3	.2	.2	1.0	1.0				.3	.3	.3	1.0	.3				
2	4	6	3	3	3	6	2	2	3	3	3	2	2	2			11	35	46	2.7
35	55	76	51	44	77	78	44	31	37	44	36	32	29	21	5		175	526	695	41

Figure 3.6 Traffic Model - Non-NASA/Non-DoD Observation (Nominal Budget)

2

FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
International Commun.		CC1-1-1	INTELSAT V	Geosync.	1.44
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
U.S. Domestic Communications		CC2-1-1	TDRS/WESTAK	Geosync.	0.98
		-2	COMSTAR	"	1.04
		-4	WESTAR	"	0.35
		-5	RCA SATCOM	"	0.94
		-6	RCA Follow-on	"	0.96
		-7	MARISAT Follow-on	"	0.40
		-8	AM. SAT. Corp (ASC)	"	0.59
		-9	SAT BUS SYST (SBS)	"	0.49
		-11	Public Service	"	1.19
		-12	Image Transmission	"	1.91
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Foreign Communication		CC3-1-1	Arab Comsat (ARCOMSAT)	Geosync.	0.42
		-2	ARCOMSAT Follow-on	"	0.49
		-3	Orbital Test Sat (OTS)	"	0.41
		-4	Eurocomsat (ECS)	"	0.41
		-5	ECS Follow-on	"	0.42
		-6	MAROTS	"	0.40
		-10	SYMPHONIE-3	"	0.48
		-11	AMSAT	"	0.08
		-12	APPLE	"	0.36
		-13	Indian Sat (INSAT)	"	0.42
		-14	INSAT Follow-on	"	0.47
		-15	PALAPA	"	0.48
		-16	PALAPA Follow-on	"	1.20
		-17	IRAN	"	0.40
		-18	IRAN Follow-on	"	0.56
		-19	SIRIO	"	--
		-20	SIRIO Follow-on	"	0.38

FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
1	3																			
1	5																			
.6	1.7																			
8	2																0	10	10	0.6
115	77																0	192	192	11.3
	2	2	1			1			2			1				2				
1																				
				1																
1																				
			1	2						1	2				2	1				
								2	1											
								1	1											
							2	1												
								1							1					
											1	2								
2	2	2	2	3		1	1	3	2	1	4	5			2	4				
.8	.7	.7	.7	.9		.4	.6	1.6	1.3	.3	1.4	1.8			1.4	1.1				
8	5	7	4	2	4	15	20	10	6	9	7	1	2	7	9	7	49	74	123	7.2
122	80	79	56	22	56	145	181	128	115	135	106	34	34	94	124	98	474	1134	1609	95
		1	1																	
									1	1						1				
		1	1																	
					1	1						1	1							
1																				
	1																			
1																				
	1																			
		1	1																	
									1	1						1				
					1	1							1	1						
		2	1																	
									2	1						2				
						1								1						

Figure 3.7 Traffic Model - Non-NASA/Non-DoD Communications (Nominal Budget)

2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Foreign Communication (cont'd)		CC3-1-21	NORDSAT	Geosync.	0.40
		-22	NORDSAT Follow-on	"	0.42
		-23	BRAZILSAT	"	0.59
		-24	BRAZILSAT Follow-on	"	0.62
		-25	NATO III	"	--
		-26	NATO Follow-on	"	0.64
		-27	Eng. Test Sat (ETS-II)	"	--
		-28	ETS IV	"	0.08
		-29	Comm. Sat. (CS)	"	--
		-30	CS Follow-on	"	0.57
		-31	Brdcst Sat. Exp. (BSE)	"	--
		-32	BSE Follow-on	"	1.19
		-33	Exp. Comm. Sat. (ECS)	"	0.42
		-34	TELESAT-B	"	--
		-35	TELESAT-C	"	0.64
		-36	TELESAT-D	"	0.28
		-37	TELESAT Follow-on	"	0.68
		-38	UHF	"	0.42
		-39	Canadian Direct Brdcst	"	1.41
		-40	Other Regional	"	0.59

Beginning of Life Power (kW)
Solar Array Weight (lb)
Power Subsystem Weight (lb X 10^3)
Solar Array Cost ($ X 10^6)
Power Subsystem Cost ($ X 10^6)
Total Program Cost ($ X 10^6)

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
			1	1																
										1	1									
					1	1														
													1	1						
				2	1						2	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	1						1	1				
				1				1				1				1				
	1	1	5	4	3	4	1	2	3	4	2	3	5	4	3	3				
	1		2	2		3		3	3	2	2			2	1					
28	33	33	36	27	18	8	13	26	17	11	15	17	11	9	13	14	130	299	329	19.4
260	312	295	308	284	187	121	156	219	159	99	130	173	135	109	149	119	1225	1990	3215	189

Figure 3.7 Traffic Model - Non-NASA/Non-DoD Communications (Nominal Budget) cont.

2 FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
U.S. Domestic		CP1-1-1	Multipurpose Payload	Low/Low	4.2
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Foreign		CP2-1-1	GEOS	Geosync.	0.18
		-2	GEOS 2	Geosync.	0.18
		-3	EXOSAT	Ellip/High	0.30
		-4	UK-6	Low/Int.	0.04
		-5	IRAS	Low/High	0.56
		-6	French Scientific	Various	0.50
		-7	European Scientific	Various	0.55
		-8	Canadian Scientific	Various	0.04
		-9	MST-3	Ellip/High	0.03
		-10	ISS Replacement	Low/Int.	0.03
		-11	TAIYO Replacement	Ellip/Low	0.02
		-12	EXOS A	Ellip/Int.	0.03
		-13	EXOS B	Ellip/Low	0.02
		-14	ASTRO A	Low/Low	0.04
		-15	ASTRO B	Low/Low	0.04
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
						1	1	1	1	1	1	1	1	1						
						4	4	4	5	4	4	4	4	4						
						1		1	1		1	1	1							
				3	7	6	4	3	4	4	4	4	2	1			8	34	42	2.5
				19	43	31	20	21	20	21	20	21	15	3			51	183	234	14
	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																		
		1			1		1	1		1	2	1		1						
							1	2		1										
10	14	8	3	7	4	3	3	2	2	5	4	1	3	2	3		29	45	74	4.4
116	148	70	44	57	36	24	36	29	44	41	32	26	43	37	29	6	215	603	818	48

Figure 3.8 Traffic Model - Non-NASA/Non-DoD Scientific (Nominal Budget)

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Earth Resource Monitoring	Automated	NO1-1-1	Landsat Follow-on	Low/Low	1.3
		-2	Earth Survey Satellite	Low/High	1.2
		-3	Sync. Earth Obs. Sat (SEOS)	Geosync.	1.2
		-4	GRANSAT	Low/High	0.35
		-5	MAGSAT B	High/Low	0.18
		-6	SMIAS		1.1
		-7	HCMM Follow-on		1.1
		-8	STEREOSAT		0.34
	Spacelab	NO1-2-1	Spacelab Payloads	Low/Int.	7.5
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Environmental	Automated	NO2-1-1.	SEASAT-B	Low/High	3.5
		-2	Environ. Monitoring Sat.	Low/High	1.8
		-3	HALOE		1.3
		-4	STORMSAT	Geosync.	1.4
		-5	ERBSS		0.47
	Spacelab	NO2-2-1	ACPL	Low/Low	1.9
		-2	Spacelab Payloads	Low/High	3.0
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
		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					
			1	1	1	1	1	1	1	1	1	1	1	1	1	1				
		1	2		2	1	2	3		2	2	3	1	3	1	4				
		100	200			100	200	100		100	100	200	100	200	100					
		.3	.8		.2	.2	.6	.9	.3	.6	.4	.6	.4	.5	.2	.9				
1	2	1			2	4	2	2		1			2	3			8	12	20	1.2
3	9	6		3	7	8	8	9	3	5	3	2	4	3	4	3	30	50	80	4.7
82	176	163	63	76	136	157	136	123	94	86	77	73	72	73	93	52	566	1166	1732	102
		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	1	1	1	1	1	1	1	1	1	1	1	1	1				
	1	3		2			2	1			3			1	2					
	70	190		140			100	80			180			80	100					
	.2	.6		.5		.4	.5				.7			.5	.4					
2	2	1	1	2		1	2						2				7	6	13	0.8
7	6	4	4	4	1	5	2	2	1	3	2		2	2	1	2	23	25	28	1.6
116	107	74	72	35	27	69	61	26	24	45	23	17	35	36	23	26	344	472	216	48

Figure 3.9 Traffic Model - NASA Observation (Optimistic Budget)

2

FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Intergovernment Links		NC1-1-1	Hotline	Geosync.	2.0
		-2	Intergovernment - I	Geosync.	2.0
		-3	Intergovernment - II	Geosync.	3.5
		-4	Intergovernment - III	Geosync.	5.0
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Gov't to People Links		NC2-1-1	Voting/Polling - I	Geosync.	1.0
		-2	Voting/Polling - II	Geosync.	50
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
People to People Links		NC3-1-1	Personal Comm.	Geosync.	10
		-2	Teleconferencing - I	Geosync.	25
		-3	Teleconferencing - II	Geosync.	100
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
		1					1					1								
				1					1					1						
					1					1					1					
								1					1							
		2		2	3		2	5	2	4		2	5	2	3					
		110		110	190		110	280	110	190		110	280	110	190					
		.5		.5	.7		.6	.8	.6	.7		.5	.8	.5	.7					
	3	2	3	1	1	2	3	2		1		2	1	2			9	14	23	1.4
3	7	7	7	5	6	6	6	4	3	2	3	5	4	3	1		29	43	72	4.2
84	222	218	208	130	152	192	186	146	98	54	95	137	126	91	24		841	1372	2213	130
							1				1				1					
														1						
							1				1			50	1					
							60				60			1380	60					
							.5				.5			2.2	.5					
					1				1	1	3	6	5	3			12	8	20	1.2
				1	2	3	1			4	6	10	10	5			24	18	42	2.5
				17	52	54	16	6	12	60	127	201	210	95	7		474	383	857	50
			1					1				1				1				
										1				1						
												1								
			10					10		25		110		25		10				
			500					600		800		2900		800		600				
			1.1					1.1		1.6		4.1		1.6		1.1				
1	3	3				2	4	6	9	11	11	5	3	2	5	7	28	42	72	4.2
4	6	5	3			2	9	10	16	17	16	9	5	3	9	10	51	73	124	7.3
112	174	169	62		6	92	235	288	359	367	360	189	132	102	181	197	1213	1812	3025	178

Figure 3.10 Traffic Model - NASA Communications (Optimistic Budget)

2

FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Intra Gov't Links	Routine	NC4-1-1	Electronic Mail - I	Geosync.	5.0
		-2	Electronic Mail - II	Geosync.	15
	Emergency	NC4-2-1	Emergency - I	Geosync.	2.0
		-2	Emergency - II	Geosync.	5.0
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Entertainment/Commercial Links		NC5-1-1	TV Broadcast - I	Geosync.	10
		-2	TV Broadcast - II	Geosync.	40
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

NEAR-TERM							MID-TERM										CCSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
					1				1					1						
							1				1				1					
	1							1						1						
			1							1						1				
	2		5		5		15	2	5	5	15		5	2	15	5				
	110		280		280		690	110	280	280	690		280	110	690	280				
	.5		.8		.8		1.3	.6	.8	.8	1.3		.8	.5	1.3	.8				
3	1	3	2	5	3	3	2	1	3	2	1	1	2	4		1	13	24	37	2.2
8	7	8	6	10	7	8	6	4	6	5	3	4	5	6	5	1	37	62	99	5.8
230	216	220	219	239	221	195	155	145	160	137	82	113	134	161	119	29	1017	1759	2776	163
				1				1			1		1			1				
										1		1				1				
				10				10		40	10	40	10			50				
				500				600		1100	500	1100	600			1600				
				1.1				1.1		2.0	1.1	2.0	1.1			3.1				
1	1	3	3			2	5	5	5	6	5	2	1	3	5	1	14	34	48	2.8
1	4	6	5	2		4	9	10	11	10	9	5	2	4	10	3	30	65	95	5.6
29	94	144	139	50	6	80	207	225	232	212	187	125	42	95	201	70	678	1460	2138	126

2

Figure 3.10 Traffic Model - NASA Communications (Optimistic Budget) cont.

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Space Processing	Spacelab	NS1-1-1	Space Processing	Low/Low	5.0
		-2	Spacelab R&D Facility	Low/Low	10
	Space Station	NS1-2-1	Extended Mission Vehicle	Low/Low	5.5
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Space Industrialization		NS2-1-1	Early Space Constr. Base	Low/Low	25.
		-2	ESCB Resupply	Low/Low	1.0
		-3	Adv. Space Constr. Base	Low/Low	60
		-4	ASCTS Resupply	Low/Low	1.0
		-5	Space Manufac. Facility	Low/Low	100
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Orbital Operations		NS3-1-1	Large Struc. Deployment	Low/Low	10
		-2	Skylab Revisit	Low/Low	1.0
		-3	Tethered Sat. Op.	Low/Low	0.5
		-4	Satellite Retrieval	Low/Low	1.0
		-5	Shuttle External Tank Usage	Low/Low	1.0
		-6	Launch Retrieval & Refueling of Upper Stages	Low/Low Low/Low	1.0
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
													1							
													6							
													310							
													.9							
												2	3				3	2	5	0.3
										1	5	5	2				9	4	13	0.8
										24	113	127	40				200	104	304	18
						1														
							1	1	1	1	1	1	1	1	1	1				
										1										
									1	1	1	1	1	1	1	1				
						1														
						25				60										
						800				1600										
						1,6				2,4										
		1	2	3	5	2	4	6	6	3							19	13	32	1.9
		1	5	7	8	5	6	11	11	4							36	22	58	3,4
		200	600	1102	1225	625	510	994	1122	435	54	54	54	54	53	33	3650	3465	7115	418
		1		1		1					1		1	1						
		1			1			1												
	1																			
			1		1		1						1		1					
			1																	
			1						1						1					
	25	10		10		10					10		10	10						
	820	550		550		550					550		550	550						
	1,6	1,1		1,1		1,1					1,1		1,1	1,1						
10	5	1	2	1	2	1			1	1	2	2	3				10	21	31	1.8
19	10	4	4	2	4	1			2	3	3	5	5	1			24	39	63	3.7
179	123	63	50	43	49	17	5	4	26	48	41	74	68	20	1	1	261	551	812	48

2

Figure 3.11 Traffic Model - NASA Support (Optimistic Budget)

FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Satellite Power		NS4-1-1	25 kW Power Module	Low/Low	25
		-2	250 kW Power Module	Low/Low	250
		-3	2 MW Power Module	Geosync.	2x10^3
		-4	15 MW Power Module	Geosync.	15x10^3
		-5	1.2 GW Power Module	Geosync.	12x10^5
		-6	10 GW Power Station	Geosync.	10x10^6

Beginning of Life Power (kW)
Solar Array Weight (lb X 10^4)
Power Subsystem Weight (lb X 10^3)
Solar Array Cost ($ X 10^6)
Power Subsystem Cost ($ X 10^6)
Total Program·Cost ($ X 10^6)

FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
			1																	
						1														
									1											
													2	2	1	2				
			25			250			2000				30000	30000	15000	30000				
			8			31			222				2140	2140	1070	2140				
			1.6			6.2			46.3				428	428	214	428				
	1	7	4	9	27	32	50	59	50	82	254	553	571	456	646	646	365	3082	3447	203
	2	12	10	17	59	72	101	111	92	155	436	914	934	744	1052	1051	726	5036	5762	338
	3	19	15	19	61	72	105	117	92	155	488	1031	1038	841	1201	1162	738	5681	6419	378

Figure 3.11 Traffic Model - NASA Support (Optimistic Budget) cont.

2 FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Astrophysics	Automated	NP1-1-1	Space Telescope	Low/Low	1.5
		-2	HEAO-D	Low/Low	2.7
		-3	HEAO-E	Low/Low	2.7
		-4	VLBI	(a) Escape (b) High/Low	(a) 0.21 (b) 0.3
		-5	Gravity Wave Detector	Low/Low	0.57
		-6	Gravity Probe B/C	Low/High	0.35
		-7	Adv. Relativity Exp.	Low/High	0.35
		-8	Explorer	Geosync.	0.18
	Spacelab	NP1-2-1	P.I. S/L Payloads	Low/Low	6.2
		-2	SIRTF	Low/Low	1.2
		-3	SUOT	Low/Low	0.72
		-4	IR Interferometer	Low/Low	1.8
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Solar Terrestrial	Automated	NP2-1-1	Solar Max. Missions	Low/Low	0.94
		-2	Out-of-eclip. Solar Obs.	Escape	0.22
		-3	Explorer (Delta Class)	Geosync.	0.31
		-4	Explorer (Scout Class)	Geosync.	0.22
		-5	Large Solar Observatory	Low/Low	2.7
	Spacelab	NP2-2-1	Solar Terr. S/L Payloads	Low/Low	3.0
		-2	Solar/Stellar IM Obs.	Low/Int.	2.9
		-3	Solar Physics S/L Block II	Low/Int.	2.7
		-4	AMPS	Low/Int.	3.9
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

FOLDOUT FRAME

	NEAR-TERM							MID-TERM										COSTS ($M)			
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
					1				1							1					
				1		1		1				1									
							1		1				1			1					
.38								1(a)			1 (b)			1 (a)			1 (b)				
								1		1		1									
					1				1												
													2								
		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	1	1	1	1	1				
				1	1	1	1	1	1	1	1	1	1	1	1	1	1				
									1												
				3	2	2	3	4	4			4	4			5	1				
		20		170	150	150	150	210	300	30	60	180	270	30		240	60				
		.1		1.2	1.3	1.0	1.1	1.5	2.3	.2	.3	1.1	1.5	.2		2.1	.2				
		2	2	3	3	3	2	1	1	2	2	1	1	2				10	15	25	1.5
	4	7	13	17	11	11	12	10	4	5	8	8	3	2	6	3	1	48	77	125	7.4
	27	57	119	168	126	104	140	112	56	56	94	107	52	40	65	35	10	494	874	1368	80
					1		1		1		1		1		1		1				
					1																
	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2				
	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2				
												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	1	1	1	1	1	1	1	1	1				
					1	2	2	2	2	2	2	2	2	2	2	2	2				
		1	1		1	1	2	1	1	2	1	5	2	1	2	1	2				
	80	80	80	80	160	80	130	160	210	160	210	310	210	160	210	160	210				
	.4	.3	.3	.3	.8	.4	.6	.6	1.0	.6	.9	2.4	.8	.8	.9	.7	.9				
	1	1		2	2	1	1	2		3	4		2	1	2	1	1	5	19	24	1.4
	4	4	3	8	5	5	5	5	9	12	16	7	5	7	5	7	2	27	82	109	6.4
	41	31	49	76	69	57	62	68	78	131	133	88	65	68	65	61	34	209	967	1176	69

Figure 3.12 Traffic Model - NASA Scientific (Optimistic Budget)

2

FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Life Sciences	Automated	NP3-1-1	BESS	Low/Low	1.1
		-2	Vestibular Func. Research	Low/Low	1.1
	Spacelab	NP3-2-1	Life Sciences Dedicated Lab	Low/Low	3.7
		-2	Mini-Lab (Multi-Mission)	Low/Low	1.1
		-3	Carry-on Lab (" ")	Low/Low	1.1
		-4	KOSMOS	Low/Low	1.6
	Space Station	NP3-3-1	Research Module	Low/Low	5.2

Beginning of Life Power (kW)
Solar Array Weight (lb)
Power Subsystem Weight (lb X 10^3)
Solar Array Cost ($ X 10^6)
Power Subsystem Cost ($ X 10^6)
Total Program Cost ($ X 10^6)

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
			1	1	2	1														
		1																		
		2	2	2	2	2														
		2	2	2	2	2														
		2	2	2	2	2														
	1																			
							1													
		1	1	1	2	2	5													
		60	60	60	120	60	300													
		.3	.3	.3	.6	.3	.9													
1	1	1		1	2	4											5	5	10	.6
2	4	3	3	4	6	5	2										15	14	29	1.7
99	173	138	102	128	178	139	40										449	548	997	59

Figure 3.12 Traffic Model - NASA Scientific (Optimistic Budget) Cont.

2

FOLDOUT FRAME

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Planetary		NL1-1-1	JUP	Escape	0.57
		-2	VOIR	Escape	1.43
		-3	Mercury Orbiter/SEPS	Escape	0.74
		-4	Saturn-Uranus Probe	Escape	0.30
		-5	Dual Comet Flyby	Escape	1.07
		-6	Sat. Orb/Tit. Lander	Escape	1.27
		-7	Mars Polar Orbiter	Escape	0.89
		-8	Follow-on Jupiter (SEPS)	Escape	0.82
		-9	Encke Rendezvous (SEPS)	Escape	0.78
		-10	Multi-Asteroid (SEPS)	Escape	0.78
		-11	Jupiter Swing by	Escape	0.52
		-12	Mars Surf. Sample Return	Escape	1.59
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Lunar		NL2-1-1	Lunar Orbiter	Escape	0.59
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
								1					1							
						1								1						
							1									1				
					1	1									1	1				
						2									1					
										1										
							1									1				
								1												
									1											
											1									
												1								
												1								
						4	2		1		1	3		2	1	1				
					30	230	90		40		40	120		80	90	120				
					.2	1.7	.6		.3		.3	1.0		.9	.5	.7				
				1	3			1	1	1	1	1					6	3	9	0.5
			2	10	16	8	2	3	4	8	6	4	5	4	4	1	41	36	77	4.5
		6	45	144	255	247	193	185	183	199	171	107	69	88	78	20	883	1107	1990	117
	1																			
	1																			
	30																			
	.2																			
3																	2	1	3	0.2
41	14																24	31	55	3

Figure 3.13 Traffic Model - NASA Planetary and Lunar (Optimistic Budget)

FOLDOUT FRAME 2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Environmental Monitoring	U.S. Domestic	CO1-1-1	Environmental Monitoring Satellite (EMS)	Low/High	1.2
		-2	GOES	Geosync	0.44
		-3	GOES Follow-on	Geosync	0.58
	Foreign	CO1-2-1	All Weather Microwave	Low/High	3.6
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Earth and Ocean Monitoring		CO2-1-1	Operational SEASAT	Low/High	4.1
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Earth Resources	U.S. Domestic	CO3-1-1	US Government LEO	Low/High	1.6
		-2	Private Industry LEO	Low/High	1.6
		-3	US Government GEO	Geosync	0.99
		-4	Private Industry GEO	Geosync	0.99
	Foreign	CO3-2-1	SPOT	Low/High	1.5
		-2	SPOT Follow-on	Low/High	1.6
		-3	ETS-III	Low/High	0.98
		-4	Earth Observation	Low/High	0.98
		-5	ESA - GEO	Geosync	0.93
		-6	Other - GEC	Geosync	0.93
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

FOLDOUT FRAME

1

FOLDOUT

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
										1		1		1						
	2	1																		
					1	1	1		1	1	1		1	1						
						1						1								
	1				1	4	1			2		4	1	3						
	.6	.3			.4	1.0	.3		.4	.7	.4	.9	.4	.6						
7	3		3	10	9	4	1	5	6	3	5	4	4				23	41	64	3.8
71	41	8	39	122	112	44	25	69	81	62	67	52	43	14			298	552	850	50.0
											2	1	1	2	4	4				
											8	4	4	9	16	16				
											1.4	.8	.7	1.4	2.9	2.9				
								1	6	9	5	6	14	19	18	13	17	74	91	5.4
								16	94	137	92	100	211	284	276	192	265	1157	1402	82
				1	1	1	1	2	2	2	2	3	3	3						
						1			1		1		1							
											1		1							
												1		1						
				1			1													
										1			1							
				1																
						1		1		1		1		1						
												1	1							
														1						
				5	1	5	2	6	4	6	6	9	9	8						
				.8	.3	1.0	.6	.8	1.0	1.2	1.4	2.0	2.3	1.9						
		4	12	7	9	6	7	7	12	14	17	16	13	3			42	85	127	7.5
		60	134	112	135	92	72	106	167	220	264	235	170	45			592	1220	1812	107

ERAME 2

Figure 3.14 Traffic Model - Non-NASA/Non-DoD Observation (Optimistic Budget)

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Weather Monitoring	Weather	CO4-1-1	TIROS	Low/High	--
		-2	TIROS Follow-on	Low/High	1.2
		-3	NOAA Follow-on	Low/High	1.5
	Foreign Meteorology	CO4-2-1	METEOSAT	Geosync.	--
		-2	METEOSAT Follow-on	Geosync.	0.46
		-3	GEO Meteorol. Sat (GMS)	Geosync.	--
		-4	GMS Follow-on	Geosync.	0.81
		-5	Other	Geosync.	0.81

Beginning of Life Power (kW)
Solar Array Weight (lb)
Power Subsystem Weight (lb X 10^3)
Solar Array Cost ($ X 10^6)
Power Subsystem Cost ($ X 10^6)
Total Program Cost ($ X 10^6)

FOLDOUT FRAME

1

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
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			1			1			1						
1	2	2	2	1	2	2	4	1	2	1	3	1	2	3	1					
.3	.2	.5	.8	.3	.5	.2	.9	.5	.2	3	1.1	.3	.3	.8	.3					
3	9	10	3	4	4	7	4	3	3	5	5	2	4	3			17	52	69	4.1
70	142	160	83	71	104	111	73	50	61	9	61	57	72	34	5		306	937	1243	73

Figure 3.14 Traffic Model - Non-NASA/Non-DoD Observation (Optimistic Budget) cont.

FOLDOUT FRAME 2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
International Communication		CC1-1-1	INTELSAT V	Geosync.	1.44
		-2	INTELSAT V	Geosync.	1.44
		-3	INTELSAT VI	Geosync.	1.91
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
U.S. Domestic Communications		CC2-1-1	TDRS/WESTAK	Geosync.	0.98
		-2	COMSTAR	Geosync.	1.04
		-3	COMSTAR Follow-on	Geosync.	1.91
		-4	WESTAR	Geosync.	0.35
		-5	RCA SATCOM	Geosync.	0.94
		-6	RCA Follow-on	Geosync.	0.96
		-7	MARISAT Follow-on	Geosync.	0.40
		-8	AM. SAT. Corp. (ASC)	Geosync.	0.59
		-9	SAT BUS SYST (SBS)	Geosync.	0.49
		-10	SBS Follow-on	Geosync.	1.91
		-11	Public Service	Geosync.	1.19
		-12	Image Transmission	Geosync.	1.91
		-13	Hi Cap. Video Brdcst	Geosync.	0.64
		-14	Other U.S.	Geosync.	0.41
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
1	3																			
		3		3	3	2														
								2	2	2	1		1	2						
1	5	4		5	4	3		4	4	3	2		2	4						
.6	1.7	1.7		1.7	1.7	1.2		1.4	1.4	1.3	.7		.7	1.4						
14	10	6	9	9	7	5	7	7	6	3	1	4	4	1			13	60	93	5.5
192	198	89	120	119	94	99	131	117	86	51	35	55	64	17			178	1289	1467	86
	2	2	1			1			2			1				2				
1																				
				2	1					1					2	1				
				1																
1																				
			1	2						1	2									
								2	1						2	1				
								1	1											
							2	1												
						2	1	1				2	2	1						
								1							1					
											1	2								
								1												
					1		2		1		2		1							
2	2	2	2	7	2	5	4	6	3	3	4	8	5	2	5	6				
.8	.7	.7	.7	2.4	1.0	1.8	1.8	2.5	1.4	1.0	1.9	3.0	1.7	.7	2.3	2.4				
8	6	11	13	15	12	24	28	16	9	14	14	8	10	14	15	9	72	154	226	13
122	104	162	208	195	204	258	274	178	172	207	213	162	166	222	201	138	867	2319	3186	187

Figure 3.15 Traffic Model - Non-NASA/Non-DoD Communications (Optimistic Budget)

FOLDOUT FRAME 2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
Foreign Communication		CC3-1-1	Arab Comsat (ARCOMSAT)	Geosync.	0.42
		-2	ARCOMSAT Follow-on	"	0.49
		-3	Orbital Test Sat (OTS)	"	0.41
		-4	Eurocomsat (ECS)	"	0.41
		-5	ECS Follow-on	"	0.42
		-6	MAROTS	"	0.40
		-7	MAROTS Follow-on	"	0.42
		-8	TV Broadcast Sat (TVBS)	"	1.57
		-9	TVBS Follow-on	"	1.56
		-10	SYMPHONIE-3	"	0.48
		-11	AMSAT	"	0.08
		-12	APPLE	"	0.36
		-13	Indian Sat (INSAT)	"	0.42
		-14	INSAT Follow-on	"	0.47
		-15	PALAPA	"	0.48
		-16	PALAPA Follow-on	"	1.20
Foreign Communication (cont'd)		-17	IRAN	Geosync.	0.40
		-18	IRAN Follow-on	"	0.56
		-19	SIRIO	"	--
		-20	SIRIO Follow-on	"	0.38
		-21	NORDSAT	"	0.40
		-22	NORDSAT Follow-on	"	0.42
		-23	BRAZILSAT	"	0.59
		-24	BRAZILSAT Follow-on	"	0.62
		-25	NATO III	"	--
		-26	NATO Follow-on	"	0.64
		-27	Eng. Test Sat (ETS-II)	"	--
		-28	ETS IV	"	0.08
		-29	Comm. Sat. (CS)	"	--
		-30	CS Follow-on	"	0.57
		-31	Brdcst Sat. Exp. (BSE)	"	--
		-32	BSE Follow-on	"	1.19
		-33	Exp. Comm. Sat. (ECS)	"	0.42
		-34	TELESAT-B	"	--
		-35	TELESAT-C	"	0.64
		-36	TELESAT-D	"	0.28
		-37	TELESAT Follow-on	"	0.68
		-38	UHF	"	0.42
		-39	Canadian Direct Brdcst	"	1.41
		-40	Other Regional	"	0.59

Beginning of Life Power (kW)

Solar Array Weight (lb)

Power Subsystem Weight (lb X 10^3)

Solar Array Cost (\$ X 10^6)

Power Subsystem Cost (\$ X 10^6)

Total Program Cost (\$ X 10^6)

FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
		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																				
	1																			
		1	1																	
									1	1						1				
					1	1							1	1						
		2	1																	
									2	1						2				
						1								1						
			1	1																
										1	1									
					1	1														
													1	1						
				2	1						2	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	1						1	1				
				1				1				1				1				
2	1	1	6	6	3	4	2	3	3	4	2	5	5	5	3	4				
.8	1.0	2.1	1.7	2.6	1.4	1.9	.6	1.7	2.3	1.3	.9	2.0	1.5	2.1	.9	2.6				
31	38	39	39	29	20	10	15	27	17	12	16	20	13	10	14	15	143	222	365	21.5
311	365	369	373	308	209	149	186	229	165	114	164	19[illegible]	154	126	177	128	1397	2327	3724	219

Figure 3.15 Traffic Model - Non-NASA/Non-DoD Communications (Optimistic Budget) cont.

FOLDOUT FRAME 2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power kW)
Disaster Warning		CS1-1-1	Disaster Warning	Geosync.	4.2
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Traffic Management		CS2-1-1	INMARSAT	Geosync.	0.50
		-2	INMARSAT Follow-on	"	0.60
		-3	INATSAT	"	0.60
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		
Space Manufacturing	U.S. Domestic	CS3-1-1	Space Processing R&D	Low/Low	5.0
		-2	Com. Manuf-Develop.	Low/Low	10.0
		-3	-Deployment	Low/Low	15.0
		-4	-Servicing	Low/Low	1.0
	Foreign	CS3-2-1	Space Processing R&D	Low/Low	5.0
		-2	Com. Manuf-Develop.	Low/Low	10.0
		-3	-Deployment	Low/Low	15.0
		-4	-Servicing	Low/Low	1.0
		-5	Spacelab Science/Tech	Low/Low	3.8
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost ($ X 10^6)		
			Power Subsystem Cost ($ X 10^6)		
			Total Program Cost ($ X 10^6)		

FOLDOUT FRAME

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
								1	1				1	1						
								4	4				5	4						
								1.2	1.2				1.3	1.2						
					1	5	8	5	1		2	4	4	1			13	22	35	2.1
					11	46	58	36	7	1	12	31	27	7			81	155	236	14
				2	1															
												2	1							
							1	1					1	1						
							1	1	1	1		1	1	1						
							.3	.2	.6	.3		.7	.6	.2						
					1	3	4	8	3	2	7	5	2				13	22	35	2.1
				6	33	77	75	70	46	50	85	69	31	6			151	397	548	32
					1	3	5	6	8	9	9	9	9	9	9	9				
							1	2	1											
									1					1						
									1	3	3	3	3	3	6	6				
						1	2	2	2	2	2	3	3	3						
							1	2	2											
									1					1						
									1	3	3	3	3	3	6	6				
		1	1	1		1	1	1		1	1	1		1	1	1				
1	1	2	3	3	10	11	18	21	21	23	19	25	27	26	21	11	0	243	243	14

Figure 3.16 Traffic Model - Non-NASA/Non-DoD Support (Optimistic Budget)

FOLDOUT FRAME 2

FUNCTION		MISSION			
Category	Subcategory	Code	Title	Destination (Alt./Incl.)	Power (kW)
U.S. Domestic		CP1-1-1	Multipurpose Payload	Low/Low	4.2
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost (\$ X 10^6)		
			Power Subsystem Cost (\$ X 10^6)		
			Total Program Cost (\$ X 10^6)		
Foreign		CP2-1-1	GEOS	Geosync.	0.18
		-2	GEOS 2	"	0.18
		-3	EXOSAT	Ellip/High	0.30
		-4	UK-6	Low/Int.	0.04
		-5	IRAS	Low/High	0.56
		-6	French Scientific	Various	0.50
		-7	European Scientific	Various	0.55
		-8	Canadian Scientific	Various	0.04
		-9	MST-3	Ellip/High	0.03
		-10	ISS Replacement	Low/Int.	0.03
		-11	TAIYO Replacement	Ellip/Low	0.02
		-12	EXOS A	Ellip/Int.	0.03
		-13	EXOS B	Ellip/Low	0.02
		-14	ASTRO A	Low/Low	0.04
		-15	ASTRO B	Low/Low	0.04
		-16	Japanese Scientific	Various	0.04
			Beginning of Life Power (kW)		
			Solar Array Weight (lb)		
			Power Subsystem Weight (lb X 10^3)		
			Solar Array Cost (\$ X 10^6)		
			Power Subsystem Cost (\$ X 10^6)		
			Total Program Cost (\$ X 10^6)		

NEAR-TERM							MID-TERM										COSTS ($M)			
1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Acq	Ops	Total	Avg
						1	1	1	1	1	1	1	1	1	1	1				
						4	4	4	5	4	4	4	4	4	5	4				
						.7	.7	.7	.7	.6	.7	.7	.7	.7	.7	.7				
				3	7	6	4	3	4	4	4	4	5	9	5	3	16	45	61	3.6
				19	43	31	20	21	20	21	20	21	32	49	29	16	101	241	342	20
	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																		
			1	1	1	1	1	1	1	1	1	1	1	1	1	1				
		1	1	1	2	1	1	2	1	2	3	2	1	2		1				
	.4	.7	.4	.3	.7	.2	.4	.6	.1	.5	.6	.7	.2	.6	.3	.4				
10	14	10	5	9	4	4	4	3	4	6	5	1	4	4	4		32	59	91	5.4
116	169	120	83	83	63	51	63	57	69	68	59	53	71	63	48	11	271	976	1247	73

Figure 3.17 Traffic Model - Non-NASA/Non-DoD Scientific (Optimistic Budget)

FOLDOUT FRAME 2

The traffic models have no official approval, either of NASA or of DoD, and are intended to be representative only. Nevertheless, the component parts have been extracted from published documents in most cases. The traffic models represent low and high average budgetary levels for the following mission categories:

1. NASA Observation
2. NASA Communication
3. NASA Support
4. NASA Scientific
5. NASA Planetary
6. DoD Surveillance
7. DoD Communication
8. DoD Navigation and Meteorology
9. DoD Weaponry
10. Non-NASA/Non-DoD Communication
11. Non-NASA/Non-DoD Observation
12. Non-NASA/Non-DoD Support
13. Non-NASA/Non-DoD Scientific

The mission categories are themselves divided into groups of missions which have functional similarities. The entries in Figures 3-1 through 3-17 are extracted from the data included in Volume III to this report. (Appendices VI through IX)

3.3 ADVANCED SYSTEM SCENARIOS

3.3.1 Background

A very large number of initiatives was identified in the 1973 NASA Mission Model, the "Outlook for Space" study, The Aerospace Corporation study "Advanced Space Systems and Their Orbital Support Needs (1980-2000)," DoD planning studies, internal NASA studies and many others. The totality of these initiatives represents a formidable data bank of ideas which could be implemented in the next 20 years or so, if desired. The concepts identified span the entire technical and functional range from current programs to massive undertakings with enormous increases in required technology and launch and support facilities. They represent varying degrees of schedule, risk, funding requirements, and potential benefits and hazards.

In order to handle the literally hundreds of known initiatives, a rationale was established in an Aerospace Corporation study for NASA (Reference 2) for categorizing the initiatives into five generic groups or eleven subgroups, as listed in Table 3-1. The generic groups attempt to subsume each of the identified initiatives and are intended to be broad enough that other initiatives yet to be identified will be likely to fall within one of the groups. A natural progressive increase in capability can be postulated for each of the eleven groups, exemplified by the deployment of a series of space systems over a period of time, with each system having a considerable increase in capability over its predecessor (but not necessarily replacing its predecessor). The increase in capability and the time period between each launch impacts the needs for technology advancements, the launch vehicle and support facility needs, and the overall space program funding requirements.

The development plan for each group provides the development required to satisfy the initiatives contained within that group. An orderly step-by-step technology program is the primary determinant of the number of time-phased steps in each of the development plans. Each step is intended to culminate in demonstrated flight hardware capable of operational use; however, the operational option may not be exercised.

In the construction of the development plans it was found expedient to lump the low and high altitude optical concepts (Groups 4 and 6) together

Table 3-1. New Space Initiative Groupings

CATEGORY	NO.	INITIATIVE GROUPINGS*
		TITLE
INFORMATION	1	Public Service Systems Using Microwave Multibeam Antennas
	2	Public Service Systems Using Long Microwave Antennas
	3	Active/Passive Radar and Power Distribution Systems
	4	Observation and Designation Systems Using Optics at Low Altitude
	5	High Altitude Navigation, Location, and Relay Systems
	6	Observation Systems Using Synchronous Altitude Optics
PROCESSING	7	Space Processing and Manufacturing
ENERGY	8	Large Scale, High Energy, Far-Term Systems
SCIENCE	9	National Operations Facilities
	11	Scientific and Research Experiments
PLANETARY	10	Planetary

* Initiative groupings and designators are identical to those identified in "Integrated Planning Support Functions" (Study 2.7) Aerospace Report No. ATR-77(7378)-1 Vols. I and II June 1977, Contract NASW-2884

and also to combine the scientific and research experiments (Group 11) with the national operations facilities required to operate them (Group 9).

The construction of development plans in this manner provides maximum flexibility for dealing with an indeterminant future for the following reasons:

1. Each development plan is not linked to a single initiative, the need for which may change radically during the development time period.
2. The decision as to which initiative to promote can be delayed until late in the development schedule.
3. The unexpected need for crash programs is minimized.

3.3.2 Typical Initiatives

Some basic characteristics of typical initiatives that might be included in the various groups are listed in Tables 3-2 through 3-11. It should be noted that most of the initiatives are concepts only and that preliminary design information is in general not available. (The design of three advanced initiatives, viz: Personal Communications, Educational TV, and Electronic Mail are being examined by The Aerospace Corporation under contract to NASA in an ongoing study. Also NASA/Langley is initiating design studies of two large multipurpose public service satellites -- a Data Acquisition Platform (DAP) and an Information Service Platform (ISP). In addition, the Air Force has recently initiated the concept design phase for the orbital assembly of a large spacecraft, using space-based radar as a representative mission). However, in the case of the Information category of initiatives a small number of primary sensors or antennas can be identified which, in general, drive the raw power requirements. Other factors, of course, influence the type of power system design to satisfy those raw power requirements.

Table 3-2. Typical Group 1 Initiatives
(Public Service Systems Using Microwave Multibeam Antennas)

YEAR	IDENTIFICATION CODE	TITLE AND DESCRIPTION	GROUND		SPACE					
			ANTENNA DIAMETER OR TYPE	TRANSMITTED POWER	ORBIT	ANTENNA DIAMETER	NUMBER OF BEAMS	CHANNELS/ BEAMS	TRANSMITTED POWER	ELEC. POWER
1985	CC-10	Diplomatic/UN Hotlines Secure Conferencing 200 Heads of State	7 m	1 W	Sync	2 m	200	1	200 W	1 kW
1985	X-1	Telephone Long Line, High Capacity Long Line Service	10 m	500 W	Sync	10 m	50	1	25 kW	100 kW
1985	CC-9 1026 1027	Personal Communications Wrist Radio - 1	Stub	0,025 W	Sync	60 m	25	10^3	6 kW	21 kW
1985	CS-9	Energy Use Monitor, Transmits Power Data on Query	Steele	25 W Peak	Sync	60 m	100	10^3	6 kW	23 kW
1985	CS-14	Burglar Alarm, Sensors Transmit When Activated	Stub	0.25 W	Sync	60 m	500	10^3	Receive Only	1 kW
1985	CC-3	Disaster Communications Net	Stub	1 W	Sync	60 m	250	100	25 kW	75 kW
1987	MC-10	Military Communications Wrist Radio - 1	Helix	1 W	Sync	60 m	25	10^3	25 kW	100 kW
1990	CC-9	Personal Communications Wrist Radio - 2	Stub	0.025 W	Sync	70 m	1600	10^3	70 kW	21 kW
1990	X-2	Computer Long Line	3 m	500 W	Sync	25 m	200	1	100 kW	400 kW
1990	CC-11	Holographic Teleconferencing, Laser Holograms Transmitted	2 m	30 W	Sync	25 m	100	25	75 kW	220 kW
1990	CC-8	National Information Service - 1	2 m	0.05 W	Sync	25 m	10^3	100	5 kW	15 kW
1990	CC-6	Advanced TV Broadcast	1 m 3 m	Receive 1 kW	Sync	25 m	250	33	50 kW	150 kW
1990	X-3	Military Aircraft Communication	1 m	0.2 W	Sync	25 m	10^3	100	20 kW	75 kW
1990	X-4	Mobile Communication - Trunk	1 m	0.2 W	Sync	25 m	10^3	10^3	200 kW	750 kW
1990	CC-4	Electronic Mail Transmission	2 m	1 W	Sync	25 m	10^3	100	100 kW	15 kW
1990	CC-2	Police Wrist Radio Communication-1	Stub	1 W	Sync	25 m	200	100	20 kW	75 kW
1990	CC-7	Voting/Polling Wrist Radio	Stub	0.25 W	Sync	60 m	100	10^3	25 kW	90 kW

Table 3-3. Typical Group 2 Initiatives

(PUBLIC SERVICE SYSTEMS USING LONG MICROWAVE ANTENNAS WITH STATIONKEPT ANTENNAS)

YEAR	IDENTIFICATION CODE	TITLE AND DESCRIPTION	GROUND		SPACE				
			ANTENNA TYPE	TRANSMITTED POWER	ORBIT	ANTENNA SIZE	NUMBER OR ARRAYS	TRANSMITTED POWER	ELEC. POWER
1980	CS-16	Personal Nav - 1: Near Term. Two Orthogonal Sweeping Fan Beams. Time of Successive Passage Gives Location	Stub	Receive	Sync	50 x 0.3 m	2	200 W	1 kW
1990	CO-8	Border Surveillance. Narrow Beam Antenna Monitors Border Sensors	Stub	0.01 W	Sync	3000 x 3 m	1	Receive	20 kW
1990	CS-7	Personal Navigation - 2	Stub	Receive	Sync	4000 x 0.5 m	2	8 W	2 kW
1990	CC-12	Vehicle or Package Locator. Self-Location of Package by Personal Navigation System. Report Location on Query by Personal Communication	Stub	3 W Peak	Combination of Personal Nav. and Voting/Polling Wrist Radio				23 kW
1990	CS-10	Vehicle Speed Limit Control. Self-Location by Personal Navigation System. Speed Limit Instruction for Each Location by Comsat.	Stub						1 kW

Table 3-4. Typical Group 3 Initiatives (Power Distribution and Active/Passive Radars)

YEAR	IDENTI-FICATION CODE	TITLE AND DESCRIPTION	ORBIT	ANTENNA SIZE	TRANS-MITTED POWER	WEIGHT METRIC TON	NUMBER OF UNITS	RESOLU-TION (M)	SWATH (NMI)	ELEC. POWER
1980	XER-9	OFT-2 Radar - Geology	400 km				1	40	55	
1980	XER-11	OFT-5 Radar - Soil Moisture	400 km				1	100	200	
1985	XER-12	Spaceborne Imaging Radar	400 km					25	100	
1985	XER-17	Customized Orbital Imaging Radar, Small Free Flyer	400 km					25	100	
1985		Advanced Sea State Monitor			10 kW			25	200	
1985		Phased Array Radiotelescope - Terrestrial	600 km	30 x 30 m	None		1			
1985		Phased Array Radiotelescope - Astronomical, Multifrequency	600 km	30 x 30 m	None		1			
1985	CO-5	Multinational Air Traffic Control Radar - Diffracting Passive Element in Space to Obtain Large Area Over-Horizon Coverage From Ground-Based Radar	600 km	75 x 75 m	None	1.7	150			1 kW
1985	MO-16	Military Over-Horizon Radar Fence	500 km		None					
1987		Radar Ground Mapper - Urban/Rural Land Use	600 km		1 kW			100	200	
1990	2007 2008	Long Wavelength Microwave Systems - Passive Microwave Receiver 1.4 GHz for Terrestrial Geology (Phased Array Version)	600 km	100 x 100 m	None		1			
1990	CO-13	High Resolution Earth - Mapping Radar	400 km		1 MW	50	1	3	400	2.5 MW
1990		UN Truce Observation Imaging Radar	400 km		1 MW	50	1	3	400	
1995		Advanced Array Radar - Multifunction Capability	600 km		1 MW	60	4	3	1200	
2000		Coastal Passive Radar	Sync		2 MW		2			
2000		Power Relay Satellite	Sync							
2000	CS-8 1012 1013	Multinational Energy Distribution - Phase Controlled Reflectors Direct Microwave Power From Power Source to Users	600 km	225 x 5 m	None	15	200			20 kW
2000	1098	Large Scale Microwave Telescope	600 km	$10^3 \times 10^3$ Thinned	None		1			

Table 3-5. Typical Group 4 Initiatives

(Observation and Designation Systems Using Low Altitude Optics)

Year	Identification Code	Title and Description	Electrical Power
1985	CO-1	Advanced Resources/Pollution Observatory - Only Optical (Not Radar) Sensors Included; 2-m Multispectral Sensor	12 kW
1985	CO-4	Ocean Resources and Dynamics System - LWIR Sensor 3-m Optics	25 kW
1985	CO-6	U. N. Truce Observation Satellite - Visible and IR 2-m Optics; CCD Focal Plane	3 kW
1990	CO-11	Atmospheric Temperature Profile Sounder - Pulsed CO_2 Laser (1 kW); 10-cm Optics	5 kW
1982	XER-1	Landsat Follow-On	
1985	XER-2	Earth Survey Satellite	
1982	XER-6	Specialized Multispectral Imaging and Analysis System	
1982	XER-7	Heat Capacity Mapping Mission	
1986	XER-8	Sterosat	

Table 3-6. Typical Group 5 Initiatives

(High Altitude Navigation and Location Systems)

Year	Identification Code	Title and Description	Electrical Power
1980	MS	Global Positioning System (GSP)	1 kW
1985		TDRSS	600 W
1985	CO-7	Nuclear Fuel Locator	300 W
1985	CC-1	Global Search and Rescue Locator	1 kW
1985	CC-5	Transportation Services Satellites	600 W
1990		TDRSS Follow-On	1 kW

Table 3-7. Typical Group 6 Initiatives
(Observation Systems Using Synchronous Orbits)

Year	Identification Code	Title and Description	Electrical Power
1985	CO-2	Fire Detection - 3-m IR Optics CCD Mosaic Detector for Prompt Small Outdoor Fire Detection	2 kW
1985	CO-3	Water Level and Fault Movement Locator - Picosecond Pulsed Laser Used in Radar Mode for 0.3 nmi Range Resolution	250 W
1985	CO-12	Synchronous Meteorological Satellite - 1-m Visible Light Optics; Photocathode-CCD Detector	1 kW
1990	CS-6	Night Illuminator	1.2 kW
1990		Synchronous Landsat - 2-m Optics; 10-m Resolution	1 kW

Table 3-8. Typical Group 7 Initiatives
(Space Processing and Manufacturing)

Year	Identification Code	Title and Description	Electrical Power
1984	1014	Hazard Waste System - Development	
1985-1990	1015	Hazard Waste System - Operational	
1981-1987	1028	"Short Term" Physical Chemical Research - Crew Operated	
1987-1999	1029	"Long Term" Physical Chemical Research - Crew Operated	
1981-1987	1030	"Short Term" Low-g Material Science Research - Crew Operated	
1987-1999	1031	"Long Term" Low-g Material Science Research - Crew Operated	
1987-1999	1032	Commercial Processing - Crew Operated	
1981-1987	1033	"Short Term" Biological Materials Research - Crew Operated	
1987-1999	1034	"Long Term" Biological Materials Research - Crew Operated	
1981-1987	1039	Preliminary Disease Process Research - Crew Operated	
1987-1999	1040	Disease Process Research - Crew Operated	
1995	1117	Industrial Space Facility	
2000	4006	Synthesis of Living Matter in Labs	

Table 3-9. Typical Group 8 Initiatives

(Large Scale, High Energy, Far-Term Systems)

Year	Identification Code	Title and Description	Electrical Power
1995	CS-1	Energy Generation - Solar to Microwave	10 GW
1995	CS-2	Energy Generation - High Efficiency Solar Cells with Thin Film Mirror Concentrator	10 GW
2000	CS-3	Energy Generation - Nuclear to Microwave	10 GW
2000	X	Energy Generation - Solar Laser (for Space Use)	
2000	CS-5	Aircraft Laser Beam Powering	
1995	CS-4	Nuclear Waste Disposal	
2000	CS-12	Ozone Layer Protection	
2000+	X	Laser Beam Reflector System as Energy Common Carrier	

Table 3-10. Typical Group 9 Initiatives
(National Operations Facilities)

Year	Identification Code	Title and Description	Electrical Power
1990		National Microwave Detection Facility - Manned Used for solar, galactic, metagalactic radio astronomy, search for extraterrestrial radio signals, interplanetary microwave link, precise radar astronomy, passive microwave scanning of earth.	10 kW
2000	CO-10	National Space Telescope Facility - Manned Visible and near visible; also high energy radiation. Basic instrument is astronomical super-telescope, but other instruments are included, such as long base interferometers, large, low quality photon buckets, cosmic ray equipment, X-ray imaging telescopes. Used for celestrial and terrestrial observation.	10 kW

Table 3-11. Typical Group II Initiatives (Scientific and Research Experiments)

Year	1980	1980	1980	1983	1985	1985	1990	1990
Space Facility						National Research Facilities		
Scientific Field	Free-Flying LEO	Free-Flying Other Orbits	Shuttle	Spacelab	Tethered Shuttle	Biological Research Laboratory	Microwave Astronomical And Terrestrial Observatory	High-Energy Radiation Observatory (Add-On To Optical)
Astrophysics								
Solar-Terrestrial								
Life Sciences - Basic Biology			See Notes*					
Life Sciences - Biology and Human Physiology in Space Environment								
Fundamental Physics - Large Scale Laws								
Fundamental Physics - Small Scale Fundamental Interactions								
Basic Physics and Chemistry								

*NOTES:

- Initiatives Constitute Matrix Elements
- Typical Initiatives are: EOTVOS Effects Experiment (Outlook for Space No. 1064)
  Solar Maximum Mission (Extended Five-Year Plan No. X ST-1)
- All Matrix Elements are not Necessarily Represented by Viable Initiatives

3.3.3 Mission Scenarios

Development plans and the resulting prime power requirements are illustrated in Figure 3-18 through 3-26. In general, the required power levels increase monotonically within each generic group. An optimistic and conservative schedule is approximated for each operational capability step. Representative initiatives are listed and coded to indicate their source as follows:

(OFS) = The NASA "Outlook for Space" study (Reference 31)

(5-YP) = The NASA Five-Year Plan (References 14 and 15)

(A) = The Aerospace Corporation "Advanced Space Systems Concepts and Their Orbital Support Needs (1980-2000)" Study (Reference 1)

DEVELOPMENT, TEST AND DEMONSTRATION	• 10-ft Antenna (lens) • 50 Beams • 1000 x 1000 Switch • 1 kW RF Transmitters • 2000 lb • Launch assembled • Test in LEO, GEO	• 50-ft Antenna (lens) • 200 Beams • 50,000 x 50,000 Switch • 7 kW RF Transmitters • 5000 lb • Unfolded/Locked in Space • Test in LEO, then GEO	• 200-ft Antenna (lens) • 1600 Beams • 10^6 x 10^6 Switch • 70 kW RF Transmitters • 20,000 lb • Orbital Assembly in LEO • Test in LEO • Raise to GEO, re-test
RESULTANT CAPABILITIES	- Operate in GEO - Perform One Function Below, (or Time-Share) - Launch Additional Units for More Functions	- Operate in GEO - Perform One Function Below, (or Time-Share) - Launch Additional Units for More Functions	- Operate in GEO - Perform One Function Below, (or Time- Share) - Launch Additional Units for More Functions
	• All-Nation Hotline (A) • Search/Rescue (5 YP, OFS) • Mobile Telephony (5 YP, OFS) • Mobile Broadcast (5 YP, OFS) • Military Communications (A)	• Nuclear Fuel Locator(A) • Electronic Mail-High Density (OFS, 5 YP) • Rail Car Locator (A) • Personal, Police Communications Demonstration System (A) • Military Applications(A)	• Personal Communications (A, OFS) • Electronic Mail - Thin Route(A,OFS) • 3-D Teleconferencing (A) • Burglar/Intrusion Alarms (A) • Military Applications (A)
INITIATIVE GROUPS	1 A	1 B	1 C
ORBIT	SYNC	SYNC	SYNC
POWER LEVEL	4 kW	25 kW	210 kW
SCHEDULE (Optimistic/Conservative)	1983/1990	1987/1994	1992/1999

Figure 3-18. Group 1 Initiatives
(Public Service Platforms Using Microwave Multibeam Antennas)

C2

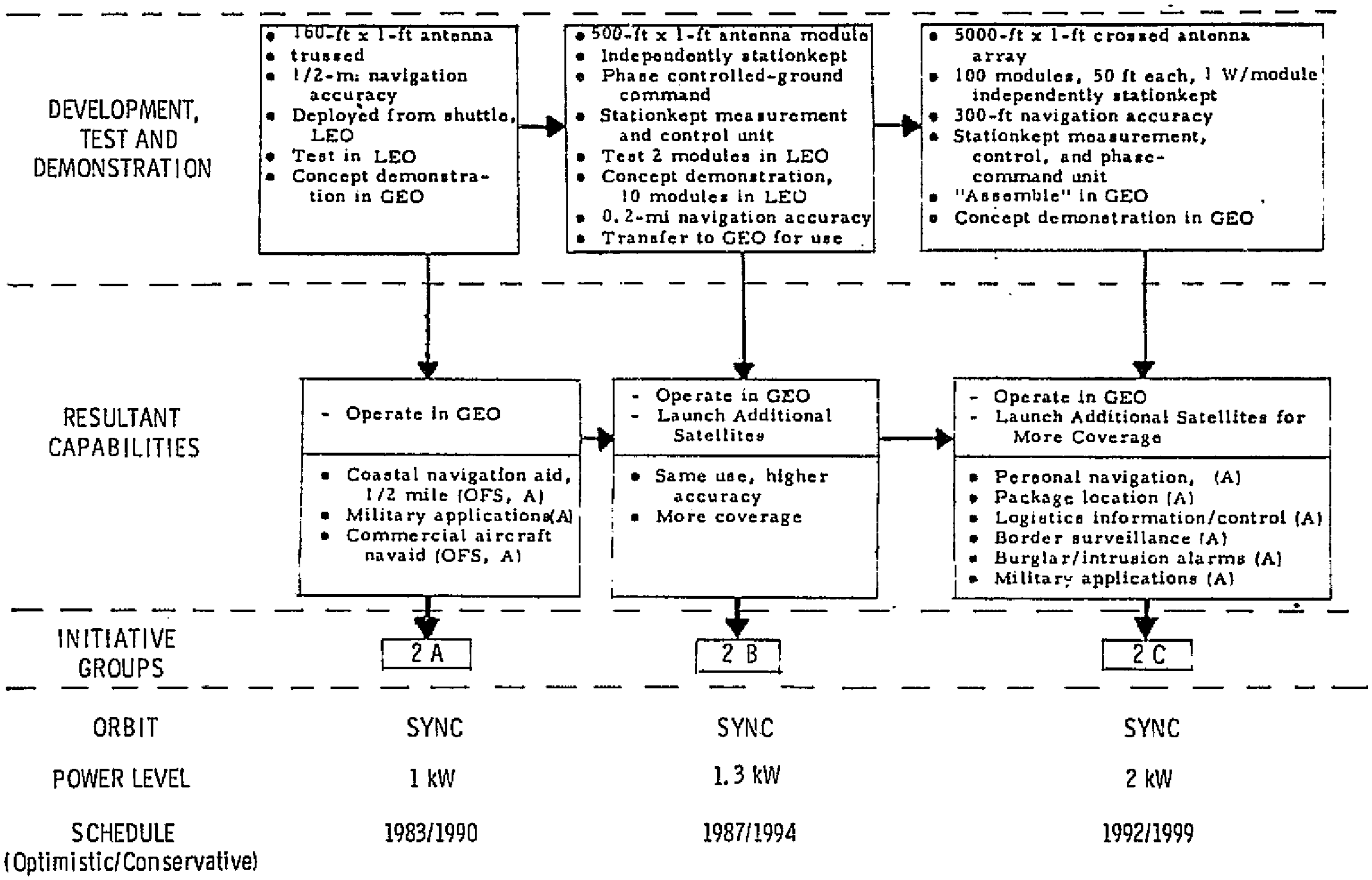
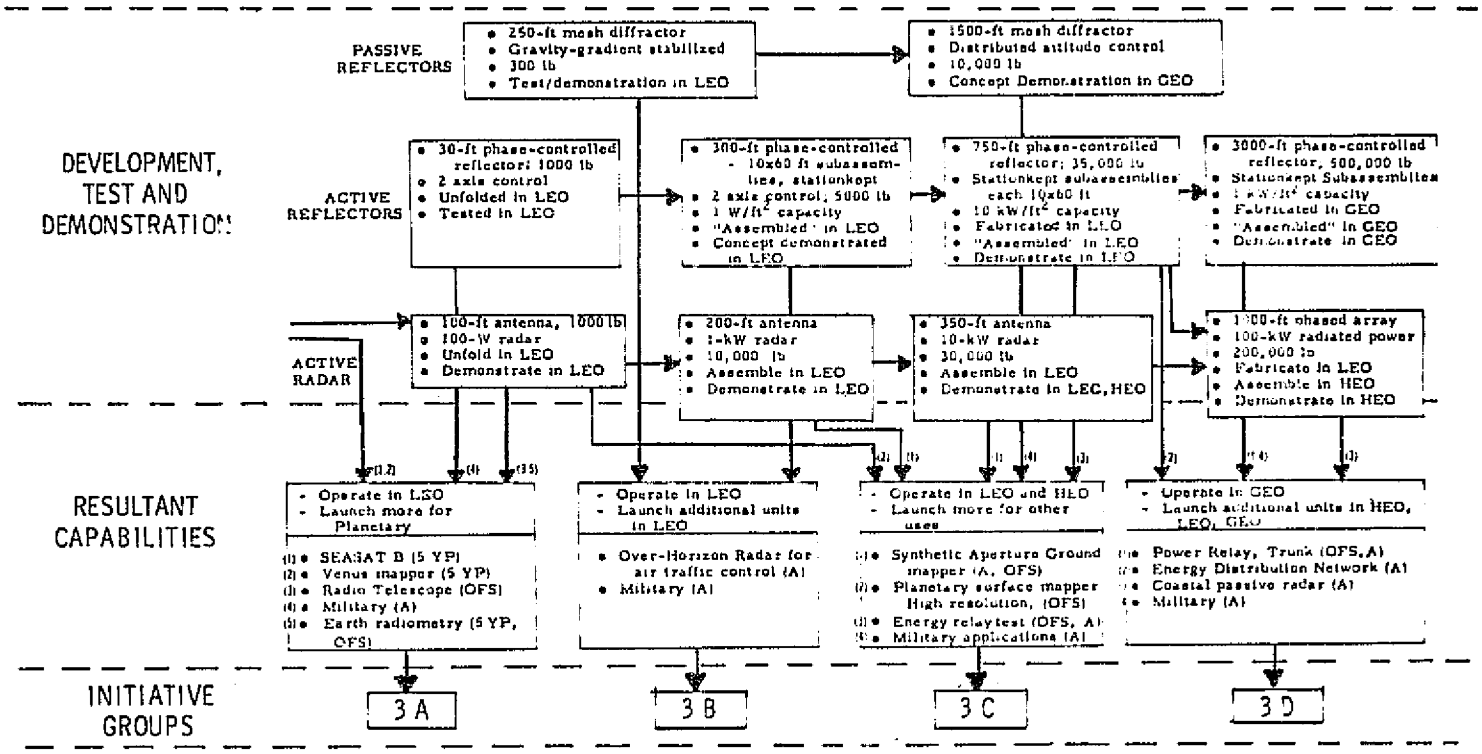


Figure 3-19. Group 2 Initiatives
(Public Service Systems Using Long Microwave Antennas with Stationkept Antennas)



ORBIT	LEO	LEO	LEO/HEO	LEO/GEO/HEO
POWER LEVEL	1 kW	5 kW	50 kW	300 kW
SCHEDULE (Optimistic/Conservative)	1982/1989	1986/1993	1990/1997	1994/2001

Figure 3-20. Group 3 Initiatives
(Power Distribution and Active/Passive Radars)

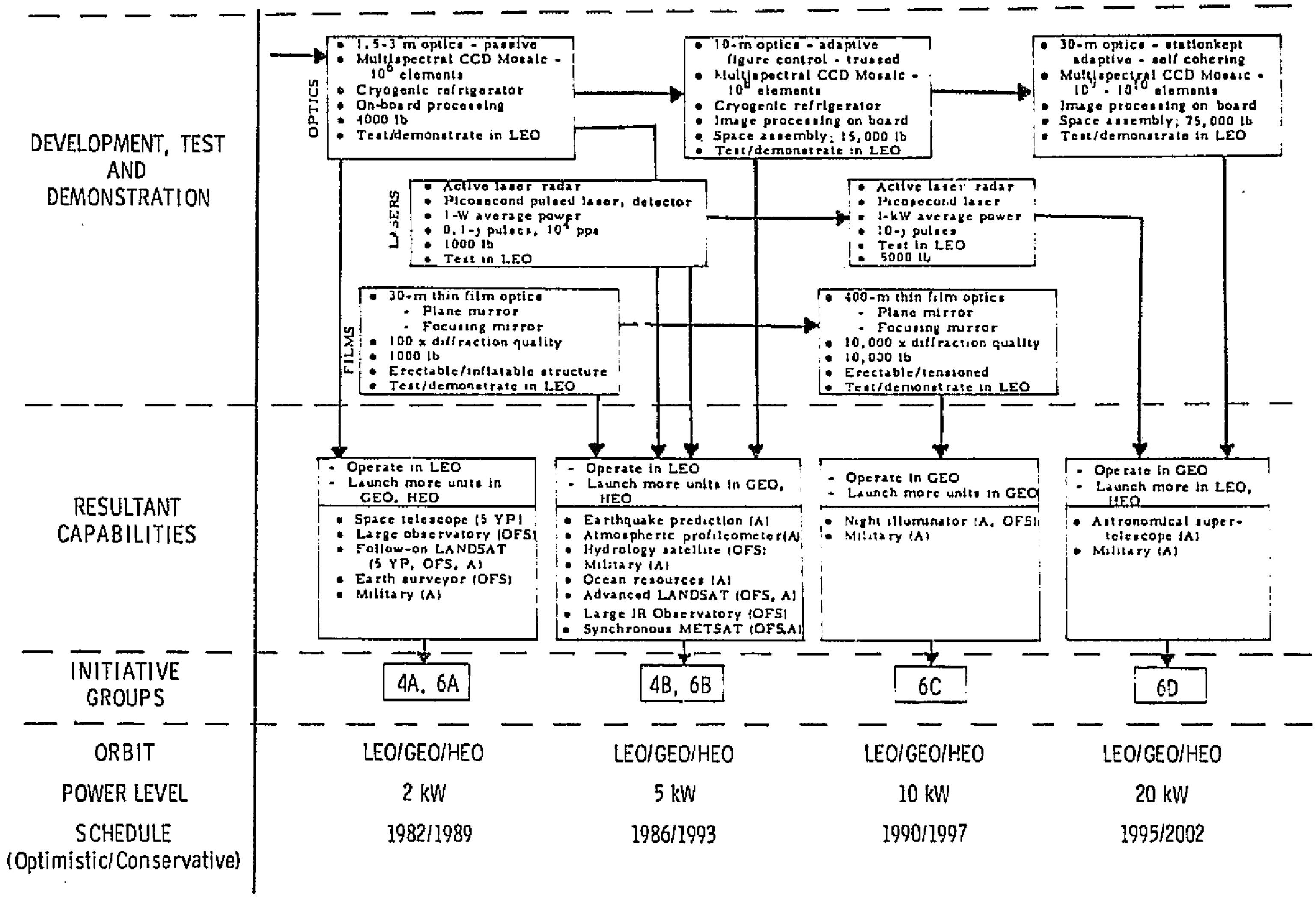


Figure 3-21. Group 4 and 6 Initiatives
(Optical Observation, Designation, and Measurement)

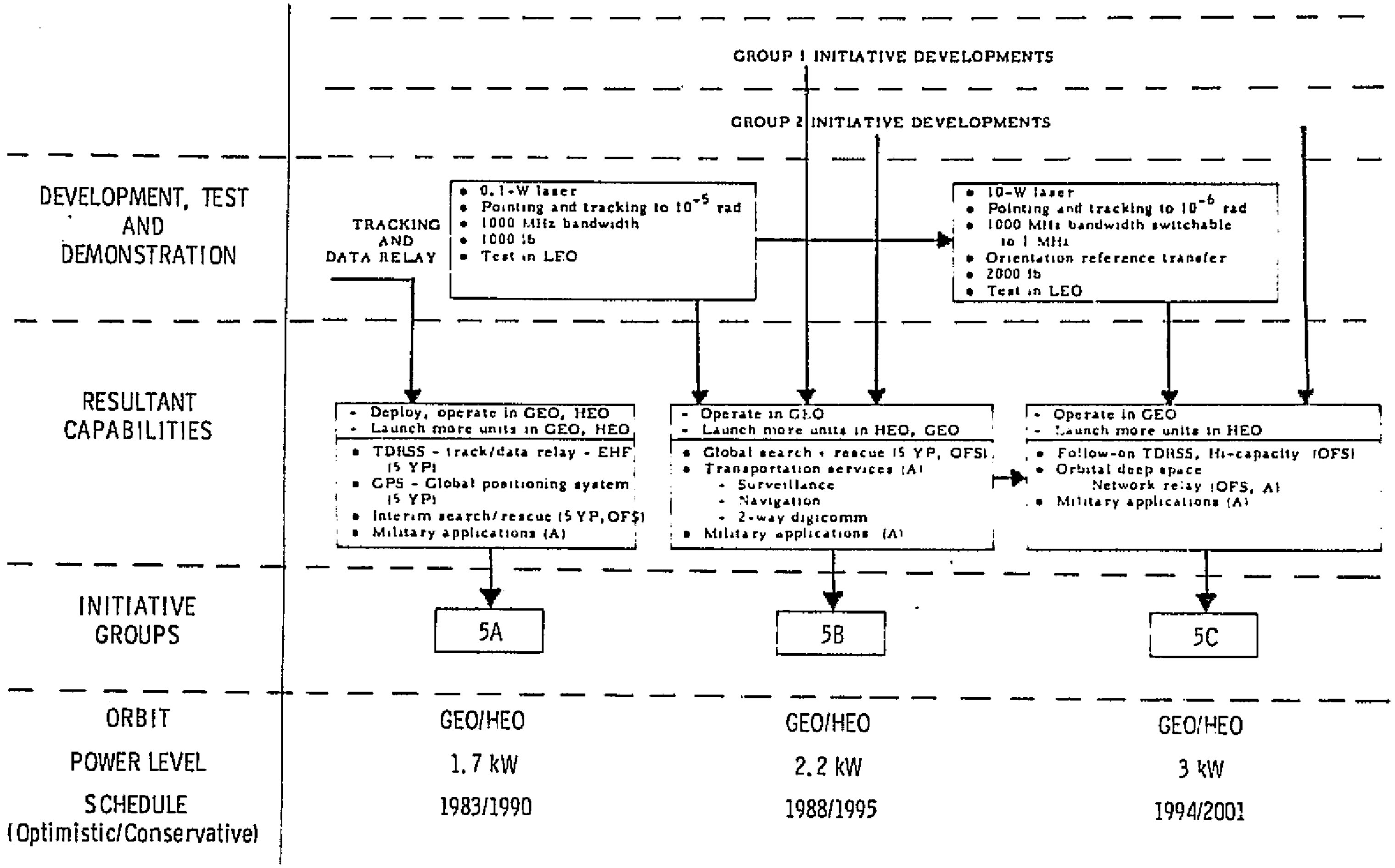


Figure 3-22. Group 5 Initiatives
(High Altitude Navigation, Location, and Relay Systems)

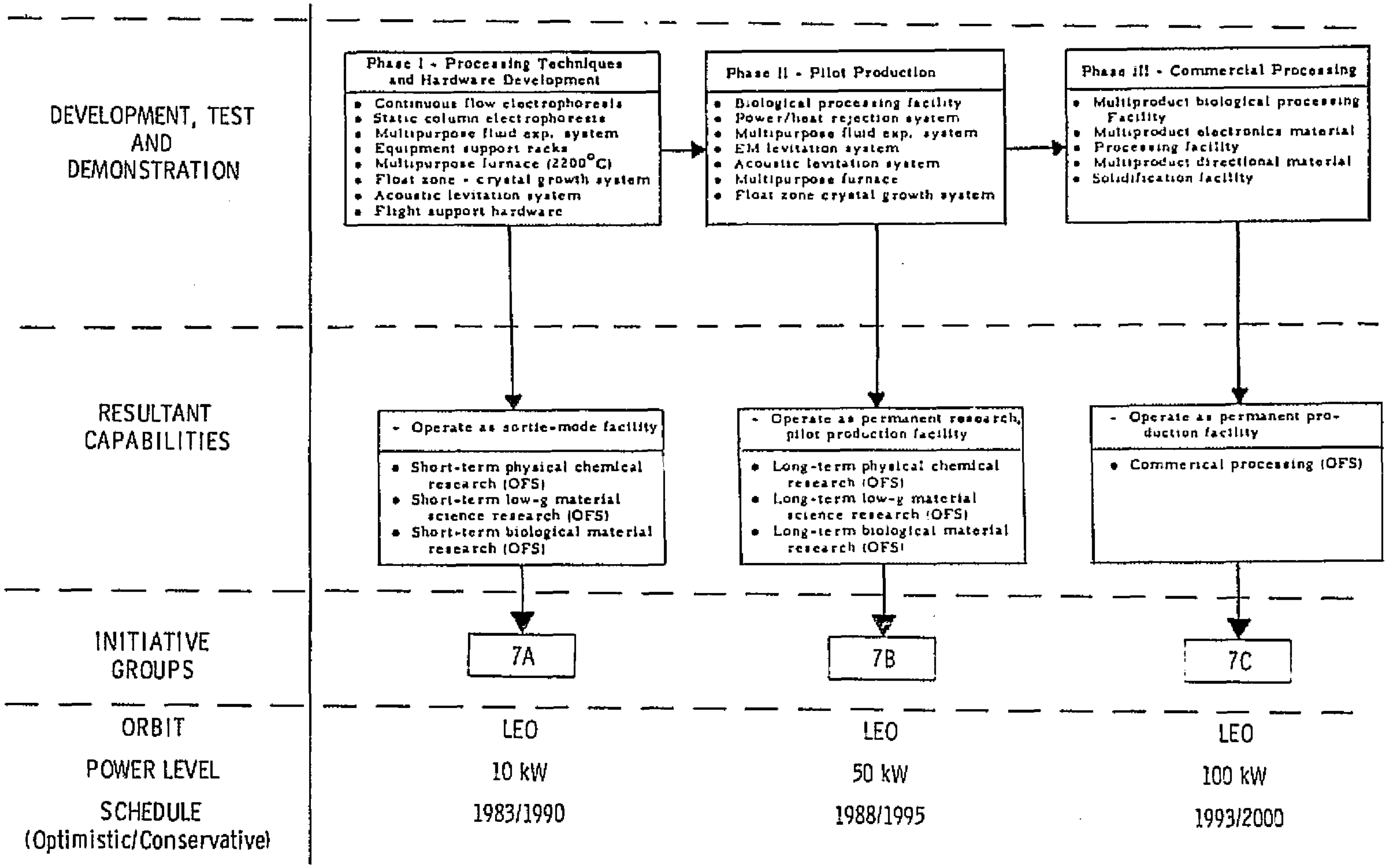


Figure 3-23. Group 7 Initiatives
(Space Processing and Manufacturing)

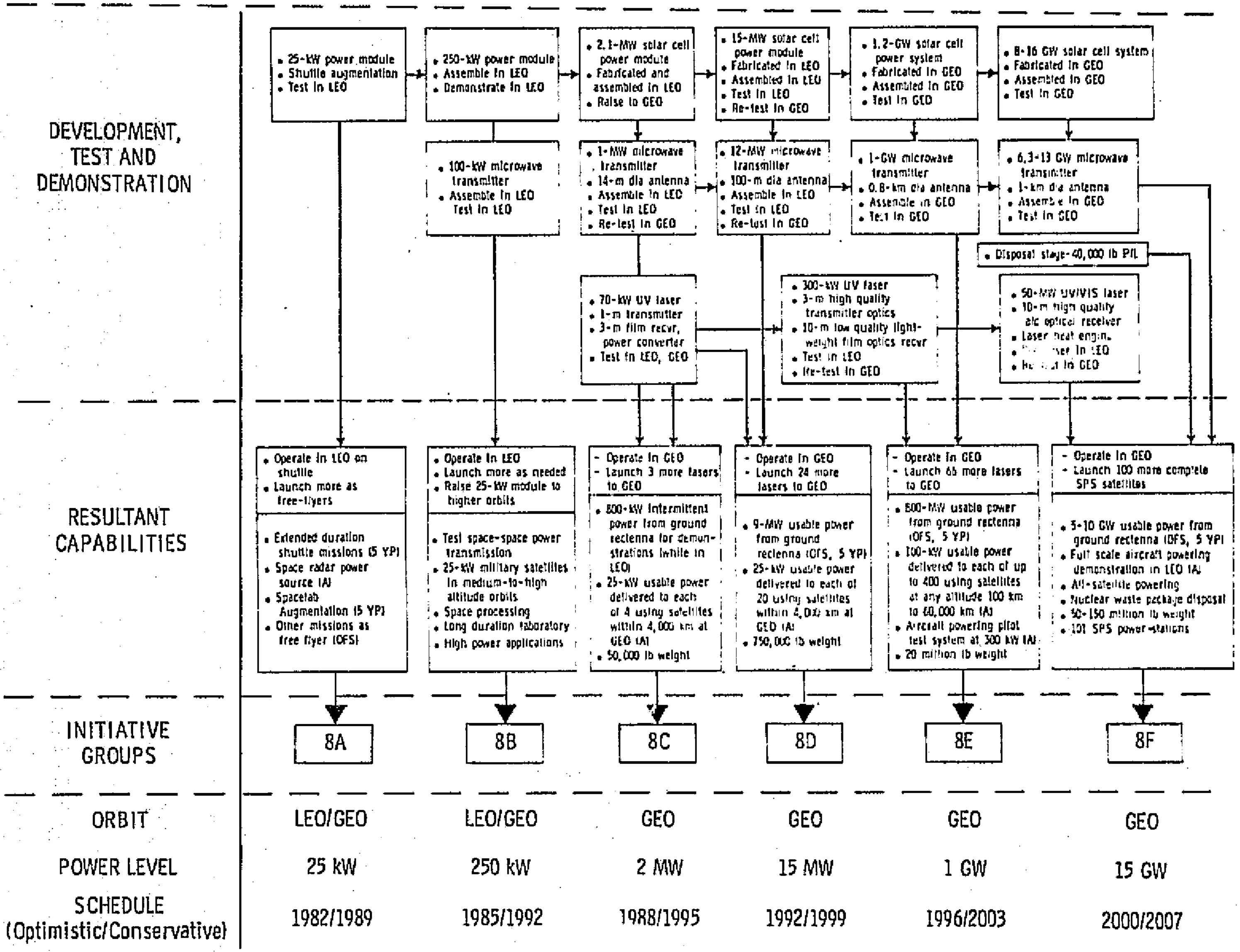


Figure 3-24. Group 8 Initiatives
(Large Scale, High Energy, Far-Term Systems)

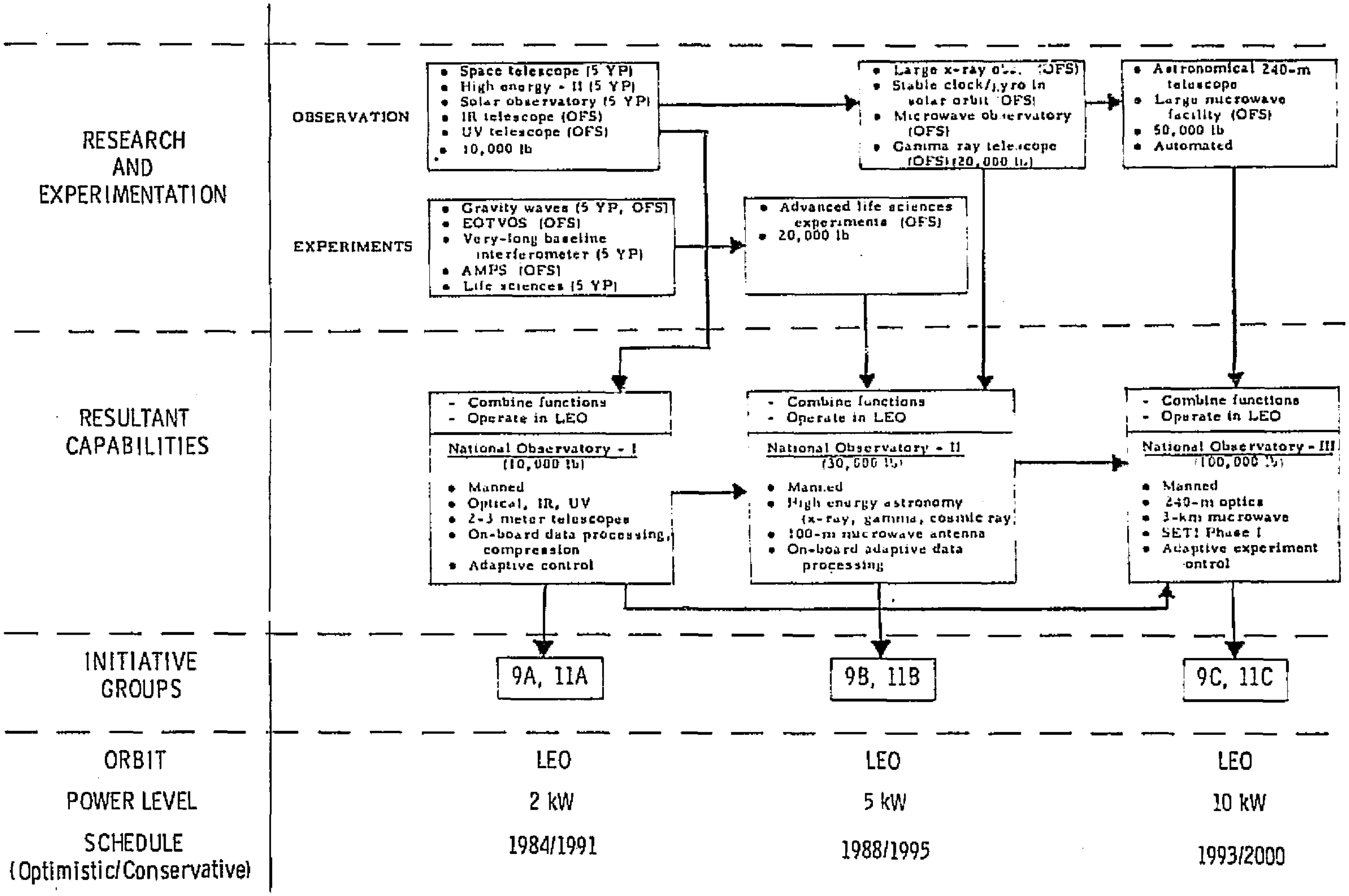


Figure 3-25. Group 9 and 11 Initiatives
(Scientific/Research Experiments and National Facilities)

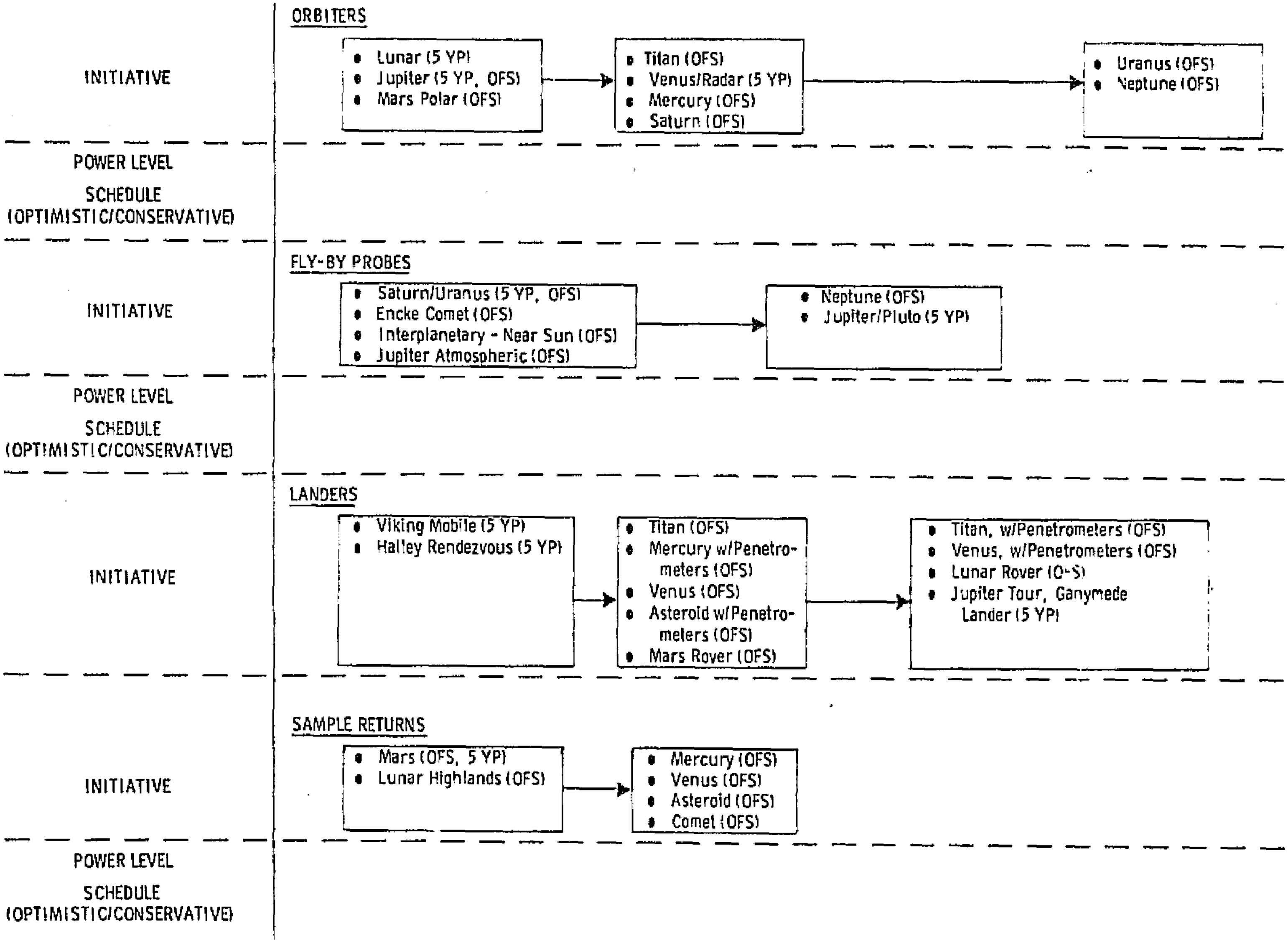


Figure 3-26. Group 10 Initiatives (Planetary Missions)

4. SPACE POWER TECHNOLOGY PROJECTIONS

4.1 INTRODUCTION

A review was made of the existing literature to assess potential future space power technology advancements, assuming that the present rate of progress and funding continues. The utility of this is that, if the projections for a particular area of technology do not meet the requirements at a specific point in time, then increased emphasis (in terms of funding, generally) must be placed on that area of technology.

4.2 SOLAR CELLS

4.2.1 Power-Efficiency Characteristics

The basic efficiences of various types of current production and developmental silicon solar cells are illustrated in Figure 4-1. Conventional cells, the best available until recently, provide typical efficiencies of 10-11%. A number of cell design and processing improvements during the past several years, (e.g., shallower junctions, finer grid designs, better anti-reflection coatings), led to the so-called "hybrid" cells, with substantially higher performance. The "Helios" cells (Spectrolab designation) are similar to the hybrid cells, but with the addition of a p+ backfield that lowers the effective resistivity of the cell material. Both the hybrid and Helios cells can be fabricated with integral back-surface reflectors that improve the basic cell efficiency and reduce the operating temperature. All new satellite programs and most recent cell procurements seem to have specified some variant of the hybrid or Helios cell types; the "conventional" cell is essentially obsolete.

A number of potential cell improvements are currently being pursued, the most prominent being the use of "sculptured" or "non-reflective" cell surfaces. These surfaces are textured (at a microscopic level) by

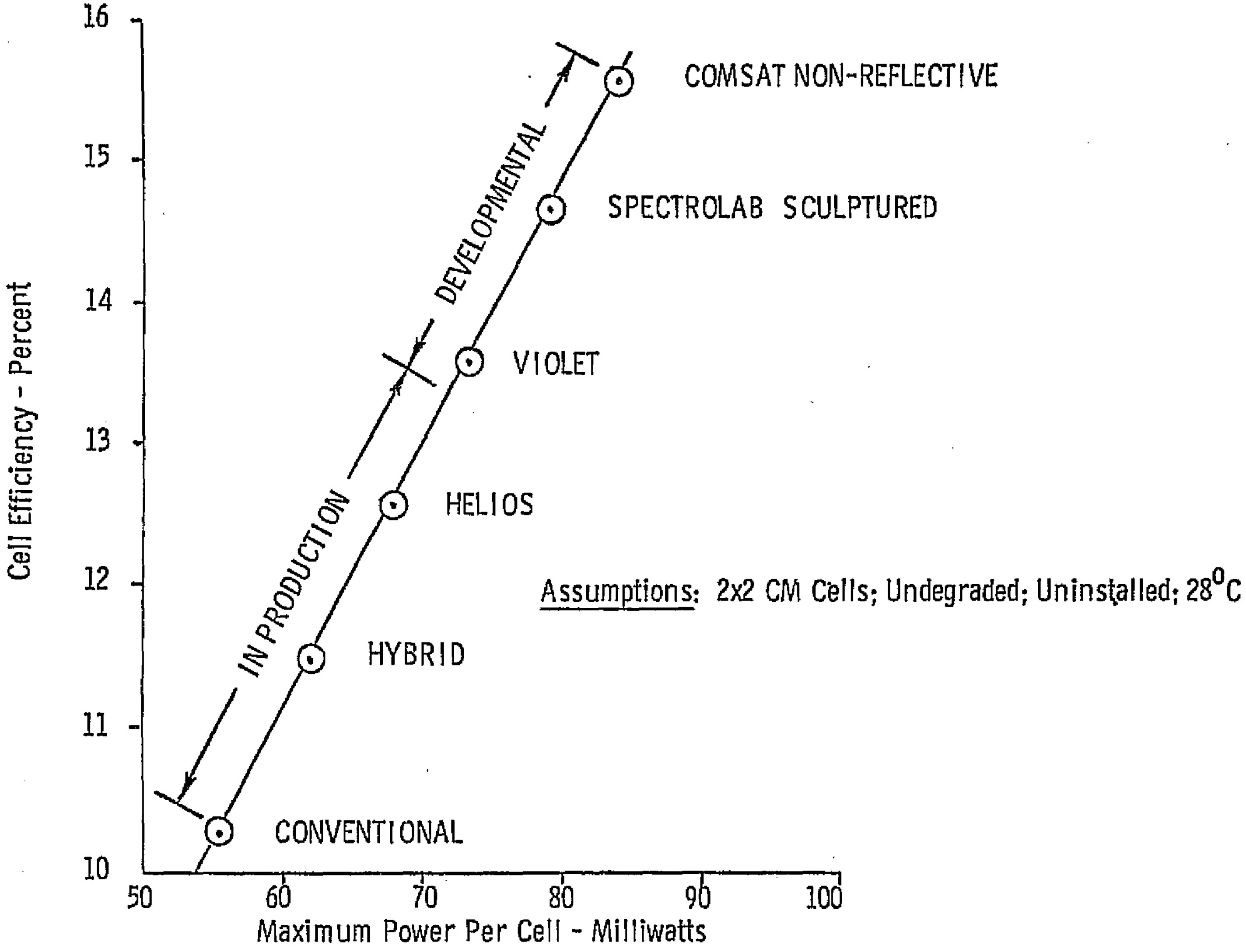


Figure 4-1. Solar Cell Power-Efficiency Characteristics

special etching processes so that absorption of solar energy is improved and reflection is reduced. These cells and their manufacturing processes have not yet been developed to the point where flightworthy cells can be produced in large quantities.

4.2.2 Efficiency Projections

Solar cell efficiency projections, based on existing technology and development programs, are shown in Figure 4-2. The silicon cell projections reflect an assumption that the developmental cell types shown in Figure 4-1 will eventually become production cells and that overall cell performance improvements will continue in the future. The long-term trend of these improvements should tend to be asymptotic, since there is a maximum theoretical limit of about 22% to silicon cell efficiency.

A projection for gallium arsenide cells is also shown to provide some idea of the potential performance of such cells, even though their state of development is far behind that of silicon cells and they have never been used on spacecraft, except as part of solar cell flight experiments. Several organizations (e.g., IBM, Varian Associates, and Hughes Research Labs) have made small cells in the laboratory with claimed efficiencies of 16 to 18%, and there appears to be good potential for still better performance. However, there is now no production capability for gallium arsenide cells and no firm indication as to when or if one will ever exist. Consequently, all solar array performance projections shown on subsequent charts have been based on silicon cells only.

The projections are shown as bands rather than single lines to reflect not only the uncertainty of the projections but also the fact that new programs do not always select the highest-efficiency cells available because of cost, schedule, or other mission requirements. In general, the midpoint of the bands should provide a realistic average projection.

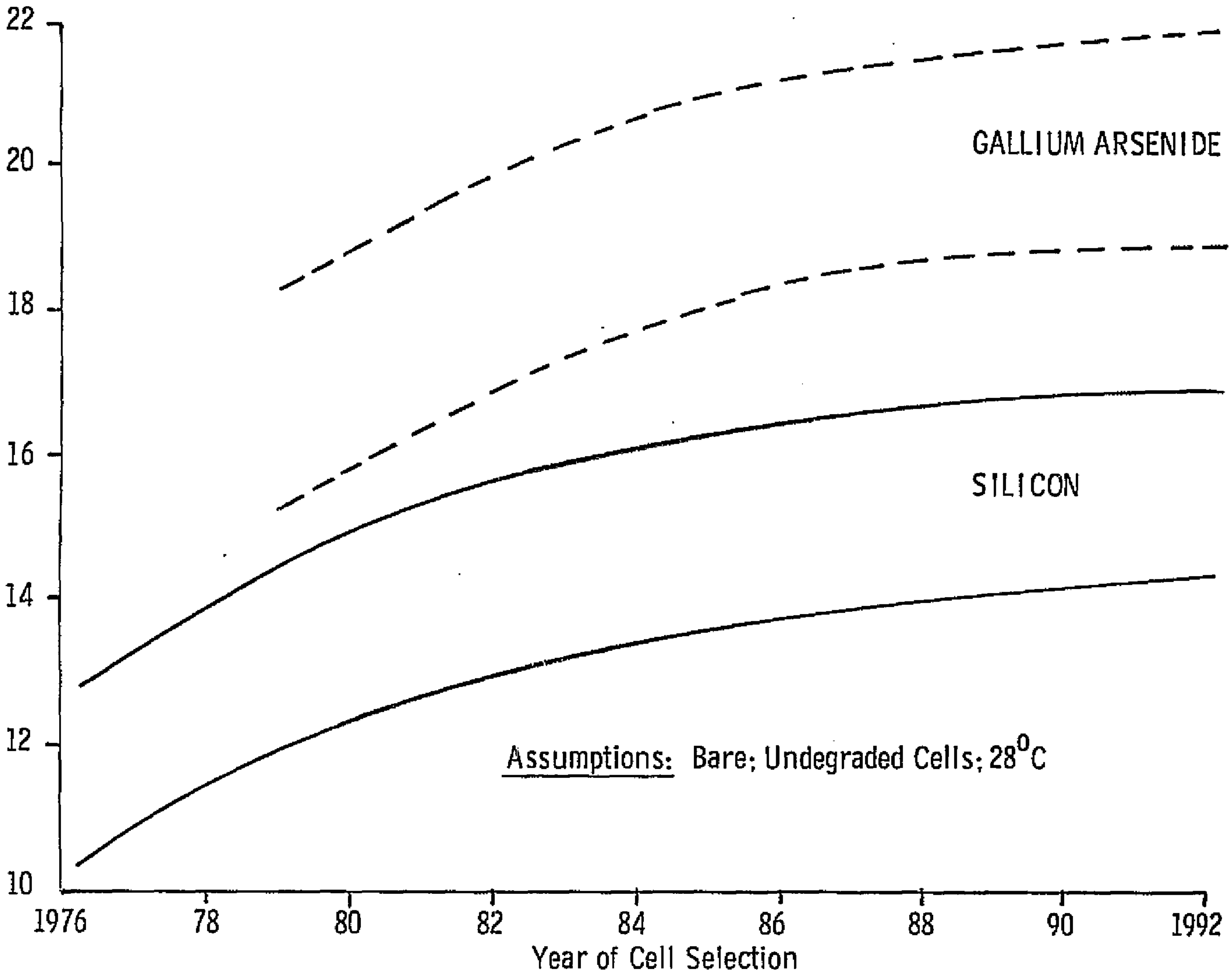


Figure 4-2. Solar Cell Efficiency Projections

4.3 SOLAR ARRAY

4.3.1 Specific Area Projections

Solar array specific area projections, in terms of array area per kilowatt of output, are shown in Figure 4-3 for fully sun-oriented arrays with silicon solar cells and no radiation degradation. These projections are derived directly from the cell efficiency projections of Figure 4-2 and reflect a cell packing factor of 80% and an array temperature of 58°C.

Specific area requirements in terms of square feet per kilowatt of electrical load can be determined approximately by multiplying the specific areas shown in Figure 4-3 by 1.5 for geosynchronous equatorial orbits and by 2.2 for low earth orbits. These factors account for the worst-case eclipsing and battery recharge requirements for each type of orbit, and also include radiation degradation allowance of 25% for geosynchronous equatorial orbits (7-10 year missions) and 10% for low earth orbits (~ 5 year missions). Intermediate-altitude or elliptical orbits that pass through the inner trapped proton belts could incur substantially higher array degradation.

4.3.2 Specific Weight and Specific Area

Figure 4-4 illustrates the estimated or demonstrated specific areas and specific weights of several advanced array designs now under development or study. The weights shown include storage and deployment equipment, but do not include orientation mechanisms or associated power transfer equipment. The developmental arrays are advanced flexible roll-out or fold-out designs (except for the TRW lightweight rigid array) with outputs of about 1 to 25 kW. The 1.5-kW Hughes FRUSA (Flexible Roll-Up Solar Array) design was flight-tested successfully as an experiment in late 1971 on the Space Test Program (STP) 71-2 spacecraft, and a similar 6-kW design has recently been selected as the prime power source for the STP 80-2 spacecraft. The 25-kW Lockheed SEPS (Solar Electric Propulsion System) array

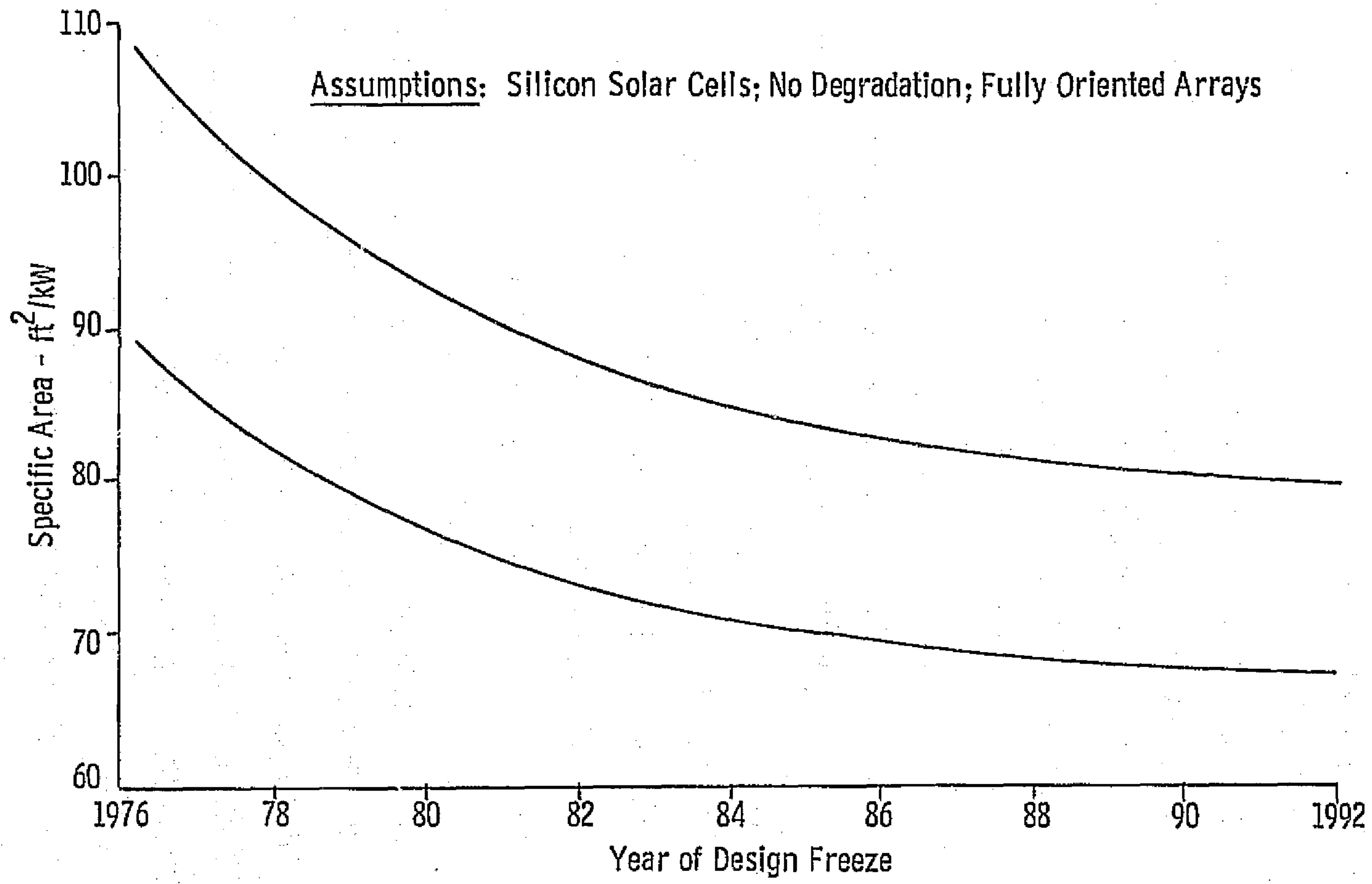


Figure 4-3. Solar Array Specific Area Projections

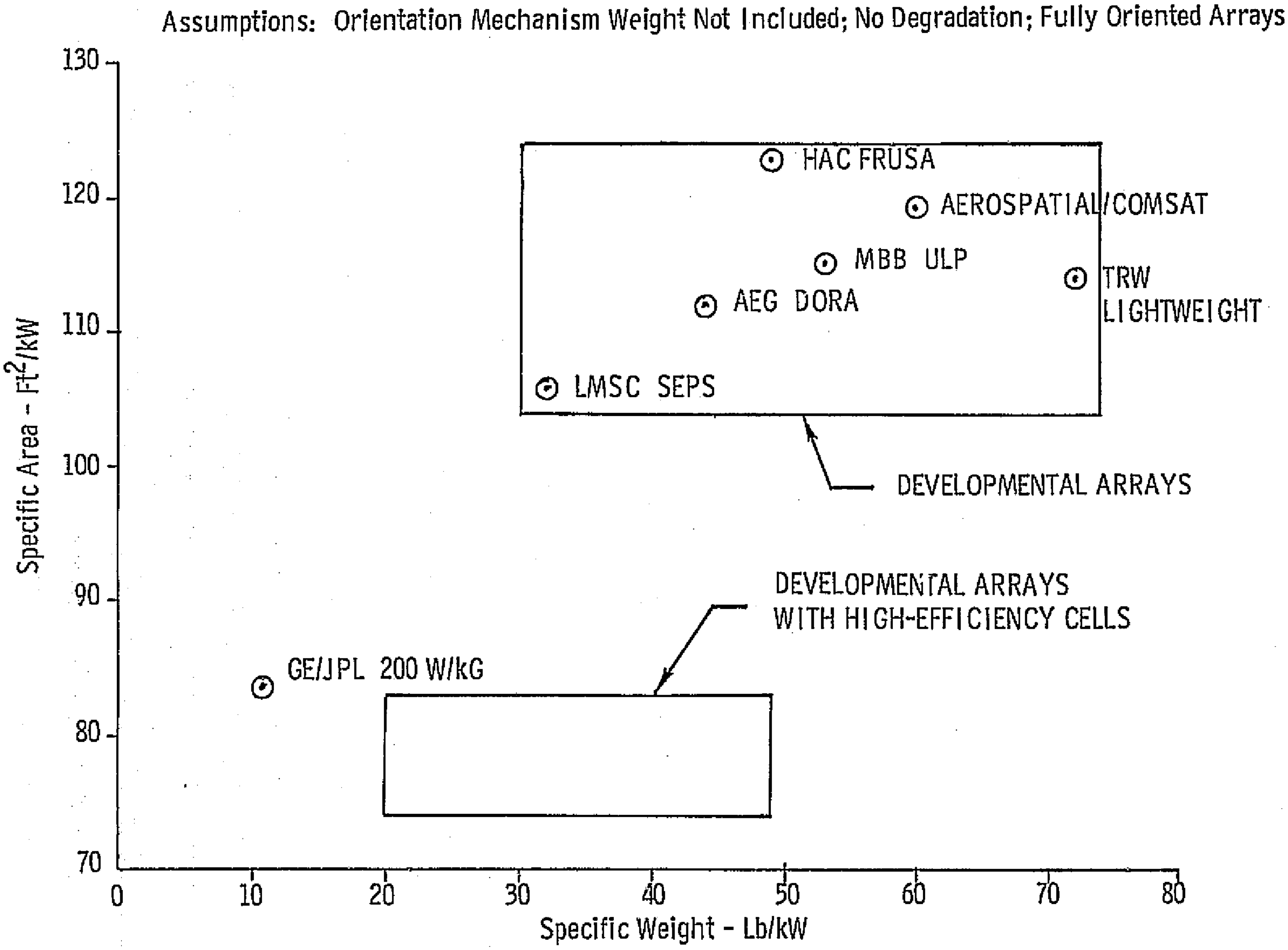


Figure 4-4. Solar Array Specific Weight and Specific Area

is a fold-out design being developed as a power source for electric propulsion. The GE/JPL 200 W/kg design exists only as a paper study and is not now under development.

The developmental array performance shown is based on conventional or early hybrid cell performance; the potential performance of these arrays with high-efficiency cells (15-16%) is also indicated.

4.3.3 Specific Weight Projections

Solar array specific weight projections are shown in Figure 4-5. These projections are based primarily on the assumption that the SEPS array technology would be available (with high-efficiency cells) by about 1980, and the GE/JPL 200 W/kg technology would be available by 1985. Also, some conservatism was applied to compensate for possible optimism in the estimated performance shown in Figure 4-4.

Projected weights of orientation mechanisms and power control equipment are also shown in Figure 4-5. Power control equipment would include components, such as voltage regulators and battery chargers, necessary to control and regulate the power system. These projections are based primarily on unpublished analyses by the Air Force Aero Propulsion Laboratory.

4.4 Battery Energy Density Projections

Virtually all spacecraft programs today use rechargeable nickel-cadmium (Ni-Cd) batteries for energy storage. Conventional Ni-Cd batteries have been used in spacecraft for over 15 years and represent a fairly well-developed technology. Such batteries of current proven design can provide a total energy density, when completely discharged, of about 10-12 watt-hr/lb. Advanced lightweight Ni-Cd battery designs are claimed to be capable of much higher performance, up to 15-20 watt-hr/lb, but the long-term reliability of such designs has not yet been proven.

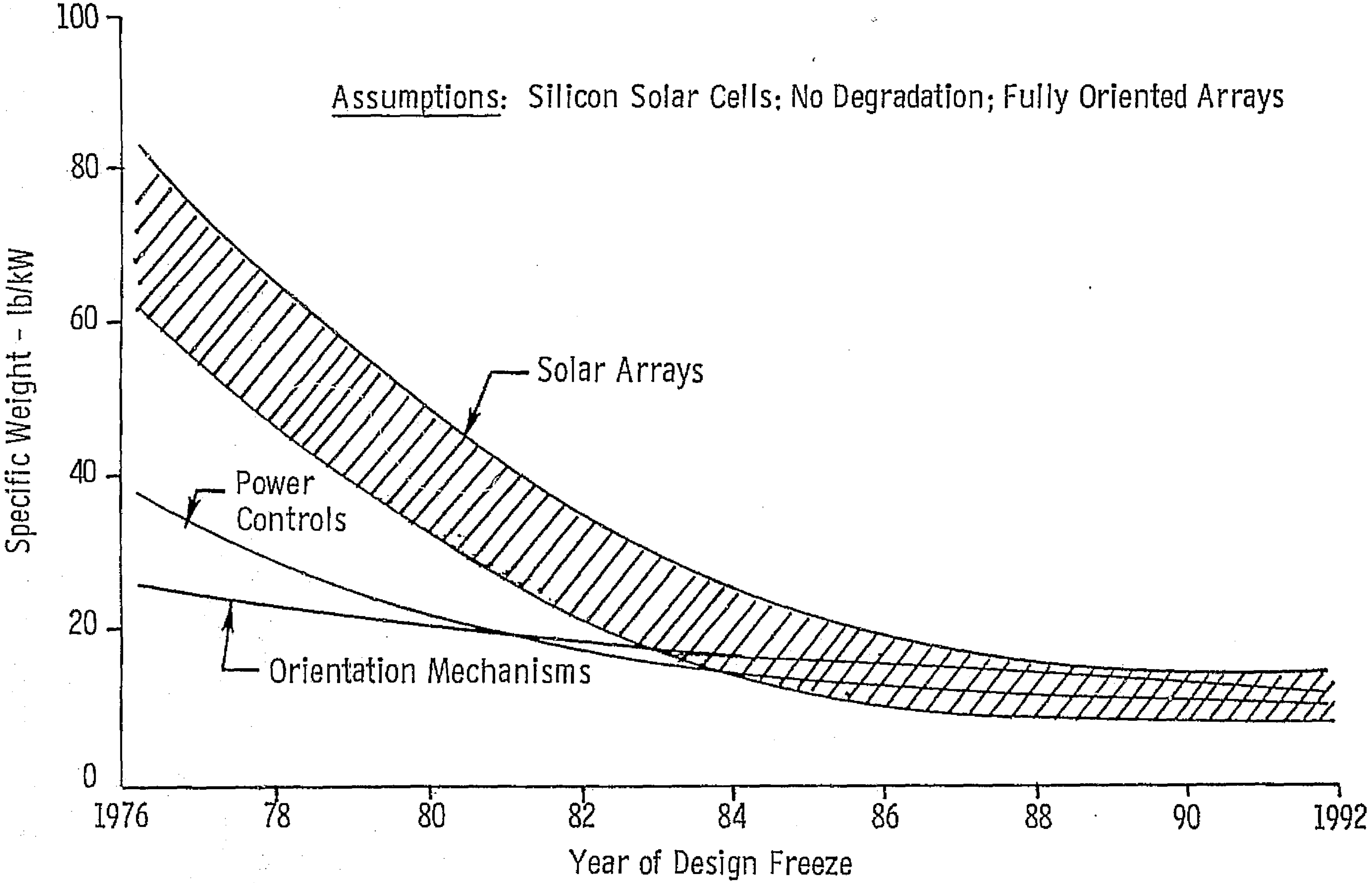
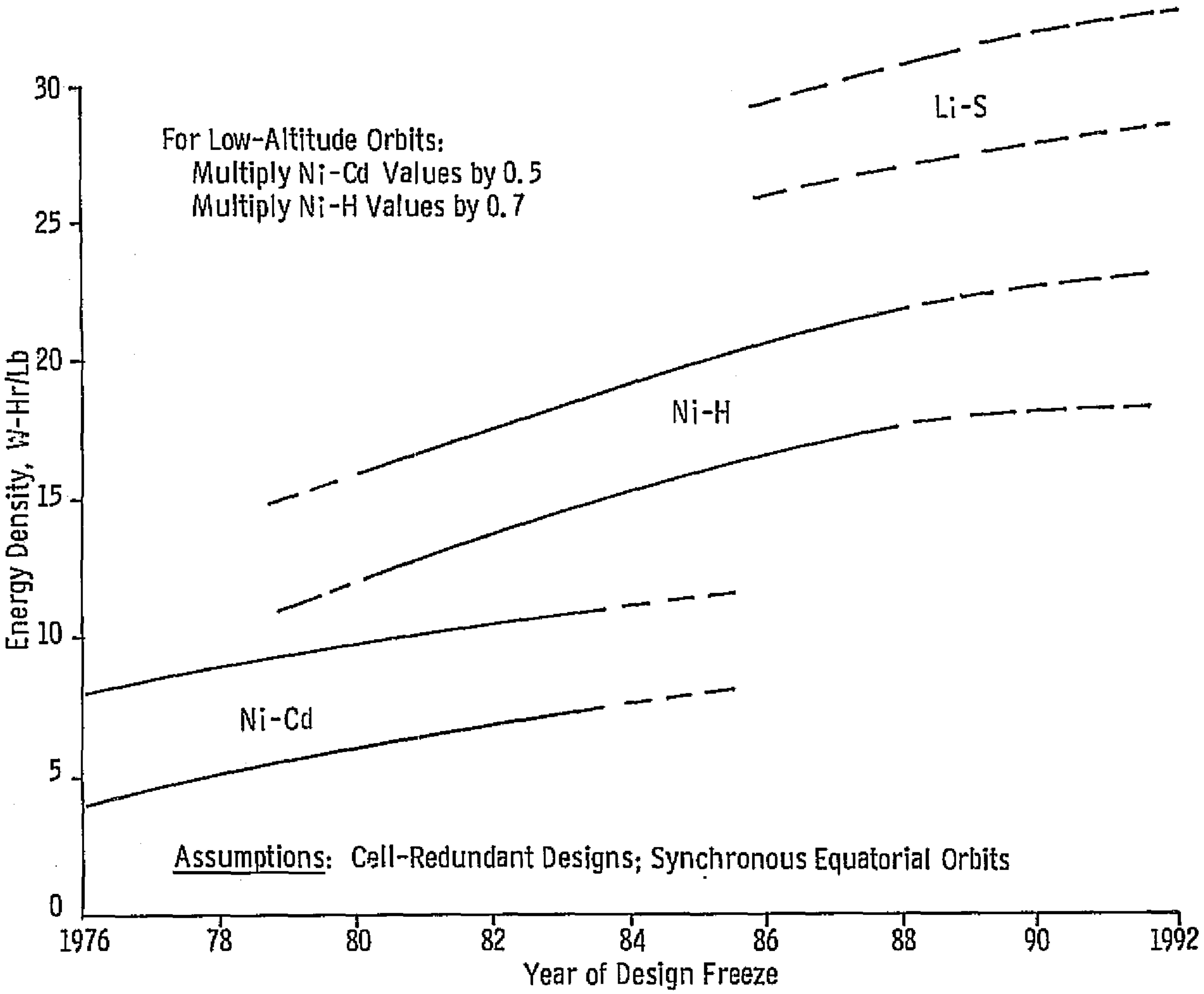


Figure 4-5. Solar Array Specific Weight Projections

The "usable" energy density of spacecraft Ni-Cd batteries is less than the totals cited above, because they must be derated, i.e., cycled at less than 100% depth of discharge, to provide the required cycle life and reliability. The amount of derating necessary depends primarily on the number of charge-discharge cycles required, which in turn depends on the mission length and the frequency of eclipses and/or peak loads requiring battery load sharing. The best current battery designs could provide a usable energy density of about 6-8 watt-hr/lb, with no redundancy, for long (5-10 yr) missions in geosynchronous equatorial orbits. In low earth orbits, for missions up to about five years, the usable densities would be about half of these values, due to the greater frequency of eclipses.

The overall usable energy density of batteries installed in a spacecraft is further reduced by whatever battery redundancy is provided to compensate for possible battery failures during the mission. Parallel battery-level redundancy has been commonly used in the past, in which multiple batteries are provided so that even if one or more failures occur, sufficient battery capacity will remain to complete the mission. Some recent, more sophisticated designs have incorporated cell-level redundancy. With this approach, each battery includes several extra cells and suitable electronic circuits that permit defective cells to be bypassed, so that failure of an individual cell does not fail the entire battery. For equivalent reliability, cell-level redundancy can provide a substantial weight advantage over battery-level redundancy.

Battery energy density projections shown in Figure 4-6 apply to complete, installed battery systems with cell-level redundancy, and include weight allowances for redundant cells, associated bypass electronics, and thermal control components such as heat pipes. The curves shown are for long (7-10 yr) missions in geosynchronous equatorial orbits, with appropriate adjustment factors for low orbit missions of up to about five years' duration. It is assumed that nickel-hydrogen batteries would begin to supplant Ni-Cd batteries in the early 1980's. A more advanced battery type,



For Low-Altitude Orbits:
Multiply Ni-Cd Values by 0.5
Multiply Ni-H Values by 0.7

Assumptions: Cell-Redundant Designs; Synchronous Equatorial Orbits

Figure 4-6. Battery Energy Density Projections such as lithium-sulfur, might become available in the late 1980's. The lithium-sulfur battery is being investigated for possible electric vehicle and electric utility load-leveling applications, but it is in a very early stage of development and its ultimate feasibility and availability are very uncertain.

4.5 SOLAR ARRAY-BATTERY POWER SYSTEMS SPECIFIC WEIGHT PROJECTIONS

The solar array and battery performance projections have been used to derive weight projections for complete solar array-battery systems and their components; these are shown in Figures 4-7 and 4-8 for geosynchronous equatorial and low earth orbits, respectively. The projections are in terms of specific weight based on load requirements, viz., lb per kilowatt of electrical load, and reflect the eclipsing and battery recharge requirements of each type of orbit. Allowances made for solar array radiation degradation were 25% for geosynchronous equatorial orbits (7-10 year missions) and 10% for low earth orbits (~ 5 year missions). Intermediate-altitude or elliptical orbits that pass through the inner trapped proton belts could suffer substantially higher array degradation.

For geosynchronous equatorial orbits the battery weight comprises roughly half the total system weight, regardless of battery type or time period. Also, the solar array weight becomes such an insignificant fraction of the total system weight after the early 1980's that further improvements in array technology would appear to have little impact on the system weight. These trends are similar, though not so pronounced, for low earth orbits.

4.6 RADIOISOTOPE POWER SYSTEMS SPECIFIC POWER

Projected radioisotope power system performance, in terms of specific power output per lb of power system weight, is shown in Figure 4-9. Cost estimates, in dollars per watt of electrical output, are also shown. These projections are based on ERDA estimates for 150-2000 watt systems. These systems would use plutonium-238 fuel, with a half-life of

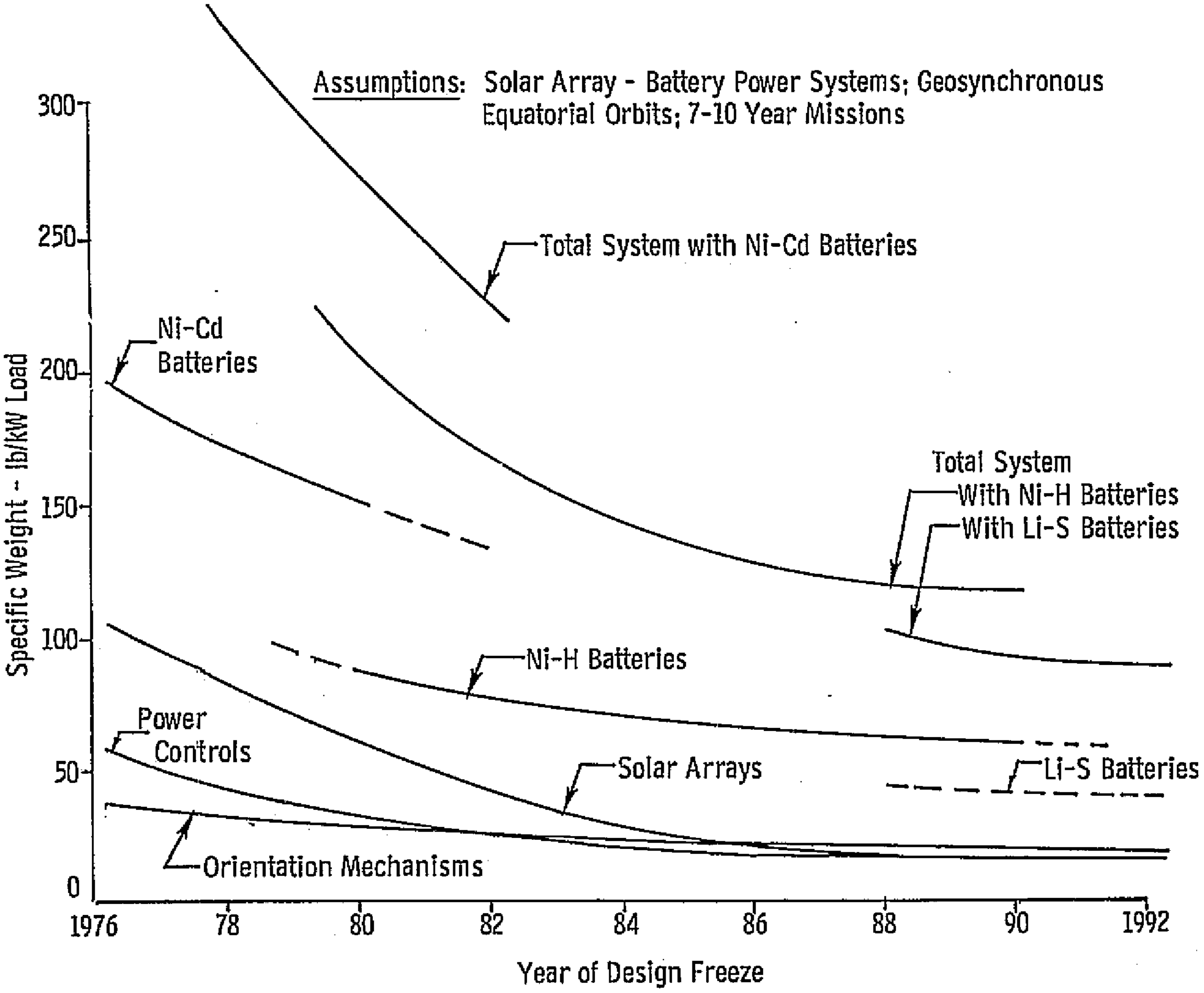


Figure 4-7. Specific Weight Projections

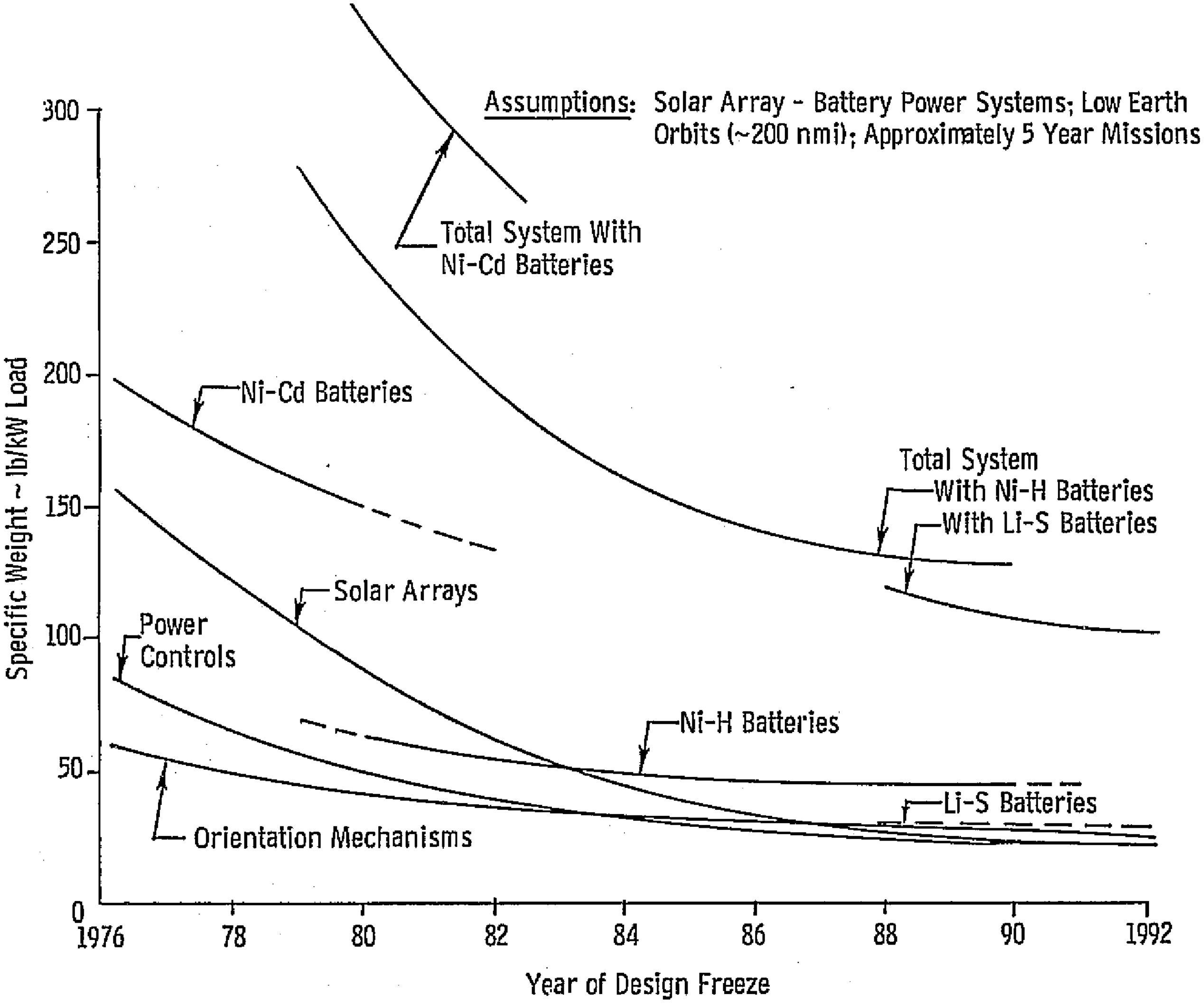


Figure 4-8. Specific Weight Projections

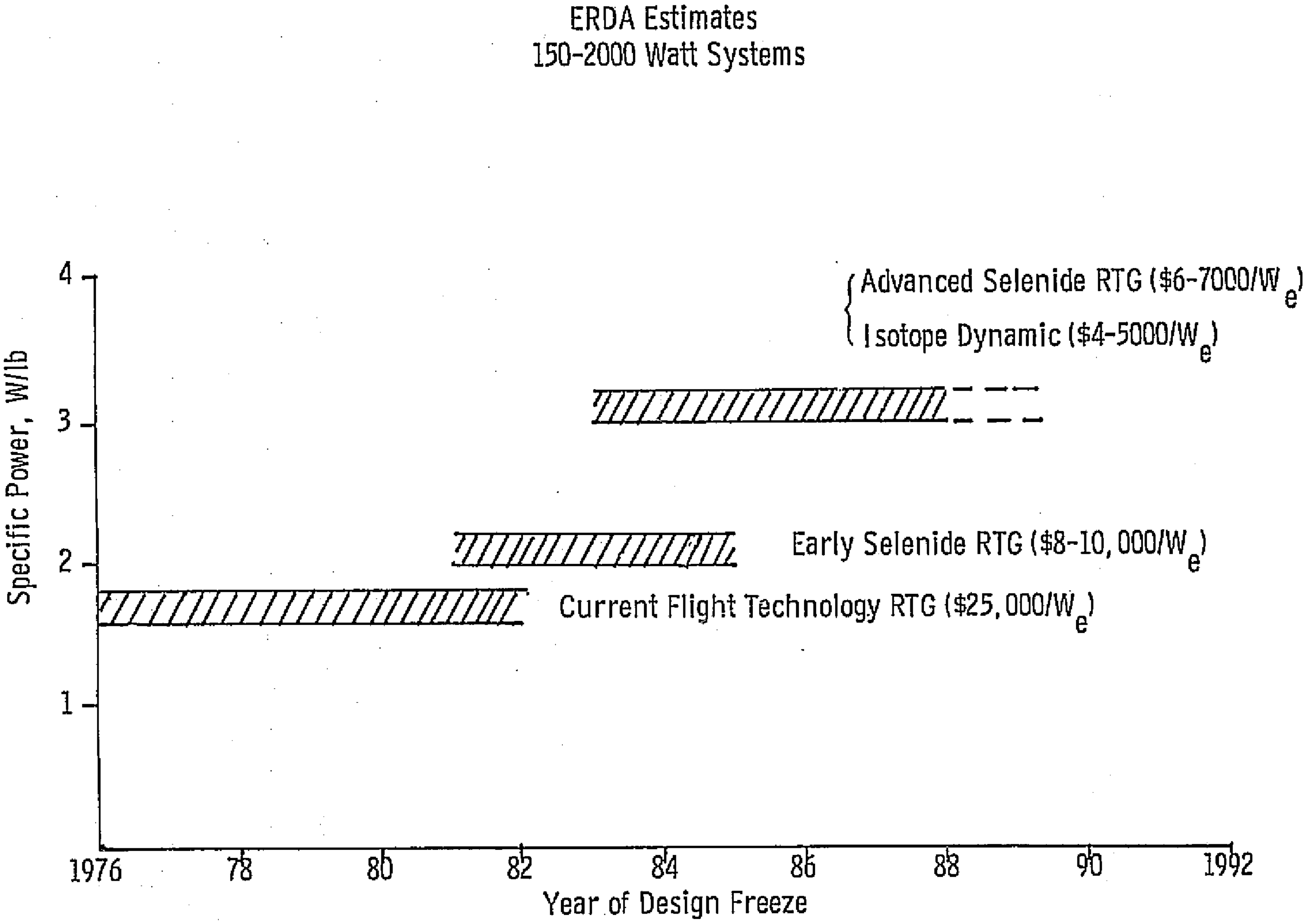


Figure 4-9. Radioisotope Power Systems Specific Power

about 86 years, to provide a nearly constant power output over a 5-10 year mission. The radioisotope thermoelectric generators (RTGs) available now and in the near future would be similar to the SNAP-19 and SNAP-27 units used on the Nimbus weather satellite and Apollo programs, respectively. Performance improvements are expected to result from the development of higher-efficiency selenide thermoelectric converter materials. Advanced designs with outputs of 2 kW or more might use Rankine or Brayton-cycle turbogenerators that have been under development for several years by NASA for possible application to isotope power systems.

4.7 NUCLEAR REACTOR SPACE POWER

4.7.1 Status

Figure 4-10 summarizes the status in the area of nuclear reactor space power system development. This development effort, though extensive and quite active in the early and mid 1960's, is virtually nonexistent now, for several reasons:

1. Performance of systems based on the relatively low-temperature zirconium-hydride thermal reactor technology generally did not provide compelling weight, size, or cost advantages over alternative systems, viz., solar array-battery systems.
2. Advanced systems based on fast reactor technology offered potentially high performance but involved such high temperatures and exotic materials (e.g., refractory metals and alkali metal working fluids) that their long-term reliability and even ultimate feasibility were doubtful.
3. No firm requirements, either military or NASA, were ever established for nuclear reactor space power systems.

Recent activity has consisted of an ERDA-sponsored study of 10-75 kilowatt zirconium-hydride reactor systems compatible with the Space Shuttle and of continuing studies of thermionic fast reactor systems at Los Alamos Scientific Laboratory.

I ZIRCONIUM - HYDRIDE TECHNOLOGY

- Extensive Development 1957-1973 (SNAP-2, SNAP-8, SNAP-10A)
  - Reactors to 1000 kW_t Built and Tested
  - Thermoelectric and Mercury - Rankine Power Conversion Components Built and Tested (0.5-60 kW_e)
  - Flight Test, 1965 (SNAP-10A)
- Currently Inactive
  - Recent Systems Studies (Thermoelectric, Brayton, Organic Rankine, Stirling, 10-75 kW_e)

II ADVANCED FAST REACTOR TECHNOLOGY

- Extensive System Studies 1960-1973 (SPUR, SNAP-50, SNAP-70)
  - Liquid - Metal Rankine (SPUR, SNAP-50, 300-1000 kW_e)
  - Thermionic In-Core (SNAP-70), Out-of-Core, On-Core
- Little Reactor Design; Considerable Liquid Metal Technology Development
- Currently Inactive
  - Thermionic System Studies

Figure 4-10. Nuclear Reactor Space Power Background

4.7.2 ERDA's "Revitalized" Space Reactor Program

ERDA is now attempting to "revitalize" the space reactor program and to redirect it primarily toward producing Space Shuttle-compatible systems in the 10-100 kilowatt range, with a tentative schedule as shown in Figure 4-11. This schedule is evidently based on certain assumptions concerning availability of development funding and the existence of at least tentative requirements for this type of power system. Recent information from ERDA indicates that the funding necessary to initiate this development program has not yet been forthcoming, so the schedule would slip at least one year.

From the information presented in this and Figure 4-10, it should be evident that the future availability of nuclear reactor space power systems is very uncertain and cannot be predicted with any confidence. If a definite need is established, radical policy changes towards space reactor development and deployment must occur.

4.8 POWER SYSTEM SPECIFIC WEIGHT VS OUTPUT

Figure 4-12 shows a time-phased comparison of the specific weight (lb/kilowatt of electrical load) of several types of solar and nuclear reactor power systems in low earth orbits. In geosynchronous equatorial orbits the solar power systems would be about 15% lighter.

The solar array-battery system weights were obtained from the projections shown in previous figures. Nuclear reactor system weights were obtained from References 32 and 33 and include shielding weights for unmanned payloads. Weights of the solar-Brayton and solar-thermionic systems were obtained from Reference 34 and are based on thermal energy storage, rather than battery storage, for eclipse operation. The availability dates shown for nuclear reactor and solar thermal systems are rough estimates of the dates that such systems could become available if a firm

- KEY OBJECTIVES/REQUIREMENTS
  - / Power Output: 10-100 kW_e
  - / Life: 5-7 Years
  - / Space Shuttle Compatible
- TENTATIVE SCHEDULE

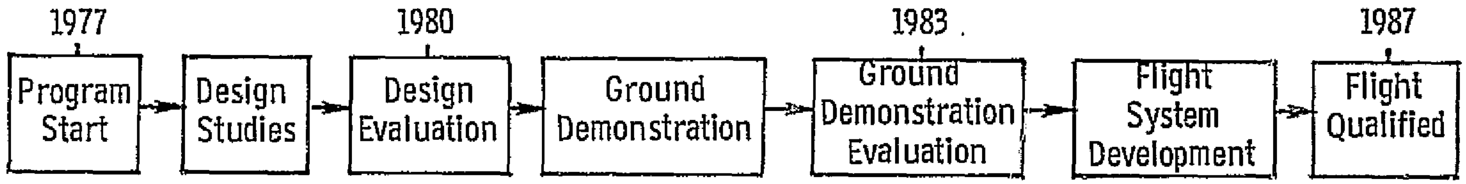


Figure 4-11. ERDA'S "Revitalized" Space Reactor Program

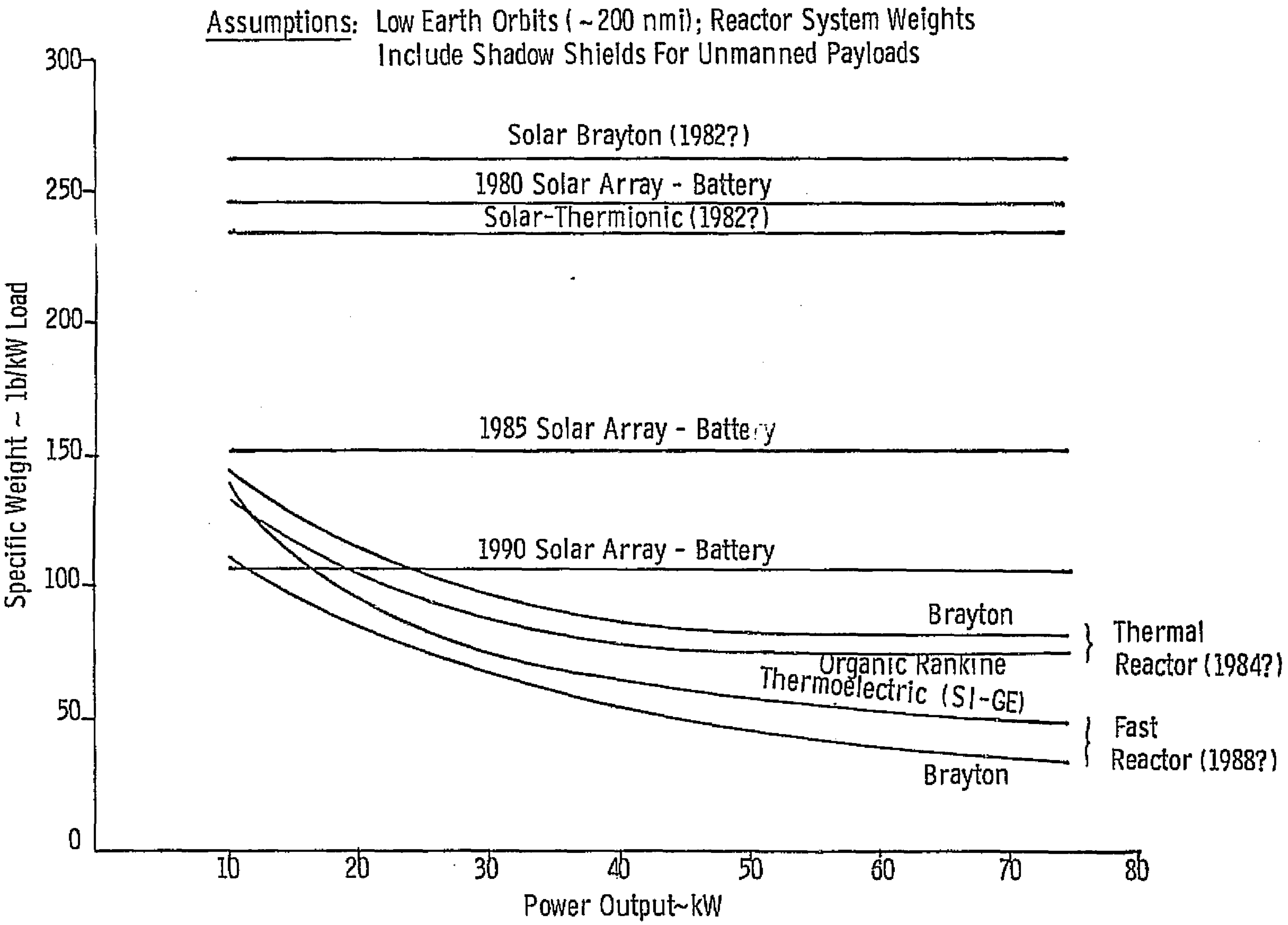


Figure 4-12. Power System Specific Weight vs. Output

requirement for them existed. Radioisotope systems are not shown in Figure 4-12, since their specific weights would exceed 300 lb/kW.

Scaling effects cause the specific weight of nuclear reactor power systems to decrease as power level increases. This effect also applies to a lesser extent to solar power systems, but is not shown in Figure 4-12 because it is assumed that large solar power systems would be built up from several smaller systems; that is, they would be modularized.

These results indicate that nuclear reactor systems, if they materialize, could offer some weight advantage over advanced solar array-battery systems at power levels above 10-20 kW. Radiator area requirements for the low-temperature thermal reactor systems would be about one-fourth to one-third the area of an equivalent solar array.

Solar thermal systems do not appear competitive with solar array-battery systems, since they offer no weight advantage and in addition would require high-quality solar concentrators, high pointing accuracy, and high operating temperatures. Previous studies have substantiated this conclusion.

4.9 POWER DISTRIBUTION WEIGHT VS SYSTEM VOLTAGE

Figure 4-13 illustrates the strong influence of system voltage on power distribution weight for large power systems. The weight penalty for low voltages results from the heavy cables required to carry high currents. It is clear that conventional 28-volt distribution will not be suitable for large multikilowatt power systems. A trend to higher system voltages is already reflected in the STP 80-2 spacecraft design, which will have a 105-volt bus to supply approximately 4 kW to an experiment payload, and, of course, solar power station studies are considering voltages of 20 to 40 kV.

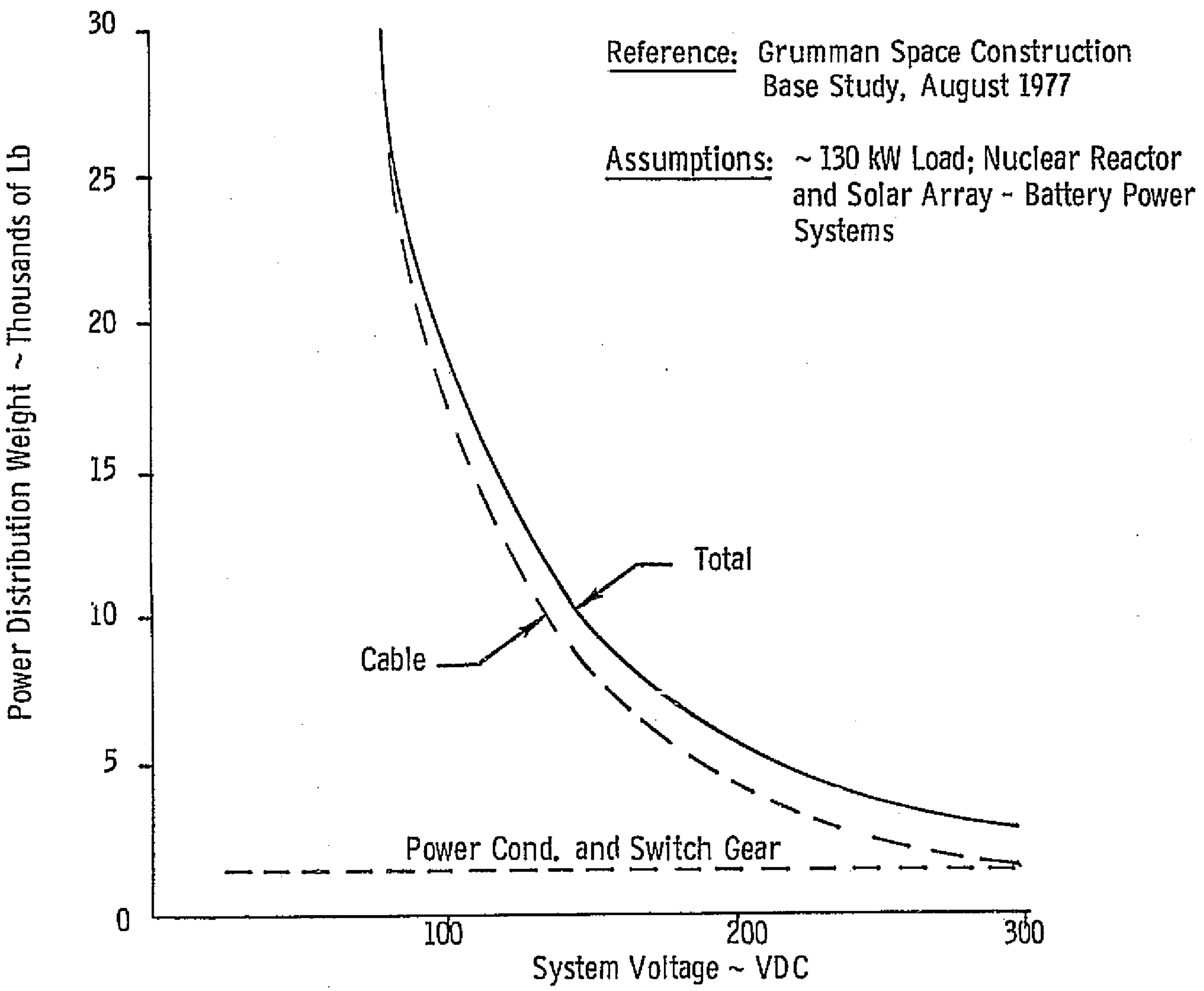


Figure 4-13. Power Distribution Weight vs. System Voltage

4.10 POWER SYSTEM HARDENING TECHNIQUES

Table 4-1 summarizes the hardening techniques in use and under study for solar array-battery power systems for military spacecraft. These techniques are intended to provide hardening against both high-altitude thermonuclear explosions and laser radiation. Such hardening can incur substantial weight and cost penalties.

Solar array hardening techniques are aimed basically at reflecting, or at least not absorbing, as much incident radiation as possible, and at minimizing the damage done by that which is absorbed. Metals with low atomic numbers, such as aluminum, are used for cell interconnects and contacts to minimize X-ray absorption. Solder is not used for interconnect bonding or grid coating because of its high X-ray absorption coefficient and low melting temperature. Laser radiation can be rejected by filter coatings that do not absorb energy at typical laser wavelengths or intensities. Adhesives and substrates with high thermal conductivity may be used to conduct heat away from solar cells and other sensitive components. Fused silica cover glass is used because of its resistance to crazing from the mechanical stresses caused by severe thermal pulses. There is no feasible way to shield solar cells from neutrons, so degradation of output due to neutron damage can be compensated for only by oversizing the array.

Hardened electronic circuits contain components and circuitry designed to suppress electromagnetic pulses and to minimize their damaging or disruptive effects. Radiation shielding may be provided for especially sensitive components.

Table 4-1. Power System Hardening Techniques

- SOLAR ARRAYS
  - Low - Z Interconnect and Contact Materials (Al)
  - Welded Interconnects
  - Solderless Contacts and Grids
  - Narrow - Bandwidth Reflective Filters
  - High Thermal Conductivity Adhesives and Substrates
  - Fused Silica Coverglass
- BATTERIES
  - None
- ELECTRONIC CIRCUITS
  - Suppression of System Generated Electromagnetic Pulse (SGEMP)
  - Shielding

5. STUDY RESULTS

5.1 GROUPED INITIATIVES POWER REQUIREMENTS

5.1.1 Power vs Time Requirements

Figures 5-1 through 5-8 show the power requirements for each initiative group as a function of time. Of the two solid plots, one represents an ambitious, well-funded, overall NASA space program, and one represents a more conservative approach where procurement of major systems is delayed approximately a further seven years. (The seven-year cycle was selected in a relatively arbitrary manner. However, it represents an estimate of the average time necessary to procure a major advanced space system, from initial go-ahead to IOC.) The dashed plot, in each case, indicates a stretched-out program in which each development program commences at approximately the same time as the optimistic program, but the procurement of major line items is spread over a longer period of time.

5.1.2 Results

The data contained in Figures 5-1 through 5-8 can be used in a number of ways. One use is to perform a rough rank ordering of the power requirements of the initiative groups. This provides information to determine which initiative groups can be "captured" by a given space power development plan at a specific point in time. In general, the initiative group development plans are divided into a number of steps or subgroups providing the option of not consummating all of the possible steps. Table 5-1 lists the subgroups of each initiative group in power demand rank order. It lists also the approximate IOC dates for an optimistic, well-funded NASA space plan, a more conservatively funded plan, and a stretched-out plan. The table demonstrates the power levels necessary to capture individual initiative group and subgroup developments.

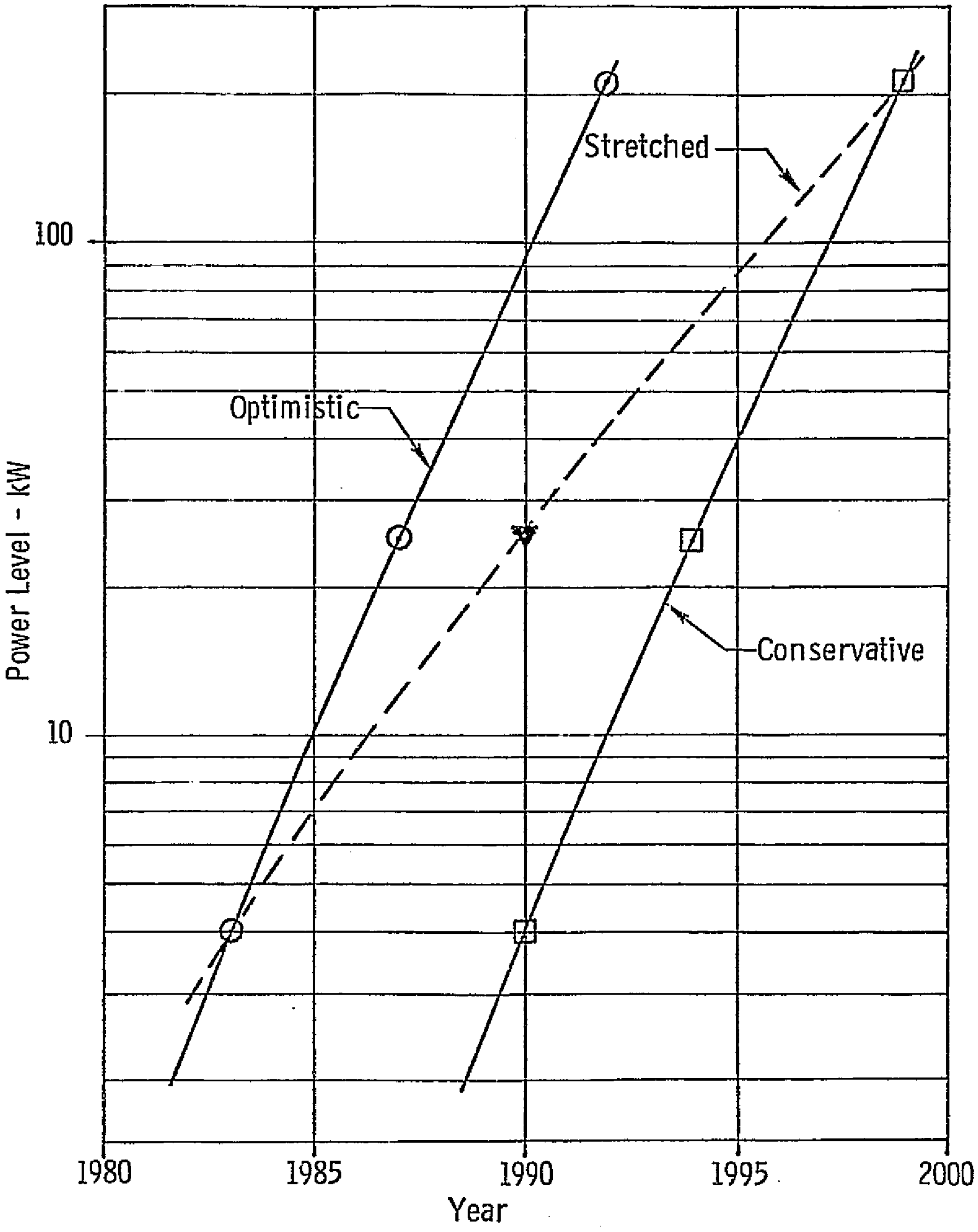


Figure 5-1. Power Requirements - Group 1 Initiatives (Service Platforms Using Microwave)

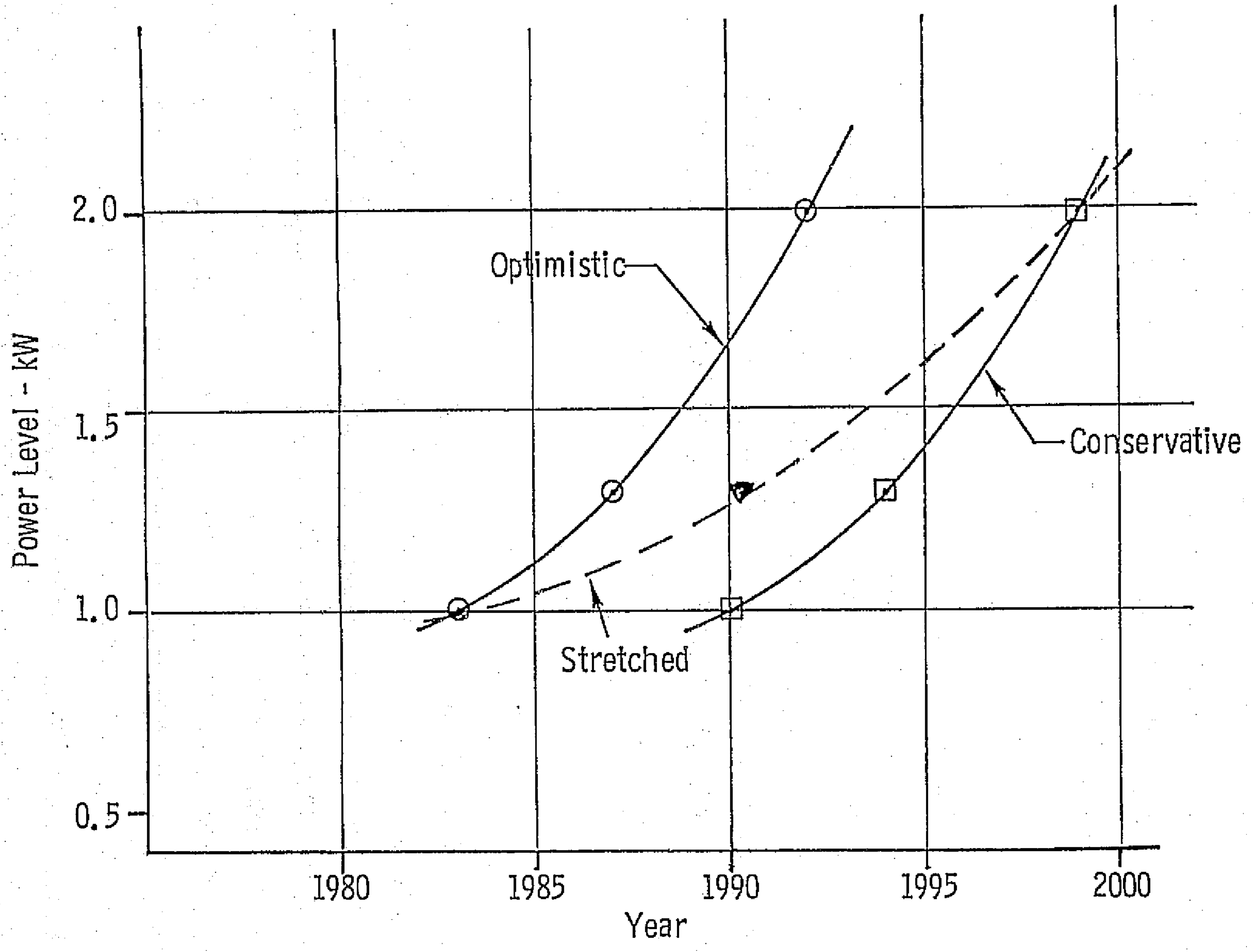


Figure 5-2. Power Requirements - Group 2 Initiatives

(Public Service Systems Using Long Microwave Stationkept Antennas)

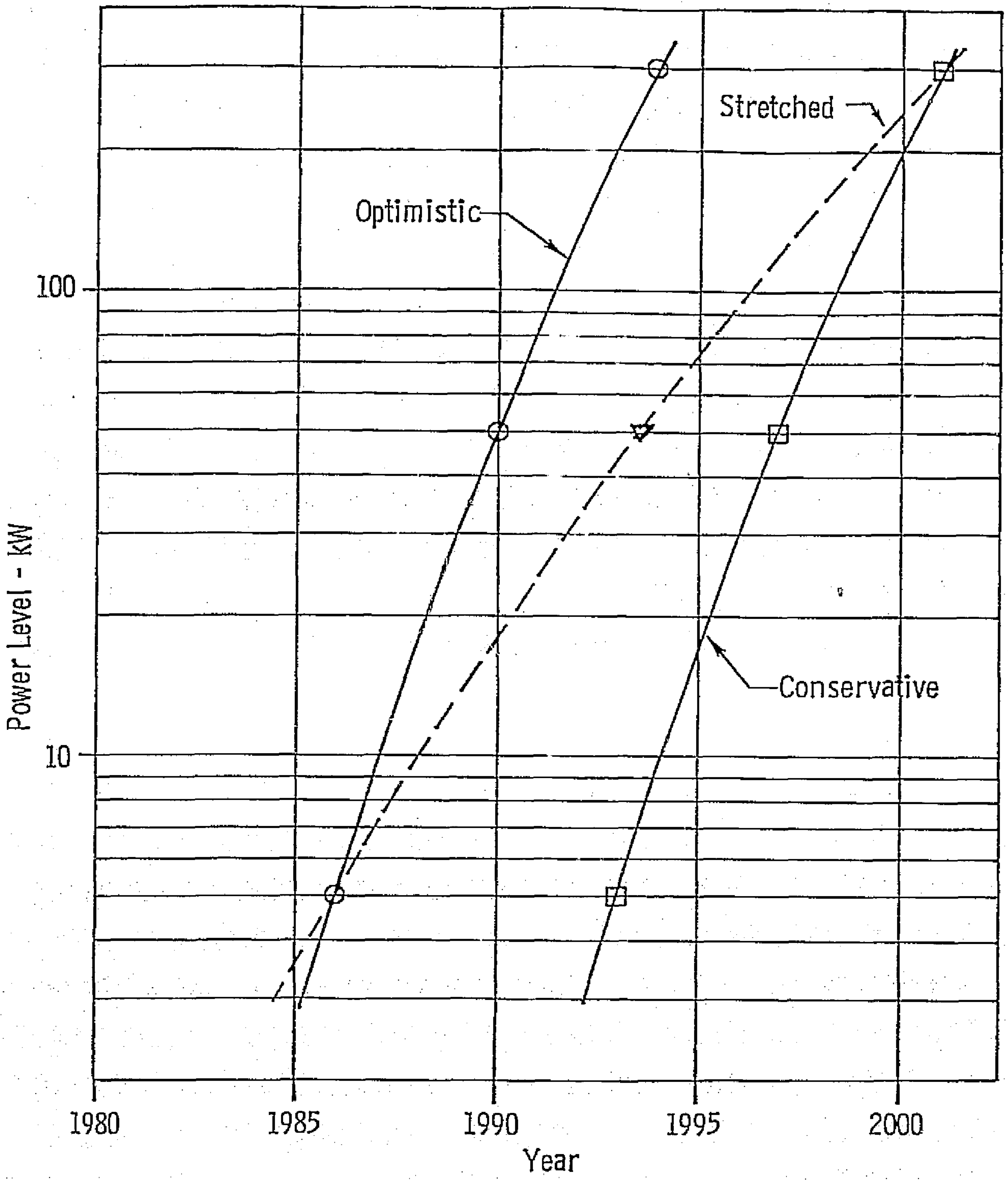


Figure 5-3. Power Requirements - Group 3 Initiatives
(Power Distribution Systems and Active/Passive Radar)

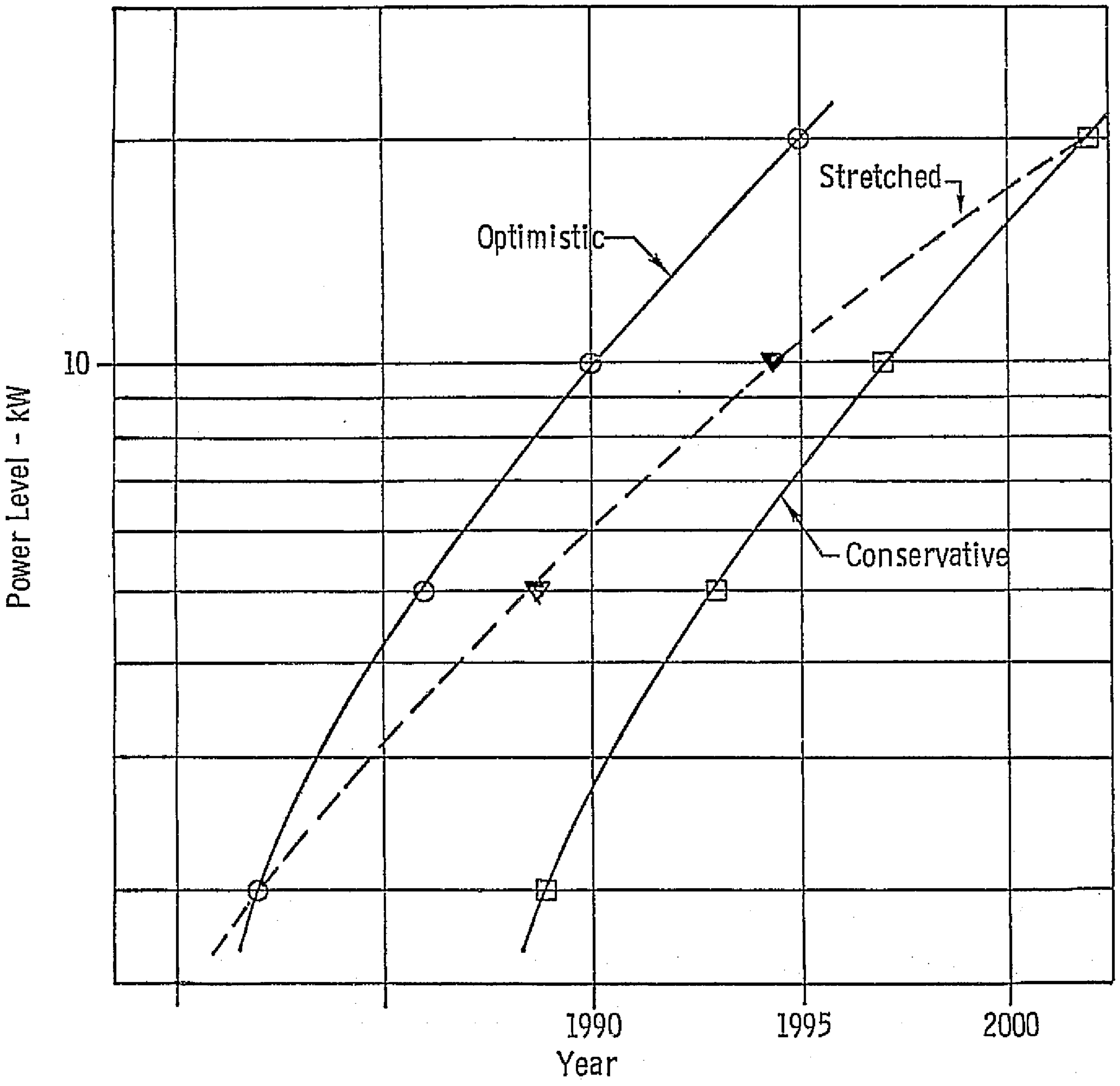


Figure 5-4. Power Requirements - Groups 4 and 6 Initiatives (Optical Observation, Designation, and Measurement)

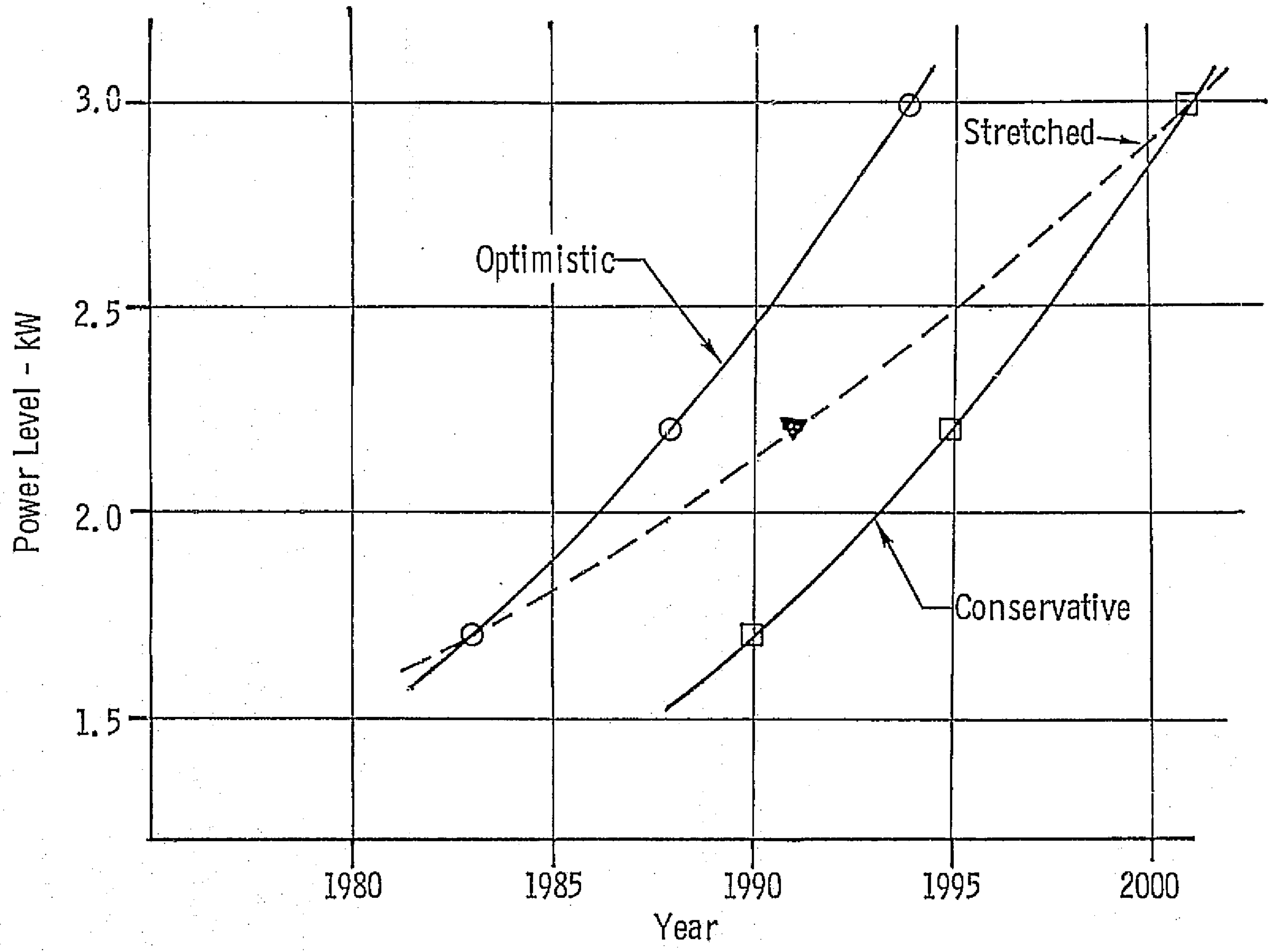


Figure 5-5. Power Requirements - Group 5 Initiatives
(High Altitude Navigation, Location, and Relay System)

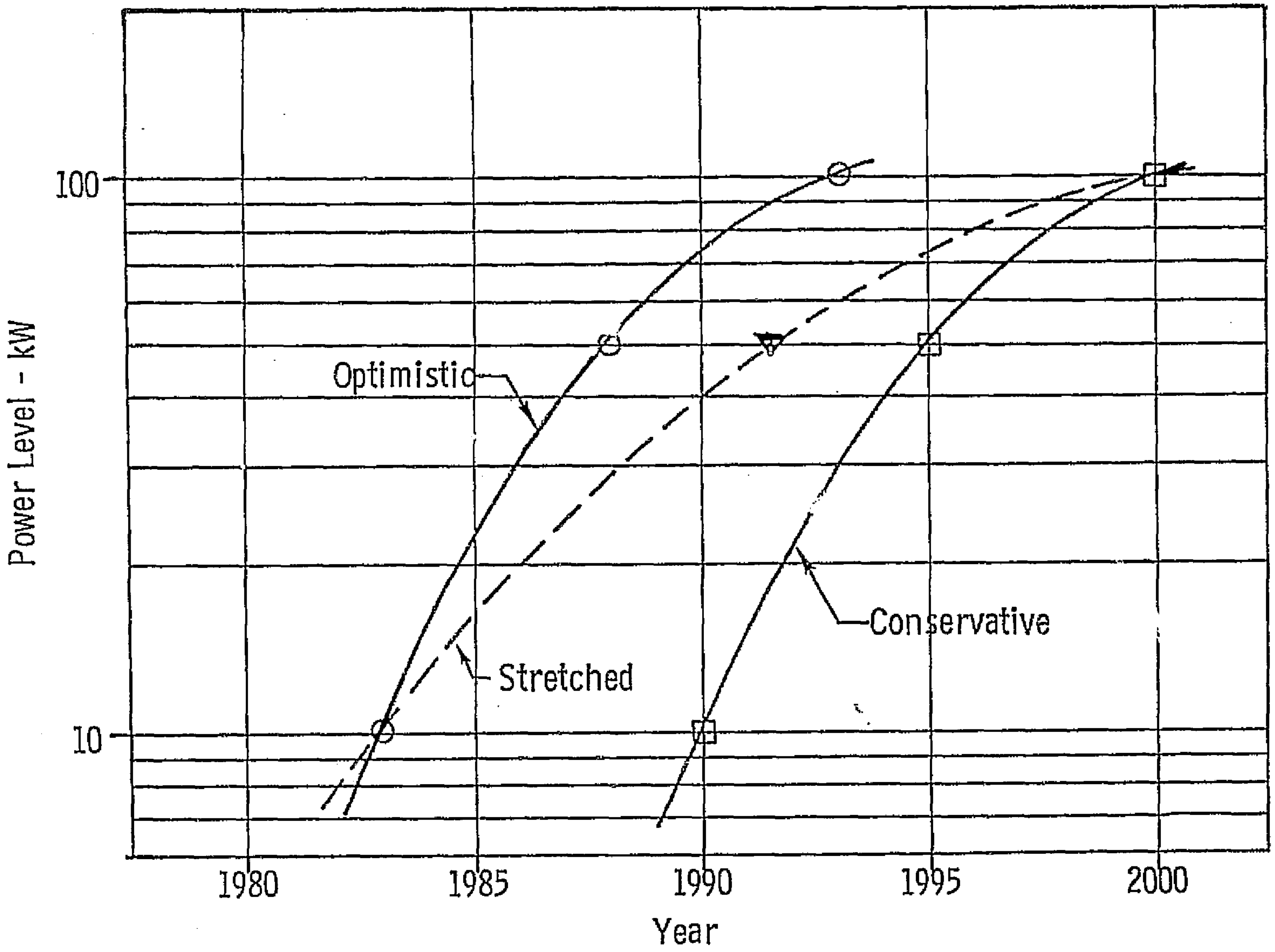


Figure 5-6. Power Requirements - Group 7 Initiatives

(Space Processing and Manufacturing)

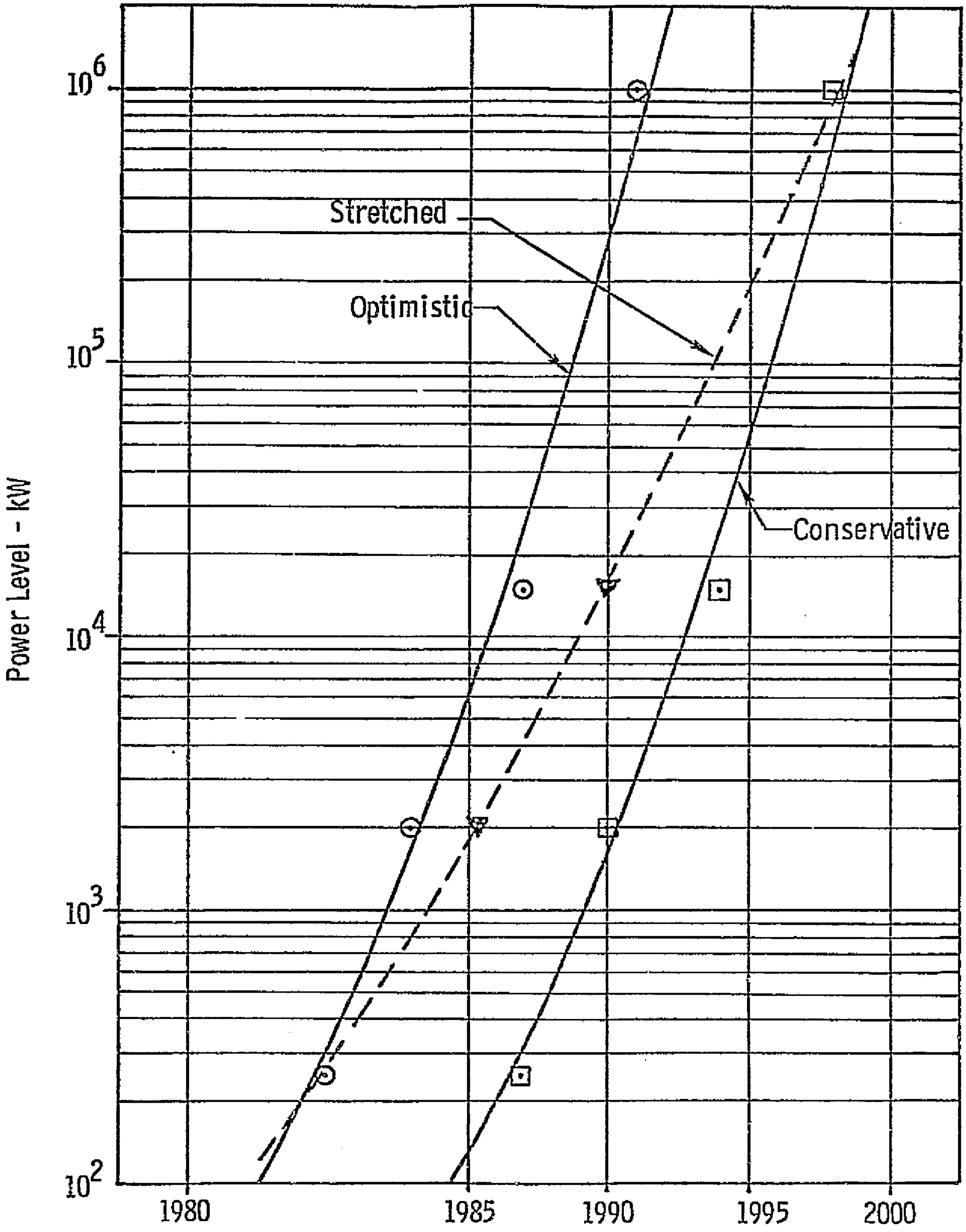


Figure 5-7. Power Requirements - Group 8 Initiatives
(Large-Scale, High-Energy, Far-Term Systems)

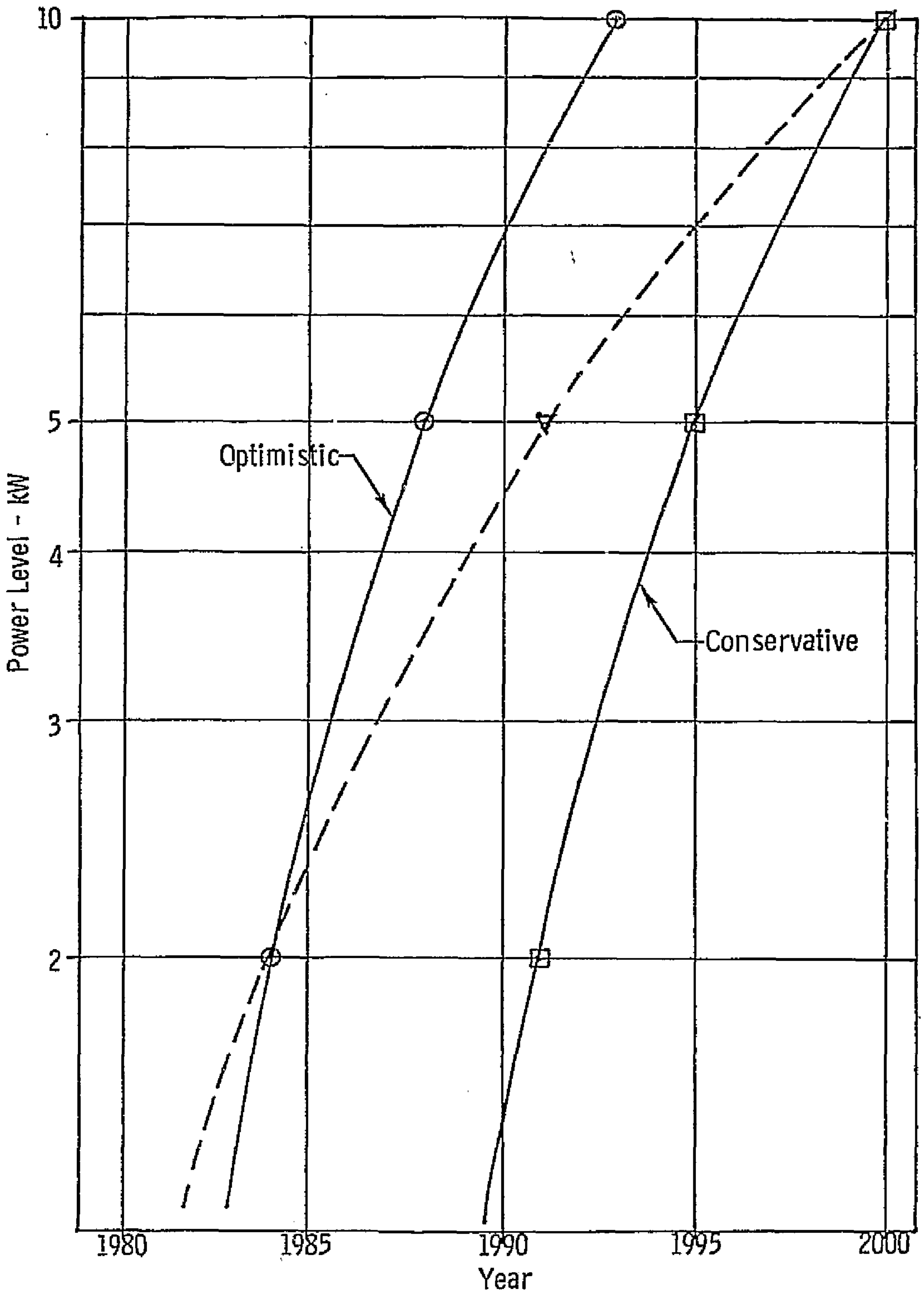


Figure 5-8. Power Requirements - Groups 9 and 11 Initiatives (Scientific Research Experiments and National Facilities)

Table 5-1. Initiative Group Rank Ordering

INITIATIVE		IOC DATE			
Group/ Subgroup	Title	Optimistic Program	Stretched Program	Conservative Program	Power Level
2/1	PUBLIC SERVICE SYSTEMS USING LONG MICROWAVE STATIONKEPT ANTENNAS - I	1983	1983	1990	1.0 kW
3/1	POWER DISTRIBUTION SYSTEMS AND ACTIVE/PASSIVE RADAR - I	1982	1982	1989	1.0 kW
2/2	PUBLIC SERVICE SYSTEMS USING LONG MICROWAVE STATIONKEPT ANTENNAS - II	1987	1991	1994	1.3 kW
5/1	HIGH ALTITUDE NAVIGATION, LOCATION, AND RELAY SYSTEM - I	1983	1983	1990	1.7 kW
2/3	PUBLIC SERVICE SYSTEMS USING LONG MICROWAVE STATIONKEPT ANTENNAS - III	1992	1999	1999	2.0 kW
4 & 6/1	OPTICAL OBSERVATION, DESIGNATION, AND MEASUREMENT - I	1982	1982	1989	2.0 kW
9 & 11/1	SCIENTIFIC/RESEARCH EXPERIMENTS AND NATIONAL FACILITIES - I	1984	1984	1991	2.0 kW
5/2	HIGH ALTITUDE NAVIGATION, LOCATION, AND RELAY SYSTEM - II	1988	1992	1995	2.2 kW
5/3	HIGH ALTITUDE NAVIGATION, LOCATION, AND RELAY SYSTEM - III	1994	2001	2001	3.0 kW
1/1	SERVICE PLATFORMS USING MICROWAVE MULTIBEAM ANTENNAS - I	1983	1983	1990	4.0 kW
3/2	POWER DISTRIBUTION SYSTEMS AND ACTIVE/PASSIVE RADAR - II	1986	1993	1993	5.0 kW
4 & 6/2	OPTICAL OBSERVATION, DESIGNATION, AND MEASUREMENT - II	1986	1988	1993	5.0 kW
9 & 11/2	SCIENTIFIC/RESEARCH EXPERIMENTS AND NATIONAL FACILITIES - II	1988	1991	1995	5.0 kW
4 & 6/3	OPTICAL OBSERVATION, DESIGNATION, AND MEASUREMENT - III	1990	1994	1997	10.0 kW
7/1	SPACE PROCESSING AND MANUFACTURING - I	1983	1983	1990	10.0 kW
9 & 11/3	SCIENTIFIC/RESEARCH EXPERIMENTS AND NATIONAL FACILITIES - III	1993	2000	2000	10.0 kW
4 & 6/4	OPTICAL OBSERVATION, DESIGNATION, AND MEASUREMENT - IV	1995	2002	2002	20.0 kW
1/2	SERVICE PLATFORMS USING MICROWAVE MULTIBEAM ANTENNAS - II	1987	1990	1994	25.0 kW
8/1	LARGE SCALE, HIGH ENERGY, FAR-TERM SYSTEMS - I	1982	1982	1989	25.0 kW
3/3	POWER DISTRIBUTION SYSTEMS AND ACTIVE/PASSIVE RADAR - III	1990	1997	1997	50.0 kW
7/2	SPACE PROCESSING AND MANUFACTURING - II	1988	1992	1995	50.0 kW
7/3	SPACE PROCESSING AND MANUFACTURING - III	1993	2000	2000	100.0 kW
1/3	SERVICE PLATFORMS USING MICROWAVE MULTIBEAM ANTENNAS - III	1993	2000	2000	100.0 kW
8/2	LARGE SCALE, HIGH ENERGY, FAR-TERM SYSTEMS - II	1984	1986	1990	210.0 kW
3/4	POWER DISTRIBUTION SYSTEMS AND ACTIVE/PASSIVE RADAR - IV	1994	2001	2001	300.0 kW
8/3	LARGE SCALE, HIGH ENERGY, FAR-TERM SYSTEMS - III	1987	1990	1993	2.0 MW
8/4	LARGE SCALE, HIGH ENERGY FAR-TERM SYSTEMS - IV	1992	1996	1999	15.0 MW
8/5	LARGE SCALE, HIGH ENERGY, FAR-TERM SYSTEMS - V	1996	2000	2003	1.0 GW
8/6	LARGE SCALE, HIGH ENERGY, FAR-TERM SYSTEMS - VI	2000	2004	2007	15.0 GW

Table 5-2 lists the power demands (in rank order) of initiative subgroups as a function of approximate IOC date. The utility of the table is to demonstrate which subgroups or development plan steps can be captured by a given space power capability in a given year. For instance, a 10 kW space power capability achieved in 1988 would capture Subgroups 5/2, 9&11/2, and 4&6/3 in the case of an optimistic space plan, but not be required until 1996 to capture the same subgroups if a conservative space plan were to be implemented. The data can be used as a tool for space planning in two ways:

1. If a projection is made of the space power technology capability at a given time in the future, the subgroups of initiatives that the projected technology will be able to "capture" is determinable.

2. If a projection is made of the total space system capability (the specific initiative subgroups implemented) at a given time in the future, the space power technology capability that will be required is determinable.

With the aid of information on expected advancements in space power technology, an assessment can be made as to whether those planned advancements will meet the requirements objectives. If not, then the plans can be modified to attempt to meet those objectives.

5.1.3 Conclusions

If national space planning embarks on a policy of deploying large multipurpose satellites the needs of DoD and the civil sector will not in general drive space power requirements. However, DoD needs, in the long term, appear to parallel NASA needs because many of the civilian initiatives have similar applications.

Present NASA space planning policy does appear to be leaning towards the eventual implementation of a few very large multipurpose satellites which can be serviced on orbit and have indefinite lifetimes. The rationale for such a policy is that it makes maximum use of the unique

Table 5-2. Initiative Subgroup Power Demand vs. IOC Date

OPTIMISTIC PROGRAM IOC											
1982-1984		1985-1987		1988-1991		1992-1994		1995-1997		1998-2000	
CONSERVATIVE PROGRAM IOC											
1990-1992		1993-1995		1996-1998		1999-2001		2002-2004		2005-2007	
Subgroup	Power	Subgroup	Power	Subgroup	Power	Subgroup	Power	Subgroup	Power	Subgroup	Power
2/1	1.0 kW	2/2	1.3 kW	5/2	2.2 kW	2/3	2.0 kW	4 & 6/4	20 kW	8/6	15 GW
3/1	1.0 kW	3/2	5.0 kW	9 & 11/2	5.0 kW	5/3	3.0 kW	8/5	1 GW		
5/1	1.7 kW	4 & 6 /2	5.0 kW	4 & 6/3	10.0 kW	9 & 11/3	10.0 kW				
4 & 6/1	2.0 kW	1/2	25.0 kW	3/3	50.0 kW	1/3	100.0 kW				
9 & 11/1	2.0 kW			7/2	50.0 kW	8/2	210.0 kW				
1/1	4.0 kW			8/3	2.0 MW	3/4	300.0 kW				
7/1	10.0 kW					8/4	15.0 MW				
8/1	25.0 kW										

capabilities of the Space Shuttle and leads as rapidly as possible to the exploitation of space for the immediate benefit of mankind. The large multipurpose satellites can be designed to service vast numbers of different users equipped with small, cheap user terminals. Some of the possible uses are personal communications, electronic mail, educational, and health and welfare TV, and personal navigation. The implication is that NASA may not be restricted to its traditional R&D role but might expand to commercial and private users by participating in commercial applications in providing orbital services as well as transportation.

The planning policy outlined above would result in the need for such space facilities as the Space Construction Base and the increased participation of man. The large satellites may be self-powered or may receive their power from separate space (the Space Power Module) or ground-based power plants.

DoD needs are somewhat different. The implementation of a few large undefended multipurpose satellites makes the space system fleet more vulnerable to enemy attack. The alternatives are either to provide active defense systems or to orbit a larger number of smaller satellites. The emphasis on survivability and anonymity in the case of DoD systems means that the DoD criteria for selection of space power system, subsystems and components may be different than the NASA criteria. For instance, at high power levels the DoD is more likely to select a more compact system than a solar cell/battery system with its large radar cross section. Solar cell design would also have to consider the susceptibility of solar cells to, for instance, intentional damage.

At this time, official DoD planning shows a less intense drive towards large multipurpose satellites than NASA planning. Nevertheless, DoD is presently initiating a well-funded study on the orbital assembly of large spacecraft (Reference 35) and a few high-powered systems are already described in DoD planning documents. In addition, during the studies conducted by Aerospace for NASA in recent years, a large number of DoD initiatives were identified which require high power. Many public sector initiatives have a parallel military application and DoD space power technology requirements, in many ways, parallel the needs of NASA.

In the civil sector, the U.S.'s lead in the commercial application of space is partly based on satisfying individual users by providing relatively small, reliable, cheap satellites that can be clearly identified with a specific customer. It is not clear that foreign countries will be willing to relinquish the prestige associated with having their own satellite or be willing or able to fund their own large multipurpose satellites. The utility and economic benefits of such systems will have to be clearly demonstrated, either by NASA or by domestic civil users, before they are accepted by foreign users. This will probably result, in the near term, in a greater tendency for foreign users to lease time on U.S. satellites or continue to purchase single-purpose systems, rather than to purchase their own multipurpose systems.

It is concluded that within the context of the above arguments, the demands of civil users on space power requirements and technology can be subsumed within those of NASA. There are some differences between the power levels and the technology requirements of NASA and DoD in the near term which are likely to be less apparent in the far term.

5.2 MISSION/TRAFFIC POWER REQUIREMENTS

The power requirements derived by using the second approach described in Section 1.3 of this volume (and illustrated schematically in Figure 1-1) are summarized in Figures 3-1 through 3-16 of this volume (Volume I) and Figures 3-3 through 3-8 of Volume II to this report. Detailed life-cycle cost data are listed in the computer printouts contained in Volume III.

The yearly kW-hr space energy demands and the 15-year totals and 15-year averages for the period 1981-1995 are listed in Table 5-3 and plotted in Figures 5-9 and 5-10. Values for all three user groups are presented. It should be noted the contributions from the Satellite Solar Power Station (SPS) are not included since they tend to obscure the total picture.

Table 5-3. ENERGY DEMAND (1981-1995) - (kW-hrs x 10^3)

ITEM	CALENDAR YEAR																	15 yr Total (1981-95)	15 yr Average (1981-95)
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995		
NOMINAL BUDGET																			
NASA	4.1	31.5	89.5	156.4	203.5	259.1	267.2	604.4	693.9	693.3	2649.6	2825.6	2754.3	2776.2	2870.4	3010.6	6842.5	26696.5	1779.8
DoD	-	85.7	174.7	198.7	364.3	411.0	527.0	1059.5	1226.7	1313.6	1451.4	1924.7	1928.6	2326.9	2949.7	3312.1	3319.0	22487.9	1499.2
CIVIL	52.7	137.4	201.6	237.0	309.3	321.2	364.0	288.8	409.0	451.9	465.0	512.8	617.9	594.8	534.2	463.3	434.4	6257.9	417.2
NASA & DoD & CIVIL	56.8	254.6	465.8	459.2	877.7	991.3	1158.2	1952.7	2329.6	2458.8	4566.0	5263.1	5300.8	5697.7	6354.3	6786.0	10595.9	55442.3	3696.2
OPTIMISTIC BUDGET																			
NASA	4.1	31.5	89.5	432.2	558.1	613.7	2790.3	2976.0	3144.3	3143.7	3917.1	3896.0	5007.3	2312.8	2801.1	2862.5	3370.6	37919.3	2528.0
DoD	-	85.7	174.7	198.7	443.1	450.4	1039.6	1288.3	1613.0	3166.6	3848.2	4392.7	6769.5	7325.2	6525.0	10344.7	10305.3	57884.9	3859.0
CIVIL	65.0	149.7	251.4	309.8	465.5	547.7	675.5	655.8	815.8	892.0	922.0	944.5	1074.0	1085.7	1111.1	1089.8	1107.4	11948.0	796.5
NASA & DoD & CIVIL	69.1	266.9	515.6	940.7	1466.7	1611.8	4505.4	4920.1	5573.1	7202.2	8687.3	9233.2	12850.8	10723.7	10437.2	14297.0	14783.3	107752.2	7183.5

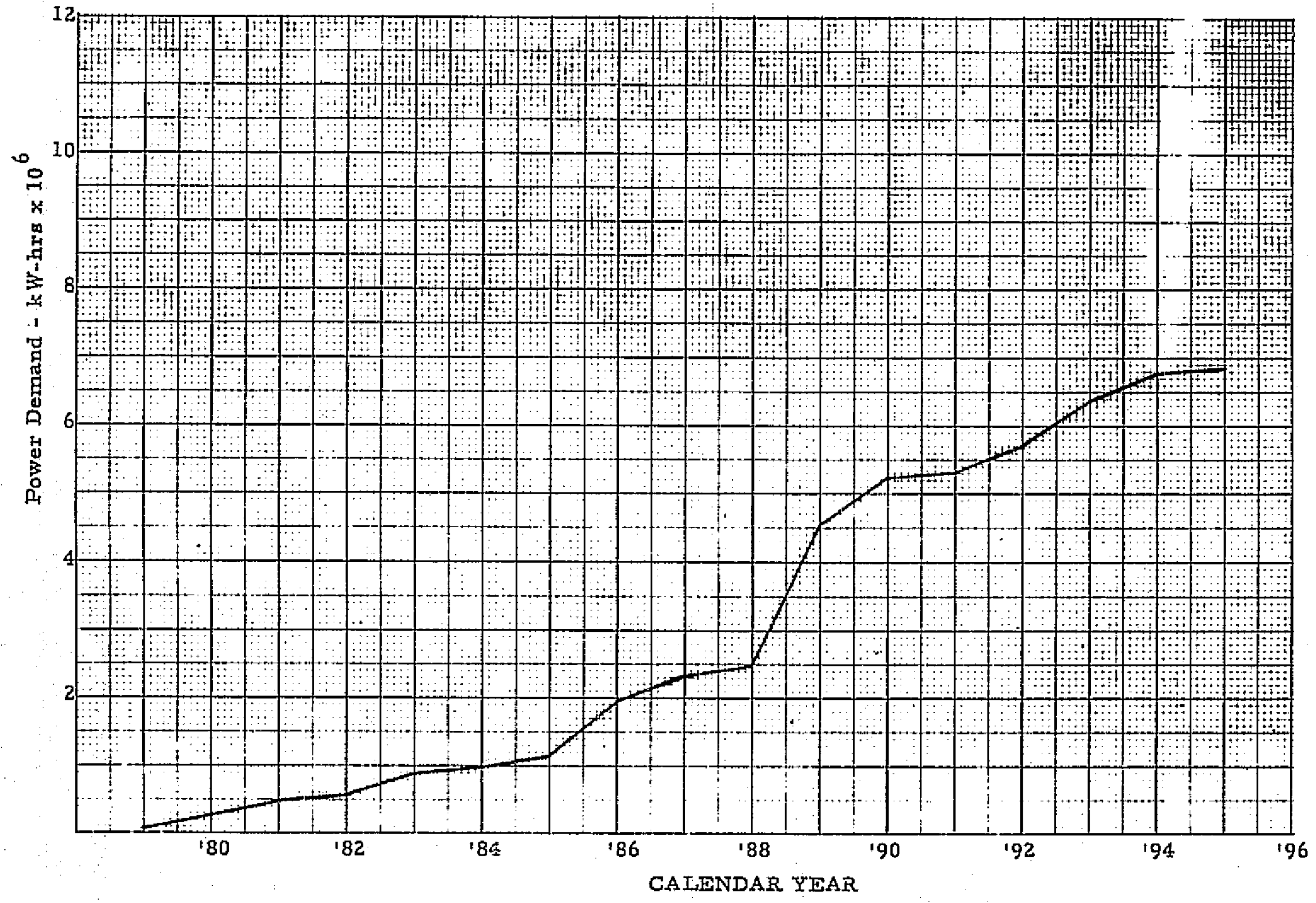


Figure 5-9. Total Space Energy Demand (NASA, DoD & Civil) 1985 to 1995 - Nominal Budget

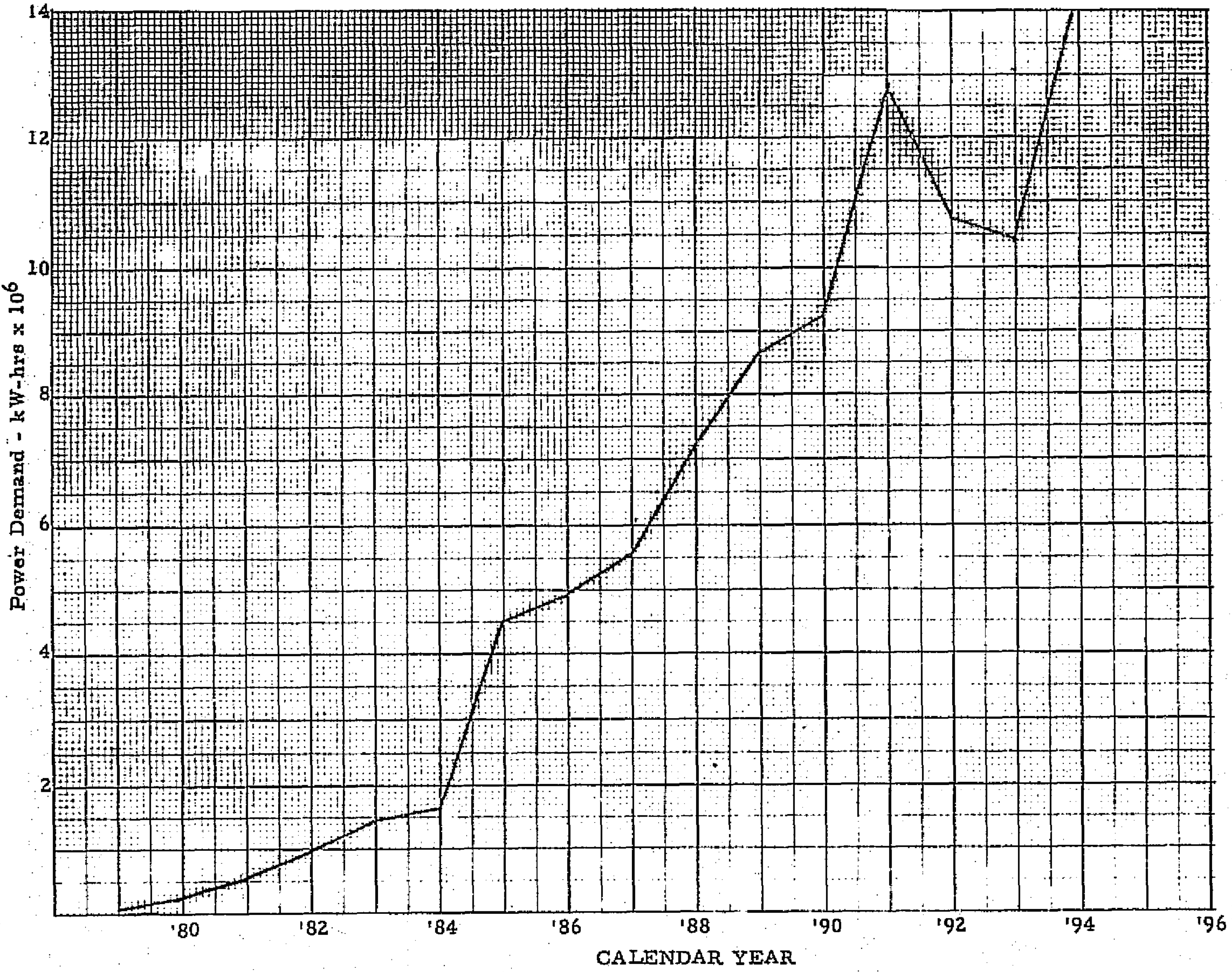


Figure 5-10. Total Space Energy Demand (NASA, DoD & Civil)
1985 to 1995 - Optimistic Budget

6. COST/BENEFIT ANALYSIS

6.1 BACKGROUND

In order to provide funding for the reoriented study effort, emphasis was placed primarily on setting up the data to enable cost/benefit analyses to be performed. The stated request by NASA was for a "market survey" for space power, or estimates of the demands for space power on a yearly basis together with estimates of the yearly expenditures on space power subsystems. The data listed in Figures 3-1 through 3-16 are intended to satisfy this request by delineating a breakout of the yearly kilowatt demands, total program costs, power system weights and cost, and solar array weights and costs, under given budgetary constraints.

The cost/performance program (Reference 29) which was used to generate subsystem weights and costs has the capacity to identify and separate space power subsystem subassemblies and components. Accordingly, for the purposes of this study, the solar cell subassembly was selected for cost/benefit analysis because it was thought that changes in solar cell technology funding can be of great significance as large solar arrays are brought into development. Further candidates for cost/benefit analysis such as battery technology and others can of course be postulated.

The method developed in this study permits varying a number of input parameters, such as budget goals, specific missions selected for inclusion in the traffic models, traffic rates and technology levels.

6.2 METHOD OF ANALYSIS

The steps used in the cost/benefit analysis consist of the following:

1. Derive permissible yearly funding for advancing the technology of space power systems.
2. Base calculations on probable demand from traffic model and associated life-cycle cost projections.
3. Identify candidate subsystem elements for receiving technology advancement funding.
4. Establish a figure-of-merit range of values.

6.3 GROUND RULES AND ASSUMPTIONS

1. Constant 1977 dollars.
2. Nominal budget conditions forecasted.
3. Only budget projections for NASA are used.
4. Large satellite power modules are separately identified and examined.
5. Continuing technology advancements projected for large capacity solar power systems.

6.4 ANALYSIS

6.4.1 Traffic Model Data

The following data were extracted from Appendix VII, Volume III to this report.

1. Total power subsystem cost (1979-1995)
    - (a) NASA = $758 million (excluding large power modules)
    - (b) NASA large power modules = $703 million*

---

* Data through 1996 included for large modules because over half their capacity is launched in that year.

2. NASA 17-year averages (excluding large systems)
   (a) 11 satellites per year
   (b) Total of 22.2 kW per year
   (c) Power system costs = $45 million per year

3. Satellite averages (excluding large systems)
   (a) Power level = 2 kW
   (b) Power subsystem weight = 395 lb
   (c) Solar array weight = 110 lb
   (d) Solar array cost = $1.1 million
   (e) Solar array cost/lb = $10,000
   (f) Launch cost/lb to synchronous orbit = $4000*
   (g) Watts per pound of solar array = 18

4. Large Power Modules
   (a) Solar array cost = $371 million
   (b) Solar array weight = 70370 lb
   (c) Solar array cost/lb = $5300
   (d) Power = 6275 kW
   (e) Watts per pound of solar array = 90
   (f) Subsystem cost = $703 million
   (g) Subsystem weight = 147000 lb
   (h) Subsystem cost/lb = $4780

6.4.2 Calculations

Based on data in Section 6.4.1 it can be seen that substantial savings are achieved in solar array cost per pound -- $10000 vs $5300 -- when the extremely large solar power modules are brought into operation. Such results stem principally from efficiencies of scale as power system arrays become larger. The important savings, however, come from the advancement of solar array technology whereby watts per pound are estimated to increase five-fold. Potential savings resulting from such technology advances can be calculated as follows:

---

* Assumes power systems placed in synchronous orbit.

		POTENTIAL SAVINGS		
		Maximum	Minimum*	
- Weight saved, 350000-70000	=	280000	105000	(lb)
- Solar array cost saved,				
350000 lb x $4000/lb	=	$1400	$770	(millions)
Less 70000 lb x $5300/lb	=	- 371	-371	
Net savings		1029	399	
- Launch vehicle cost savings, 280000 lb x $4000/lb*	=	1120	420	
- Total Savings		$2149	$819	(millions)

A figure-of-merit can be used to derive permissible funding amounts for technology R and D. The first step is to adopt an estimate of savings based on the above data -- let us assume $1 billion, for example. Next, pick a figure-of-merit that is reasonable -- the lower the figure the higher the R and D funding will be and vice versa. If 5 and 10 are used to establish a range the resulting total permissible fundings would be 200 and 100 million dollars, respectively; i.e., total savings divided by the two figures-of-merit. The final step would be to spread such funds over a period sufficiently early to provide technology demonstrations before incorporation in the satellite power system designs -- prior to 1987 for the 250 kW module and prior to 1991 for the 2000 kW system. A conservative method would result in funding at approximately $10 million per year during the 1980's -- possibly less in the earlier period and more in the later 80's to coincide with start of development of the large 2000 kW system.

6.5 OBSERVATIONS

From these preliminary results the following observations can be made:

1. To achieve the considerable savings demonstrated by the analysis, power subsystem technology must be advanced.

---

* Assumes weight is reduced to 175000 lb because of size efficiencies with no technology advance, viz., total weight saved would be 175000 - 70000 = 105000.

2. The solar arrays exceed 50% of electrical subsystem cost for the large power modules.
3. Based on historical data and the results of the above preliminary analysis, the solar array is an attractive candidate for such technology advancement.
4. Other components of the power subsystem, such as power control and conditioning equipment, also appear to be potential candidates.
5. The battery subsystem is less important from a cost point-of-view; however, it is important from the standpoint of weight and its effect on launch costs.
6. If a figure-of-merit of 5 to 10 is assumed, R&D expenditures for solar array technology could be funded at 10 to 20 million dollars per year in the 1980's.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The funding allocated to this study permitted only a general sweep through the subject with many decisions having to be made without in-depth consultation with the appropriate authorities. For this reason, the results should be considered representative rather than definitive. At the same time, broad conclusions can be drawn which would still be valid even if individual items in the data base diverged somewhat from the values shown.

It can be concluded that there is a monotonically increasing need for both higher power levels (kilowatts) and higher energy levels (kilowatt-hours) into the foreseeable future, whatever future is assumed. (That is, whether single-purpose satellites continue to be deployed or whether there is a movement towards large multipurpose satellites; whether the space budget continues much as it is today or whether increased funding is allocated for space activities.)

In the case of large multipurpose systems, Table 5-1 shows a need for primary mission power levels up to 10 kW in the late 1980's. However, the method of deployment of these large systems necessitates on-orbit construction facilities and support missions which themselves require power levels of 25 kW or more, justifying the need for both low altitude and high altitude 25 to 50 kW power modules. A particularly favored DoD radar system could demand a primary power level of 50 kW in the late 1980's.

In the mid to late 1990's, of course, the large scale, high energy systems (for instance, the Solar Power Satellite) could generate a need for very high power levels, possibly up to 15 GW. This corresponds, in turn, to a high total space power energy requirement in the same time period, as illustrated in Figure 5-10.

If a future is assumed which emphasizes single-purpose satellites, absolute power levels may be lower up to the late 1980's; nevertheless, individual satellites requiring power levels of 5 kW are likely. Total energy demands will be essentially the same for both futures, reaching levels of over 5 x 10^6 kW-hrs/year (for a nominal budget) to about 10 x 10^6 kW-hrs/year (for an optimistic budget) by 1990. If such systems as the Satellite Power Satellite (SPS) are planned for, the power levels and the total energy demands will be the same for both approaches. Total energy demands could reach 15 x 10^6 kW-hrs/year by the mid 1990's. Present proposals for an IOC date of 1998-2000 for a 5 GW SPS call for an extensive development program which includes Phase C and D development of geosynchronous flight articles as early as the mid 1980's. If such a program is followed, much of the space power technology developments for other systems can be subsumed within the SPS activity.

Whichever future is foreseen, the simple example shown in Section 6 illustrates a potential for sizeable cost savings, particularly if large power modules are to be employed and funds for continual R&D efforts are budgeted. The method outlined for analyzing such cost benefits (that is, in the context of an overall space program mission and traffic model) can be applied to a variety of alternative futures and also to a number of technologies other than solar array technology.

7.2 RECOMMENDATIONS

Because more up-to-date planning information (both for NASA and for DoD) has recently become available, it is recommended that the computer techniques and procedures developed herein should be used to examine a wider range of possible futures and to derive specific cost benefit break-even points. The methodology should also be applied to other technology areas to determine how to best distribute total technology expenditures. This is particularly important for the types of satellite systems now being planned which will require much longer development times than the types of satellites built today. Relatively high figures of merit must be assured to justify R&D expenditures because of the longer time delay between expenditure and payoff. This is particularly important in programs such as, for instance the SPS program.

REFERENCES

1. Advanced Space System Concepts and Their Orbital Support Needs, (1980 - 2000), U, Vol. I through V, Aerospace Corp. Report ATR-76(7365)-1, 1 December 1976 (Secret).

2. Integrated Planning Support Functions (Study 2.7) Vols. I and II, Aerospace Corp. Report ATR-77(7378)-1, June 1977.

3. Buehl, F. W., and Hammond, R. E., "A Review of Communications Satellites and Related Spacecraft for Factors influencing Mission Success", Aerospace Corp. TOR-0076(6792)-1, Vol. II, 17 November 1975.

4. Nagler, R. G., and Schlue, J. W., "624-3 Special Programs Office Satellite Capability Handbook and Data Sheets", Prepared for NASA Office of Applications by Jet Propulsion Laboratory, California Institute of Technology, July 1976.

5. Scott, E., (editor), TRW Space Log Vol. 14, 1975.

6. Scott, E., (editor), TRW Space Log Vol. 15, 1975.

7. Satellite Situation Report Vol. 17, No. 1, Office of Public Affairs, Goddard Space Flight Center, Greenbelt, Maryland, Feb. 28, 1977.

8. Hasbach, W. A., Jet Propulsion Laboratory California Institute of Technology to J. P. Mullin, NASA Headquarters, Letter, dated March 7, 1977.

9. Elson, B. M., "Solar Array Capabilities Increase", Aviation Week and Space Technology, September 13, 1971, pp 50-55.

10. The 1973 NASA Payload Model, Space Opportunities 1973-1991, National Aeronautics and Space Adminstration, June 1973.

11. The 1973 Space Shuttle Traffic Model, George C. Marshall Space Flight Center, NASA TMX-64751, July 1973.

12. The October 1973 Expendable Launch Vehicle Traffic Model, George C. Marshall Space Flight Center, NASA TMX-64752 Revision 2, January 1974.

13. Working Draft. National Payload Model for Joint NASA/USAF Study on Space Shuttle Orbiter Procurement, National Aeronautics and Space Administration (Internal Planning Use Only), July 1976.

14. Draft NASA Five Year Plan, 1976 Review, National Aeronautics and Space Administration, July 14, 1976.

15. Draft Report on NASA Five-Year Planning, Fiscal Years 1978 Through 1982, National Aeronautics and Space Administration, Undated.

16. DoD Transition Planning/SAMSO Revision 6 to Mission Model, (U), 1 February 1977 (Secret).

17. Draft Preliminary Input to the DoD/ERDA Space Power Activity, Task 1: Mission Requirements, (U), Aerospace Corp. Report AS-77-01743, 18 April 1977 (Secret).

18. Mission Analysis on Future Space Activities, (U), SAMSO TR-75-217, October 1975 (Secret).

19. Project New Horizons II, Conference No. 2 on Technology Opportunities, (U), Aerospace Corp. Briefing by P.M. Diamond, 19 November 1974 (Secret).

20. Summarized NASA Payload Descriptions, Automated Payloads, Level A Data, George C. Marshall Space Flight Center, July 1975.

21. Payload Descriptions, Volume 1, Automated Payloads, Level B Data, George C. Marshall Space Flight Center, July 1975.

22. Summarized NASA Payload Descriptions, Sortie Payloads, Level A Data, George C. Marshall Space Flight Center, July 1975.

23. Payload Descriptions, Volume II, Sortie Payloads, Level B Data, George C. Marshall Space Flight Center, July 1975.

24. Space Shuttle Program. Space Shuttle System Payload Accommodations, Level II. Program Definition and Requirements, Vol. XIV, Lyndon B. Johnson Space Center, JSC 0770, Vol. XIV, Revision E, June 1977.

25. NASA Payload Data Book, Payload Analysis for Space Shuttle Applications (Study 2.2), Final Report, Vol. II, Aerospace Corp. Report ATR-72 (7312)-1, 31 July 1972.

26. Launch Vehicle Users Guide, Aerospace Corp. Report TOR-0073 (3419)-1, Reissue A, 21 May 1975.

27. Edgecombe, Donald S., Battelle Columbus Laboratories to J. W. Stearns, Jet Propulsion Laboratories, Letter, Reference BMI-NLVP-IL-77-35, April 8, 1977.

28. Outside Users Payload Model, Battelle Columbus Laboratories Memo, BMI-NLVP-IM-77-4, August 15, 1977.

29. Systems Cost/Performance Analysis (Study 2.3) Final Report, Vols. I, II and III, Aerospace Corp. Report ATR-75 (7363)-3, 31 March 1975.

30. Spacecraft Design and Cost Model Development, Final Report, Aerospace Corp. Report ATM-76 (8191)-3 Addendum, 30 June 1976.

31. Outlook for Space, Report to the NASA Administrator by the Outlook for Space Study Group, NASA SP-386, January 1976.

32. 10 to 75 kW Reactor Power Systems for Space Applications, Atomics International Div., Rockwell International Corp., March 24, 1976.

33. Boretz, J. E., "Reactor Hybrid-Organic Rankine Cycle Electric Power Systems (ORCEPS) for Space Applications, "Proceedings of 12th IECEC, Sept. 1977.

34. Space Station Systems Analysis Study, Grumman Aerospace Corp., August 1977.

35. Statement of Work, Orbital Assembly of a Large Spacecraft Concept Design Phase, Issued by USAF/SAMSO, Undated.