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Volume II: Equipment Commonality Analysis

31 July 1975

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Prepared for

LOW COST SYSTEMS OFFICE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C. 20546

Systems Engineering Operations

THE AEROSPACE CORPORATION

Aerospace Report No.
ATR-76(7364)-1, Vol II

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Volume II: Equipment Commonality Analysis

Prepared by

Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

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STANDARDIZATION AND PROGRAM EFFECT ANALYSIS (STUDY 2.4) FINAL REPORT

Volume II: Equipment Commonality Analysis

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FOREWORD

This report documents The Aerospace Corporation effort on Study 2.4, Standardization and Program Effect Analysis, which was performed under NASA Contract NASW 2727 during the fiscal year 1975. The study direction at NASA Headquarters was under Mr. N. Rafel, Director of Program Practices of the Low Cost Systems Office.

This volume is one of four volumes of the final report for Study 2.4. The volumes are:

Volume I	Executive Summary
Volume II	Equipment Commonality Analysis
Volume III	Program Practice Analysis
Volume IV	Equipment Compendium

Volume I summarizes the overall study in brief form and includes the relationship of this study to other NASA efforts, significant results, study limitations, suggested research, and recommended additional effort.

Volume II documents the analyses performed in selecting the flight-proven hardware for the NASA new starts. Volume III provides information on the design-to-cost procedures used on an Air Force satellite program and the available cost data on program practices that exist at The Aerospace Corporation.

Volume IV catalogs housekeeping subsystem components from eight NASA and nine DoD current satellite programs. The compendium provides a summary of programmatic, technical, and environmental data for each component.

ACKNOWLEDGMENTS

The equipment commonality analysis was performed by members of various technical disciplines and cost specialists. The study director would like to extend thanks and acknowledge their contributions.

H. Campbell	Cost
C. Davenport	Stabilization
V. Gentry	Communications
F. Hughes	Stabilization
G. Manke	Stabilization
R. Mascolo	Propulsion
D. Rufus	Electrical Power
H. Sampson	Electrical Power
E. Tarca	Communication

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CONTENTS (Cont.)

APPENDIXES

NOMENCLATURE

AP	Auxiliary Propulsion
AVHRR	Advanced Very High Resolution Radiometer
BAU	Baseband Assembly Unit
BER	Bit Error Rate
BOL	Beginning of Life
CDH	Communication and Data Handling
CEA	Control Electronics Assembly
CMG	Control Moment Gyro
DOD	Depth of Discharge
DPA	Digital Processor Assembly
DTU	Digital Telemetry Unit
EIRP	Effective Isotropic Radiated Power (dBW)
EOL	End of Life
EP	Electrical Power
FOV	Field of View
FSK	Frequency Shift Keying
FST	Fixed-head Star Tracker
GMT	Greenwich Mean Time
GSFC	Goddard Space Flight Center
HCMM	Heat Capacity Mapping Mission
HEAO	High-Energy Astronomical Observatory
LCSO	Low Cost Systems Office
LMSC	Lockheed Missiles and Space Company
LOS	Line of Sight
LST	Large Space Telescope
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration

NOMENCLATURE (Continued)

OTA	Optical Telescope Assembly
PCM	Pulse Code Modulation
PCU	Power Control Unit
PM	Phase Modulation
PRN	Psuedorandom Noise
PSK	Phase Shift Key
RGA	Reference Gyro Assembly
RW	Reaction Wheel
SAD	Solar Array Drive
SADE	Solar Array Drive and Electronics
SAGE	Stratospheric Aerosol and Gas Equipment
SC	Stabilization and Control
SCM	Spacecraft Cost Model
SDCM	Spacecraft Design Cost Model
SDF	Single Degree of Freedom
SGLS	Space Ground Link Subsystem (AF)
SI	Scientific Instruments
SMM	Solar Mapping Mission
SOC	State of Charge
SSM	Support Service Module
STDN	Spaceflight Tracking and Data Network
STP	Space Test Program
SWA	Scan Wheel Assembly
TA	Transfer Assembly
TDRS	Tracking and Data Relay Satellite
USB	Unified S-Band (NASA)
VDA	Valve Driver Assembly
WASS	Wide Angle Sun Sensor
nh	New Hardware

FIGURES

FIGURES (Continued)

TABLES

TABLES (Continued)

TABLES (Continued)

1. INTRODUCTION

During the early satellite era, spacecraft components were generally custom designed for each new program. As spacecraft technology progressed, there was emphasis on the use of developed hardware in an attempt to reduce cost and shorten the development time, and yet maintain system reliability. The current trend is to inherit equipment from a spacecraft within its own "family." The concept of using components from outside the "family" can be expected to be limited, because the accessibility of information such as a comprehensive listing of developed hardware that provides technical and cost data is not currently available to designers.

This task was conducted to examine the feasibility and cost savings of using flight-proven components from a large sample of current NASA and DoD satellites for new starts. The accumulation of component data was conducted during the earlier part of this study and is cataloged in the Equipment Compendium, Vol. IV (Ref. 1). This catalog and the LCS Standard Equipment Announcement were used as the information source on available flight-proven hardware.

The new starts that were analyzed for application of flight-proven components are:

a. Large Space Telescope (LST)
b. Heat Capacity Mapping Mission (HCMM)
c. Stratospheric Aerosol and Gas Equipment (SAGE)
d. Solar Maximum Mission (SMM)
e. TIROS-N

The new starts represent a spectrum of satellite sizes in low-earth orbit. They range from 136 to 11,340 kg (300 to 25,000 lb) satellites. The technical information describing the new starts was obtained from reports such as conceptual studies, contractor studies, or spacecraft specifications.

The selection of the components for the new starts was performed by subsystem specialists who used technical data supplied by NASA and the Spacecraft Design and Cost Model (SDCM) computer program. The catalog provided information on component capability, but the most important task of the specialist was to establish the required component parameters and component inventory from the data in the new starts. The component parameters were developed from spacecraft performance requirements and were integrated with the subsystem requirements. Spacecraft variations were also analyzed where the subsystem design concepts could be reconfigured to study the cost impact of design alternatives.

A cost estimating method that can account for selected components was required to cost the integrated spacecraft and alternative configurations. Existing cost models are basically subsystem oriented and are not sensitive to component variations. For this task, a routine within an existing computer program was modified to cost the spacecraft on the basis of selected components. This spacecraft cost model was developed for use on DoD and NASA satellites.

2. ANALYSIS

2.1 INTRODUCTION

The method of analysis that has been used in examining the application of flight-proven components to new starts consists of three major steps. First, a suitable preliminary configuration is generated by a computer-based design model that is inputed with data on the new start. Next the design by computer is supplied to the spacecraft subsystem specialists who use the computer printout along with component requirements to make the component selection from the equipment compendium (catalog). Finally, the engineer-selected components are inputed to a computer cost model (that is component oriented) and comparisons are run between designs for baseline ("business as usual") spacecraft and flight-proven component spacecraft, i.e., spacecraft that employ previously developed components. The purpose of this section is to describe the analytical procedure that has been followed and to describe the models that have been used in the procedure.

2.2 SPACECRAFT DESIGN AND COST MODEL

The selection of developed components for use in a particular spacecraft design depends on (1) establishing the satellite performance requirements, (2) identifying components and subsystems that will meet the required performance, (3) analyzing the interrelationships among all the components and subsystems, and (4) developing a sufficiently large source (data base) from which a variety of components can be selected. The first step is accomplished by consulting study reports such as those referenced in this report covering new start satellites. For the remaining steps, it was determined that an effective tool for starting the design procedure was to use the Spacecraft Design and Cost Model (SDCM)*. The SDCM is currently operating and has been used in numerous applications for both NASA and DoD. Conceptually, the model first accepts as inputs such basic design considerations as operating altitude, system reliability, type of subsystems, mission equipment weight and power, and pointing requirements. It then produces a series of subsystem characteristics that meet the input requirements, and, finally provides as output the cost associated with each configuration. The model comprises technical, reliability, and cost portions. The technical portion of the model consists of a two-step process: the first step selects subsystem configurations that meet the basic design considerations, and the second step selects equipment from a data base to mechanize each subsystem configuration. The reliability portion of the model adds redundancies to provide component quantities to meet the system reliability requirements. The output of the technical model is a number of spacecraft configurations that meet or exceed the basic requirements. Each configuration is provided with information down to the subsystem component (assembly) level. The cost required to design, build, and operate the spacecraft is estimated by summing the individual costs for each component called out by the computer as part of the particular configuration. (The cost portion of the SDCM is not required at this juncture in the analysis; however, a variant is needed later and is described in succeeding paragraphs.)

The data base in the SDCM contains component data drawn from the catalog (Ref. 1) and components from other sources. The numbering system is cross-referenced in the data base between the catalog numbers and the SDCM identification numbers as shown in an example of selected data base information in Table 2-1. A complete printout of the data base can be found in Appendix B and a printout of the SDCM is provided in Appendix C.

* The SDCM was derived from a cost/performance spacecraft model developed for NASA over the past several years. A complete description of the model can be found in Reference 2.

Table 2.1 Communications Subsystem

CODE	PROGRAM	COMPONENT	QTY PER SAT	UNIT WT (LB)	UNIT VOL (CUFT)	AVG PWR (W)	FAIL RATE (/E9HR)	DATA RATE (KBPS)	MAX FREQ (MHZ)	MIN FREQ (MHZ)	GAIN OR PWR OUTPUT	NO OF CHNLS
103	D 3-4- 5	BASEBAND ASSY UNIT		2.0	.03	6	4050	128				1
106		BASEBAND ASSY UNIT					2000	128				1
109	D 3-4- 6	BASEBAND ASSY UNIT		2.0	.02	0	23	256				1
112	D 2-4- 3	BASEBAND ASSY UNIT		4.0	.05	3	13300	264				2
199		BASEBAND ASSY		.3	.01	0	1147	256				1
202	N 2-4- 6	ANTENNA		8.4	.71		40		2300	2090	-11	
203	D 6-4- 7	ANTENNA		10.4	.13		293		2300	1750	-7	
206	D 2-4- 2	ANTENNA		1.5	.14		40		2300		-6	
212	D 2-4- 1	ANTENNA		.5	.02		40		2300		0	
213	N 1-4-14	ANTENNA		14.2	2.51		11		2218			
215	D 1-4- 7	ANTENNA		2.6	.03		39		2300	1750	0	
218	D 4-4- 4	ANTENNA		.8	.02		23		2300	1750	0	
221	D 3-4- 5	ANTENNA		5.8	.20		14		2300	1750	2	
227	D 3-4- 8	ANTENNA		.8	.01		16700		2300	1750	2	
230	D 3-4- 9	ANTENNA		1.8	.30		20		2300	1740	3	
233	D 3-4-10	ANTENNA		2.1	.03		400		2300	1750	6	
236		ANTENNA		1.0	1.00		100				10	
239	D 8-4- 9	ANTENNA		2.1	.03		400		2300		20	
303	D 5-4- 3	TRANSMITTER		2.2	.04	10	1050		2311	UNIFIED	1	1
306	D 8-4- 2	TRANSMITTER		2.1	.03	10	3080		2300	UNIFIED	1	1
309	D 8-4-21	TRANSMITTER		1.8	.02	8	1370		2300	UNIFIED	1	1
312	D 8-4- 3	TRANSMITTER		2.2	.03	15	3800	1024	2300		2	0
315		TRANSMITTER		2.4	.04	10	14000		2300	UNIFIED	2	1
318	D 2-4- 4	TRANSMITTER		7.0	.07	30	22000		2300	UNIFIED	2	1
321	D 3-4-11	TRANSMITTER		2.3	.03	22	10000	28	2300	UNIFIED	2	1
324	D 3-4- 1	TRANSMITTER		7.5	.20	37	2500		2300	UNIFIED	2	1
325	N 1-4- 2	TRANSMITTER		3.3	.09	9	976	128	2300		2	0
327	D 1-4- 3	TRANSMITTER		4.7	.05	16	6870		2300	UNIFIED	3	1
328	N 7-4-10	TRANSMITTER		3.0	.04	55	102459		1704	UNIFIED	4	2
333		TRANSMITTER		2.3	.02	20	14000		2300	UNIFIED	5	1
336	D 4-4- 7	TRANSMITTER		2.5	.03	70	2840		2300	UNIFIED	9	2
339		TRANSMITTER		2.5	.02	40	14000		2300	UNIFIED	10	1
342	D 3-4- 7	TRANSMITTER		3.0	.03	70	10000	1024	2300		10	0
345	D 3-4- 3	TRANSMITTER		13.0	.41	130	21700		2300	UNIFIED	10	1
348	D 2-4- 6	TRANSMITTER		3.0	.03	75	12500	256	2300	UNIFIED	11	0
351	D 7-4- 1	TRANSMITTER		1.9	.20	52	5600	2562	2289		12	0
354		TRANSMITTER		2.8	.02	90	14000		2300	UNIFIED	20	1
357	N 7-4- 9	TRANSMITTER		10.3	.12	67	10009	24	2265		20	0
397		TRANSMITTER		1.9	.19	10	2336		2300	UNIFIED	1	1
398		TRANSMITTER		2.1	.21	16	3022	1024	2300		50	0
399		TRANSMITTER		2.1	.21	16	3022	1024	2300		5	0
403	D 3-4-16	RECEIVER		2.3	.03	3	3330	1	1842	1760		
406	D 6-4-26	RECEIVER		2.3	.02	7	3350	1	1840	1760		
409	D 4-4-16	RECEIVER		2.7	.03	3	630	1	1850	1750		
415	D 1-4- 5	RECEIVER		3.9	.05	3	5790	1	1840	1760		
418	D 5-4- 4	RECEIVER		4.2	.08	2	611	1	1850	1750		
421	D 3-4- 1	RECEIVER		4.2	.05	1	5180	1	1850	1750		
424	D 7-4- 2	RECEIVER		5.0	.07	3	1150	1	1850	1750		
427	D 3-4-12	RECEIVER		9.0	.21	10	2400	1	1850	1750		
513	D 5-4- 8	COMMD SIG COND		1.5	.02	0	3120	1				
514	D 3-4- 6	COMMD SIG COND		1.6	.01	0	5560	1				

2.3 TECHNICAL ANALYSIS

The procedure for selection of the components was performed by the subsystem specialists. The information supplied to the specialists was the SDCM machine-produced configuration and the new start data. The SDCM provides such data as the estimate of load power, solar array area, battery capacity, satellite mass inertia, control impulse, and quantity of each component to meet system reliability requirements. The type of information produced by the SDCM would generally require many design iteration cycles before spacecraft integration could be achieved by the various subsystem specialists. The SDCM performed the initial design cycles and thus shortened the design time. The specialists used the computerized design as applicable in generating the component requirements; however, in most instances the development of the component characteristics required extensive analysis of the new start reports. At times, the reports provided component specifications, but most often they were subsystem specifications from which component characteristics were generated by the specialist. This was generally the case with stabilization and communication subsystems where mission equipment and ground support specifications are required to be integrated into the spacecraft. The requirements that were generated during the study or obtained from NASA-supplied reports are included, along with the characteristics of the selected candidate components.

The comparison between component requirements and candidate characteristics provided the selection rationale. The catalog (Ref. 1) was used to provide data on the component characteristics, and if information was lacking, the contractor component specifications were further examined for additional data. Some of the components could be used as is, and others that did not match up on all parameters required modifications to adapt the unit to the subsystem. The extent to which previously developed components required design modifications and repackaging or whether they could be incorporated with no changes was determined by the specialist. He also determined which components could not be based on previous designs and thus required new development.

In addition to conceptually designing the nominal spacecraft, alternative designs were also configured to increase the use of flight-proven hardwares from the catalog. To allow use of more components from the catalog, the subsystem performance in terms of weight and power control was varied, but the basic requirements such as communication links and spacecraft pointing accuracy were not varied in the study.

2.4 SPACECRAFT COST MODEL (SCM)

Previously, where the incremental costs associated with alternative designs were to be examined, no method of cost analysis was available that could accurately model such effects because prior models dealt with aggregate subsystem rather than with component costs. Improvements in cost data acquisition have made possible the development of a spacecraft model (SDCM) that is component oriented. This model has been adapted so that the cost portion of the program can be used independently. Thus, the engineering design subroutine can be bypassed in favor of a detailed analysis by subsystem specialists. Accordingly, changes made in the computer program provide for direct inputs to the cost subroutine of (1) engineering data concerning component identities and characteristics, and (2) performance information related to structure, thermal, wiring, and other non-component assemblies. The result was a modified cost model computer program called SCM.

In essence, the inputs to SCM represent those that normally would be produced by the engineering model subroutine within the complete model. Inputs can be grouped into three classes--one general, one subsystem oriented, and the third component oriented. The first group covers the following items:

a. Satellite name
b. Quantity of qual units (full-flight design but not to be flown)
c. Quantity of flight units
d. Year of constant dollars (e.g., 1975 dollars)

The next group covers data for each subsystem, i.e., stabilizations and control, auxiliary propulsion, data processing, communications, electrical power, structure, thermal control and mission equipment:

a. Type of subsystem configuration

b. Weight of subsystem (plus dry weight of auxiliary propulsion)

c. Mission equipment design, development, test, and engineering (DDT&E) and unit cost (if needed--treated as thru-put)

The third group includes the following information:

a. Identity code number of each component in each subsystem

b. Percentage of normal DDT&E that each component requires

c. Quantity of each component required

d. Percentage of normal DDT&E that non-catalog assemblies and subsystems require

e. Thrust of attitude control and translational thrusters

f. Data processing bit rate for spacecraft housekeeping and rate for mission equipment

g. Harness weight

h. Power control weight

i. Weight of converters

j. Solar array area (square-foot) and weight

k. Battery capacity (A-hr) and number of cells per battery

Figures 2.1 and 2.2 are copies of input keypunch forms actually used in preparing SCM cost estimates; they show all of the above input data requirements. An example of the machine output is illustrated in Figure 2.3 where breakdowns are shown for major categories of DDT&E and unit (recurring) cost by subsystem and total spacecraft. Figure 2.4 contains a further breakdown by components.

The key to the usefulness of the SCM is that it allows the analyst to select all components and their quantities, and most importantly, it allows percentage factors to be applied to DDT&E for all components. Such a procedure gives an analyst the ability to vary component development cost from 0 to 100 percent. (In fact, percentages greater than 100 can also be applied.) When percentages less than 100 are applied to a particular

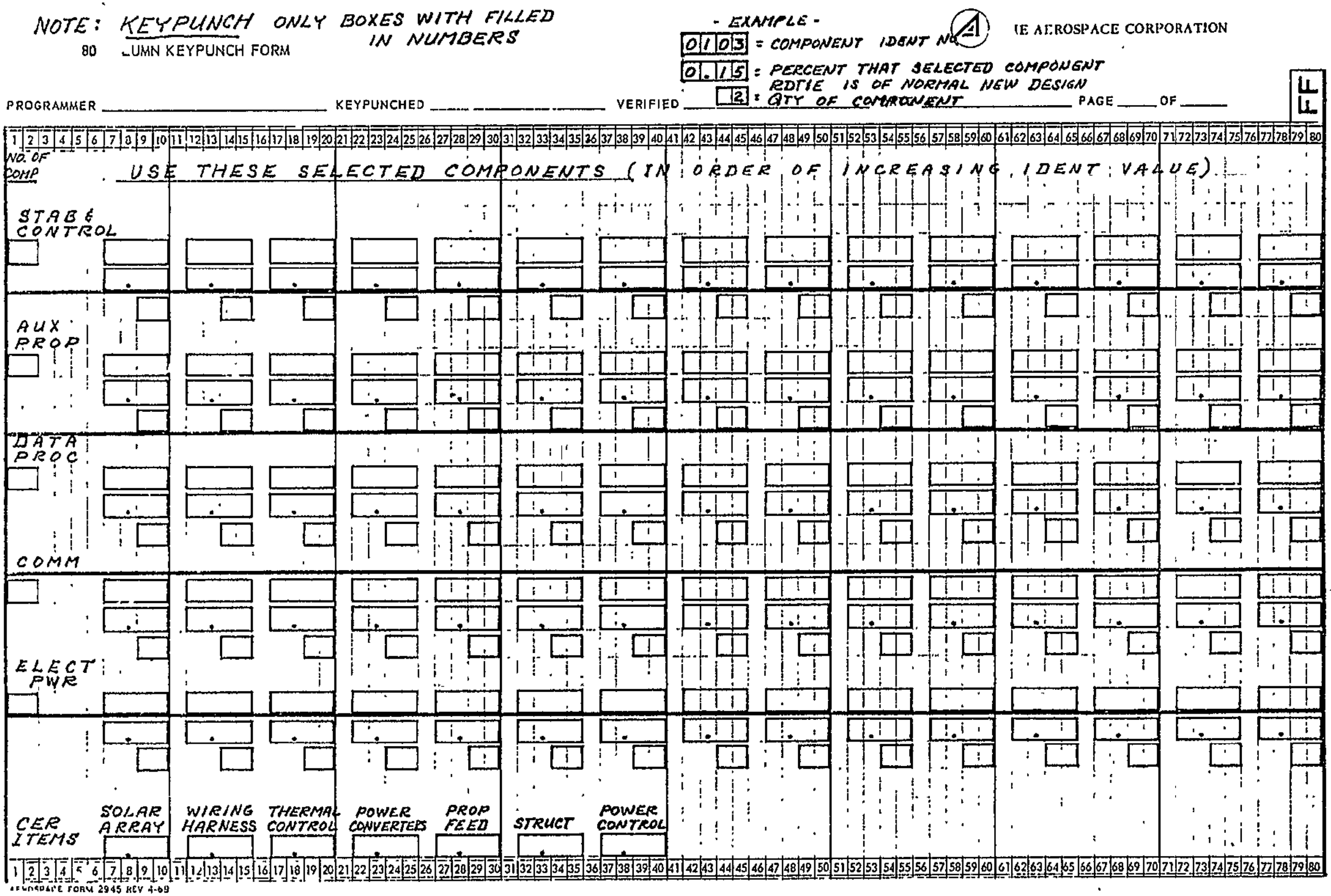


Figure 2.1 SCM Component Input Data Form

ORIGINAL PAGE IS OF POOR QUALITY

NOTE: KEYPUNCH ONLY BOXES WITH FILLED IN NUMBERS O LETTERS

80 C...UMN KEYPUNCH FORM

THE AEROSPACE CORPORATION

FF

PROGRAMMER ______ KEYPUNCHED ______ VERIFIED ______ DATE ______ PAGE ___ OF ___

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

SATELLITE NAME | SAT. QUANTITY: QUAL, FLT | YEAR OF CONSTANT $ | MISSION EQUIPMENT: TYPE, WEIGHT, RDTE $, UNIT $

1= COMM 3= PLANETARY
2= EOS 4= LUNAR

(COSTS IN CONSTANT $ PLUS FEE)

SUBSYSTEM TYPE OF CONF. WEIGHT

STAB & CONTR
1= DUAL SPIN
2= YAW SPIN
3= MASS EXPUL, 3-AX
4= " " CMG
5= " " MOM

AUX PROP
1= COLD GAS
2= MONO PROP
3= BI PROP

DATA PROC
1 = GEN PURP PROC
2 = SPEC " "

COMM
1= UP & DN LINK SEP
2= UNIF LNK-COM ANT
3= " " - SEP "
4= 2 + SEP DN LINK
5= 3 + " " "

ELEC PWR (+ HARN)
1= SHUNT REG, PADDLE
2= " " , BODY MTD
3= SHUNT & DISCH, PADDLE
4= " " , BODY MTD
5= SER LD REG, PADDLE
6= " " , BODY MTD

STRUCTURE
1= CYLINDER
2= BOX
3= SPHERE

THERMAL CONT

AUX PROPULSION: WT. OF PROP | THRUST (ATT. CONT THRUSTER) | THRUST (TRANSLATIONAL THRUSTER)

DATA PROC BIT RATE (BPS): S/C HOUSEKEEPING | MISS EQUIP

ELECTRICAL: HARNESS WT. | PWR CONTROL WT. | CONVERTERS WT.

SOLAR ARRAY: AREA, SQ FT | WEIGHT

BATTERIES: CAPACITY (A-H) | NO. OF CELLS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

AEROSPACE FORM 2945 REV 4-66

Figure 2.2 SCM System Input Data Form

SPACECRAFT COST MODEL

LST BASELINE

(MILLIONS OF 1975 DOLLARS)

	DDT+E			RECURRING		
SUBSYSTEM COST	DESIGN ENGINEERING	TEST AND EVALUATION	TOTAL RDT+E	PRODUCTION ENGINEERING	FAB AND ASSEMBLY	TOTAL RECURRING
STRUCTURE	12.2	5.5	17.7	0.0	4.3	4.3
THERMAL CONTROL	7.0	2.5	9.5	0.0	1.2	1.2
ELECTRICAL POWER	23.5	22.4	45.9	7.9	14.0	21.8
COMMUNICATIONS	1.9	1.9	3.9	.5	1.4	1.9
DATA HANDLING	7.8	5.5	13.3	1.5	5.7	7.2
STABILITY AND CONTROL	11.2	7.3	18.5	9.7	11.3	20.9
AUXILIARY PROPULSION	2.6	2.1	4.7	1.7	1.2	2.9
SPACECRAFT	66.2	47.3	113.5	21.2	39.2	60.4
MISSION EQUIPMENT			250.0			100.0
SATELLITE			363.5			160.3
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			19.3			
LAUNCH SITE SUPPORT						1.1
CONTRACTOR FEE			9.3			4.3
TOTAL SATELLITE			392.1			165.8
AVERAGE UNIT COST						165.7
TOTAL SATELLITE DDT+E AND RECURRING COST						557.9

Figure 2.3

LST BASELINE

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	24	1.8	.1	35.2	242824.7	314722.5	410364.5	891390.1
306	SUN SENSOR	5	.2	.0	0.0	144934.2	231078.7	168193.4	171418.4
503	GIMBAL ELECTRONCS	2	6.3	.3	31.6	0.0	0.0	0.0	0.0
1733	RATE INTEGR GYRO	3	13.0	.1	12.0	1202337.6	1103308.6	645001.8	846135.4
1901	CONTROL ELECT.	2	10.3	1.0	26.5	1172070.0	752440.0	465651.4	468342.6
2006	CTRL MOMENT GYRO	4	170.0	6.0	30.8	2894000.0	2170500.0	5986959.2	2774884.7
2109	STAR SENSOR	3	11.8	.5	8.0	1681386.0	558296.0	497237.8	1183261.8

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
133	THRUSTER	12	1.4	.0	0.0	336434.7	659137.4	224940.1	786368.7
212	ISOLATION VALVE	8	3.3	.0	0.0	0.0	0.0	0.0	0.0
312	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
418	PRESSURE REGULATR	2	4.1	.1	-0.0	740502.2	307487.5	156325.8	295894.2
524	TANK	2	21.6	1.4	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
109	GEN PURP PROCESR	1	15.0	.1	20.0	2676950.0	1664050.0	1847819.0	0.0
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	183045.5	181453.8	207547.5	73142.4
312	TAPE RECORDER	2	11.0	.2	4.0	483298.0	392137.0	947933.2	193119.0
345	TAPE RECORDER	2	16.8	.4	25.0	648545.4	499359.7	245464.8	259149.6
424	COMMAND DIST UNIT	2	19.1	.7	4.6	1141339.3	1121960.4	914672.4	456063.1

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	41384.2	12733.6	29749.9	0.0
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	260460.0	221391.0	106434.6	104076.1
239	ANTENNA	2	2.1	.0	-0.0	150486.0	115760.0	38249.9	60132.9
309	TRANSMITTER	2	1.8	.0	8.8	27058.9	31544.6	109760.7	10812.4
324	TRANSMITTER	2	7.5	.2	37.5	162064.0	95502.0	139695.4	64753.5
351	TRANSMITTER	2	1.9	.2	52.0	39069.0	39069.0	256108.3	15611.4
415	RECEIVER	2	3.9	.1	3.0	107946.2	244253.6	115415.0	43133.8
418	RECEIVER	2	4.2	.1	2.0	109972.0	247437.0	116412.8	43943.3
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6
714	POWER CONVERTER	24	12.1	.3	29.2	0.0	0.0	0.0	0.0

Figure 2.4

component, the computer program treats the component as an off-shelf item and assumes that its production cost is less than normal, i.e., its cost has decreased on the basis of learning-curve assumptions. System engineering and program management costs are included in the cost output; however, it is assumed that such costs would be relatively unchanged when previously developed components are used in a design. Such an assumption appears to be borne out by an initial examination of certain Air Force STP costs. Accordingly, the SCM can provide the data to permit comparisons of full development programs with programs that employ previously developed hardware in their designs.

2.5 STUDY CONSIDERATIONS

The foregoing discussion described the technical approach, cost methods, and tools that were used in the study. It should be recognized that all areas did not fall within the described technique. The exceptions were in the structures and thermal subsystems, component environmental requirements, and component modification cost factors.

The structure and thermal subsystems were examined parametrically by the SDCM computer model. The model is programmed to provide subsystem characteristics which are based on housekeeping equipment data and spacecraft size. This model was developed by technical specialists using the Aerospace data bank to develop the necessary coefficients. The structures and thermal costs that are generated by this method are applied with 100 percent DDT&E to each new start and to both baseline and low cost configurations. The baseline configurations are business-as-usual spacecraft, and low cost configurations are spacecraft with a great amount of flight-proven hardware. The structure and thermal subsystems are generally not transferable between programs and, therefore, incur new development costs.

The environmental requirements in terms of component vibration and temperatures were not supplied or developed in the study. Generally the derivation of suitable component vibration levels for NASA/GSFC satellites is a task typically performed by the prime contractor.

Effort was not expended in this study to quantify the environmental levels except to review the general environmental specification (Ref. 3). The values in Reference 3 which are interface vibrations could be factored by a resonant magnification factor. It is known in some instances that the levels have been multiplied by a resonant magnification factor of five at frequencies where component resonances may be expected. This approach would result in increasing the power spectral density values in the general environmental specification by a factor of 25. Such an approach would probably result in prohibitively high levels over the broad frequency range of possible resonances which would have to be assumed in the absence of detailed information. If such an approach was taken, the estimated environmental requirements may have disqualified most of the flight-proven components. In the absence of definitive component criteria, it was concluded that reasonable consideration of required component capabilities could not be made at this time.

When component modification is judged to be needed by the technical specialist, costs are estimated by reviewing each equipment and applying cost factors consistent with the amount and kinds of changes required. Such factors are used uniformly across all of the new starts considered. A schedule of the factors that are used is shown in the following tabulation.

Component Modification	DDT&E (%)
No change (use as is)	0
Minimum change (minor adjustments)	10 to 25
Repackaging and requalification	50
Partial redesign, repackaging and requalification	75
Redesign, repackaging and requalification	100
New development	100

The preceding cost percentages are applicable to DDT&E cost only; however, they can have an effect on unit (recurring) cost as explained in Section 2.4.

3. LARGE SPACE TELESCOPE (LST)

3.1 MISSION DESCRIPTION

The LST mission equipment consists of an optical telescope assembly (OTA) and scientific instrument (SI). The OTA includes the 3-meter aperture optics, associated structures, thermal control, fine guidance sensors optical performance sensors and controls and electrical distribution. The associated structures are optics mounting structure, focal plane structure, internal light baffles, and interface structure.

The SI is a package of individual scientific instruments such as cameras, IR spectrographs, and polarimeters. The support hardware which is dedicated to the SI is also considered part of SI. The weight and power of the OTA and SI are listed in Table 3.1.1 (Reference 4) and the overall arrangement of the payload is shown in Figures 3.1.1 and 3.1.2. The function of the SI is to convert the OTA focal plane energy into scientific information which is transferred to the support service module (SSM) for transmission to earth stations. The SSM houses the electrical power, communication, data handling, thermal control, sun shield, coarse attitude sensing, and attitude control subsystems.

The nominal operating orbit is a 500 km (270 nmi) circular orbit in 28.8 deg. inclination. The satellite will be launched and serviced by the Space Shuttle. The initial launch is scheduled for CY 82 with the first servicing being return to ground by the Shuttle. The nominal servicing interval is two years.

3.2 MISSION EQUIPMENT REQUIREMENTS

The housekeeping subsystem requirements to meet the mission requirements are summarized in Table 3.2.1. These basic subsystem requirements were obtained from References 4 and 5. The system design goals and system weight limit are also included since they influence the component redundancy.

3.3 SPACECRAFT DESCRIPTION

The information supplied in the MSFC requirements document (Reference 4) was inputed into the SDCM computer program to provide the initial set and type of component required for each subsystem. The computer output along with the MSFC LST Phase A report (Reference 6) provided the necessary information for the engineer to select candidate components from the catalog. The rationale for the selected candidate components is described in subsystem sections that follow.

The estimated total satellite weight and electrical power using as many catalog components as feasible, is 10,600 kg (23,300 lb) and 1880 W, respectively. The subsystem weight and power that are listed in Tables 3.3.1 and 3.3.2 are actual values for selected components and estimated component weights and powers for the units requiring new development. The structure and mission equipment (payload) data were obtained from the referenced sources and were not determined in this study. The estimated spacecraft reliability is 0.88 at two years. This reliability is estimated for the LST configuration with the auxiliary propulsion (AP) desaturating the control moment gyros (CMG). The recommended configuration is to use magnetic torques to desaturate the CMGs and to use AP as an emergency backup. The spacecraft reliability increases to 0.9 at two years when magnetic torques are used to desaturate the CMGs. The spacecraft reliability which was computed by the SDCM is presented in Table 3.3.3.

The reliability calculation used the actual failure rates for candidate components, and representative failure rates for new hardware and redundancy.

Table 3.1.1 LST Payload Weights, Power and Reliability

	Weight		Power	Reliability (one year)
	kg	lb	W	
OTA (3m optics)	4,598	10,136	825	0.90
SI	907	2,000	440	0.90*
TOTAL	5,505	12,136	1,265	0.81

* assumed overall SI reliability

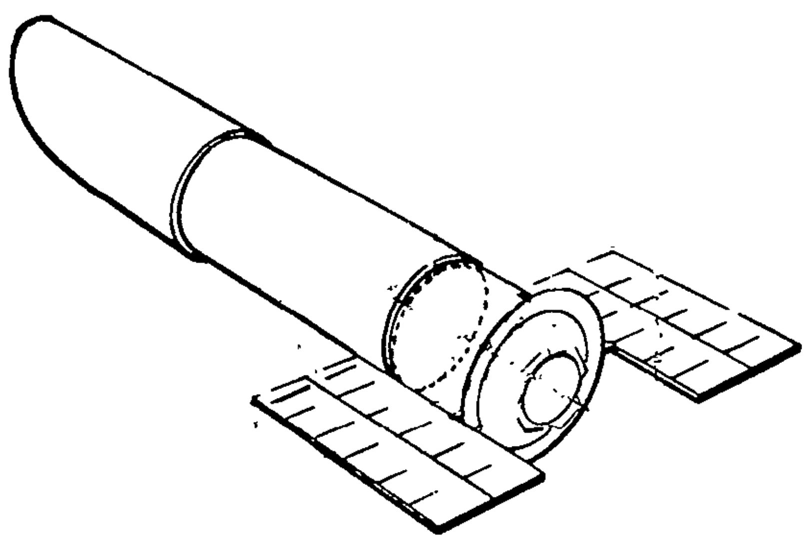


Figure 3.1.1 LST Operational Configurations.

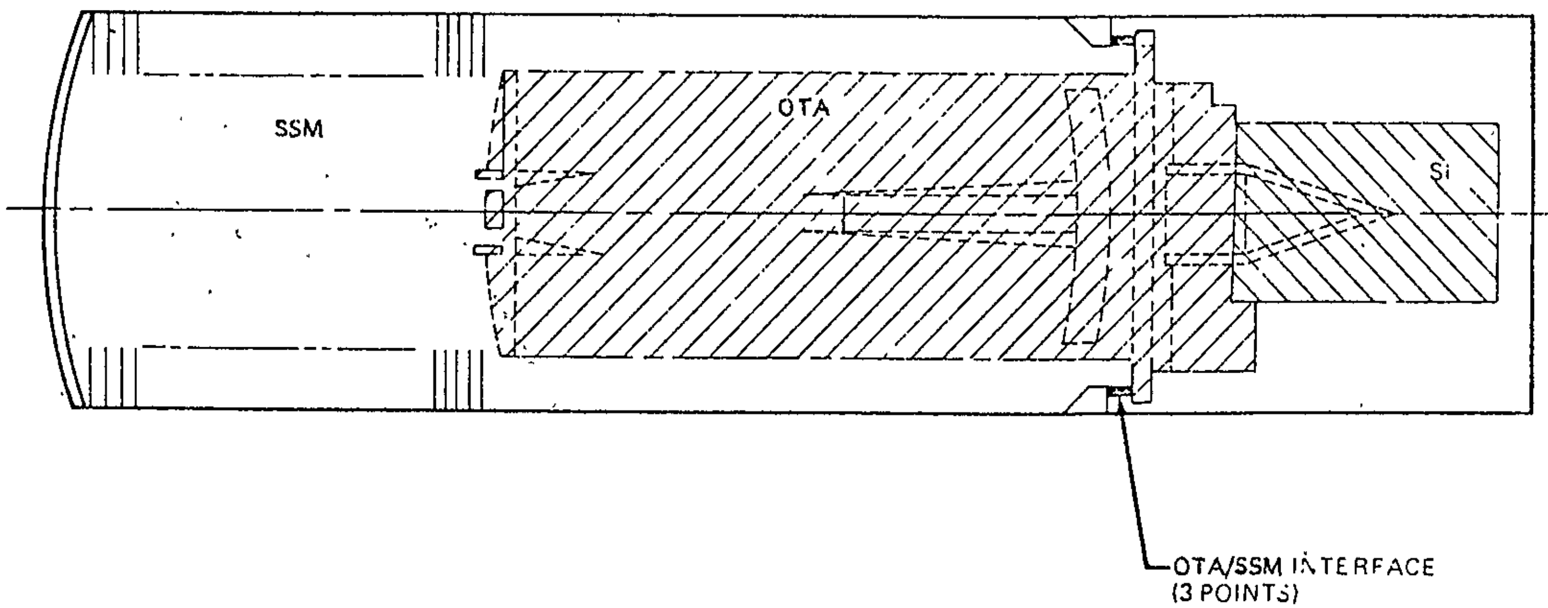


Figure 3.1.2 LST Configuration and Payload Arrangement (Reference 3)

Table 3.2.1 LST Mission Requirements

Items	Requirements
Stabilization and Control	
Coarse pointing	2 axis ± 0.15 μrad (30 $\widehat{sec}$) 3σ LOS ±1.75 μrad (0.1 deg) 3σ
Fine pointing (using OTA)	3 axis ± 4.8 μrad (1 $\widehat{sec}$) 1σ
Auxiliary Propulsion	0.079 rad/min (4.5 deg/min) 100 maneuvers/axis
Electrical Power	Solar and rechargeable battery 28 ± 2% V supply
Communication and Data Handling	
Primary network	TDRS Single access available 1/3 of orbit Multiple access available 85% of orbit
Alternate network	STDN
Data storage	10^9 bits
Command storage	24 hours
Payload data rates	1 frame/orbit 600 M bits/frame
System	
Design life	One year reliability goal degraded mode between one and two years
System weight	<11,340 kg (25,000 lb)
Orbit	
Circular nominal	500 km (270 nmi)
Range	480-590 km
Inclination	28.8 deg

Table 3.3.1 LST Weight Summary

SUBSYSTEMS	WEIGHT	
	kg	lb
Stabilization and Control	534	1178
Auxiliary Propulsion		
Dry Weight	48	106
Expendables	20	44
Communication and Data Handling	83	184
Electrical Power	1162	2562
Structure		
Equipment Bay [a]	1058	2333
Adapters [a]	2007	4424
Thermal Control [a]	136	300
Mission Equipment		
OTA [b]	4598	10,136
SI [b]	907	2,000
TOTAL	10,554	23,267

[a] Reference 5

[b] Reference 4

Table 3.3.2 LST Power Requirements

Subsystems	Average Power (W)
Stabilization and Control	178
Auxiliary Propulsion	0
Communication and Data Handling	136
Thermal Control	0
Structure	0
Mission Equipment[a]	1265
Electrical Power and Contingency	299
Total Average Load	1878

[a]Reference 4

Table 3.3.3 Reliability Estimate

ITEMS	RELIABILITY [a]
Stabilization and Control	0.9657
Auxiliary Propulsion	0.9474
CDH	0.9638
Electrical Power	0.9988
Spacecraft	0.88
Mission Equipment	0.81
Satellite	0.71
MMD [b] months	21.6

[a] Mission lifetime of two years.

[b] Expected duration of the mission before a failure occurs.

STABILIZATION AND CONTROL (SC)

The SC is to provide the capability for the LST to view any source on the celestial sphere at any time while avoiding sun, moon, and earth interferences. The spacecraft course pointing system is to provide sufficient accuracy for the fine pointing system to take over the stabilization. The fine pointing is to be achieved with the OTA fine guidance system providing the sensor information.

The SC functional block diagram is shown in Figure 3.4.1 (References 5 and 6). The subsystem uses sun, star, and magnetic field sensors; momentum wheels, magnetic torquers, and reaction control actuators; and a centralized computer. Either CMGs or reaction wheels (RWs) can provide the required pointing accuracy; however, the CMG is preferred over the RW (Reference 6) because CMGs are lighter, consume less power, and provide faster spacecraft repointing. The control torquers to desatuate the CMGs are provided by the magnetic torquers. The reaction control thrusters are used for emergency sun acquisition mode and control of large disturbances during docking operation. The attitude sensors are the sun sensors, fixed-head star trackers, the reference gyro assembly, magnetometers, and the OTA find guidance system. All of the sensor signals are inputted to the transfer assembly for routing to the digital processor assembly in accordance with the control mode in operation at the time. The transfer assembly serves as the interface between the sensors, computer, and actuators. The digital processor receives the appropriate sensor data and computes the commands for the CMG gimbals, magnetic torquers, solar panel drive motors, and valve drive amplifiers, and compensates for gyro drift.

The selected candidate components for SC are summarized on Table 3.4.1. This table provides a listing of components, quantity of each component, catalog index number, weight, and power. Also shown in the table is the alternate control actuator unit. The RW is shown as an alternate to the CMG.

Table 3.4.1 LST Stabilization and Control Weight and Power

COMPONENTS	No. Rq'd.	Index No.	Weight		POWER				
					Operate		Standby		Tot. Pwr.
			kg	lb	W	Duty	W	Duty	W
Reference Gyro Assy. (1)	3	N1-1-1	17.7	39.0	24	100%			24
Fixed Head Star Tracker	3	HEAO	16.0	35.4	10	100%			10
Coarse Sun Sensor	5	HEAO	0.5	1.0	0				0
Magnetometer	2	N3-1-1	0.7	1.5	1	100%			1
Magnetic Torquers & Elect.	6	(nh)[a]	143.3	315.9	20	100%			20
Control Moment Gyro & Elect. (2)	4	HEAO	308.0	680.0	70	100%			70
Transfer Assembly	2	(nh)	9.3	20.6	27	100%			27
Digital Processor Assembly (1)	1	HEAO	6.8	15.0	16	100%			16
Valve Driver Assembly	2	(nh)	17.4	38.4	0				0
Solar Array Drive	2	D1-1-5	14.1	31.1	10	100%			10
TOTAL			534	1178					178
(1) internally redundant									
(2) alternate configuration									
Reaction Wheel	4	D8-1-2	128	282.0	435	20%	60	80%	135
Reaction Wheel Electronics	4	D8-1-3	18	40	50	100%			50

[a] New hardware

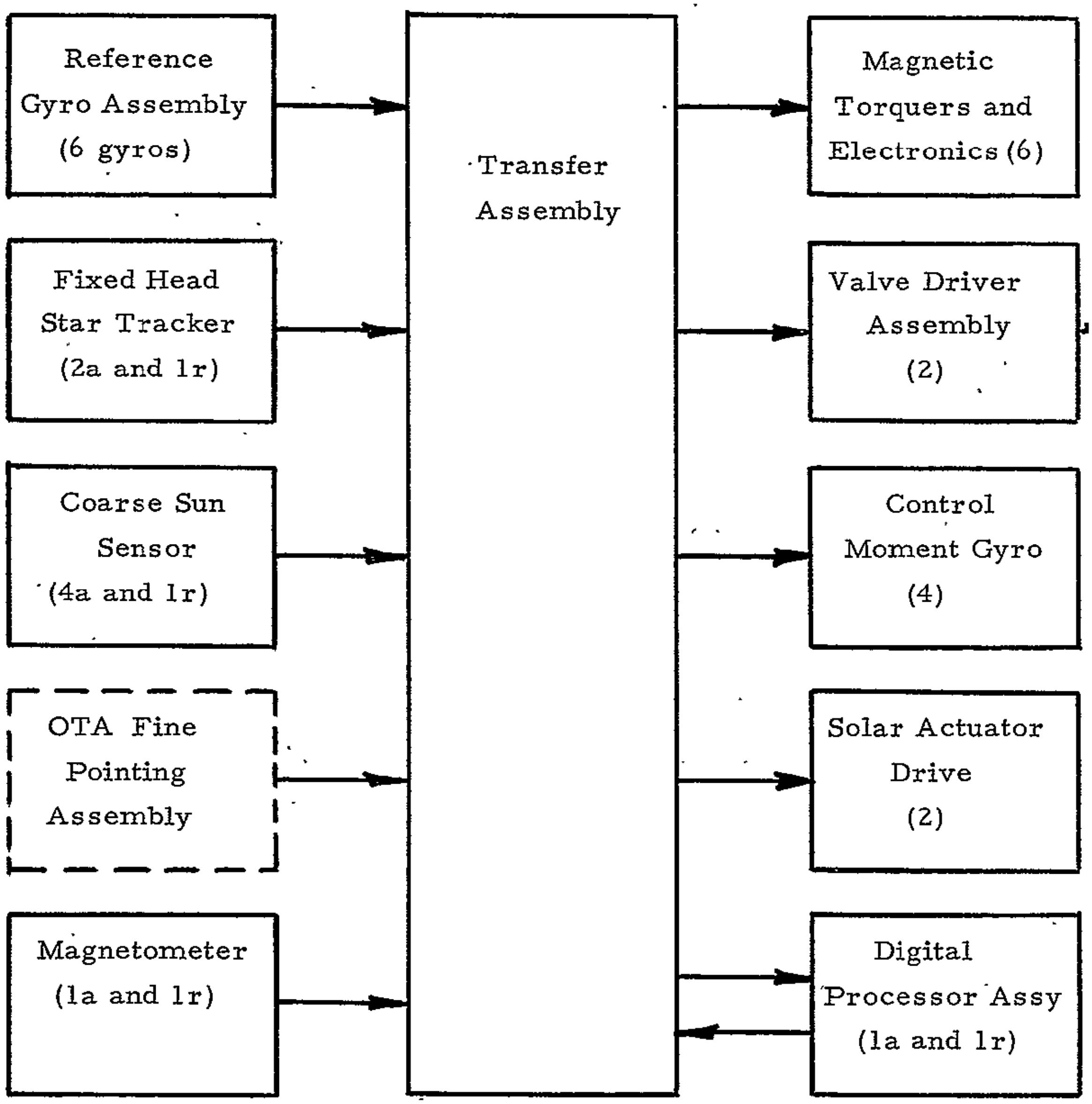


Figure 3.4.1 LST Stabilization and Control Subsystem

3.4.1 Reference Gyro Assembly (RGA)

The RGA is an assembly with six floating single-degree-of-freedom rate integrating gyro units. The gyros are arranged in a skewed dodecahedron configuration. The unit provides rate and position information during the star tracker or guide star occultation control modes. Any three of the six gyros are to provide the three-axis attitude measurement data. The most suitable assembly should be the unit selected for HEAO or the unit described in the NASA Low Cost System Standard Equipment Announcement, assuming it can be flight qualified. The NASA standard unit employs non-floating, strapdown gyros and is called Dry Gyro Inertial Reference Unit (DRIRU). Two RGAs from the catalog which have performance characteristics that may be equivalent to the HEAOs Bendix gas bearing spin axis tyros are:

a. OSO-I (Nl-1-1), Azimuth Reference Assemblies. Each unit consists of a pair of gyros in a thermal enclosure which also houses ancillary electronics and heaters. The bias drift stability is ±0.001 rad/hr (± 0.06 deg/hr) over a four-hour period.

b. Nimbus/ERTS (N7-1-3), Rate Measuring Package. Each unit has one gyro and associated electronics. The bias drift change over one year is less than ±0.004 rad/hr (±0.25 deg/hr).

The candidate OSO-I (N1-1-1) unit will require repackaging to arrange the six gyros in dodechedron orientation. It is estimated that the development is approximately 50 percent of a new development assembly.

3.4.2 Fixed-Head Star Tracker (FST)

The FSTs are used for pointing the spacecraft within the fine pointing field of view (FOV) of the OTA. The FST requirements are:

Detection	+6 magnitude stars or higher
Accuracy	0.15 m rad (30 arc sec), 3σ transverse axis 1.80 m rad (0.1 deg), 3σ LOS
FOV	±0.052 rad (3 deg)

Three FST are positioned 0.79 rad (45 deg) apart in the transverse plane of the LST longitudinal axis. The two other FSTs are positioned along the telescope viewing axis and located in the OTA fine guidance system. The catalog does not provide any star trackers meeting the LST requirements. The closest candidate unit is used on SAS-C (N3-1-3). The capability of the N3-1-3 unit is;

FOV	0.09 x 0.17 rad (5 x 10 deg)
Detection	+4 magnitude star
Accuracy	$\pm$0.00145 rad. ($\pm$5 arc min)

The HEAO star tracker recommended in Reference 6 appears to be the best candidate.

3.4.3 Coarse Sun Sensor

The coarse sun sensor requirements are:

FOV	2π steradian
Linear range	$\pm$0.175 rad ($\pm$10 deg)
Linearity	2%
Null accuracy	1.8 m rad (6 arc min)

The only passive units in the catalog with the required FOV are the ATS-F two-eye (N6-1-10) and three-eye (N6-1-9) devices. These units do not meet the requirements since the accuracy of the ATS-F devices are $\pm$0.05 rad ($\pm$3 deg). The HEAO sun sensor which is not in the catalog should be the candidate unit.

3.4.4 Magnetometer

The magnetometer requirements are based on the unit used on the OAO program ; it has a range of $\pm$50 microtesla. The catalog has three magnetometers that should be suitable candidates. The three candidates exceed the performance requirements and their weight is less. The characteristics of the candidate units are compared in Table 3.4.2.

Table 3.4.2. Candidate Magnetometers

Parameters	OAO Spec.	SAS-C (N3-1-1)	P72-1 (D2-1-3)	S3[a] (D4-1-3)
Range (microtesla)	± 50	± 50	± 50	± 60 (± 10)
Sensitivity (V/microtesla)	4.2×10^{-2}	12×10^{-2}	4.9×10^{-2}	4.2×10^{-2} (25×10^{-2})
Linearity (microtesla)	± 1.5	± 0.2	± 0.5	± 0.06 (± 0.006)
Drift (microtesla)	± 0.6	± 0.36	NA	± 0.2 (± 0.06)
Weight (kg)	3	0.68	1.5	0.91

[a] The dual figures are for high range and low range, respectively.

3.4.5 Magnetic Torquer

The required size of the magnetic torquerer is to provide a dipole moment of 2,000 A m^2 (0.15 ft-lb/Gauss) per electromagnet. Two such electromagnets per axis are required to desaturate the CMG and to provide a backup direct control torquer in event of CMG failure. There are no magnetic torquers in the catalog with the required magnitude of dipole moment. The largest unit in the catalog is 98 A m^2 which is used in the atmospheric explorer. The hardware will have to be developed.

3.4.6 Control Moment Gyro

The total momentum required to provide a maneuvering capability of 1.57 rad (90 deg) in five minutes is 1000 Nm about the major axis of the LST. The CMG momentum per actuator is 333 Nm for three double-gimballed CMGs, and 265 Nm for four single-gimballed CMG. A four-RW configuration will require twice the CMG momentum per actuator because a RW does not use its total momentum capacity effectively. The RW unit weights will, therefore, be twice the CMG and will use more power during maneuvers. At 1000 Nm output torque, the RW power requirement will be in the order of ten times that used by CMG.

The only CMG listed in the catalog is the unit used on STP 71-2. The unit momentum capacity is only 4.5 Nm and is therefore unsuitable. The HEAO unit appears to be the only available CMG.

A candidate RW is the unit used on the Defense Support Program (DSP) (D8-1-2). This unit has an angular momentum of about 508 Nm which is nearly twice that required. The data on the associated electronics unit are provided in the catalog data sheet D8-1-3. The combined reliability of the wheel plus electronics is 0.922 for 15 months. Although the RWs will consume much more power than CMGs during a slew maneuver, this will probably occur only during a small percentage of the time, and the average power level might be acceptable. It is understood that the requirement for slewing 1.57 rad (90 deg) in five minutes may be waived, in which case RWs become more attractive.

3.4.7 Transfer Assembly (TA)

The transfer assembly is the interface unit that interconnects the sensors, actuators, computer, and electronics for control mode logic, power converter, and switching. Although the TA can be a modification of the HEAO TA, it will be assumed in this study as new hardware because of the amount of modification that will probably be required.

3.4.8 Digital Processor Assembly (DPA)

The design reference of the DPA is the CDC 469 computer that was selected for HEAO. The software must be developed for the LST but the hardware will be essentially identical to HEAO. There are no DPAs in the catalog that will meet the CDC 469 computer capability which is six 2000-word memory expandable to 64,000 words, and 16 bit instruction and data words. The software effort is estimated to be 50 percent of a new development.

3.4.9 Valve Drive Assembly (VDA)

The valve driver for the selected reaction control thrusters is recommended. The VDA will, however, require redesign and repackaging for the logic signal and command signal input interfaces because the unit is packaged within the STP 72-2 control logic box. The estimated DDT&E is 50 percent of a new unit.

3.4.10 Solar Array Drive (SAD)

The SAD requirements are:

Torque	4.07 Nm
Angular position	±0.07 rad (4 deg)
Rotational rate	8.7 mrad/s (0.5 deg/s)

The FLTSATCOM SAD (D1-1-5) appears to be the best candidate. The unit produces a minimum of 8.2 Nm torque and a proportional accuracy of ±0.02 rad (±1 deg). The fastest rotational rate is 4.2 mrad/s (0.24 deg).

This maximum rate is used for slewing and is established by the minimum stepping period. The data on the unit indicate that the minimum period is not a limitation of the stepper motor but of the chosen design of the SAD electronics. The rate could probably be increased by a minor redesign of the electronics. The electronics will have to be repackaged since they are contained within the FLTSATCOM control electronics assembly, and redesigned to ensure proper input and output signals. Other important SAD requirements such as the number of slip rings, current, noise, and torsional and transverse stiffness must be defined and compared.

3.5 AUXILIARY PROPULSION

The auxiliary propulsion subsystem is used for emergency control in event of SC failure, backup control in the vicinity of the Shuttle, and large control authority in case of misdock. The performance requirements to provide the emergency backup to the SC was determined in Reference 6 and is summarized in the following tabulation.

PARAMETERS	REQUIREMENTS
Type	Cold gas
Total Impulse (2515 lb sec + 10%)	12200 Ns (2720 lb-s)
Thrust Level	44.7N (10 lb)
Number of Thrusters	6
Design Life	2 years
Refurbishment	Ground servicing
Reliability	No. Single Point Failure Mode

Because of the low total impulse requirements, the recommended type of propellant is cold gas nitrogen. The tank and propellant weight are low and the cold gas nitrogen system is inherently most simple and reliable.

Redundancy is to be provided at each component to meet the single point failure mode criteria, i.e., redundant tanks, regulators, and thrusters. In the event of leakage, each component may be isolated by a command to close a latching solenoid. The functional diagram of the AP is shown in Figure 3.5.1. The thrusters are to be mounted in a cluster of three primary and three backup. The 20 kg (44 lb) of nitrogen is contained in two 36,200 cm^3 (2200 $in.^3$) volume tanks and under 2480 N/cm^2 (3600 psia) pressure. The pressure regulator is to provide a regulated outlet pressure of 103 N/cm^2 (150 psia).

The candidate components are listed in Table 3.5.1 and the selected components are listed in Table 3.5.2 with the rationale for selection. All selected components are flight-proven units with modification limited to changing the "set point" of the pressure regulator. No new component development is necessary; however, the integration of components including the plumbing will require the normal development procedure. The NASA standard propellant control assembly that is listed in the LCS Standard Equipment Announcement is not applicable because the unit is for hydrazine propellant.

Table 3.5.1 AP Candidate Components

Components	Index No.	No. Rq'd.	Remarks
Tank	D3-2-1 D9-2-3 D9-2-2	4 3 2	29 kg (64 lb) 22 kg (49 lb) 20 kg (43 lb)
Thruster	D3-2-2	2	Thrust must be derated from 67 to 44 N (15 to 10 lb) by reducing inlet pressure
	D9-2-1	4	3 valve cluster, early version of above design
Pressure Regulator	D3-2-5	2	Integral relief, set point change from 148 to 103 N/cm^2 (215 to 150 psi)
	N1-2-3	2	Max. pressure marginal set point change from 152 to 103 N/cm^2 (220 to 150 psi)
	D7-2-5	2	Integral relief, set point change from 345 to 103 N/cm^2 (500 to 150 psi)
Filter	N1-2-6	1	MS fittings must be added
Isolation	N1-2-4	8	One year design life
Valve	D3-2-8	8	Six month design life
Fill/vent	D3-2-7	1	Flight proven 0.1 kg (0.16 lb)
Valve	D7-2-6	1	Not flown 0.3 kg (0.72 lb)

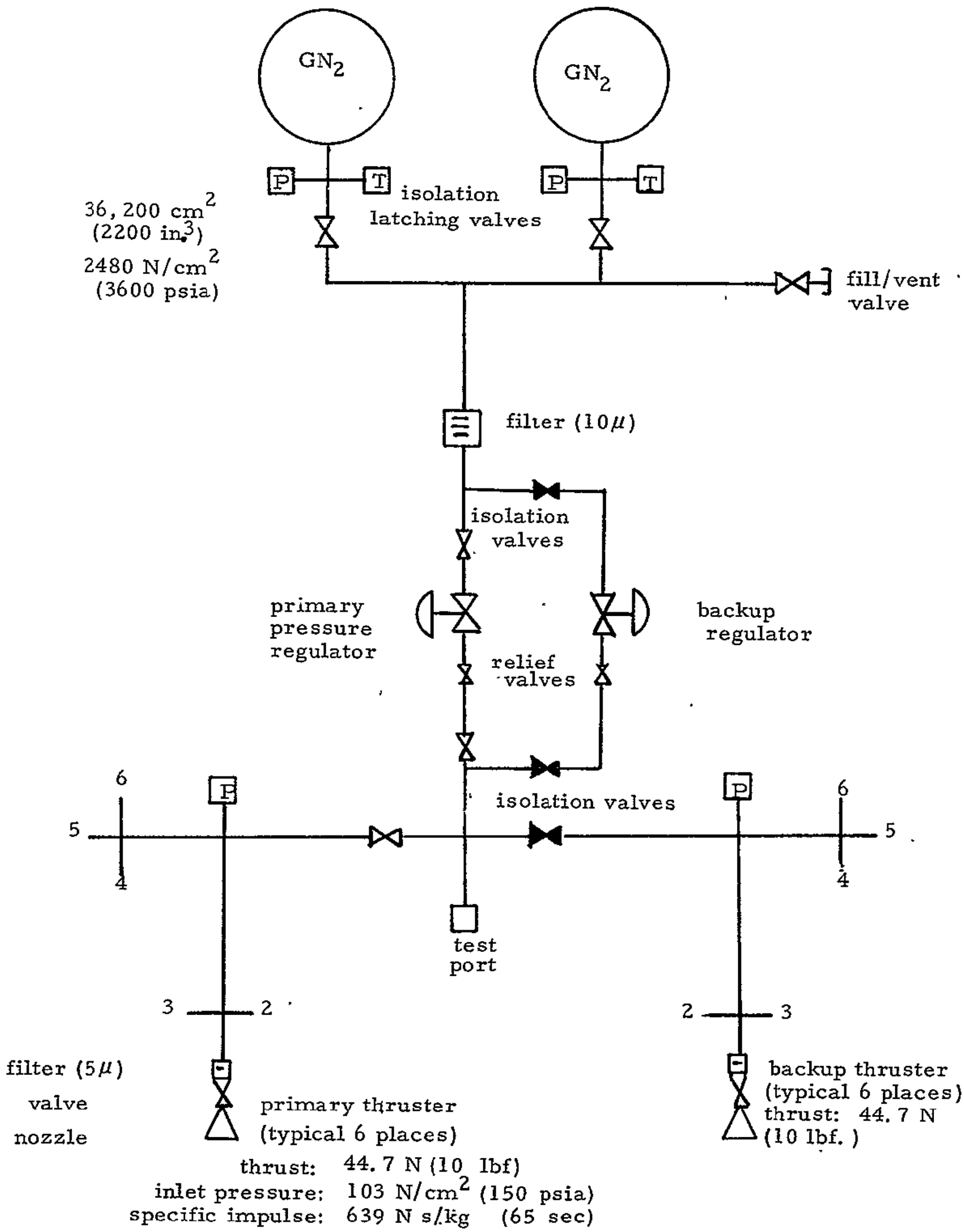


Figure 3.5.1 LST Auxiliary Propulsion Functional Diagram

Table 3.5.2 Selected Components for AP

Components	Index No.	No. Rq'd.	Weight kg	Weight lb	Reason for Selection
Nitrogen Tank	D9-2-2	2	19.6	43.2	Lower weight tank
Thruster	D3-2-2	12	7.4	16.4	Latest design
Pressure Regulator	D3-2-5	2	3.7	8.2	Minimum set point change
Filter	N1-2-6	1	0.1	0.3	10 micron absolute filter
Isolation Valve, Latching Solenoid	N1-2-4	8	12.0	26.4	Longer design life units good for longer durations
Fill/Vent Valve	D3-2-7	1	0.1	0.2	Flight demonstrated unit
Relief Valve	Integral w/press reg	2			Integral unit (pressure reg)
Temperature Transducer	(std)	2	0.2	0.4	Off-the-shelf
Pressure Transducer	(std)	4	0.4	0.8	Off-the-shelf
Test Port	(std)	1	0.1	0.2	Off-the-shelf
Plumbing	(nh)[a]	15 m	4.6	10.0	
Dry Weight			48.1	106.0	
Nitrogen Prop.			20.0	44.0	
Wet Weight			68.1	150.0	

[a]New hardware

3.6 ELECTRICAL POWER (EP)

The electrical power subsystem is required to provide an average power of 1878 W (see Table 3.3.2) at a bus voltage of 28 Vdc ±2%. This average total power includes 300 W for power conditioning and storage, and overall contingency. The EP is an oriented solar array - battery type system. The required power conditioning is achieved with the series load regulation configurations. This configuration is shown in Figure 3.6.1; it functionally meets the conditioning requirements but has a relatively high power loss in the selected power converter units. The type of components, number of components to achieve EP reliability, candidate components from the catalog, and the weight are listed in Table 3.6.1.

Alternate configurations have been analyzed to evaluate the effects of having a higher percentage of flight-proven components in the EP subsystem. The alternate configurations are the shunt and discharge voltage regulation, and the shunt voltage regulation configurations. The functional diagrams of these two alternate configurations are shown in Figures 3.6.2 and 3.6.3 and the candidate components are listed in Tables 3.6.2 and 3.6.3. The shunt and discharge voltage regulator configuration will provide 28 Vdc ± 4% service and the shunt voltage regulator configuration will provide 28 Vdc ± 16% service. The components in the shunt voltage regulation configuration can use all flight-proven units except for the solar array.

The shunt and discharge voltage regulator configuration, being slightly out of the required voltage control range, has a significant reduction in the solar array area because of its more efficient converters. The cost comparison of the three configurations is presented in the cost estimates section.

For both of the alternate configurations it is assumed that the voltage control can be achieved by secondary converters located at the load unit, i.e., decentralized power conditioning. The alternate configurations provide design flexibility since equipment power requirement changes are limited to the converter at the load unit.

Table 3.6.1 LST Electrical Power Subsystem
Weight, Series Load Regulator Configuration

COMPONENTS	No. Req'd	Index No.	Weight (kg)	Weight (lb)
Power Converter	24	D1-3-4	131.7	290.4
Power Control Equipment (A-hr meter)	6	D4-3-2	9.4	20.7
Battery Charger	6	(nh)	8.2	18.0
Solar Array (547 ft^2)	2	(nh)	372.0	820.0
Battery (20 A-hr, 22 cells)	6	D8-3-6	143.4	316.2
Harness			446.8	985.0
Solar Array Boom			50.8	112.0
TOTAL			1,162.2	2,562.3

Table 3.6.2 LST Electrical Power Subsystem
Weight, Discharge Voltage Regulator Configuration

COMPONENTS	No. Req'd	Index No.	Weight	
			(kg)	(lb)
Power Control Equipment (A-hr meter)	6	D4-3-2	9.4	20.7
Power Control Unit	1	(nh)	4.3	9.4
Shunt Regulator	20	D2-3-1	10.4	23.0
Discharge Regulator	6	D2-3-2	26.6	58.6
Battery Charger [a]	6	(nh)	13.6	30.0
Battery (20 A-hr, 22 cells)	6	D8-3-6	143.4	316.2
Solar Array (391 ft^2)	2	(nh)	265.4	585.2
Harness			446.8	985.0
Solar Array Boom			50.8	112.0
TOTAL			971	2,140.1

[a] Battery charger to include current sensor

Table 3.6.3 LST Electrical Power Subsystem Weight, Shunt Voltage Regulator Configuration

COMPONENTS	No. Req'd	Index No.	Weight	
			(kg)	(lb)
Power Control Unit [a]	2	D8-3-1	10.9	24.0
Shunt Regulator	34	D8-3-2	64.8	142.8
Solar Array (391 ft^2)	2	(nh)	265.4	585.2
Battery (20 A-hr, 22 cells)	6	D8-3-6	143.4	316.2
Harness			446.8	985.0
Solar Array Boom			50.8	112.0
TOTAL			982	2,165

[a] Modify to drive 34 shunt regulators

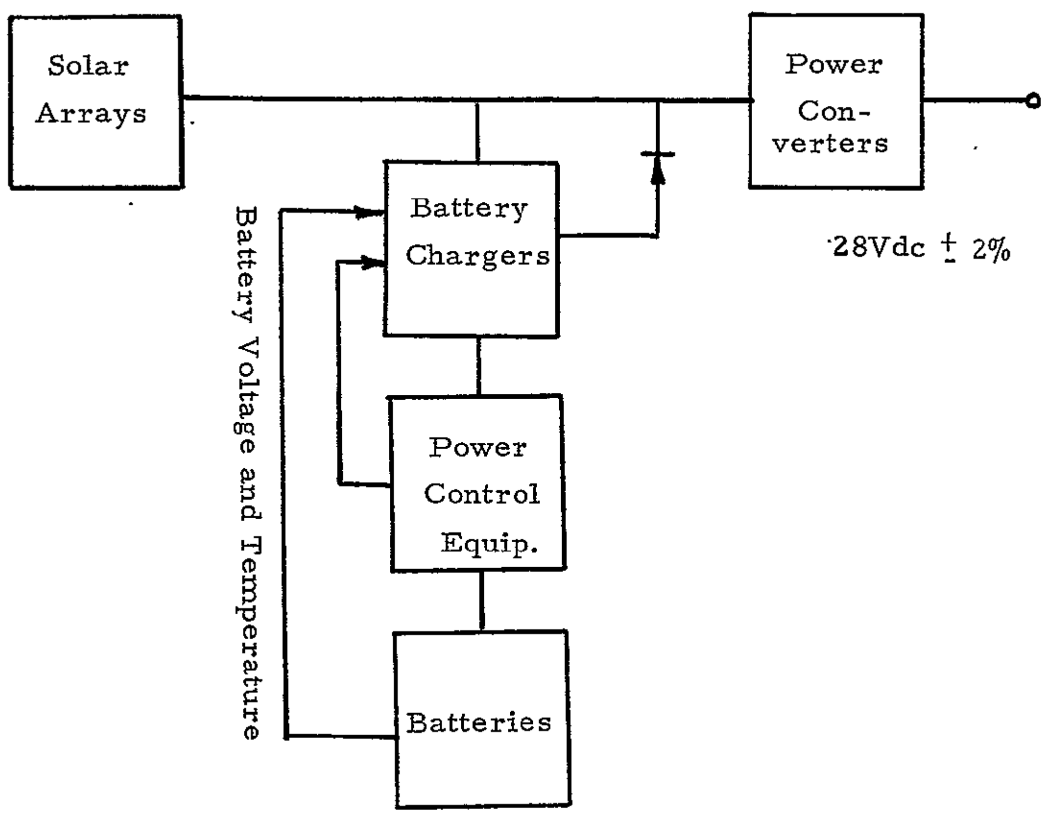


Figure 3.6.1 LST Electrical Power,
Series Load Regulation Configuration

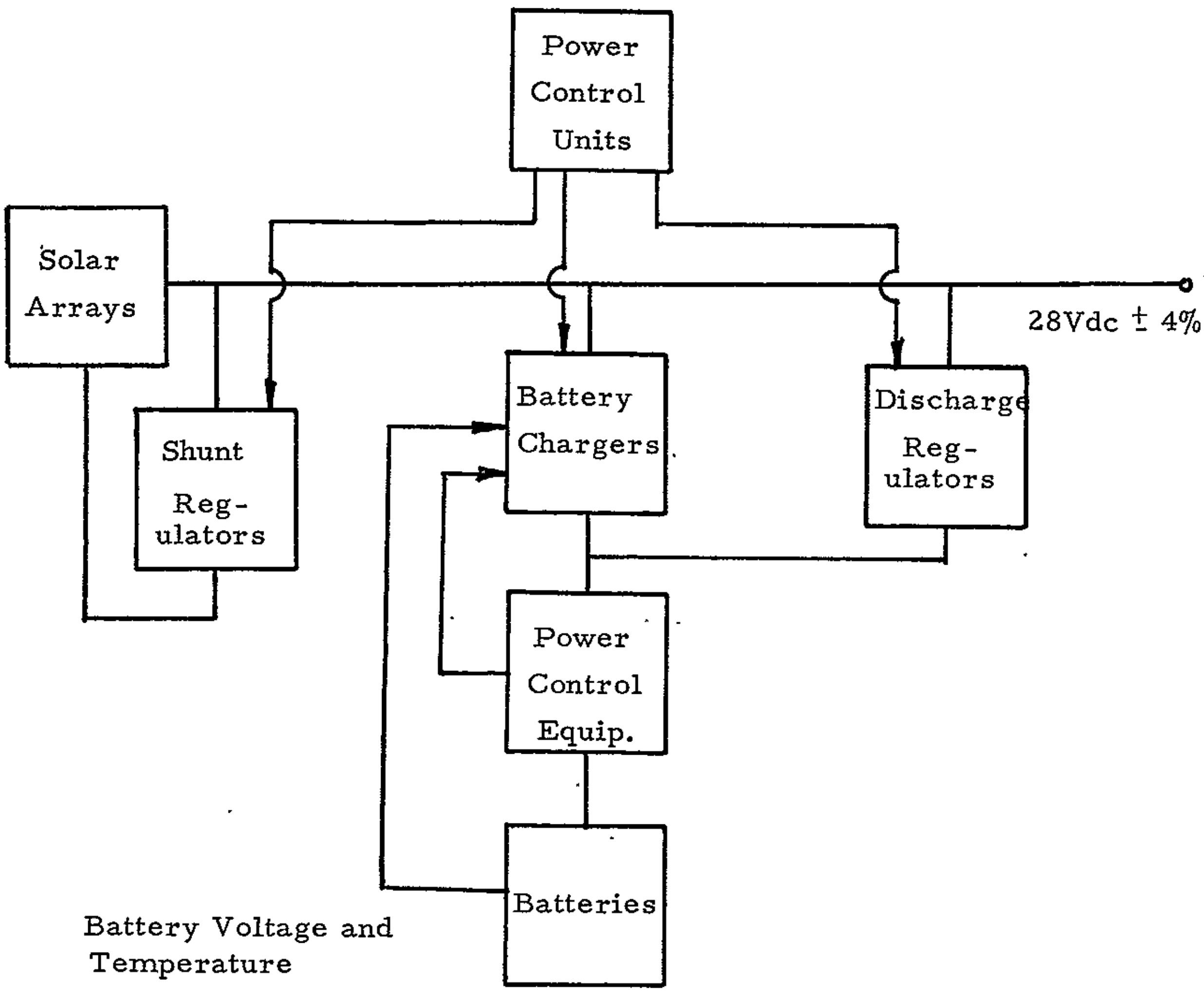


Figure 3.6.2 LST Electrical Power,
Shunt and Discharge Voltage Regulation Configuration

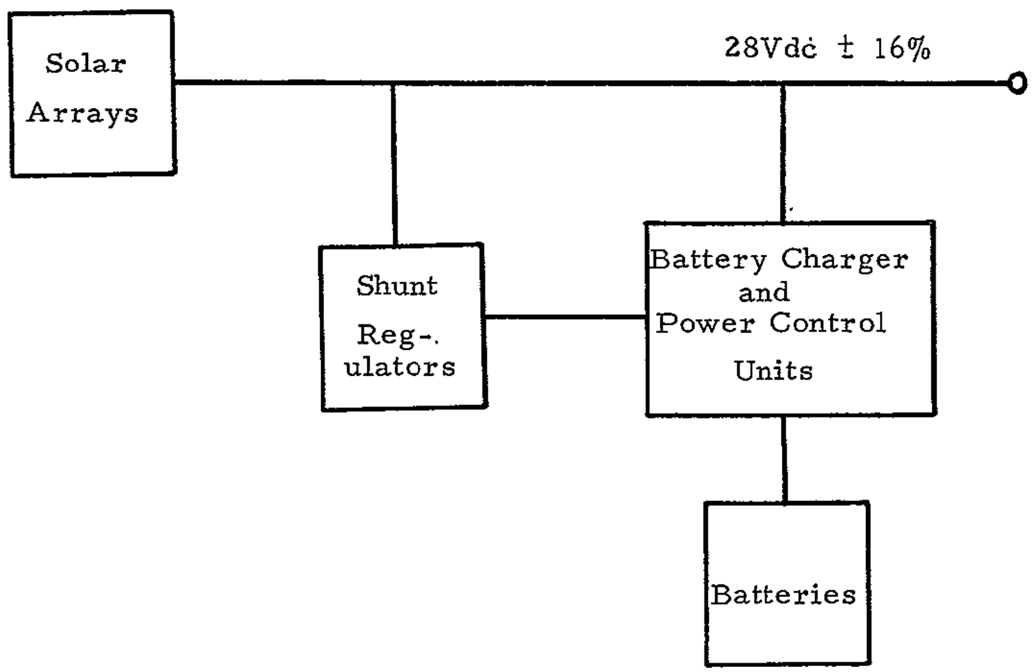


Figure 3.6.3 LST Electrical Power,
Shunt Voltage Regulation Configuration

3.6.1 Power Converter

The power converter requirements and candidate unit capability are as follows:

Parameters	Requirements	Candidate (D1-3-4)
Input Voltage	20 to 60 Vdc	20 to 70 Vdc
Output Voltage	28 Vdc $\pm$ 2%	28 Vdc $\pm$ 1%
Output Power/Unit	300W Max.	75W
Efficiency @ Max. Load	90%	72%
On/Off Command Cap.	Yes	Yes
Current Limiting	Yes	Yes

The candidate unit is used on Fltsatcom and is a buck boost load regulator type that controls the varying input into a 28 Vdc $\pm$ 1% supply. The parameters not met by the candidate unit such as efficiency and power rating can be satisfied by increasing the solar array area and the number of units. The other units in the catalog do not meet the input voltage range and output voltage limits. The DDT&E is estimated at 10 percent of a new development unit. This unit is used in the series load regulator configuration.

3.6.2 Power Control Equipment

The power control equipment is an ampere-hour meter and a current sensor for the battery charger. The requirements and the characteristics of the candidate equipment are as follows:

Parameters	Requirements	Candidates	
		(D4-3-2)	(D3-3-2)
State of Change (of 20 A-hr)	100%	100%	100%
State of Change (for load removal command)	30%	50% 30%	50%
Charge and Discharge (Battery Current)	Yes	No	No

The candidate units will require modifications, i.e., the second candidate unit must be modified to provide a 30 percent state of change (SOC) signal, and both candidate units must be modified to provide battery current. The units can be powered from the regulated 28 V output. The DDT&E for the modifications is assumed to be 25 percent of a new development unit. This device is used for both the series load regulators, and shunt and discharge voltage regulation configurations.

3.6.3 Battery Charger

The battery charger for the series load regulation configuration requires the following characteristics:

Parameter	Requirements
Type	Current and voltage limited with trickle standby
Input Voltage	40 to 60 Vdc
Charge Current Limit	20 A
Charge Voltage Limit	Temperature dependent, linearly decreasing from 33V at 272K (30°F) to 31V at 305K (90°F)
Trickle Current	0.5 A
Special Design Features	Automatic switch from high to trickle rate upon receipt of 100% SOC signal from A-hr meter or reach the voltage limit. Automatic cut-off of charge current for battery temperature greater than 308K (95° F)

There are no charger units in the catalog that will operate at the input voltage range and have the desired control functions.

The battery charger for the shunt and discharge voltage regulator has the same requirements as listed above except for the following:

Parameters	Requirements
Type	Voltage boost-current and voltage limited with trickle charge
Input Voltage	28V ± 4%
Special Design Features	On/off command capability from the power control unit

The catalog does not list a charger with the preceeding design parameters.

The battery charger for the shunt voltage regulator configuration includes the power control unit (PCU) since the candidate unit has incorporated both functions within one box. The candidate unit D8-3-1 controls battery charge and discharge, drives the shunt regulator to limit the maximum bus voltage, senses minimum bus voltage, and distributes the main bus to spacecraft loads. The candidate unit will provide 23 to 32V bus voltage, and can charge three batteries and drive four shunt regulators per unit. The unit must be modified to drive 17 shunt regulators per charger unit. To make this modification, it is estimated that the DDT&E effort will be 75 percent of a new unit.

3.6.4 Battery

The battery requirements as determined by the SDCM computer program to supply an average power of 1878 Watts are as follows:

Electrical Power Config.	No. Cells	A-hr/Bat.	No. Bat.	Total A-hr
Shunt Voltage Regulator	22	32.4	3	97
Series Load Regulator	20	32.4	3	97

The catalog listed batteries do not meet the requirements as determined by the SDCM. The alternate approach is to select larger quantities of batteries to meet the total required A-hr. The depth of discharge (DOD) that was used in the SDCM was 30 percent whereas NASA normally uses a 20 percent DOD. Thus, to be conservative, a larger number of batteries will be used in this study than indicated by the SDCM. The selected quantity was six 20-A-hr or four 30-A-hr batteries as indicated in the following tabulation.

Electrical Power Configuration	Candidate Index No.	No. Cells	A-hr/bat.	No. Bat.	Total A-hr
Shunt Voltage Regulator	D7-3-4	22	30	4	120
Series Load Regulator	D6-3-2	20	20	6	120

Battery assemblies using the standard cells in the Low Cost Systems Office (LCSO) Standard Equipment Announcement can also be used. The assemblies will require temperature protection and automatic charge inhibit/terminate at 308K (95°F). Under-voltage protection should also be provided by automatic shedding of all nonessential loads as a result of either a ≤ 24V signal from a battery or a 70 percent DOD from an A-hr meter if one is used.

3.6.5 Solar Array

The solar array requirements for an oriented flat paddle as determined by the SDCM computer program are as follows:

Parameters	Requirements		
	Shunt Voltage Regulator	Series Load Regulator	
	SDCM	SDCM	Modified [a]
Power, W			
BOL	3883	4350	5438
EOL_2	3689	4133	5166
Area, m^2	36	41	51
(ft^2)	(390)	(437)	(547)
Weight, kg	265	297	372
(lb)	(584)	(654)	(820)

[a] Values reflect the low efficiency of the candidate load regulator.

The average power load is 1878 W. None of the arrays in the catalog meet the power output and the mechanical design constraints imposed by the LST. The array is a new development.

3.6.6 Power Control Unit

The PCU is used in the shunt and discharge voltage regulation configuration. The unit optimizes the use of array energy through control of duty cycle for the shunt regulator, battery charger, or discharge regulator. The unit senses the load bus and commands the charger "on" after an eclipse. If the bus voltage is high, the shunt regulator is commanded "off" until the bus voltage drops to its low range. Then the discharger regulator is commanded "on" and the charger and shunt regulator are commanded "off".

The PCU requirements are as follows:

Parameters	Requirements
Type	Autonomous and ground commandable
Input voltage	28V ± 4%
Special design features	Control the "on/off" status of the EPS equipment so that the battery recharges immediately after an eclipse. If bus voltage reaches its upper limit, the PCU can command portions of the shunt regulator "on." If the bus voltage reaches its lower limit, the PCU can command the boost regulators "on," and the shunt regulator and battery charger "off." Ground command can override the PCU and selectively operate components of the PCU.

There are no PCUs in the catalog. The unit will require new development.

3.6.7 Shunt Regulator

The shunt regulator requirements are as follows:

Parameters	Requirements	
	At BOL Peak Power	At BOL Minimum Load
Array Current	88 A	12.5 A
Load Current (max - min)	63.8 A	12.5 A
Shunt Current	24.2 A	75.2 A
Required Power (dissipation at max - min load)	677 W	2110 W
Type	Series dissipative across full bus (so that it does not complicate array design).	
Input Voltage	20 to 60 Vdc	
Limiting Voltage when "on"	29.12 Vdc	
Shunt Current - max	75.2 A	
Power Dissipation max (including external resistors)	2110 W	

The candidate regulators from the catalog are listed in the following tabulation.

Satellite	Index No.	Input Volt	Power Diss/Unit	Number Needed	Remark
DSCS II	D5-3-2	16.3 V (tapped array)	70 W	31	Driven by PCU
DSP	D8-3-2	"	64.5 W	33	"
P72-1	D2-3-1	30 V	110 W (with external resistor)	20	Self driven
S-3	D4-3-1	24 to 31.4 V	100 W (with external resistor)	22	"
OSO-I	N1-3-1	33 V	66 W (with external resistor)	32	"
SMS	N5-3-2	15 V (tapped)	10 W	211	"
AE-C	N2-3-1	-38.5 V	29.2 W	73	"
ATS-F	N6-3-4	14 V	35 W	61	Driven by PCU

The prime candidate for the series load regulator configuration is the unit used on STP 72-1 (D2-3-1) since it uses the smallest number of regulators and is self driven. The DDT&E is assumed to be 10 percent of a newly developed hardware.

The prime candidate for the shunt voltage regulator configuration is D8-3-2 since this unit is compatible with the battery charger and PCU that has been selected for this configuration. The unit will provide a bus voltage range of 23 to 32 V. This configuration is the least complex of the configurations and will use flight-proven hardware, but it will not provide the bus regulation required by LST. This unit can be used with no modifications.

3.6.8 Discharge Regulator

The discharge regulator is to be commanded by the PCU whenever the bus voltage drops to its low range. The requirements and the characteristics of the candidate regulator are as follows:

Parameter	Requirements	Candidate (D2-3-2)
Type	Boost pulse width regulator	
Input Voltage	24 to 31 V	19 to 26 V
Output Voltage, min.	26.88 V	26.25 $\pm$ 1 V
Output Power (one per battery)	150 W	340 W
Efficiency	90% at max. load	N/A
Special Design Feature	Load sharing for parallel ops. "on/off" command capability, current limiting	

The candidate regulator is a self-contained unit and would be compatible with the battery and load parameters by resetting the unit to provide a minimum of 26.88 V.

The other discharge regulators in the catalog are an integrated part of the PCU.

3.7 COMMUNICATION AND DATA HANDLING (CDH)

The basic communication network for the LST is the tracking and data relay satellite (TDRS) system; an alternate communication network is the spacecraft tracking and data network (STDN). The description of the TDRS and STDN that was used in this effort was based on the 1975 edition of the TDRS User's Guide and the 1974 edition of the STDN User's Guide (References 7 and 8).

The mission data to be transmitted per orbit were assumed to be one image frame per orbit where the bit content of one frame is 600 M bits (Reference 6). Since it is required to transmit one frame over one earth station, the direct data rate to ground is 1 Mbps for a 10-min station pass.

The data rate via TDRS is 0.3 Mbps during one orbit access. The access time is 33 percent of the orbit for single access link and 85 percent of the orbit for multiple access link. The multiple access link was not selected for mission data transmission because the data rates are higher than 50 kbps and the transmitting power will be relatively high.

The housekeeping data which are lower in data rates can, however, use the TDRS multiple access link. The use of multiple access links will require a spread spectrum transponder for maintaining the flux density restriction imposed by the International Radio Advisory Committee. This link will also be used to transmit tracking data [pseudo random noise (PRN)] and commands.

The LST communications requirement for both the mission and housekeeping data is summarized on Table 3.7.1. The CDH functional block diagram to meet these requirements is shown in Figure 3.7.1. The information on component redundancies which is not shown in the block diagram is provided in Table 3.7.2 for each component along with the catalog index number, weight, and power.

Table 3.7.1 Communication Requirements

	Sensor Data Rates	TDRS Link	STDN Link
Mission Equipment	1 frame/orbit 600 Mbps/frame	300 kbps Pulse modulation	1 Mbps Pulse modulation
Housekeeping	1.6 kbps	1 kbps Spread spectrum	51.2 kbps Pulse modulation
Data Storage		1×10^9 bits	1×10^9 bits
Antenna Coverage			
Telemetry		Directional	Omni
Command		Omni	Omni

Table 3.7.2 LST Communication and Data Handling
Subsystem Weight and Power

COMPONENTS	No. Req.	INDEX No.	WEIGHT		POWER				
					OPERATE		STANDBY		TOT. PWR.
			(kg)	lb	W	Duty	W	Duty	W
Communication									
Receiver/Demodulator	2	N5-4-5	3.7	8.1	6.9		4.9		6.9
Baseband Assy [a]	1	D8-4-5	0.9	2.0	0.5		0		0.5
Transmitter (mission)	2	D7-4-1	1.7	3.8	24.0		0		24.0
Transmitter (hskpg)	2	D6-4-2	1.6	3.6	16.3		0		16.3
Diplexer	2	(nh)	1.4	3.0	0		0		0
Tracking Receiver Gimbal	2	(nh)	3.5	7.8	6.0		0		6.0
Spread Spectrum Transp.	2	NASA [b]	6.8	15.0	10.0		4.0		10.0
Omni-Antenna, S-band	1	(nh)	3.8	8.4	0		0		0
Hi Gains Ant. Gimbal	2	A	11.0	24.2	10		0		10
Hi Gains Antenna	2	D8-4-9	1.9	4.2	0		0		0
Data Handling			36.3	80.1					73.7
Command Decoder	2	(nh)	17.3	38.2	23.6		0		23.6
Digital TM Unit-Hskp.	2	(nh)	4.5	10.0	5.0		0		5.0
Tape Recoder (mission)	2	D3-4-3	15.2	33.6	25 30	Record Playback			30.0
Tape Recoder (hskpg)	2	NASA	10.0	22.0	4.0				4.0
Sub Total			47.1	103.8					62.6
Total			83.4	183.8					136.0

[a] Internally redundant

[b] Being developed under separate efforts by NASA

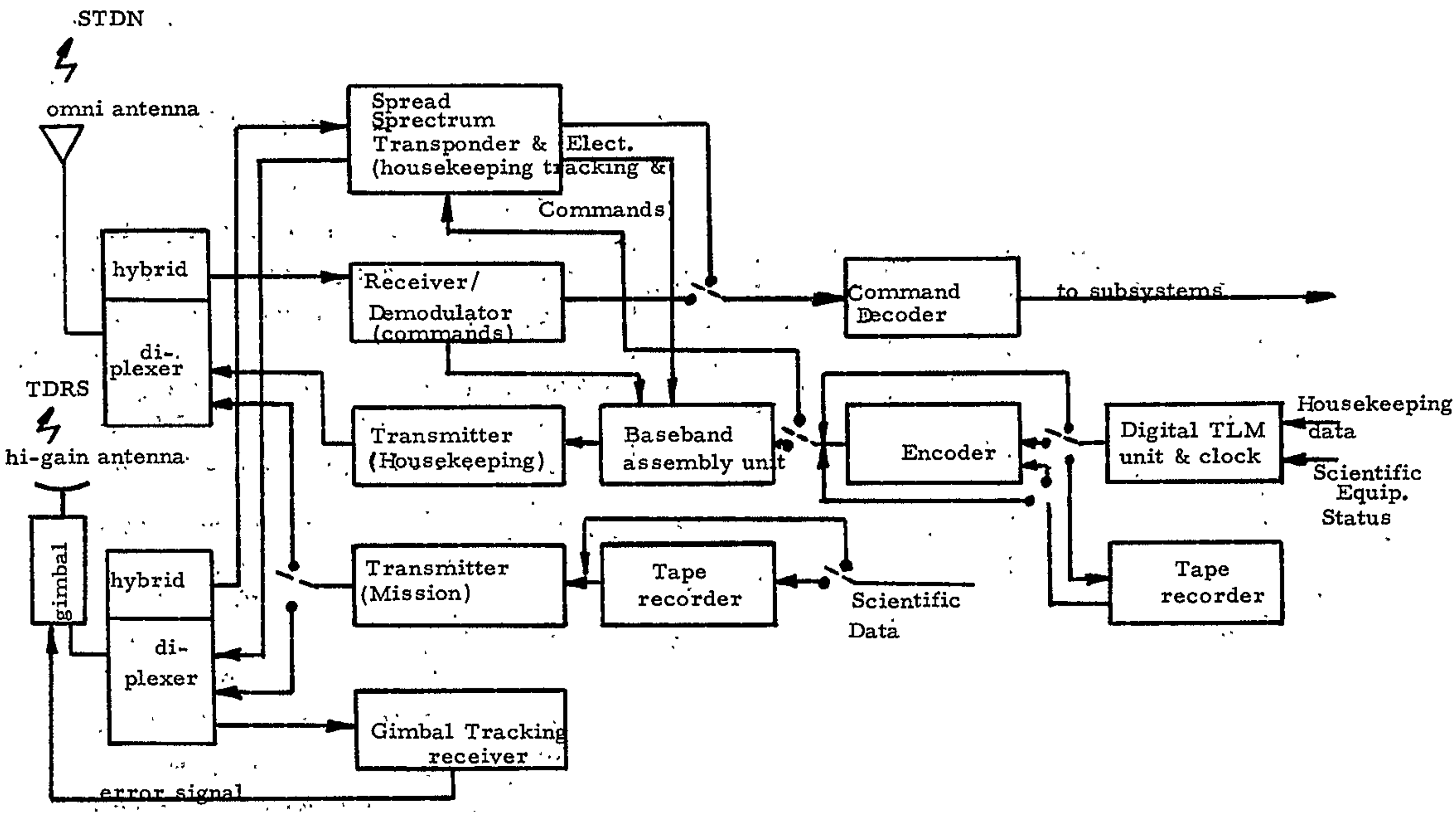


Figure 3.7.1 LST Communication and Data Handling Configuration

3.7.1 Receiver

The receiver requirements and characteristics of the candidate unit are as follows:

Parameters	Required	Candidate (N5-4-5)
Frequency	2.09 to 2.12 GHz	2.03 GHz [a]
Acquisition	109 dBm or lower	-110 dBm
Noise Figure	Low	8 dB
Track	$\pm$ 90 kHz from record frequency	$\pm$ 90 kHz from record frequency
Time Delay Variations	Low	10 nsec
Dynamic Range	Good	-70 to -110 dBm

[a] Units are generally tunable to required band.

The candidate unit is a part of the S-band transponder which has a demodulator included. Other candidate receivers that are flown on AE-C and ERTS-A would meet the general requirements but are less desirable because of the higher power, heavier unit, and noise figure. The estimated DDT&E is 50 percent of a new unit.

3.7.2 Baseband Assembly

The baseband assembly requirements and characteristics of the candidate assembly are as follows:

Parameters	Required	Candidate (D8-4-5)
Subcarrier Frequency	1.024 MHz	1.024 MHz
Modulation	1.6 and 51.2 kbps PCM	1 to 128 kbps PCM
Ranging Code	PRN	PRN

The selected candidate assembly consists of two redundant units with each unit containing a 1.024 MHz subcarrier oscillator and a summation amplifier. The PCM is put on the subcarrier and is summed with the PRN ranging as input to the transmitter. Another unit was considered because it probably can meet the requirements with minor modifications.

3.7.3 Transmitter (Mission)

The transmitter requirements and the candidate transmitter for the mission data are as follows:

Parameters	Required	Candidate D7-4-1
Transmitter Power[a]	3.6 W	5.5 W
Modulation	PM	PM
Efficiency	High	23%
Frequency	2.2 to 2.3 GHz	2.2 to 2.3 GHz

[a]See Table 3.7.3 for link calculation

The transmitter used on DMSP (D7-4-1) will meet the requirement with excess power capablity. A second transmitter that is used in SAS-C (N3-4-1) will also meet the requirements but it is not as efficient. The NASA standard spacecraft transponder in the LCS Standard Equipment Announcement will also meet the requirements for this link.

3.7.4 Transmitter Housekeeping

The housekeeping data transmitter requirements and candidate unit are as follows:

Parameters	Required	Candidate D6-4-2
Transmitter Power[a]	0.1 W	1 W
Modulation	PM	PM
Frequency	2.2 to 2.3 GHz	2.2 to 2.3 GHz
Spurious Response	Low	-40 dB
Coherency	USB	SGLS

[a]See Table 3.7.4 for link calculation

The only flight-proven transmitter in the catolog that will meet the requirements is the unit used on NATO-III with minor modification. The candidate transmitter is about 10 dB overkill in power for this link.

The second choice is the SMS transmitter which is rated at 0.2W power but it has quadriphase modulation. The NASA standard spacecraft transponder in the LCS Standard Equipment Announcement will meet the requirements of this link.

Table 3.7.3 Link Calculations (300 kbps link to TDRS[a]; 1000 kbps link to STDN)

<u>Output Power Requirements - 300 kbps Link</u>

31 + EIRP	55.2
TDRS Antenna Gain	20 dB
EIRP	24.2 dBm
Power	4.2 dB = 2.6 W

<u>Onmi Antenna Gain Requirement - 1000 kbps Link</u>

LST Transmitter Power (dBm)	32
LST Line loss (dB)	-2
LST Antenna gain (dB)	G
EIRP (dBm)	30 + G
Space loss (1400 nmi) (dB)	-168
Ground antenna gain (dB) -30 ft dia	44
Total received power (dBm)	-94 + G
Ground station spectral noise density (dBm/Hz)	-176.3
Received power to spectral noise density (dBm/Hz)	82.3 + G
Noise bandwidth (1000 kbps) (dB)	60
Received power to noise spectral density (dB)	25.3 + G
Required signal-to-noise ratio (dB)	9.6
Ground station degradation (dB)	4
Link margin (dB)	3

$$25.3 + G = 19.6$$
$$G = -5.7 \text{ dB}$$

[a]From TDRS User's Guide (Reference 8) single access S-band return link

Table 3.7.4 Link Calculations (51.2 kbps housekeeping link to STDN)

Required Transmitter Power - 51.2 kbps Link

LST Transmitter Power (dBm)	P_t
LST Line loss	-2
LST Antenna gain (dB)	-5.7
EIRP (dBm)	P_t -7.7
Space loss (dB)	-168
Ground antenna gain (dB) -30 ft dia	44
Total received power (dB)	-131.7 + P_t
Ground station spectral noise density (dBm/Hz)	-176.3
Received power to spectral noise density (dBm/Hz)	44.6 + P_t
Noise bandwidth (dB)	47.1
Received power to noise	-2.5 + P_t
Required signal-to-noise ratio (dB)	9.6
Modulation loss (dB)	3.0
Ground station degradation (dB)	4
Link margin (dB)	6.0

$$-2.5 + P_t = 22.6$$

$$P_t = 20.1 \text{ dBm}$$

$$P_t = 100 \text{ mW}$$

3.7.5 Diplexer

The diplexer must transmitt and receive at USB frequencies for theTDRS and STDN links. Each unit must contain a hybrid to allow both receivers to monitor the uplink continuously and to allow simultaneous transmission of two downlink data streams. There are no diplexers in the catalog that will meet the requirements

3.7.6 Tracking Receiver (Gimbal)

The tracking receiver is used to direct the hi gain antenna. This type of component is not contained in the catalog. It must be a new design, possibly a monopulse tracking type. The pointing or tracking accuracy requirements are in the order of ±0.02 rad (± 1 deg). Two receivers are required to provide continuous line of sight when the LST is in view of the TDRS.

3.7.7 Spread Spectrum Transponder and Electronics

When the TDRS is used, the forward and return links must incorporate spread spectrum modulation techniques. The modulation being staggered quadriphase PRN. The command data is (modulo-2) added to the PRN on both I and Q channels of the forward link. I and Q channels are the data stream transmitted by 0 and 180 degrees, and 90 degree phase modulation of the reference carrier, respectively. The housekeeping data, tracking, and command can use the TDRS multiple access communication service system since the data rate is less than 50 kbps. However, the mission data at 300 kbps must use the TDRS single access service system.

The equipment to provide this function of spread spectrum transponder, a correlator for extracting the command data, a modulo-2 adder, and an error correcting encoder is not currently available. NASA is planning to develop a standard TDRS compatible transponder. The schedule delivery date for the first unit is May 1978.

3.7.8 Omni Antenna - S-Band

The omni antenna for the S-band link to the STDN stations is a low gain, two boom-mounted conical log spirals. There are no antennas in the catalog that will meet both transmit and receive USB requirements. There is an antenna (D2-4-1) in the catalog that meets the transmit requirements and may possibly be modified to incorporate the receive capability. The unit is a boom-mounted conical log spiral that was used on STP 72-1. The gain requirement is at least -5 dB over 85 percent of 4π steradian. Two boom-mounted conical log spirals would have to be used to get this coverage and gain.

3.7.9 Hi-Gain Antenna and Gimbal

The hi-gain antenna for the TDRS link requires a gain of -20 dB (see link calculation, Table 3.7.3). The only known hi-gain unit is the parabolic antenna used on the DSP (D8-4-9). The antenna diameter is 0.61 m (2 ft) and weight is 1 kg (2.1 lb). An antenna gimbal system that appears suitable for this application has been flown on an Air Force program. The unit has been designed to provide a pointing accuracy of ±0.02 rad (1 deg), and was fabricated at Aerospace (Reference 9). The unit gimbal weight including electronics for motor, detections, and circuitry is 5.4 kb (12 lb). Power usage is 5 W. No other known gimbal system has been designed and flown in space. Two hi-gain antenna and gimbal assemblies are required to provide TDRS line of sight. The estimated DDT&E is 25 percent of a new unit.

3.7.10 Command Decoder

The basic requirements of the decoder are as follows.

Parameter	Requirements
Number of stored commands	4000 words
Stored command time interval	24 words
Word length	28 bits

The command decoders in the catalog cannot meet the required capability. The 28-bit word length and 24-hour command storage time are beyond the capability of the flight-proven units. The longest word length amongst the decoders is 16 bits. The OSO-I memory unit (N1-4-7) has 4096-word memory capacity and 16-bit word size. The AE-C memory unit (N2-4-14) also has 4096-word memory capacity but only 10-bit word size. The unit will require new development.

3.7.11 Digital Telemetry Unit (DTU) and Clock

The DTU which includes a multiplexer, analog-to-digital converter, clock, and conditioner has the following requirements.

Parameter	Requirements
Bit rate	1.6 kbps
Word length	
Number of main frame words	
Number of words per subframe	
Clock stability	1 in 10^9 in 24 hours
Time resolution	1 μs
Time error recoverable to GMT	10 ms

The catalog has no DTUs that can provide such a low bit rate (1.6 kbps). Furthermore, sufficient information on requirements is not provided to estimate the number of channels required. The clock is arbitrarily included in this unit. It provides timing for the LST transmitted data. This unit will be a new development.

3.7.12 Tape Recorder (Mission Data)

The mission data recorder requirements and the characteristics of the candidate recorder are as follows:

Parameters	Requirements	Candidate D3-4-3
Record Rate	500 kbps	32, 512 and 1,024 kbps
Total Storage	1×10^9 bits	1.53×10^9 bits
Record/Playback Speed Ratio	1:0.6 & 1:1	32:1/2:1/1:1
Bit Error Rate (BER)	1 in 10^6	1 in 10^6

The candidate recorder that was used on STP 72-2 would have to be modified to accommodate the record rate and the record playback speed ratios. The NASA standard 10^9 magnetic tape recorder will meet the requirements. The DDT&E is estimated at 10 percent of a new development.

3.7.13 Tape Recorder (Housekeeping)

The tape recorder requirements for the housekeeping and scientific equipment status data are as follows:

Parameters	Requirements	NASA Std Tape Recorder - 10^8
Record Rate	1.6 kbps	1.7 kbps (min)
Total Storage	30×10^6 bits	3.2×10^8 bits
Record/Playback Speed Ratio	1:32	160:1 to 1:160
Bit Error Rate (BER)	1 in 10^6	5 in 10^7 @ BOL 1 in 10^5 @ EOL

None of the tape recorders in the catalog could meet the low record rate of 1.6 kbps. The lowest record rate in the catalog is 6.4 kbps. The NASA standard 10^8 magnetic tape recorder that is described in the LCS Standard Equipment Announcement meets the requirement except for the record rate and BER. For this study it is assumed that the requirement or capability will be changed to meet the needs.

4. HEAT CAPACITY MAPPING MISSION (HCMM)

4.1 MISSION DESCRIPTION (Reference 10)

The primary mission objective is to produce a thermal map of the continental United States at the optimum times for thermal inertial measurements for discrimination of rock types and mineral resource location. The secondary mission objectives are to:

a. Measure plant canopy temperatures at frequent intervals to determine the transpiration of water and plant stress.

b. Measure soil moisture effects by observing the temperature cycle of soils.

c. Map thermal effluents, both natural and man-made.

d. Provide frequent coverage of snow fields for water runoff prediction.

To accomplish the mission objectives, the spacecraft is to provide the following:

a. Desirable and minimum lifetime - 12 months.

b. 600 km (324 nmi) circular orbit x 97.8-deg inclination (sun synchronous). The allowable orbit must be correctable with the orbit adjust system to 600 $\pm$ 30 km circular sun-synchronous orbit.

c. Ground communication - STDN network.

The launch vehicle is the four-stage standard Scout. The fourth stage, including the payload, is spin-stabilized.

4.2 MISSION EQUIPMENT DESCRIPTION

The HCMM instrument characteristics are summarized in the following tabulation, and a drawing is shown in Figure 4.1 (References 10 and 11).

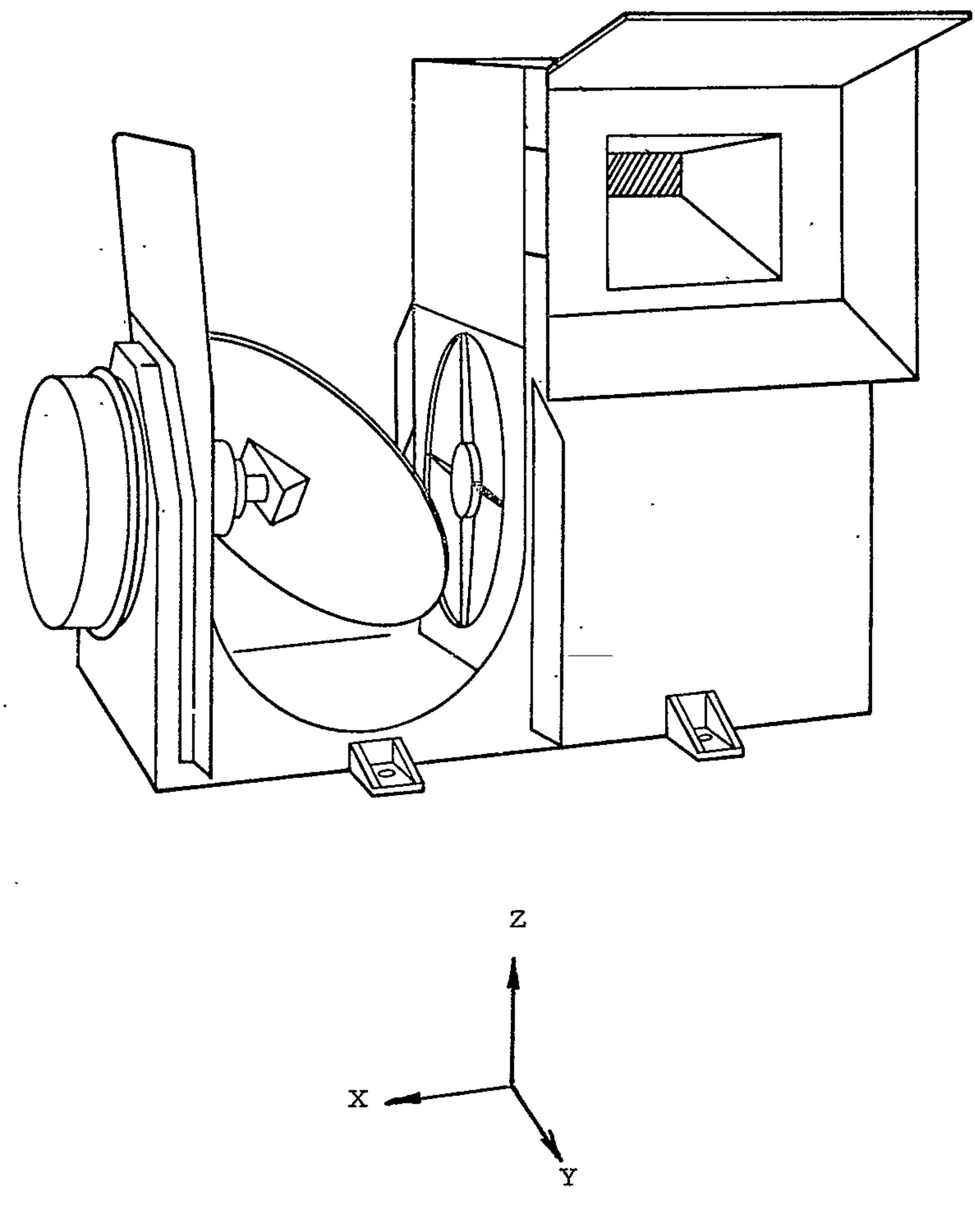


Figure 4. 1 HCMM Instrument

Weight	37.4 kg (82.5 lb)
Power	40W max. 34 W data taking 22 W standby 26 W average/orbit*
Pointing accuracy	3-axis stabilized ± 0.17 rad (± 1 deg) roll and pitch ± 0.35 rad (± 2 deg) yaw
Voltage	28 Vdc ± 2%
Size (m)	$0.54\ell \times 0.43h \times 0.23w$
Data rate	Wideband data S-band (2.2-2.3 GHz)

The instrument is earth pointing along the Z axis and three-axis stabilized (see Figure 4.2). The weight includes sensor, converter, support electronics, multiplexer, structure, thermal control, and harnesses.

4.3 SPACECRAFT DESCRIPTION

The spacecraft (base module) which houses the housekeeping subsystems is constrained in size to fit within the standard Scout shroud and in weight to 97 kg (214 lb). The housekeeping subsystems are the stabilization and control (SC), auxiliary propulsion (AP), electrical power (EP), and communication and data handling (CDH) subsystems. Alternative configurations for SC and EP subsystems were examined; however, the AP and CDH subsystems were limited to one design each because of the weight constraint and communication requirements.

The spacecraft is launched and inserted into orbit with the fourth stage attached and spinning. After insertion and separation from the spent fourth stage, two stabilization methods were considered for earth

*Calculated from the power profile in Reference 11.

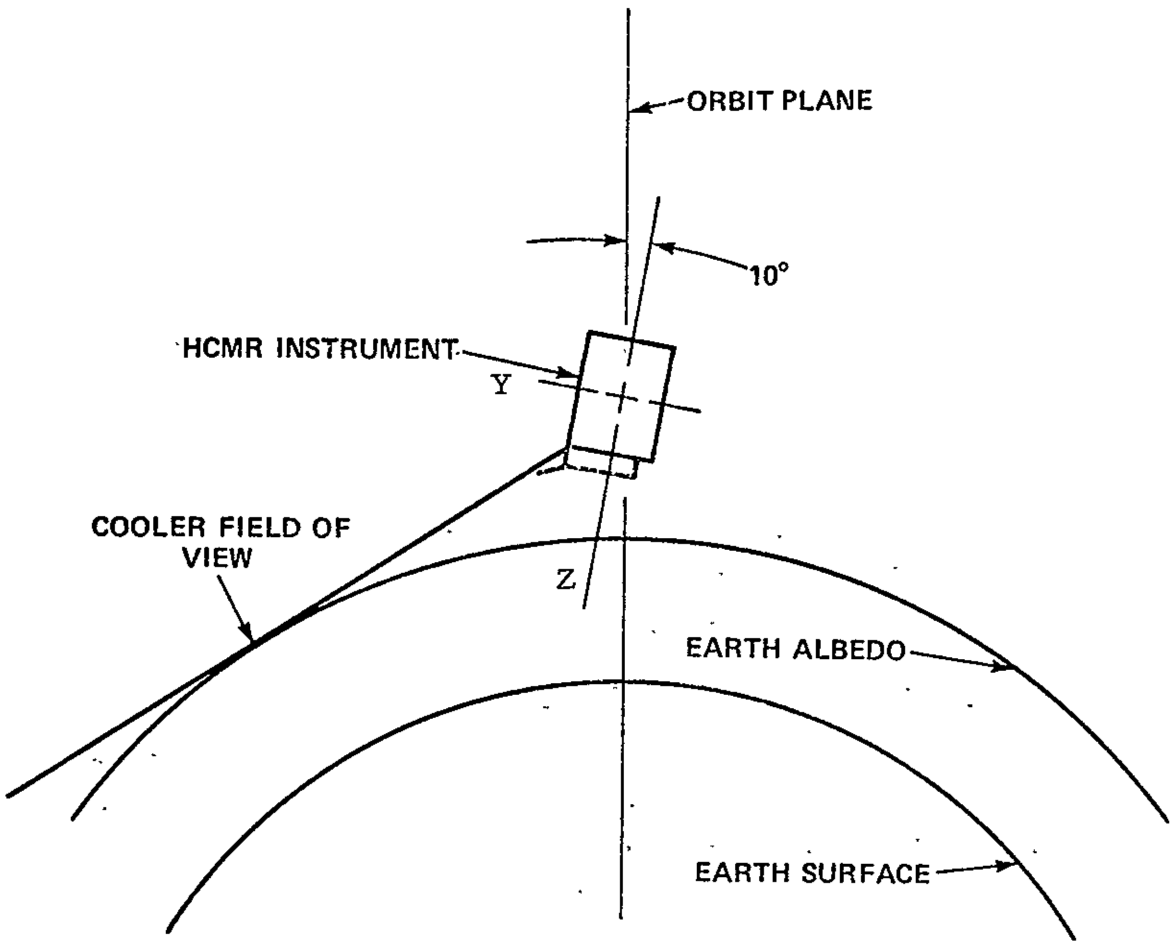


Figure 4.2 HCMM Spacecraft Orientation

acquisition. The stabilization sequence for HCMM includes a sun pointing mode followed by earth acquisition. The second stabilization sequence which can be used for both HCMM and SAGE is configured to acquire the earth directly. The HCMM-only configuration is lighter since only one scan wheel assembly is required. The HCMM/SAGE configuration has two scan wheel assemblies. Both designs will provide the same on-orbit pointing accuracy. The HCMM-only configuration is not applicable to the SAGE mission because of the orbit characteristics.

The EP subsystem considered two types of power control methods: series load regulation and discharge voltage regulation configurations. The oriented arrays were not traded against fixed arrays because oriented arrays are generally lighter than fixed arrays for sun synchronous missions and require cells on only one side. The deployable array arrangement with respect to orbit plane and spacecraft pointing direction is shown in Figure 4.3.1

The total HCMM spacecraft weight is 102.5 kg (Table 4.3.1). The estimated weight exceeds the maximum allowance of 97 kg. Weight reduction can be achieved by design optimization; however, it can be expected that extensive use of flight-proven hardware can result in high weight since in many areas the component capability exceeds requirements.

Table 4.3.1 HCMM Weight and Average Load Power

SUBSYSTEM	WEIGHT		AVERAGE LOAD POWER W
	kg	lb	
Stabilization and Control	24.8	54.7	24.0
CDH	11.1	24.6	19.6
Auxiliary Propulsion			
Dry Weight	6.5	14.3	0
Hydrazine	9.2	20.3	
Electrical Power	30.5	67.1	0[a]
Structures and Thermal	20.4	45.0	0
Spacecraft Total	102.5	226.0	43.6
Mission Equipment	37.4	82.4	26.0
Satellite Total	139.9	308.4	69.6

[a] Electrical power converter and storage efficiencies not considered as load power.

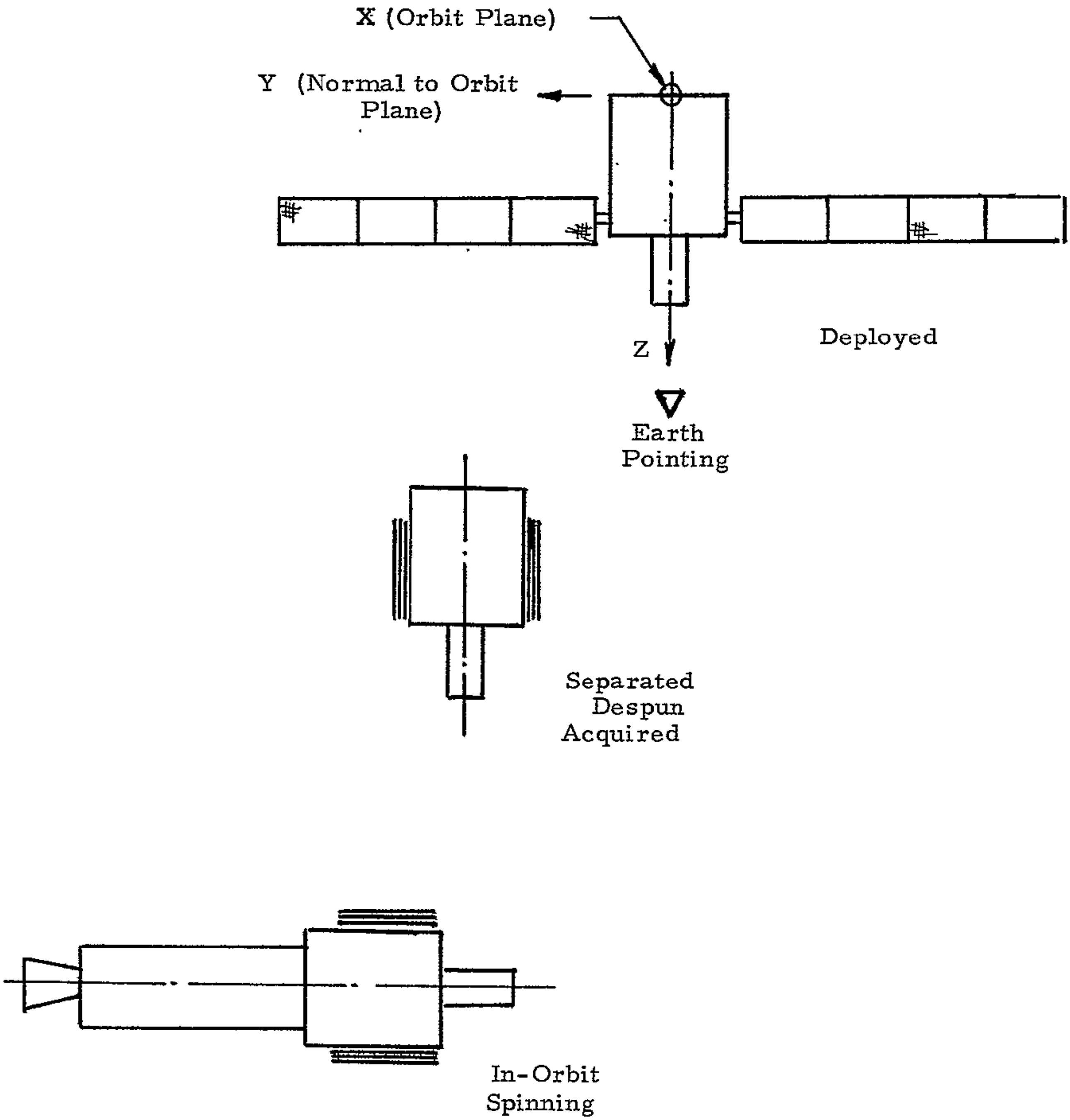


Figure 4.3.1 HCMM Deployment and On-Orbit Orientation

4.4 STABILIZATION AND CONTROL

The satellite is injected into orbit by the launch vehicle at about a 90 rpm spin rate. The SC must despin, three-axis stabilize, and earth point the satellite. The SC is also required to be capable of stabilizing the satellite from a tumbling mode at any time in the mission lifetime. To provide this capability, two SC approaches were considered for HCMM. The first version, which is suitable for HCMM, does not meet the SAGE requirements because of the different orbit. The SAGE orbit is 50-deg inclination, and the HCMM orbit is 97.8-deg inclination for a sun-synchronous 2:00 PM ascending node. Both orbits are circular at 600 km altitude. The two types of orbits during the one-year orbit about the sun are depicted in Figure 4.4.1 for a specific set of launch conditions.

The acquisition of the satellite for the first version is performed by initially acquiring the sun and then acquiring the earth. This maneuver sequence results in requiring only one scan wheel assembly. The second version, which is applicable to both HCMM and SAGE, acquires the earth directly, but the maneuver will require two scan wheels. The scan wheels are heavy. The weight of the HCMM-only configuration is lighter than the HCMM/SAGE configuration by 3.6 kg (7.9 lb). The two types of SC configurations use basically the same components, but they differ in the quantity of each component and the control electronic assembly.

The candidate components, along with the quantity, weight, and power for the two configurations, are listed in Tables 4.4.1 and 4.4.2. The estimated weights for HCMM and HCMM/SAGE are 24.8 kg (54.7 lb) and 28.4 kg (62.8 lb). The block diagrams of HCMM and HCMM/SAGE are shown in Figures 4.4.2 and 4.4.3. The HCMM configuration uses four sun sensors for the sun acquisition mode and one scan wheel assembly. The HCMM/SAGE configuration uses two scan wheel assemblies and no sun sensor information for automatic acquisition.

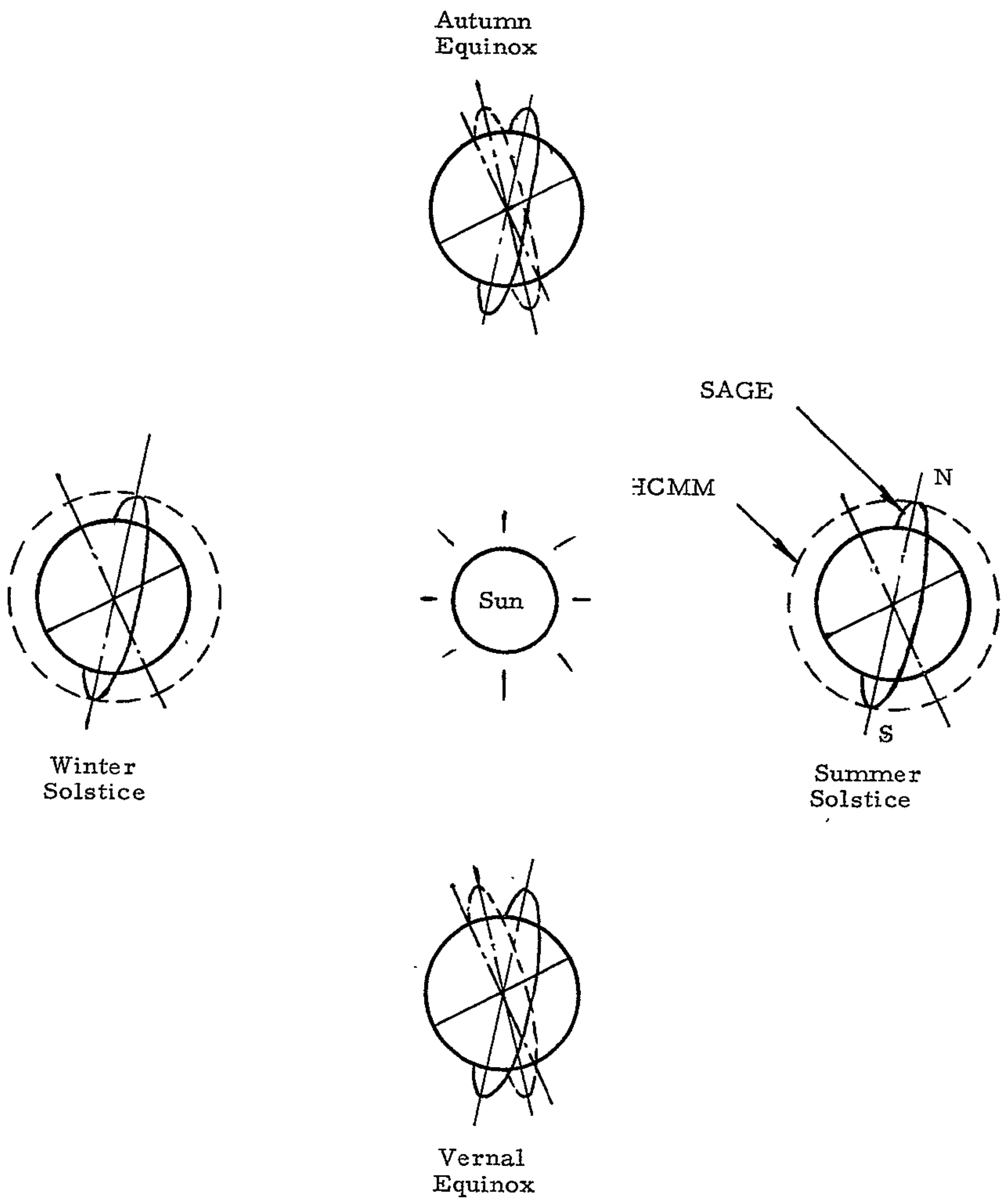


Figure 4.4.1 HCMM and SAGE Orbits for Specific Launch Condition

Table 4.4.1 HCMM Stabilization and Control Subsystem

COMPONENTS	No. Req.	INDEX No.	WEIGHT (kg)	WEIGHT lb	POWER OPERATE W	POWER OPERATE Duty	POWER STANDBY W	POWER STANDBY Duty	POWER TOT. PWR. W
Scan Wheel Assembly[a]	1	D3-1-1	6.6	14.6	4	100%			4
Rate Gyro Assembly	1	(nh)	0.9	2.0	8	b	0	b	0
Coarse Sun Sensor	4	N6-1-9	1.3	2.8	0	b	0	b	0
Sun Sensor Elect.	1	(nh)	1.8	4.0	4		0		0
Wide Angle Sun Sensor	2	developed	0.1	0.3	0		0		0
Solar Array Drive Mtr	2	(nh)	5.5	12.0	0	100%	0		0
Solar Array Drive Elect.	2	(nh)	2.3	5.0	10	100%	0		10
Valve Driver[c]	1	(nh)	0.9	2.0	0		0		0
Control Elect. Assembly[c]	1	(nh)	5.4	12.0	10	100%			10
			24.8	54.7					24

[a] Reaction wheel and earth sensor combination (RI/MC409-0003)

[b] Operates only during acquisition maneuvers

[c] Internally redundant

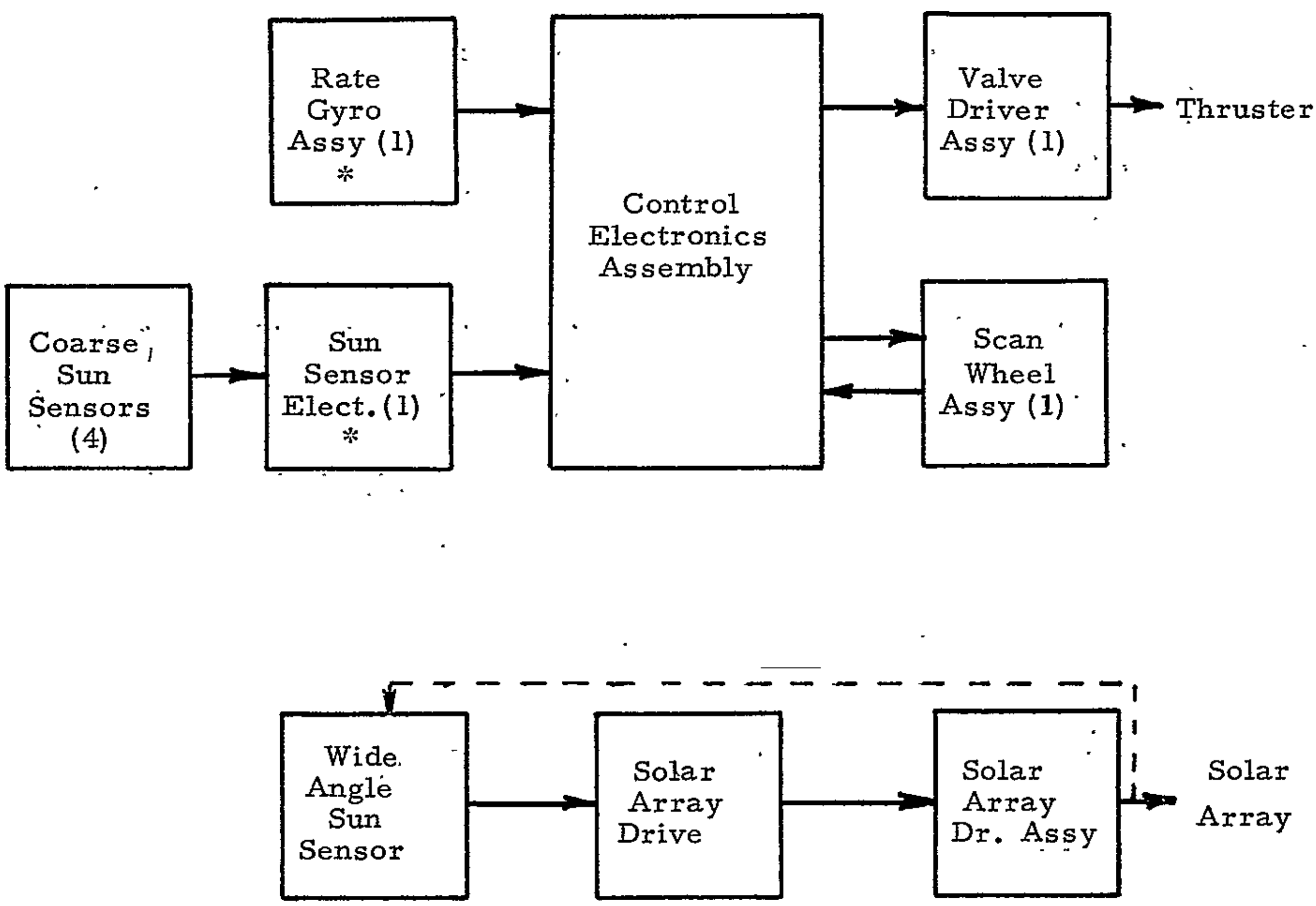
Table 4.4.2 HCMM/SAGE Stabilization and Control Subsystem

COMPONENTS	No. Req.	INDEX No.	WEIGHT (kg)	WEIGHT lb	POWER OPERATE W	POWER OPERATE Duty	POWER STANDBY W	POWER STANDBY Duty	POWER TOT. PWR. W
Scan Wheel Assembly[a]	2	D3-1-1	13.2	29.2	8	100%			8
Rate Gyro Assembly	1	(nh)	0.9	2.0	8	b	0	b	0
Sun Sensor	1	N5-1-1	0.1	0.3	0.03	100%			0
Wide Angle Sun Sensor	2	developed	0.1	0.3	0		0		0
Solar Array Drive Mtr.	2	(nh)	5.5	12.0	0		0		0
Solar Array Drive Elect	2	(nh)	2.3	5.0	10	100%	0		10
Control Elect. Assembly[c]	1	(nh)	5.4	12.0	10	100%	0		10
Valve Driver[c]	1	(nh)	0.9	2.0	0		0		0
			28.4	62.8					28

[a] Reaction wheel and earth sensor combination (RI/MC409-0003)

[b] Operates only during acquisition maneuvers

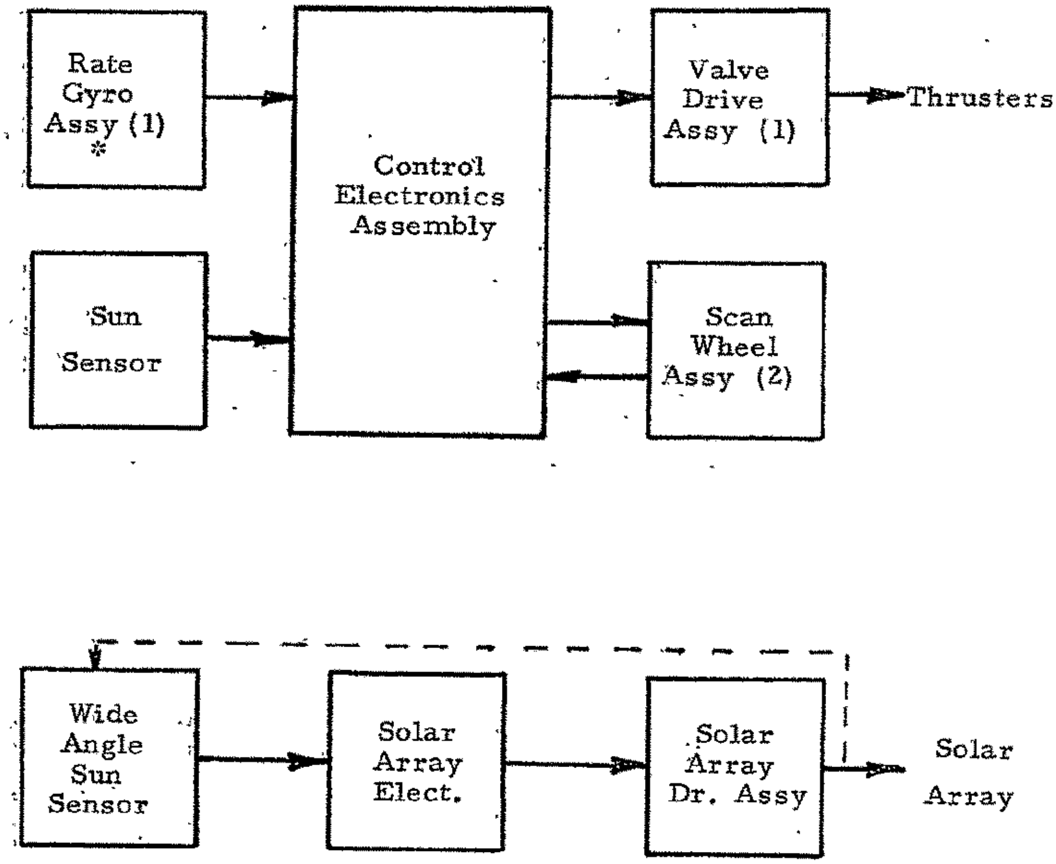
[c] Internally redundant



* Active only during acquisition mode

Figure 4.4.2 HCMM Stabilization and Control Subsystem

C.2



* Active only during acquisition mode

Figure 4.4.3 HCMM/SAGE Stabilization and Control Subsystem

Both of the SCs assume that the satellite can be launched at any time of the year and that orbital reacquisition capability at any time of the year shall be provided. It is also assumed that the spacecraft "Z" (yaw) axis is to be earth pointing and the "Y" (pitch) axis is to be normal to the orbit plane throughout the mission life. The acquisition sequence of events is summarized in Table 4.4.3.

Detailed discussion and analysis of the two control concepts are presented in Appendix A.

4.4.1 Scan Wheel Assembly (SWA)

The scan wheel assembly scans the earth and controls the spacecraft attitude by momentum exchange. The requirements of the SWA and the characteristics of candidate components are as follows:

Parameter	Requirement	Candidate D3-1-1
Angular momentum mkgs (ft-lb-sec)	0.41 to 0.55 (3 to 4)	0.55 to 0.69 (4 to 5)
Accuracy, mrad (deg)	8.7 (0.5)	3.5 (0.2)
Altitude, km	600	< 2780
Output	pitch and roll	pitch and roll
Power, W	21	19
Weight, kg (lb)	low	6.6 (14.6)
Design life, yr	1	0.5

The candidate units exceed the requirements in all the listed parameters except the design life: the STP 72-2 specified design life was 0.5 yr; however, the plan was to use the unit for 1 yr. The weight can be reduced since the angular momentum capability exceeds the

Table 4.4.3 HCMM Acquisition Sequence of Events

HCMM	HCMM/SAGE
Despin (thrusters)	Despin (thrusters)
Acquire Sun	Runup Wheels
Point at Sun (thrusters)	Acquire Earth
Runup Wheels	Point at Earth (thrusters)
Acquire Earth	Fine Earth Pointing
Point at Earth (thrusters)	
Fine Earth Pointing	

requirement by about 25 percent. For this study, it is assumed that this weight reduction will not be performed. The wheel spin (pitch) axis is perpendicular to the orbit plane.

4.4.2 Rate Gyro Assembly

The RGA is used only during the acquisition phase and is not used during the fine attitude control. The requirements of the RGA are as follows:

Parameter	Requirement
Range, yaw rate	0.17 mrad/s to 0.35 rad/s (0.01 to 20 deg/s)
Tolerance	Withstand 18.85 rad/s (1080 deg/s) about any axis while not operating without subsequent degradation
Design life	1 year

There are no RGAs in the catalog; however, there exists a flight-proven single-axis channel of a three-axis RGA unit that was manufactured by Timex Corp. for LMSC. It is recommended that the gyro unit be repackaged for a single-axis only to conserve weight and power. For this study, it will be assumed that the repackaging and requalification is equivalent to a new development effort. The characteristics of the unit using the Timex components should be as follows:

Parameter	Characteristics of Candidate CD040 Gyro
Input range	± 0.35 rad/sec (± 20 deg/s)
Threshold	0.17 mrad/sec (0.01 deg/s)
Nonlinearity	± 12% to ± 0.1 rad/s (± 6 deg/s)
Features	Will withstand design rates with no significant degradation subsequently
Design life	1000 hours min. of operation

4.4.3 Coarse Sun Sensor and Electronics

The sun sensor is used to align the yaw axis of the spacecraft with the sun. During the initial acquisition or reacquisition, the spacecraft orientation can be in any direction. The sun sensors must, therefore, provide 4π steradian coverage. The requirements of the sun sensor and the characteristics of the candidate unit are as follows:

Parameter	Requirement	Candidate (N6-1-9)
FOV	4π sr	4π sr with 4 units
Accuracy error	$< \pm 10\%$	+3% -12% within $\pm$ 0.22 rad ($\pm 13^{\circ}$) of null
Design life	1 year	NA
Measurements	pitch and roll about sun line	pitch and roll about sun line

Two of these sensors, which are used on ATS-F, should be located on the +X axis and two on the -X axis. It is theoretically possible to get the necessary spherical coverage with two three-eye sensors (N6-1-9) and two two-eye sensors (N6-1-10); however, actual installation may not provide a completely unobstructed FOV. Also, to exclude unwarranted reflections from the spacecraft, it may be necessary to restrict the FOVs of the heads by appropriate restrictions. The sensors should be applicable without any changes.

The electronics for the sensors, however, will require new development. The electronics must process the coarse sun sensor pitch and roll signals from all four sensors. The output representing pitch and roll signals of the satellite to the sun line will be fed to the control electronics assembly. This unit is only energized during the acquisition phase.

For the HCMM/SAGE control configuration, the sun sensor data is used only to provide spin rate data to the ground station. This information is not used in the control logic, and therefore only one unit is required.

4.4.4 Wide Angle Sun Sensor (WASS)

The WASS is mounted on the active side of each solar array to provide pointing data for the solar array drive electronics. The output will be a function of the angle between the sensor and the array normal. The requirements of the WASS and characteristics of the candidate are as follows:

Parameter	Requirement	Candidate
FOV	1.57 rad (± 90 deg)	1.57 rad (± 90 deg)
Accuracy	± 0.09 rad (±5 deg)	± 0.035 (± 2 deg)

The candidate device is a Bendix wide angle sun sensor (P/N 1771858). These devices were to be used in a similar application on the Earth Limit Measurement Satellite (ELMS) Program, which has since been cancelled. No suitable devices are in the catalog.

4.4.5 Solar Array Drive and Electronics (SADE)

The requirements of the SADE are as follows:

Parameter	Requirement
Load	SAS-C type arrays
Rotation rate	0.07 rad/min. (3.75 deg/min)
Accuracy	0.175 rad (10 deg)
Weight	Low (< 6 lb)
Power	Low (< 5W)

The SAS-C solar panel rotation system was examined for this application, but was found to be unsuitable because of the following reasons:

a. No slip rings are incorporated, since the shaft rotates only 1.57 rad (90 deg).

b. Mechanical linkage of levers and pulleys would probably be difficult to adapt to HCMM.

c. Rotation speed is probably too high. A new speed reducer or a lower speed motor will probably be required.

d. The power usage is high (8W).

The electronic assembly to drive the motors with inputs from the WASS and ground commands will also be required. The assembly should contain dc-dc converters, internal logic and control elements, and angular position sensors.

4.4.6 Valve Driver Assembly

The VDA is required to accept the control signals from the CEA and to apply 28V to the eight 1-lbf and the two 0.1-lbf thruster solenoids. The 1-lbf thrusters and the 0.1-lbf thrusters are from the ERTS and FLTSATCOM Programs. The FLTSATCOM valve drive and electronic units are contained within a larger package of other subassemblies, and the unit is capable of driving 20 thruster solenoids. The unit weighs too much because it has too great a capability. Specification data for ERTS were not available.

The VDA must be completely redundant since the candidate thrusters have dual solenoids, and the active circuitry should be selectable by ground command. Also, the thrusters should be controllable from the ground as a backup mode. The VDA will be a new development.

4.4.7 Control Electronics Assembly (CEA)

The CEA is required to provide the following functions during the acquisition and fine control phases:

a. Process and filter the inputs from sun sensors and rate gyros during the acquisition mode, and the earth sensor inputs from the SWA for the spacecraft fine pointing mode.

b. Process ground commands including ΔV corrections.

c. Compute the pitch and roll analog signals according to the control laws governing the momentum exchanger devices and sequence the control events.

d. Drive the SWA motors and provide signals to the VDA.

e. Convert 28V bus voltage to regulated secondary dc voltages and and ac reference waveforms for the SWA.

The circuitry should be completely redundant to enhance reliability and minimize or preclude single point failures. Only one-half of the circuit should be active at any one time. Ground commands should select the circuits to be energized. No units exist in the catalog that will provide the above logic functions. The CEA is a new development

4.5 AUXILIARY PROPULSION

The AP design requirements for providing attitude control, velocity correction, and acquisition are as follows:

Parameter	Requirement
Total Impulse	16,000 Ns (3600 lb-s) + 10% margin *
Thrust levels	Eight 4.4N (1 lbf) Two 0.4N (0.1 lbf)
Life	One year, 50,000 pulses
Reliability	No single point failure mode with exception of tank and pressurant fill valve

Hydrogen monopropellant was selected because of the critical weight constraint. The hydrazine propellant subsystem is 13.6 kg (30 lb) less than a cold gas nitrogen system. A pressure blowdown method is recommended which eliminates a separate nitrogen pressurization source. The propellant tank may be isolated with the latching valve in the event of

* Total impulse required has been increased to 20,172 Ns (4535 lb s) (see Appendix A, page A-11)

a plumbing leak. The thrusters have dual seat and dual coil valves and are not isolated. Redundancies are not provided in the AP subsystem.

The total impulse was obtained from the SDCM program which computes the torques from aerodynamics, solar radiation, and gravity gradient disturbances. The 0.44N thrusters are to provide the fine pointing for roll-yaw correction, and the 4.4N thrusters are to provide pitch, roll, and yaw torques and velocity correction.

The functional diagram of the AP is shown in Figure 4.5.1. The candidate units for each component are listed in Table 4.5.1, and the selected components with the selection rationale are shown in Table 4.5.2. All of the AP components will be flight proven. The plumbing and integration, however, will require the usual DDT&E expenditure. The total weight is 15.7 kg (34.6 lb), and the average power is zero.

4.6 ELECTRICAL POWER

The basic requirements for the EP subsystem were determined from the SDCM computer program. The SDCM selects components from the data base and scans the component power, assuming 100 percent duty cycle. The program computes the power in this manner and uses this level as an average load power. The average load power was recomputed using the components selected by the engineers and the estimated duty cycle of each component. The average load power is shown in Table 4.3.1. The required solar area was also recomputed to reflect the reduced average load power and the efficiencies of the selected components. The comparison of the SDCM results and the modified values for duty cycles and efficiencies are as follows:

	SDCM	Modified
Average load power, W	113.2	69.6
BOL power, W	275.7	201.4
EOL power, W	262.0	191.4
Solar array area, $m^2 (ft^2)$	2.58 (27.7)	1.88 (20.3)

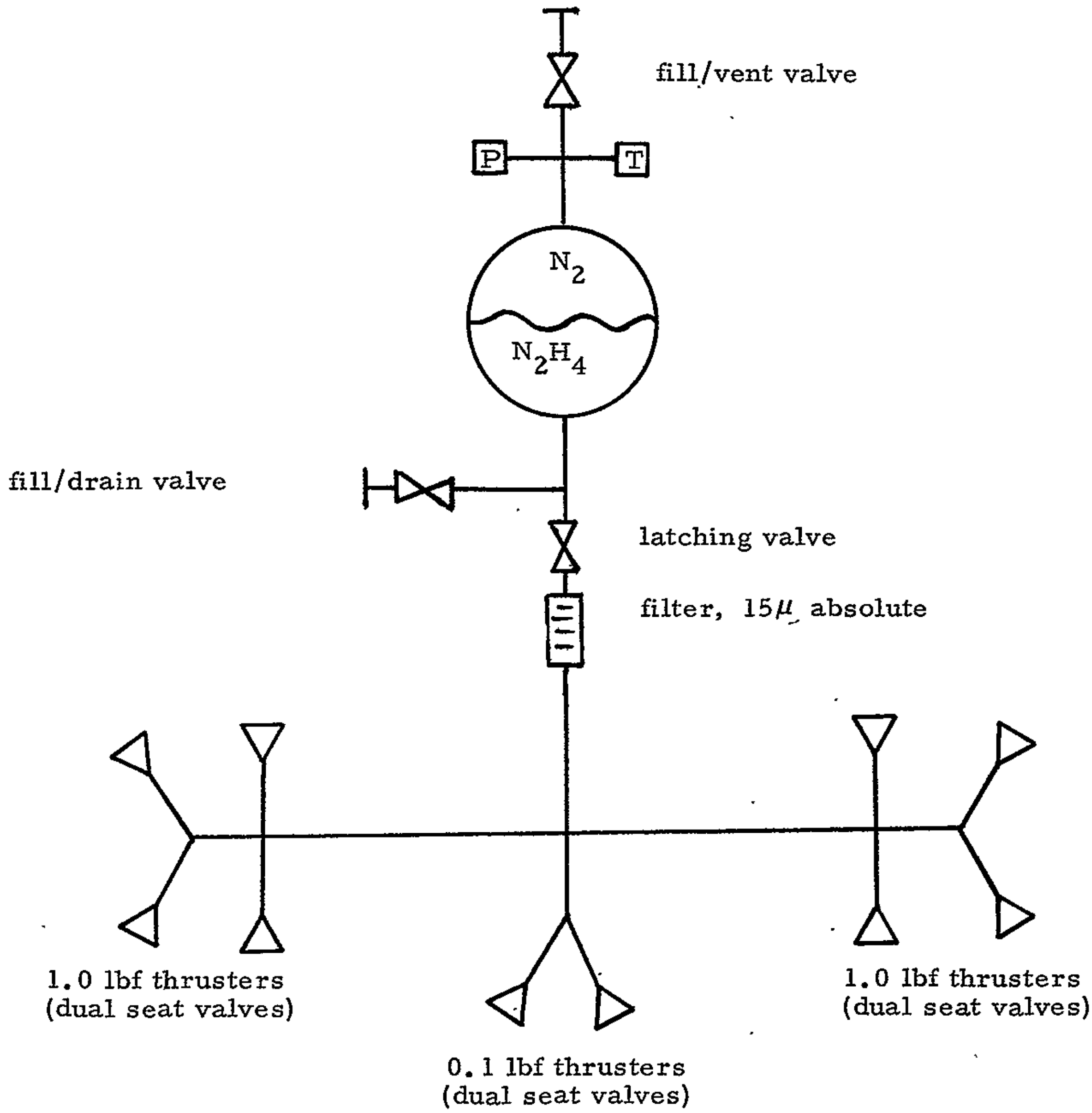


Figure 4.5.1 HCMM Auxiliary Propulsion Subsystem

Table 4.5.1 Candidate AP Components for HCMM

COMPONENT	INDEX NO.	CHARACTERISTICS	WT/COMP. (kg)	NO. REQD.
Tank, hydrazine, diaphragm	D7-2-1	7, 374 cm^3 (450 $in.^3$)	1.6	2
	N6-2-1	38, 100 cm^3 (2325 $in.^3$)	4.6	1
	CTS[a]	17, 700 cm^3 (1080 $in.^3$)	2.5	1
Thruster 1 lbf	N7-2-7	Dual seat valves	0.3	8
	D1-2-3	Dual seat valves (unflown)	0.4	8
Thruster 0.1 lbf	N6-2-2	Single seat valve		2
	D1-2-4	Dual seat valve		2
Filter	N2-2-7	15 micron	0.13	1
	N6-2-4	25 micron	0.05	1
	D1-2-6	10 micron		1
	D5-2-4	15 micron	0.20	1
Isolation Valve	N2-2-3	Non-sliding	0.08	1
	N5-2-4	Non-sliding	0.24	1
	N6-2-3	Sliding solenoid	0.54	1
Fill/drain Valve	N1-2-5		0.11	2
	N2-2-6		0.10	2
	N5-2-5		0.11	2
	N6-2-5		0.13	2
	D1-2-5		0.07	2

[a] Flown on Canadian Technology Satellite, P/N PS1 80187-1.

Table 4.5.2 HCMM AP Components

COMPONENT	INDEX NO.	NO. REQD	TOTAL WEIGHT (kg)	TOTAL WEIGHT (lb)	RATIONALE FOR SELECTION
Tank, hydrazine diaphragm	(developed) [a]	1	2.5	5.5	Min. weight and vol.
Thruster, 1 lbf	N7-2-7	8	2.3	5.1	Unit flight proven
Thruster, 0.1 lbf	D1-2-4	2	0.6	1.3	Dual seat valve
Isolation valves latching	N2-2-3	1	0.1	0.2	Min. weight and non-sliding configuration
Filter	N2-2-7	1	0.1	0.2	Min. weight and filter rating
Fill/vent valve	D1-2-5	2	0.1	0.3	Min. weight
Temp. trans.	---	1	0.1	0.2	
Press. trans.	---	1	0.1	0.2	
Plumbing	---	2 m	0.6	1.3	
Dry Weight			6.5	14.3	
Hydrazine [b]			9.2	20.3	
Wet Weight			15.7	34.6	

[a] Tank developed for Canadian Technology Satellite by PSI

[b] Required hydrazine has been increased to 11.6 kg (25.6 lb) because of required increase in total impulse. It is proposed that this increase be accommodated by reducing ullage volume in the tank.

The solar area requirements were computed for sun-oriented flat panel configuration.

The voltage control specified in Reference 11 is 28V ± 2 percent. The EP configuration that would be simple and meet the voltage requirement is the series load regulator. As an alternative configuration, the shunt and discharge voltage regulator has been included to examine the effects of providing a more efficient power control but less voltage control. The alternate configuration provides 27V ± 6%. The functional block diagrams of these concepts are shown in Figures 4.6.1 and 4.6.2. The components that have been selected for the two configurations are listed in Table 4.6.1. The series load regulator configuration weight is 30.5 kg (67.1 lb) and the alternate configuration is 31.3 kg (68.6 lb).

4.6.1 Power Converter

The requirements of the power converter and the characteristics of the candidate units are as follows:

Parameter	Requirements	Candidates		
		D1-3-4	N1-3-3	N6-3-1
Input voltage, V	20 to 60	20 to 70	23 to 33	30.5 ± 0.6
Output voltage, V	28 ± 2%	28 ± 1%	32 ± 1	28.0 ± 1.6%
Output power, W	70	75	60	150
Efficiency, %	80	71		
Design life, yr	1	5	1	2
Special design	Current limiting and fault protection	Commandable triple section	Commandable redundant section	Part of power regulator unit
Weight, kg(lb)	5.5 (12.1)	5.5 (12.1)	3.2 (7.0)	na

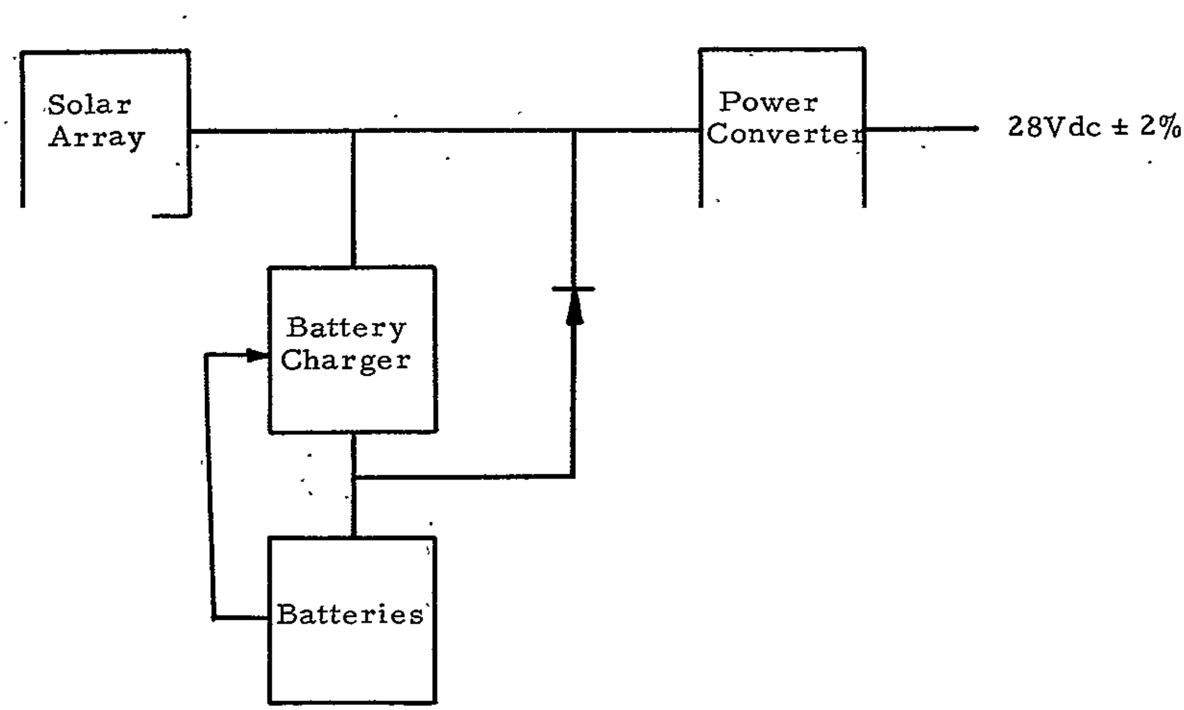


Figure 4.6.1 Series Load Regulator Configuration

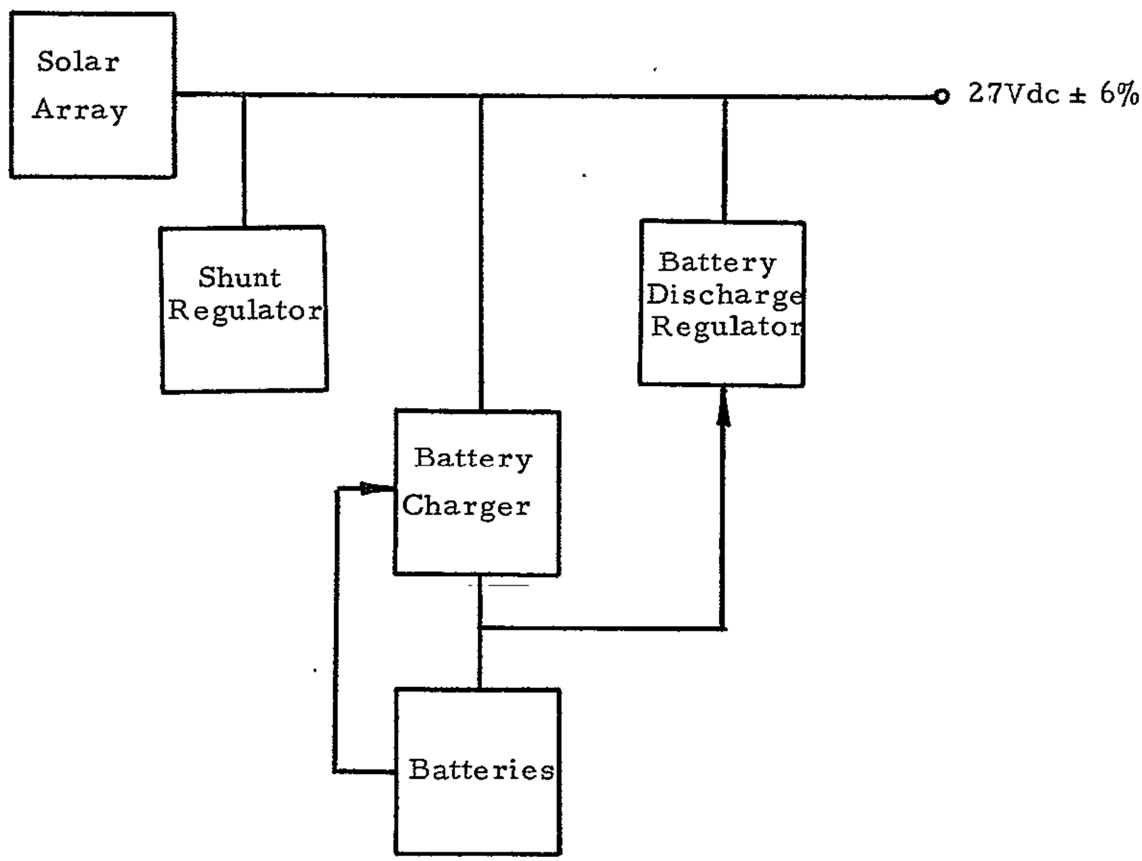


Figure 4.6.2 Shunt and Discharge Voltage Regulator Configuration

Table 4.6.1 Electrical Power Subsystem Component Listing

COMPONENTS	NO. REQD.	INDEX NO.	WEIGHT (kg)	WEIGHT (lb)
Series Load Regulator (28V ± 2%)				
Power Converter	1[a]	D1-3-4	2.2	4.9
Battery Charger	2	(nh)	2.4	5.2
Battery	2	N5-3-4	6.8	15.0
Solar Array (21.6 ft^2)	2	N3-3-1[b]	14.1	31.0
Harness			5.0	11.0
			30.5	67.1
Discharge Voltage Reg-Alt (27V ± 6%)				
Shunt Regulator	2	D4-3-1	1.2	2.8
Discharge Regulator	1	D2-3-2	4.5	9.8
Battery Charger	2	(nh)	2.4	5.2
Battery	2	N5-3-4	6.8	15.0
Solar Array (17.3 ft^2)	2	N3-3-1[c]	11.2	24.8
Harness			5.0	11.0
			31.1	68.6

[a] Remove two of the three sections in this unit.

[b] SAS-C array panel modified by adding two panel segments to each solar wing for a total of five segments/solar wing

[c] SAS-C array panel modified by adding one panel segment to each solar wing for a total of four segments/solar wing.

The prime candidate is the first unit (D1-3-4) since it will operate over the wide input range and provide the desired output voltage. Each unit contains three 75-Watt sections that can operate in parallel. Since weight is critical, two sections should be removed. This should reduce the weight to about 2.2 kg (4.9 lb). The modification to remove two sections is estimated to be about 20 percent of the DDT&E.

4.6.2 Battery Charger

The requirements of the battery charger for the series load regulator, and shunt and discharge regulator configurations are as follows:

Parameter	Series Load Regulator	Discharge Regulator
Type	Current and voltage limited with trickle standby	Same
Input Voltage	20 to 60 V	20 to 28.56 V
Maximum Charge Current	2A	Same
Charge Voltage Limit	Temp. linearly decreasing from 30V at 272K to 22V at 305K	Same
Trickle Current	0.1A	Same
Special Design	Automatic switch from maximum charge rate to trickle rate upon reaching charge voltage limit. Automatic cutoff for battery temperature is greater than 308K.	Command charger "off" when discharge regulator is delivering battery power

There is no battery charger in the catalog that will provide either of the desired control functions. The chargers will require new development.

4.6.3 Battery

The requirements for the battery and the characteristics of the candidate units were determined from the SDCM computer program and modified to reflect the reduction in average load power when duty cycle and selected components are considered.

	SDCM	Modified	
	Discharge Req.	Series Load Req.	Discharge Reg.
Average Load Power, W	113.2	69.6	69.6
Total Capacity Req'd, A-hr	8.8	6.4	5.4
Number of Cells	17	20	17
Number of Batteries	2		

The candidate batteries are as follows:

Parameters	Candidates		
	N5-3-4	N4-3-4	N7-3-2
Capacity/Battery, A-hr	3	6	4.5
Number of Cells	20	23	23
Weight/Battery, kg (lb)	3.4 (7.5)	6.1 (13.4)	7.0 (15.5)

For the series load regulator configuration, two N5-3-4 batteries should provide the best power storage since they meet the cell requirements. Although their capacity is marginal, the actual capacity available from NiCd batteries is generally 1.15 times greater than the manufacturers rated capacity.

For the shunt and discharge voltage regulator configuration, two N5-3-4 batteries are also the best candidates. To meet the required cells, the battery must be modified by shorting 3 of the 20 cells to provide a 17-cell battery.

4.6.4 Solar Array

The solar array requirements for the series load regulator, and shunt and discharge voltage regulator configuration are as follows:

Parameters	SDCM		Modified	
	Series Load	Discharge Voltage	Series Load	Discharge Voltage
Average Load Power, W	113.2	113.2	69.6	69.6
BOL Power, W	275.6	275.6	201.4	166.3
EVL Power, W	262.0	262:0	191.4	158.0
Solar Array Area, m^2 (ft^2)	2.58 (27.7)	2.58 (27.7)	1.88 (20.3)	1.59 (17.1)
Number of Array segments (2.16 ft^2/seg.)	14	14	10	8

A sun-oriented solar array based on the SAS-C panel segments were selected because the panel segments appear to be additive to provide adequate area. With a sun-synchronous orbit, an oriented array would be very efficient. Results of a previous study (Ref. 12) showed that when both thermal and sun angle effects are accounted for, the average power output of a sun-oriented array is 1.43 larger than the average power output of a fixed array on an earth-pointing satellite of the same area. In addition to increases in array area for fixed array, the battery charging requirements would also increase causing further increase in array area. The larger area will increase the weight and volume.

The types of modifications for the SAS-C panels are to add array segments to mount cells on only one side and to provide array drive mechanism. These modifications would be considered major and are estimated to be about 75 percent of a new solar array development.

4.6.5 Shunt Regulator

The requirements of the shunt regulator and the characteristics of the candidate units are as follows:

Parameters	Requirements	Candidates		
		D2-3-1	D4-3-1	N1-3-1
Input Voltage, V	20 to 60 (unregulated)	30 (reg. max)	31.4 (reg. max)	33 (req. max)
Power Dissipation, W	132	110	100	66
Limiting Voltage, V	28.6	30	27.2 to 31.2	32.8
Weight/Unit, kg (lb)	Low	0.5(1.2)	0.6(1.4)	0.4(0.9)
Design Features		Self Driven	Self Driven Adj. volt limit	Self Driven

This unit is used in the shunt and discharge voltage regulator configuration. The prime candidate is the second unit (D4-3-1) since it is self-driven and the voltage limit is adjustable in 0.5V increments, so that a limit of 28.2 ± 0.2V can be obtained. The other candidates do not provide the desired voltage control.

4.6.6 Discharge Regulator

The requirements of the discharge regulator and the characteristics of the candidate unit are as follows:

Parameters	Requirements	Candidate D2-3-2
Type	Boost pulse width regulator	Same
Input Voltage, V	22 to 29.5	19.1 to 26
Output Voltage, Minimum, V	27.44	26.25 ± 1
Output Power, W	69.6	341
Efficiency	90% at maximum load	80 to 90%
Design Feature	Current limiting fault protection. Signal to turn "off" battery charger when regulator is delivering battery power.	No current limiting. Current discharge output available.

The unit is used for the shunt and discharge voltage regulator configuration. This is the only candidate in the catalog, and the unit does not meet the requirement. Since this is the only available candidate, this unit determines the minimum voltage limit of the configuration which is 25.25V. The unit does not provide current limiting fault protection. This feature is desirable but not required.

4.7 COMMUNICATION AND DATA HANDLING

The HCMM communication link is the STDN network, i.e., TDRS is not planned to be used for this mission. The description of the STDN has been obtained from the 1974 User's Guide (Ref. 7). The basic requirements for CDH were obtained from References 10, 11, and 13 and are summarized as follows:

Commands

Frequency:	149 MHz
Modulation:	PCM/FSK/AM/AM
Real-time Commands:	112 (56 for instrument plus 56 for housekeeping)
Stored Commands:	256
Storage Time:	2 hours
EIRP (uplink):	-74 dBm (includes space loss)

Tracking

Frequency:	136 MHz

Interferometer system using the VHF telemetry link.

Telemetry

VHF link (instrument and housekeeping data)

Frequency:	136 MHz
Modulation:	PCM/PM
Bit Rate:	1200 bps
EIRP:	+14 dBm

S-Band link (all mux. and encoding performed in Instrument Module).

Frequency:	2.2 to 2.3 GHz
Modulation:	PM
Three Subcarriers:	2 subcarriers for instrument video 1 subcarrier for 1000 bps hskg data
EIRP:	+29 dBm

The CDH subsystem functional diagram is shown in Figure 4.7.1 and the list of candidate components that have been selected or that are representative candidates from the catalog is shown in Table 4.7.1. In a few instances a selection could not be made because adequate component data were not available, and only a representative component was selected assuming one of the candidates can meet the requirements.

The instrument video data for the S-band transmitter are assumed to be multiplexed and encoded in the instrument module. The downlink VHF link transmits the housekeeping and instrument status data at a data rate of 1200 bps. The tracking is provided by the VHF interferometer system which uses the VHF transmission link. The command messages are in binary form which eliminates signal conditioning in the CDH. The CDH total weight is 12.3 kg (27.1 lb) and the average power is 19.6 W.

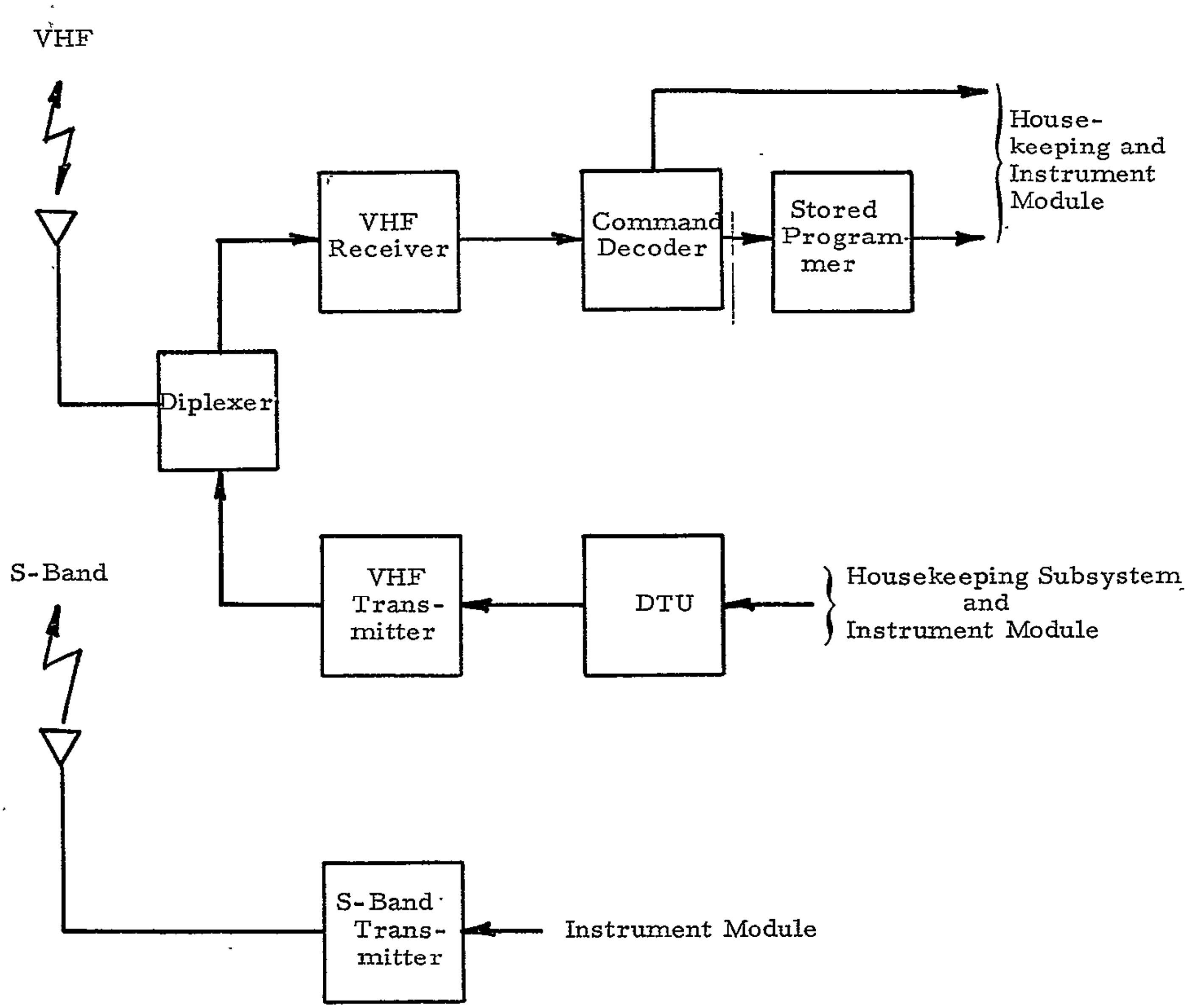


Figure 4.7.1 Communication and Data Handling, Block Diagram

Table 4.7.1 HCMM Communication and Data Handling Weight and Power

COMPONENTS	No. Req.	INDEX No.	WEIGHT (kg)	WEIGHT lb	POWER OPERATE W	POWER OPERATE Duty	POWER STANDBY W	POWER STANDBY Duty	POWER TOT. PWR W
Communication[a]									
VHF Antenna	1	N1-4-11	0.8	1.8	0		0		0
VHF Transmitter	1	N1-4-3	0.5	1.2	4.4	100%	0		4.4
VHF Diplexer	1	N5-4-3	0.7	1.5	0		0		0
VHF Receiver	1	N6-4-7	0.6	1.3	0.5	100%	0		0.5
S-Band Antenna	1	D4-4-4	0.4	0.8	0		0		0
S-Band Transmitter	1	D1-4-3	2.1	4.7	18.2	20%	0		4.0
Subtotal			5.1	11.3					8.9
Data Handling									
Command Decoder	1	D3-4-5	1.9	4.2	6.0	20%	0.8	80%	1.8
Stored Programmer	1	D1-4-6[b]	2.3	5.1	5.7	50%	0		2.9
Digital TM Unit	1	(nh)[c]	1.8	4.0	6.0	100%	0		6.0
Subtotal			6.0	13.3					10.7
Total			11.1	24.6					19.6

[a] See Page 45 in Ref. 11 for duty cycle

[b] Major modification required

[c] Estimated values

4.7.1 VHF Antenna

The desired characteristics of the VHF antenna and the characteristics of the candidate components are as follows:

Parameters	Desired Characteristics	Candidate (N1-4-11)
EIRP		
Transmit	+14 dBm	
Receive	-74 dBm	
Gain		
Transmit		- 6 dBm
Receive		-13 dBm
Coverage	4π steradian	97% minimum 4π steradian
Frequency		
Transmit	136 MHz	136.92 MHz
Receive	149 MHz	149.52 MHz
Polarization	Circular	Circular

The candidate meets the required characteristics without modification. There are two other candidates but they do not match the requirements as well. The selected unit was used on OSO-I.

4.7.2 VHF Transmitter

The desired characteristics of the VHF transmitter and the characteristics of the candidate units are as follows:

Parameters	Desired Characteristics	Candidates		
		N1-4-3	N2-4-3	N3-4-2
Frequency, MHz	136	136	137	136.68
Output Power, W	0.5 to 1	1	1 to 3	0.25 to 1.5
Modulation	Phase	Phase	Phase	Phase
Frequency Stab.	±0.0025%	±0.0015%	±0.0037%	±0.001%
Frequency Acc.	±0.001	ns	ns	ns
Carrier Phase Instability	<0.05 rad rms	ns	≤0.35 rad	ns
Modulation Deviation	1.1 rad	0.8 to 1.5 rad	1.25 rad	0.80 rad
Deviation Linearity	±10% 0 to 1 rad	ns	ns	<1%
Deviation Response Amp.	± 10% 100 Hz to 10 kHz	ns	ns	ns
Deviation Stability	±10% over temp range	50.05 rad	ns	ns
Noise, Harmonics and Spurious Emission	< 60 dB	ns	< 60 dB	< 60 dB
Weight, kg	Low	1.68		0.74
Power, W	Low	4.4		6.2

With the available information, the N1-4-3 appears to best meet the required characteristics. The unit should be applicable with only minor modifications.

4.7.3 VHF Diplexer

The desired characteristics of the VHF diplexer and the characteristics of the candidate units are as follows:

Parameters	Desired Characteristics	Candidates		
		N5-4-3	N1-4-9	N6-4-4
Frequency				
Transmit, MHz	136	136.38	136.92	136.67
Receive	149	148.56	149.52	151.20
Isolation				
Transmit port to receive port	~ 50 dB	55 dB	60 dB	ns
Insertion Loss				
Transmit chl	≤ 2 dB	0.4 dB	1.5 dB	≤1.0 dB
Receive chl		5.0 dB	1.0 dB	≤1.0 dB
Bandwidth				
Transmit chl	2 MHz	2 MHz	ns	2 MHz
Receive chl	1 MHz	1 MHz	ns	6.6 MHz
Power Rating, W	2	10	2	10
Weight, kg	low	0.7	0.2	0.70

The N5-4-3 unit should be applicable without any modification.

4.7.4 VHF Receiver

The desired characteristics of the VHF receiver and the characteristics of the candidate units are as follows:

Parameters	Desired Characteristics	Candidates		
		N4-4-7	N4-4-1	N3-4-4
Frequency, MHz	148	154.20 148.26±2 kHz	148.56	148.96
Modulation	PCM/FSK/AM/AM	PCM/FSK/ AM/AM	AM	PCM/FSK/ AM/AM
Command Bit Rate	600-1200 bps	ns	ns	64 kbs
Receiver Sensitivity	-105 dBm for BER 10^{-5}	-110 dBm	ns	-95 dBm
Frequency stab.	±0.0025%	±0.0014%	±0.005%	±0.005%
Noise figure	7 db max	ns	≤ 10 db	ns
Preselector Bandwidth	< 4 MHz	ns	20±0.003% MHz	ns
Intermediate Predetection Filter, kHz	50 ± 10	40	48	55±7
Dynamic Range, dBm	-30 to -105	-27 to -110	ns	-95 to -40
Weight, kg	Low	0.6	1.1	0.5
Power, W	Low	0.5	0.4	0.2

The candidate receivers are listed in the order of best meeting the desired characteristics. The amount of modification appears to be in tuning the frequency and electrical connectors.

4.7.5 S-Band Antenna

The desired characteristics of the S-band antenna and the characteristics of the candidate units are as follows:

Parameter	Desired Characteristics	Candidates		
		D4-4-4	D2-4-10	D1-4-7
Frequency, GHz	2.2 to 2.3	2.2 to 2.3	2.2 to 2.3	2.2 to 2.3
Gain, dB	0	0	-0.5	-3
Coverage, deg	150	180	±50	107
Power Rating, W		2.6	2	4
Weight, kg	Low	0.4	0.9	1.2

The D4-4-4 antenna appears to be the best selection because of its low weight and adequate coverage and gain.

4.7.6 S-Band Transmitter

The desired characteristics of the S-band transmitter and the characteristics of the candidate units are as follows:

Parameters	Desired Characteristics	Candidates		
		D1-4-3	D6-4-2	N1-4-2
EIRP	+29 dBm			
Frequency, GHz	2.2 to 2.3	2.2 to 2.3	2.2 to 2.3	2.2 to 2.3
Modulation	PM	PM	PM	PM
Output power, W	1 to 2	2 to 2.8	1	1 to 2
Frequency Stabil.	±0.0025%	±0.003%	ns	±0.002%
Frequency Accur.	±0.001%	ns	ns	ns
Carrier Phase instab.	< 0.05 rad rms	ns	ns	ns
Modulation devi.	0.3VRMS=1rad	1.8 rad	1.5 rad	ns
Devi. linearity	±10% 0 to 1.5rad	ns	±7% @ 1 rad	ns
Deviation stab.	±10%	<3.5 deg	ns	±3 deg
Incidental AM	< 5% @ 1.5 rad	ns	ns	ns
Incidental FM	< 20HZ p to p	ns	ns	ns
Spurious Emission	< 60 dB	60 dB	40 dB	60 dB
Efficiency	High	11%	6.1%	10.5%
Weight	Low	2.1	1.5	1.5

The three listed candidates are listed in the order of preference and they will meet the basic requirements.

4.7.7 Command Decoder and Stored Programmer

The desired characteristics of the command decoder and stored programmer, and the candidate units are as follows:

Parameters	Desired Characteristics	Candidates		
		Decoder		Programmer
		D3-4-5	D6-4-6	N1-4-6
Real-time Commands	112	288	168	
Stored program Commands	256			1360
Stored Command Storage Time	2 hr			2.9 hr
Command message rate	10/sec	~30/sec	~50/sec	
Bit rate, bps	ns	1000	1000	
Word length, bits	ns	33	20	48
Number of Memory Addresses	ns			12
Weight, kg	Low	1.9	2.8	2.3

Additional information is required to make a selection. The units will probably require major modifications for the components to match and be compatible.

4.7.8 Digital Telemetry Unit

The desired characteristics of the DTU are as follows:

a. Bit rates: 1.25, 2.5, 5 kbps; or 1.6, 3.2, 6.4 kbps

b. Bit rate stability: $\pm$ 0.001% over the qual. temp. range

c. Word structure: 8 bits min/word

d. Provide synchronous pattern and subcommutator identification in every minor frame.

e. Convert analog inputs to 8-bit resolution with accuracy better than one half the least significant bit.

f. Dump command memory on command within 100 seconds.

b. Bit rate selection to be by ground command.

In addition to the above listed desired characteristics, information to establish the number of channels is required before the unit can be adequately parametized. However, with the available data it can be determined that the catalog does not contain a DTU that remotely resembles the requirements. A new special design is required or the requirements must be changed to fit existing design, namely the 1.2 kbps transmission bit rate. More common bit rates are 16, 32 (and up) kbps.

5. STRATOSPHERIC AEROSOL AND GAS EXPERIMENT (SAGE)

5.1 MISSION DESCRIPTION

The mission objective of SAGE is to determine the spatial distribution of stratospheric aerosols and ozone on a global scale. The specific objectives are:

a. Locate stratospheric aerosol and ozone sources and sinks.

b. Monitor circulation and transfer phenomena to a limited extent.

c. Observe hemispheric differences.

The satellite orbit is 600 km near circular, 50 deg inclination. Stationkeeping or maneuvers will not be required during the one year mission life. The launch vehicle is the four-stage standard Scout vehicle. The communication link is the STDN network (Reference 10).

5.2 MISSION EQUIPMENT DESCRIPTION

The SAGE mission equipment characteristics and description are as follows:

Weight	26.4 kg (58.2 lb)
Size	40.6 x 40.6 x 67.1 cm (16 x 16 x 24.4 in.)
Power	4 W min., 20 W peak 8 W average 28 Vdc $\pm$ 2%
Pointing Accuracy	3-axis stabilized $\pm$ 0.017 rad ($\pm$ 1 deg) roll and pitch $\pm$ 0.035 rad ($\pm$ 2 deg) yaw axis
Communication	S-band 2.0 to 2.1 GHz range uplink 2.2 to 2.3 GHz downlink PCM/PM modulation
Data Storage	7×10^8 bits 2.56×10^5 bps playback

The mounting and sensor pointing direction of the mission equipment is shown in Figure 5.2.1. A sketch of the equipment is shown in Figure 5.2.2.

5.3 SPACECRAFT DESCRIPTION

The goal in configuring the SAGE spacecraft is to be identical to HCMM. Any subsystem deviations from HCMM configurations are thus limited to meeting the SAGE mission requirements and to reduce the combined HCMM and SAGE program cost. The SAGE mission requirements basically determined the SC and CDH configurations. The SC configuration is the two-scanwheel arrangement of HCMM. The communication portion of the CDH is SAGE unique but the data handling portion uses HCMM components. The EP subsystem considered the same alternative power regulation methods that were studied for HCMM. The SAGE solar arrays are, however, larger than HCMM due to the orientation and orbit of the spacecraft with respect to the sunline during the one year mission lifeline.

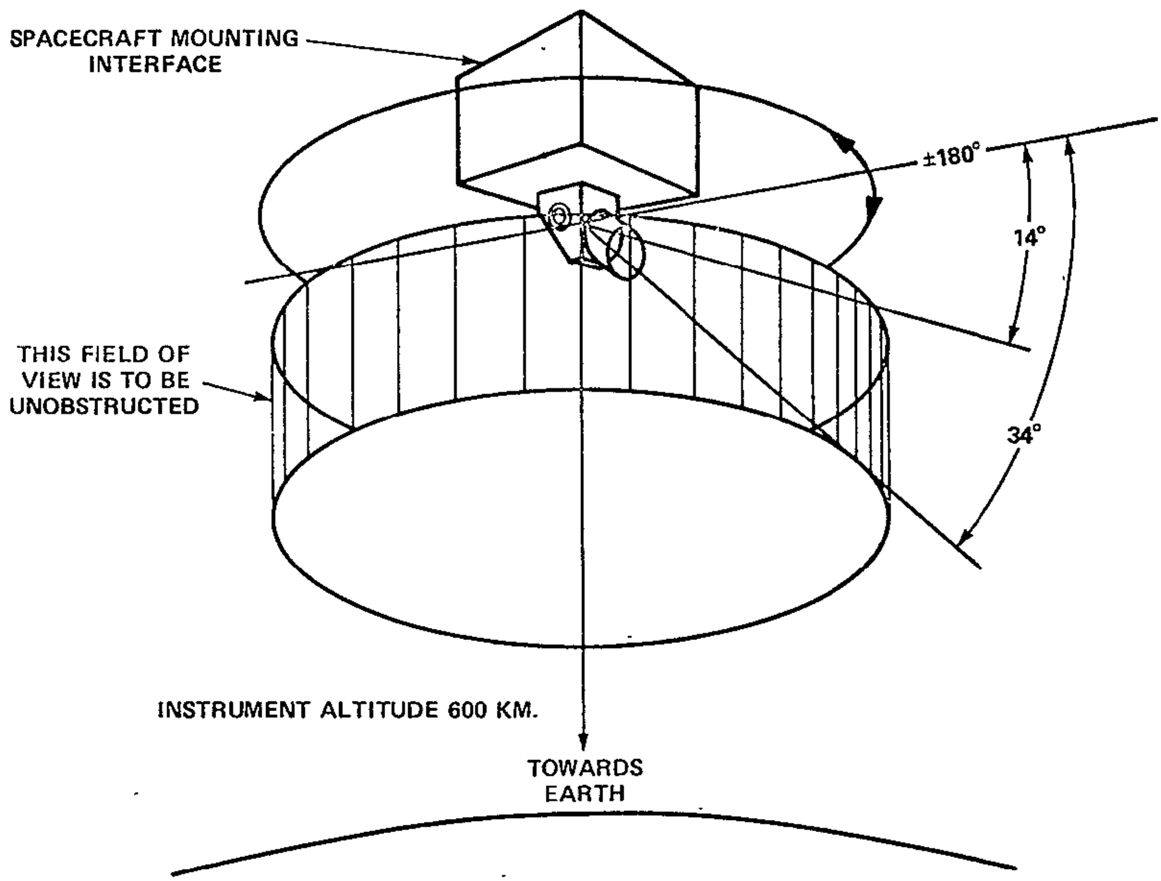


Figure 5.2.1 SAGE Mission Equipment Pointing Direction

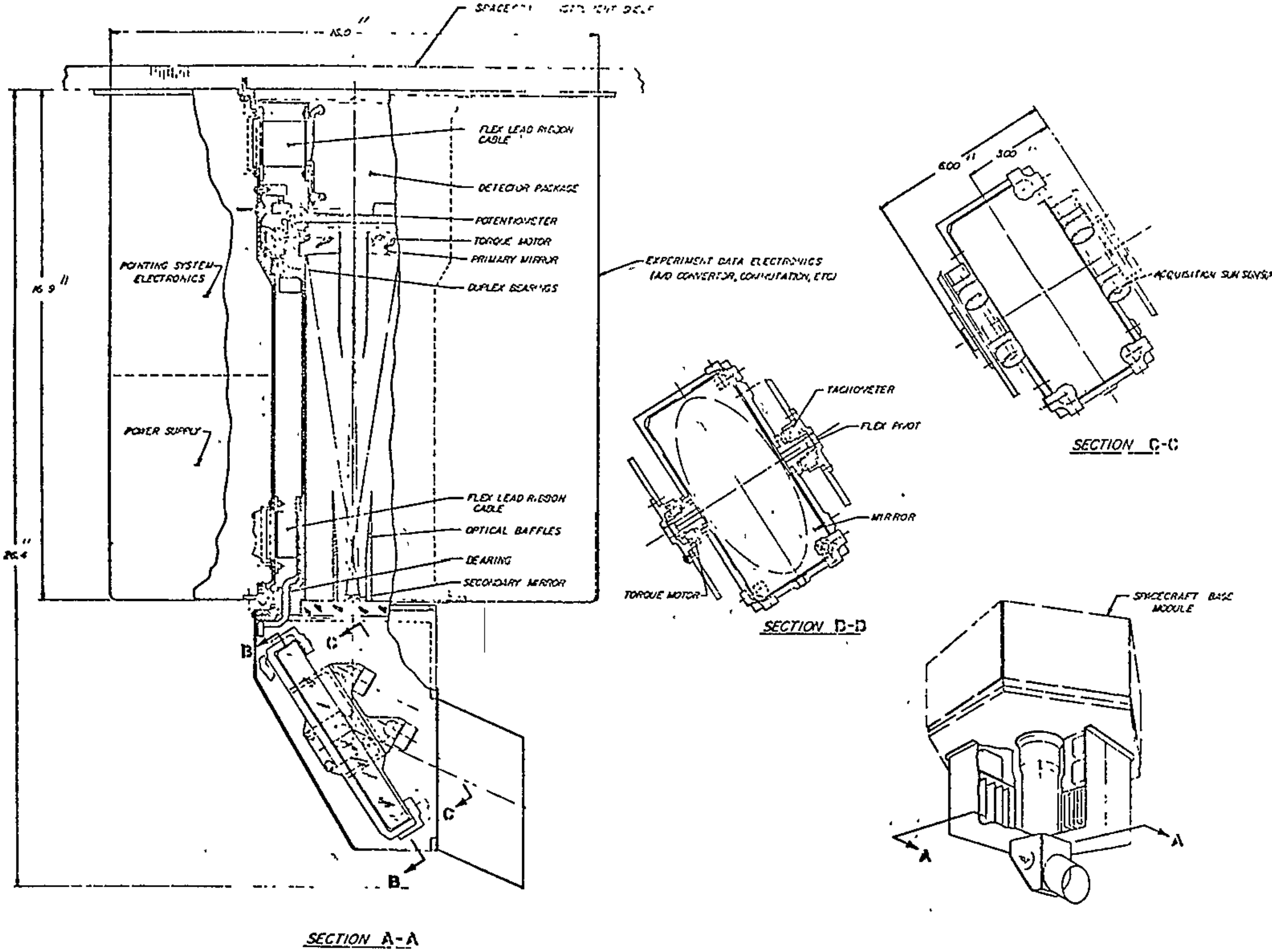


Figure 5.2.2 SAGE Mission Equipment Instrument

The AP subsystem considered three alternatives. They are (1) the HCMM AP, (2) a low weight hydrazine unit that meets SAGE requirements, and (3) a cold gas propellant system. The HCMM unit exceeds SAGE needs by an order of magnitude but is attractive since the development will have been accomplished in the HCMM program. A cold gas propellant system was considered because of its low cost aspects. The various SAGE combinations that were considered are tabulated in Table 5.3.1.

Table 5.3.1 SAGE Configuration Combinations

Title	Subsystem Configuration (program developing subsystem	Total Weight kg	Total Weight lb
1. Low Cost - (Baseline)	SC - SAGE (HCMM) AP - Hydrazine (SAGE) EP - Series Load Reg. (HCMM) CDH - (SAGE)	147.7	325.7
2. Low Cost - AP/Cold Gas	SC - SAGE (HCMM) AP - Cold Gas (SAGE) EP - Series Load Reg. (HCMM) CDH - (SAGE)	161.0	354.9
3. Low Cost - AP/HCMM	SC - SAGE (HCMM) AP - Hydrazine (HCMM) EP - Series Load Reg. (HCMM) CDH - (SAGE)	156.9	346.0
4. Low Cost - EP 2	SC - SAGE (HCMM) AP - Hydrazine (SAGE) EP - Discharge Volt Reg. (HCMM) CDH - (SAGE)	147.5	325.2

The baseline SAGE consists of the HCMM alternative SC, SAGE hydrazine AP, HCMM EP, and SAGE CHD. This configuration provides a margin of 2.7 kg (6 lb) since the total spacecraft weight is estimated at 121.3 kg (see Table 5.3.2) and the allowable spacecraft weight is 124 kg (Reference 11).

Table 5.3.2 SAGE Weight and Average Load Power

Subsystems	Weight		Average Load Power, W
	kg	lb	
Stabilization and Control	34.0	75.1	38.0
Communication and Data Handline	22.3	49.4	27.3
Auxilary Propulsion			
Dry Weight	5.4	11.9	0
Propellant	1.1	2.4	0
Electrical Power	39.9	87.7	0[a]
Structures and Thermal	18.6	41.0	0
Spacecraft Total	121.3	267.5	65.3
Mission Equipment	26.4	58.2	8.0
Satellite Total	147.7	325.7	73.3

[a] Electrical power converter and storage efficiency considered but not included as load power.

For additional weight margin, there are two potential areas that can be changed to reduce the weight. They are the scanwheel assembly and the solar arrays. The selected scanwheel which exceeds the capability can be replaced with a smaller unit that is available on the market. The solar array is another area where weight reduction should be possible if an extensive analysis is conducted to optimize the array arrangement and launch time. The use of fixed arrays as specified in Reference 10 was not analyzed in this study. Only the four-array configuration was considered for the one year mission

5.4 STABILIZATION AND CONTROL

The acquisition mode for HCMM will not work for SAGE orbit, but the SAGE acquisition mode will work for the HCMM orbit. The SAGE orbit results in large variations in sun to spacecraft to earth radii angles. These large angles require a larger FOV earth sensor if the HCMM configuration is to be used. To achieve a large enough FOV to acquire the earth from SAGE orbit using the HCMM configuration, an additional scanwheel must be added. By adding this scanwheel for SAGE orbits the FOV of the earth sensors is increased and the need for body-mounted sun sensors is eliminated. An added benefit with two earth sensors is the independence from altitude variations, i.e., first orbit can be circular or elliptical.

The details of the above discussion are presented in Appendix A. The discussion on the candidate components is presented in Section 4.4 except for the sun sensor and devices associated with the control of the solar arrays. The selected candidates are listed in Table 5.4.1 and the functional diagram is shown in Figure 4.4.3.

The listed scanwheel is sized for HCMM requirements. This unit can be replaced with a smaller unit because of the lower disturbance for SAGE. The use of available smaller units which are not included in the catalog can reduce the spacecraft weight by approximately 6 kg. This study did not incorporate the smaller unit since the goal is to select cataloged components.

Table 5.4.1 SAGE Stabilization and Control Subsystem, Component Listing

COMPONENTS	No. Rq'd.	Index No.	Weight		POWER				
					Operate		Standby		Tot. Pwr.
			kg	lb	W	Duty	W	Duty	W
Scanwheel Assembly	2	D3-1-1	13.2	29.2	8	100%			8
Rate Gyro Assembly	1	(nh)[a]	0.9	2.0	8	b	0	b	0
Sun Sensor	1	N5-1-1	0.1	0.3	0.03	100%	0		0
Wide Angle Sun Sensor	4	Developed[a]	0.3	0.6	0				
Solar Array Dr. Mtr.	4	(nh)[a]	10.9	24.0	0				
Solar Array Dr. Elect.	2	(nh)[a]	2.3	5.0	20	100%	0		20
Control Elect. Assembly	1	(nh)	5.4	12.0	10	100%	0		10
Valve Driver	1	(nh)[a]	0.9	2.0	0		0		
Total			34.1	75.1					38

[a] Same as HCMM (no development).

[b] Operates only during acquisition mode.

The controls portion of HCMM and SAGE can be identical; however, the solar array drive electronic portion of SC will differ if oriented arrays are selected. Analysis to determine a satisfactory concept is necessary, as discussed in the EP section (5.6). A tradeoff analysis of fixed versus oriented arrays and optimization of oriented arrays are suggested before the solar array electronic drive characteristics are defined. For this portion, the study assumed that four solar array drive motors and electronics are required.

5.4.1 Sun Sensor

The HCMM and SAGE missions have a requirement to telemeter the spin rate of the fourth stage. This requirement was met for HCMM by the coarse sun sensors which provided information on the sun-line angle about the spacecraft axis and the spin rate. Since the need is to supply only the spin rate for SAGE, a single sun sensor with a wide FOV is all that is required. The requirements and the characteristics of the candidate unit are as follows:

Candidate	Requirement	Candidate (N5-1-1)
Spin rate	90 ± 0.5 rpm	50 to 110 rpm 0.03 rad (2 deg) accuracy
FOV	As wide as practical	3 rad (174 deg)
Design life	1 year	5 years

The candidate sensor outputs can be used to drive a timing pulse whenever the sun crosses a selected spacecraft plane containing the spin axis. The sensor should be applicable without any modification.

5.5 AUXILIARY PROPULSION

The SAGE auxiliary propulsion subsystem requirements differ from HCMM because SAGE has less instrument disturbance torque and does not require ΔV corrections to maintain sun synchronous orbit which results in less total impulse and two less thrusters. With the lower total impulse, the inherently more reliable and lower cost cold gas propellant systems may be a suitable application. The requirements of the SAGE auxiliary propulsion are as follows:

Parameters	Requirements
Total Impulse	1855 Ns (417 lb-s)* + 10%
Thrust Levels	Six 2.22 N (0.5 lbf) thrusters Two 0.44 N (0.1 lbf) thrusters
Life	One year, 50,000 pulses
Reliabilities	No single point failure mode

A cold gas propellant and a hydrazine system were configured to meet the above requirements.

The cold gas propellant system is shown in Figure 5.5.1. The tank can be isolated in the event of a plumbing leak. The candidate components are listed in Table 5.5.1. The selected thrusters have redundant series and soft-seat valves, and are not isolated. A backup pressure regulator is provided in the event the primary regulator fails closed or can be detected open before the downstream thrusters are damaged.

The selected tank which is the closest to meeting the requirements is oversized for the required impulse. The tanks can be off-loaded to 2069 N/cm^2 (3000 psia). The pressure regulators will have to be reset to 21 N/cm^2 (30 psig) pressure. All of the candidate components were selected from the catalog on the basis of minimum weight except for

*Reference Appendix A.

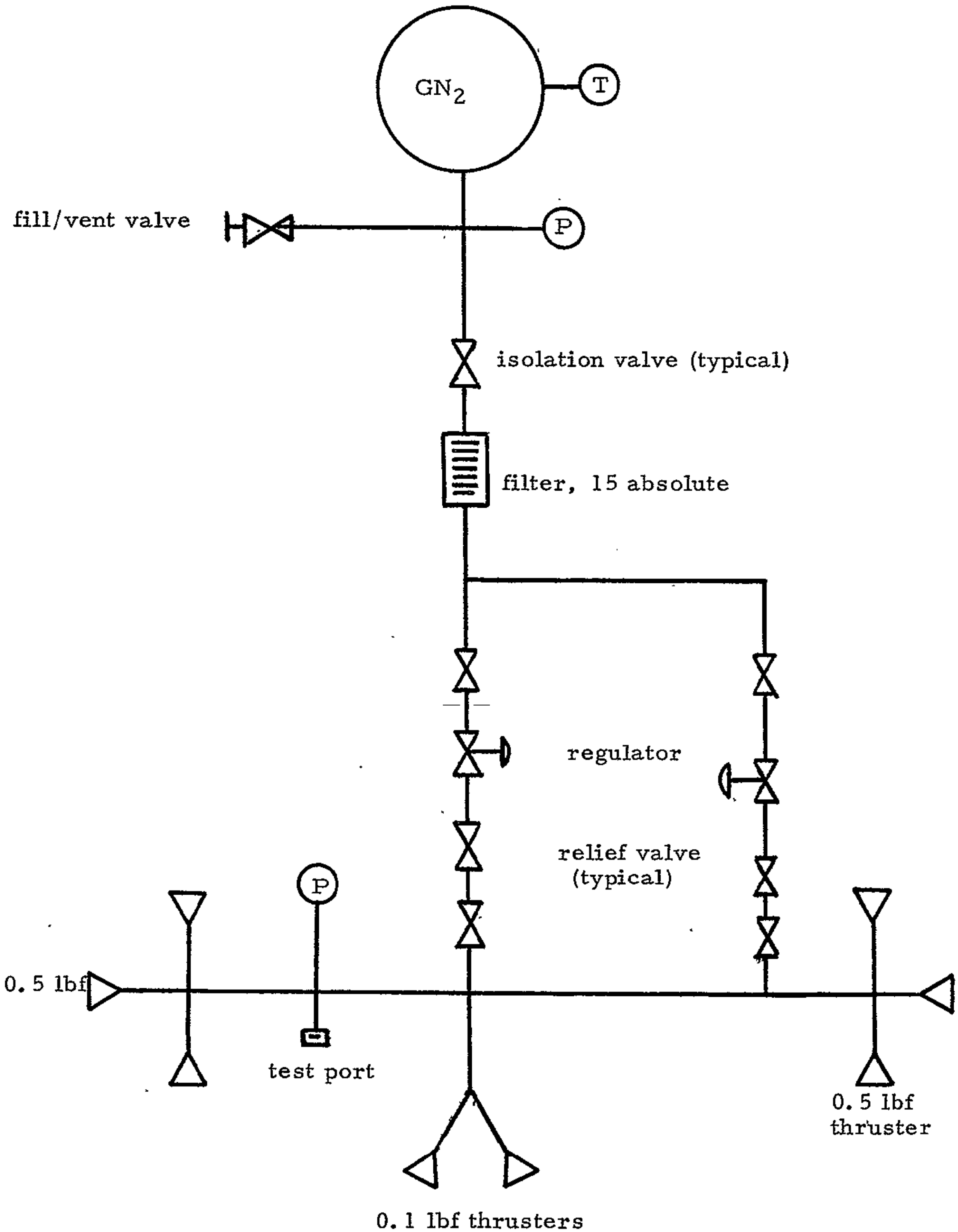


Figure 5.5.1 AP Cold Gas Propellant Schematic Diagram for SAGE

the thrusters and regulators. The selection of the thrusters was based on dual seat arrangement and regulators were based on minimum change in set point (see Table 5.5.2).

The hydrazine system components are listed in Table 5.5.3. These components are described in Section 4.5. The selected tank is smaller than the candidate unit for HCMM but still oversized for SAGE. Larger tanks will provide ullage volume which should provide less change in thrust level for the blowdown pressurization system. The total wet weight of the hydrazine system is substantially lower than the cold gas propellant system. Because of the weight reduction, the hydrazine system is selected as the baseline AP.

5.5.1 Candidate Components for AP

Components	Index No.	Remarks
0.5 lbf thrusters	N1-2-1 N7-2-5 N7-2-3	0.5 kg 0.3 kg, dual seat 0.2 kg
0.1 lbf thrusters	D3-2-4	0.4 kg, dual seat
Isolation Valve	N1-2-4 D3-2-8	0.7 kg 1.1 kg
Filter, (15 μ absolute)	N1-2-6 N2-2-7 N7-2-3 D8-2-6	10 μ, 0.14 kg 15 μ, 0.13 kg 10 μ, 15 μ, 0.16 kg
Pressure Reg. (100 psig)	N1-2-3 N7-2-4 D3-2-5	152 N/cm^2(220 psig) set point, 0.55 kg 10 to 26 N/cm^2(0 to 40 psig) set point, 0.59 kg 138 N/cm^2(200 psig) set point, 1.96 kg
Tank, 8244 cm^3 (503 in^3) 2069 N/cm^2 (3000 psia)	N1-2-2 D3-2-1	15,652 cm^3 (955 in^3) @ 2482 N/cm^2 (3600 psia), 5.22 kg 14,522 cm^3(886 in^2) @ 3172 N/cm^2 (4600 psia), 7.26 kg
Fill/Vent Valve	N7-2-9 N7-2-2 D3-2-7	2482 N/cm^2(3600 psig), 0.13 kg 1793 N/cm^2(2600 psig), 0.18 kg 3172 N/cm^2(4600 psig), 0.07 kg

Table 5.5.2 SAGE Auxiliary Propulsion, Cold Gas Propellant

Component	No. Rq'd.	Index No.	Weight	
			kg	lb
0.5 lbf thruster	6	N7-2-5	1.9	4.2
0.1 lbf thruster	2	D3-2-4	0.7	1.6
Isolation Valve	5	N1-2-4	3.4	7.5
Filter	1	N2-2-7	0.1	0.3
Regulator	2	N7-2-4	1.2	2.6
Tank	1	N1-2-2	5.2	11.5
Fill/Vent Valve	1	D3-2-7	0.1	0.2
Relief Valve	2		0.2	0.4
Temp. Transducer	1		0.1	0.2
Pres. Transducer	2		0.2	0.4
Tubing	2 m		0.6	1.4
Dry Weight			13.7	30.3
Nitrogen			1.9	4.2
Wet Weight			15.6	34.5

Table 5.5.3 SAGE Auxiliary Propulsion, Hydrazine

Component	No. Rq'd.	Index No.	Weight	
			kg	lb
Tank	1	D7-2-1	1.58	3.5
Thrusters				
(1 lbf)	6	N7-2-7	1.71	3.8
(0.1 lbf)	2	D1-2-4	0.64	1.4
Valve, Latching	1	N2-2-3	0.08	0.2
Filter	1	N2-2-7	0.13	0.3
Valve, Fill & Vent	2	D1-2-5	0.14	0.3
Transducers	2		0.18	0.4
Plumbing	3 m		0.64	2.0
Dry Weight			5.4	11.9
Hydrazine & Nitrogen			1.1	2.4
Wet Weight			6.5	14.3

5.6 ELECTRICAL POWER

The SAGE power subsystem is basically the same as HCMM except for the solar array. The average load powers for HCMM and SAGE are 69.6 and 73.3W, and the bus voltages are identical. The two oriented solar arrays are efficient for the HCMM sun synchronous orbit; however, SAGE requires additional arrays to provide adequate power during the one year of flight operations. The range of sun angle during the four seasons is illustrated in Figure 5.6.1. The sunline can range from 0 to 73 deg from the roll axis. The angle is dependent on the time of launch and the time of year. From the range of the sunline, it is apparent that three or four arrays will be required for SAGE. To determine the optimum arrangements and area, a tradeoff analysis is necessary; however, for this study, four arrays will be used where the area of the second pair is 75 percent of the area of the HCMM solar arrays. The four arrays are assumed to be programmable to provide the required orientation for one year.

The lists of components for the series load regulator and discharge voltage regulator configurations are shown in Tables 5.6.1 and 5.6.2. The functional diagrams of the two candidates are shown in Figures 4.6.1 and 4.6.2.

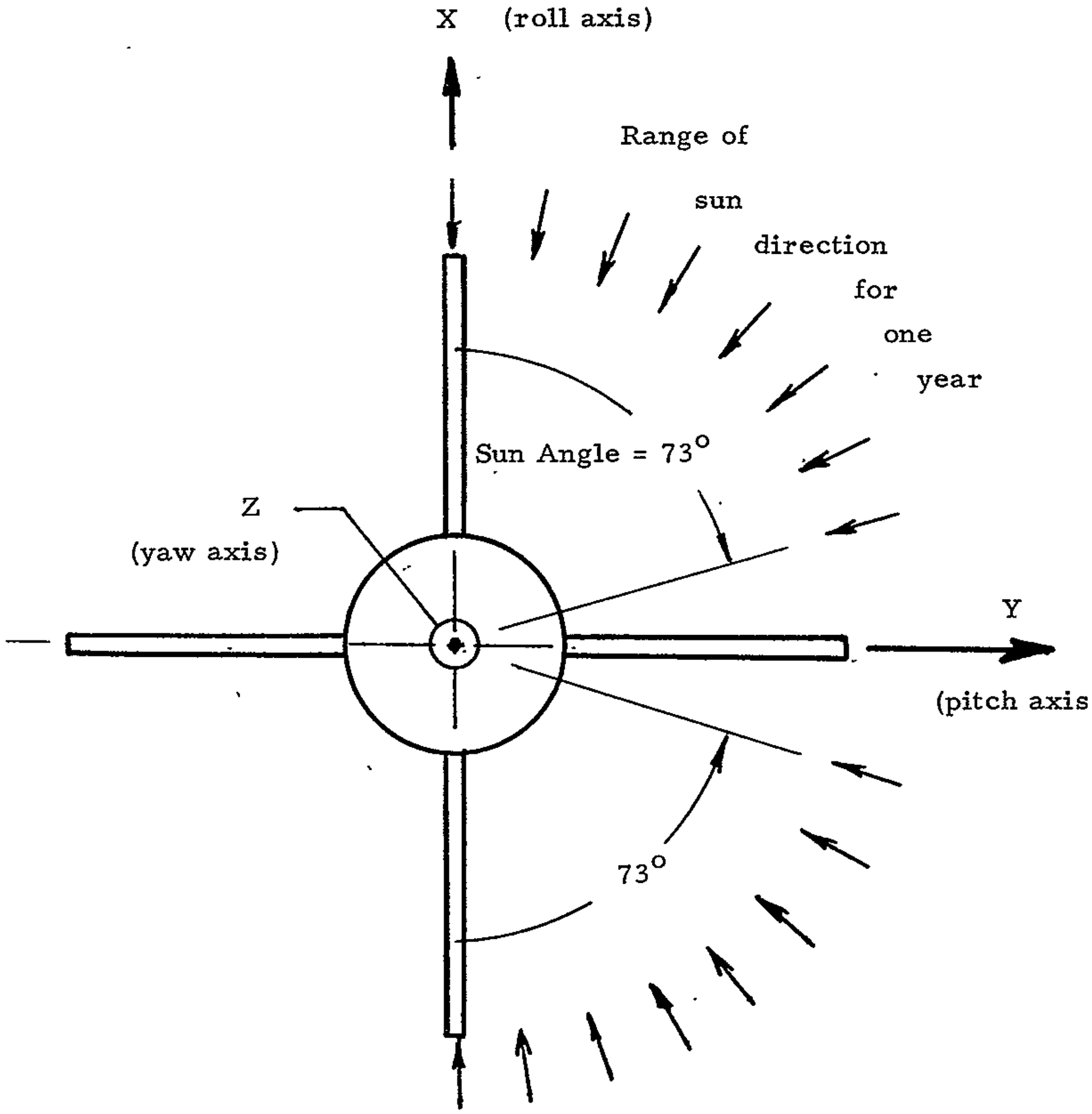


Figure 5.6.1 SAGE Range of Sun Direction Over One Year

Table 5.6.1 SAGE Electrical Power Component Listing, Series Load Regulator Configuration

COMPONENTS	No. Rq'd.	Index No	Weight	
			kg	lb
Power Converters	1[a]	D1-3-4	2.2	4.9
Battery Charger	2	(nh)	2.4	5.2
Batteries	2	N5-3-4	6.8	15.0
Solar Array (~36 ft^2)[b]	4	N3-3-1	23.5	51.6
Harness			5.0	11.0
TOTAL EP WEIGHT			39.9	87.7

[a] Remove two of the three modules in this unit.

[b] SAS-C array panels modified by adding segments.

Table 5.6.2 SAGE Electrical Power Component Listing, Shunt and Discharge Voltage Regulator Configuration

COMPONENTS	No. Rq'd.	Index No.	Weight	
			kg	lb
Shunt Regulator	2	D4-3-1	1.2	2.8
Discharge Regulator	1	D2-3-2	4.5	9.8
Battery Charger	2	(nh)	2.4	5.2
Batteries	2	N5-3-4	6.8	15.0
Solar Array (~30.3 ft^2)	4	N3-3-1	19.7	43.4
Harness		N3-3-1	5.0	11.0
TOTAL EP WEIGHT			39.6	87.2

5.7 COMMUNICATION AND DATA HANDLING

Although the SAGE communications and data handling subsystem utilizes the STDN network and the spacecraft is the same as HCMM in many areas, the transmission links for command, tracking and telemetry are not the same as HCMM. The HCMM transmission frequencies are basically a combination of VHF and S-band, and SAGE uses only S-band frequencies. A comparison of the basic communication links between HCMM and SAGE are as follows:

Items	HCMM	SAGE
Command	VHF/2 hr	S-band/24 hr memory
Tracking	VHF	S-band
Housekeeping	VHF and S-band	S-band
Mission Data	S-band real-time	S-band, playback

The general requirements of the SAGE CDH which are itemized in Table 5.7.1 were obtained from References 9, 10, and 11. The transmission links are all on STDN S-band and not planned to interface with the TDRS. The information concerning STDN was obtained from the User's Guide, baseline document (Reference 7). The CDH configuration that meets the general requirements is shown in Figure 5.7.1. The candidate components along with the quantity, weight, and power are listed in Table 5.7.2.

The communication configuration is a unified link with common antenna and a separate downlink. The baseband assembly unit (BAU) modulates the housekeeping data from the digital telemetry unit on a subcarrier and combines this subcarrier with a PRN ranging code from the S-band receiver. The low data rate transmitter modulates the housekeeping data, amplifies the power to required levels, and accepts ranging code and driver signals for coherent operations. The hi data rate transmitter dumps the stored mission data once per day at a rate of 256 kbps.

The low data rate is transmitted via omni antenna during ascent and early stabilization period. Once the spacecraft is stabilized, the low data rate is switched over to the hemispherical antenna. The high data rate uses the hemispherical antenna at all times.

Table 5.7.1 SAGE Communication General Requirements

Parameters	Requirements
Command	
Real time	112
Stored	256
Time to execute	24 hr
Command bit rate	10 commands/sec
EIRP	-74 dBm
Frequency (uplink)	2.09 to 2.12 GHz
Tracking	PRN ranging and range rates coherent for 2-way Doppler and PRN ranging
Telemetry	
Links	2 downlinks @ 2.2 to 2.3 GHz
Housekeeping and command verification	1200 bps transponder
Mission data	Recorded @ 1200 bps
Transponder antenna	Omni during ascent and early orbit before stabilization on transponder link EIRP = + 14 dBm
Mission/tape recorder antenna	EIRP = + 30 dBm

Table 5.7.2 SAGE Communication and Data Handling Subsystem Components

COMPONENTS	No. Rq'd.	Index No.	Weight kg	Weight lb	POWER Operate W	POWER Operate Duty	POWER Standby W	POWER Standby Duty	POWER Tot. Pwr. W
Communication									
Baseband Assembly Unit	1	D8-4-5	0.9	2.0	0.5	20%	0		0.1
S-Band Receiver	1	N5-4-5	1.8	4.0	6.9	100%	0		6.9
Diplexer	1	(nh)	0.7	1.5	0		0		0
Hemispherical Antenna	1	(nh)	0.6	1.3	0		0		0
Omni Antenna	1	N2-4-6	3.8	8.4	0		0		0
S-Band Xmtr-Mission	1	D1-4-3	2.1	4.7	18.2	0.5% [a]	0		0.1
S-Band Xmtr-Housekpg.	1	D6-4-2	1.9	4.2	16.3	20%	0		2.3
Subtotal			11.8	26.1					9.4
Data Handling									
Command Decoder	1	D3-4-5	1.9	4.2	6.0	27%	0.8	73%	2.2
Stored Programmer	1	N1-4-6	2.3	5.1	5.7	100%	0		5.7
Digital Telemetry Unit	1	(nh)	1.8	4.0	6.0	100%	0		6.0
Tape Recorder (10^8 bit)	1	(NASA Std)	4.5	10.0	4.0	100%	0		4.0
Subtotal			10.5	23.3					17.9

[a] Reference 10

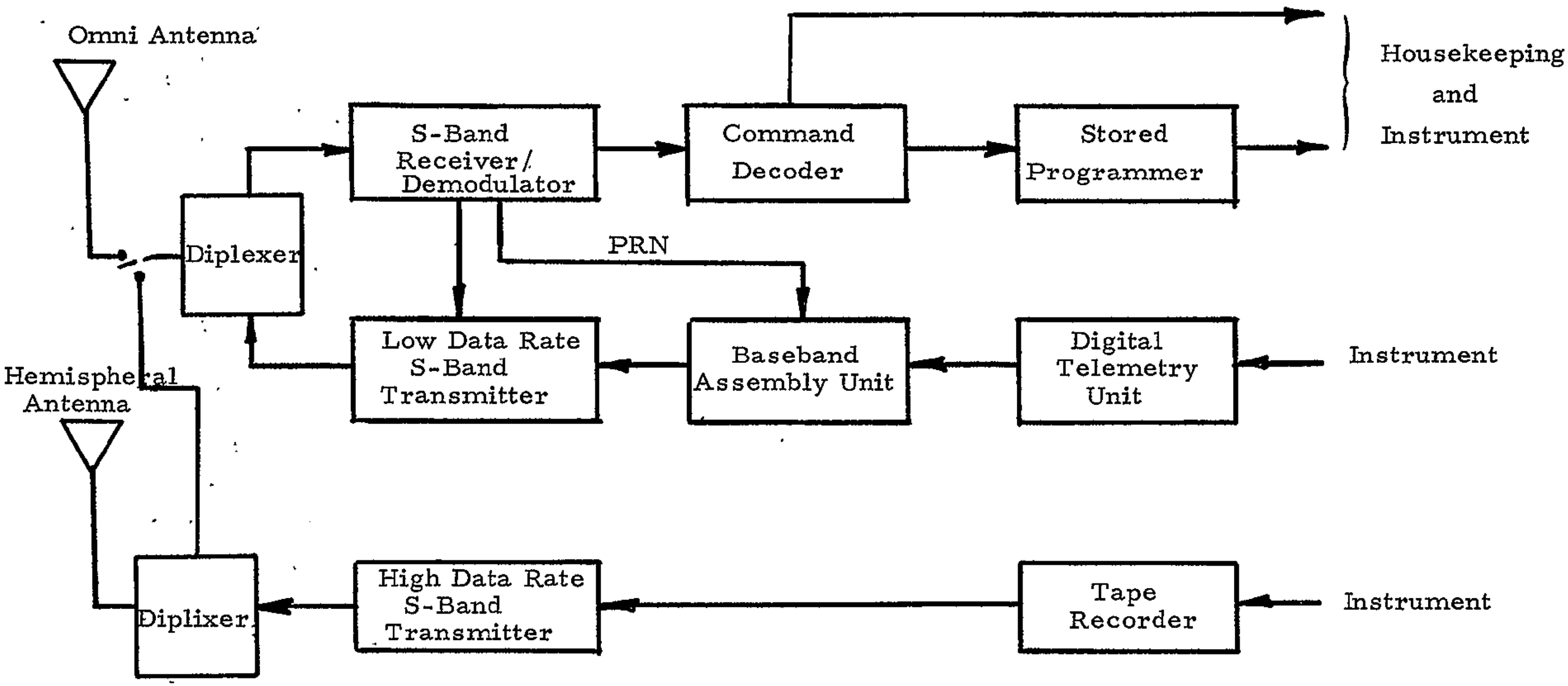


Figure 5.7.1 SAGE Communication and Data Handling Subsystem Configuration

5.7.1 Baseband Assembly Unit

The requirements of the BAU and the characteristics of the candidate unit are as follows:

Parameters	Requirements	Candidate (D8-4-5)
Input bit rate	1.2 kbps	1 to 128 kbps
PRN input	Yes	Yes
Subcarrier	1.024 MHz	1.024 MHz
Power	Low	0.52 W
Weight	Low	0.9 kg (2 lb)

The selected candidate appears to meet the requirements. Any other device in the catalog would require modifications to match the bit rate requirements. DDT&E should not be required.

5.7.2 S-Band Receiver

The requirements of the receiver and the characteristics of the candidate unit are as follows:

Parameters	Requirements	Candidate (N5-4-5)
Frequency	2.09 to 2.12 MHz	2.09 to 2.12 MHz
Frequency Stability	$\pm$ 30 kHz	1 part in 10^6
Dynamic Range	-50 to -110 dBm	-70 to -110 dBm
Ranging	Provide coherent two-way range-rate and ranging	Provide coherent two-way range-rate and ranging
Tracking Range	>120 kHz	N/A
Noise Figure	≤7.5 dB	8 dB
Power	Low	6.9 W
Weight	Low	1.8 kg (4 lb)

The only receiver in the catalog that comes close to the requirement is the unit (N5-4-5) from the SMS program. It appears from the available specifications that the unit may need some modifications to the wideband filters to meet the SAGE requirements. If this modification is found necessary, the unit would have to be repackaged and requalified.

5.7.3 Diplexer

The diplexer requirements are as follows:

Parameters	Requirements
Frequencies	
Transmit	2.20 to 2.30 GHz
Receive	2.09 to 2.12 GHz
Isolation (transmit to receive port)	50 dB
Insertion Loss (transmit channel)	2 dB
Bandwidth	
Transmit channel	2 MHz
Receive channel	2 MHz
Power Rating	2 W

The diplexers listed in the catalog do not meet the requirements because they are not applicable to unified S-band frequencies. A new unit will have to be developed.

5.7.4 Hemispherical Antennas

The 2π steradian antenna requirements are as follows:

Parameters	Requirements
Coverage	Horizon to Horizon (<130 deg)
Gain	
Transmit	0 to -3 dB for downlink EIRP = + 30 dBm and power limited to 2 W transmitter
Receive	Receive link can operate at lower signal level than attained with transmitter gain since uplink EIRP = -74 dBm
Frequency	
Transmit	2.20 to 2.30 MHz
Receive	2.09 to 2.12 MHz
Polarization	Right hand circular
Power Rating	2 W

The catalog does not list an antenna that approaches the above requirements. The antenna will have to be developed.

5.7.5 Omni Antenna

The omni antenna is used for transmitting telemetry and receiving commands during ascent and on orbit phases, and to receive commands during the periods when the spacecraft is not stabilized. The requirements of the antenna and the characteristics of the candidate unit are as follows:

Parameter	Requirement	Candidate (N2-4-6)
Frequencies		
Transmit	2.20 to 3.30 GHz	2.2895 GHz
Receive	2.09 to 2.13 GHz	2.108 GHz
Type	Omnidirectional	Omnidirectional
Gain		
Transmit	(EIRP = +14 dBm)	-7 dB @ 90 $\pm$ 50° -15 dB @ 130 to 170°
Receive	(EIRP = -74 dBm)	-9 dB @ 90 $\pm$ 50° -17 dB @ 130 to 170°
Polarization	Circular	Linear
Power Rating	2 W	10 W

The AE-C antenna (N2-4-6) comes close to meeting the above requirements. Modification for circular polarization may be required. The estimated DDT&E is 10 percent.

5.7.6 S-Band Transmitter for High Data Rates (Mission)

The requirements for the high data rate transmitter and the characteristics of the candidate unit are as follows:

Parameter	Requirement	Candidate (D1-4-3)
Frequency	2.2 to 2.3 GHz	2.2 to 2.3 GHz
Modulation	PCM/PSK/PM	PCM/PSK/PM
Frequency	5 in 10^{-6} for an average time of 5 hr	± 0.003% long term 1 part in 10^7 short term
Modulation linearity	5% max	N/A
Efficiency	High	13%
Weight	Low	2.1 kg (4.7 lb)
Power	2 W	2 W min 2.8 W max

The FLTSATCOM (D1-4-3) transmitter was selected based primarily on efficiency and weight. Other candidates in the catalog including the NASA standard transponder will meet the basic requirements. Information indicates that there should not be any DDT&E effort.

5.7.7 S-Band Transmitter for Low Data Rates (Housekeeping)

The requirements of the low data rate S-band transmitter and the characteristics of the candidate device are as follows:

Parameter	Requirements	Candidate (D6-4-2)
Frequency	2.2 to 2.3 GHz	2.2 to 2.3 GHz
Ranging Bandwidth	50 kHz to 3 MHz	N/A
Frequency Accuracy	± 20 kHz	N/A
Frequency Stability	5×10^{-6} for 5 hr	N/A
Modulation Linearity	5% max	± 7%
Ranging Mod Index	0.3 radians	N/A
Modulation	PCM/PSK/PM	PM
Output Power	0.5 W	1 W
Efficiency	High	6%
Weight	Low	1.9 kg (4.2 lb)
Coherency	USB receiver	SGLS receiver

The NATO-III (D6-4-2) transmitter will meet the requirements with minor modifications. The unit will require modifications for coherency with the USB receiver. These modification are in the catagory of frequency adjustments which can be accomplished without repackaging or requalification.

5.7.8 Command Decoder and Stored Programmer

The requirements of the command decoder and stored programmer, and the characteristics of the candidate units are the same as described for HCMM (see Section 4.7.7) except for the storage time duration. HCMM and SAGE desire 2 hr and 24 hr memory duration. For this study it will be assumed that the storage time can be made to accommodate both program needs. The HCMM decoder/programmer should be suitable for SAGE.

5.7.9 Digital Telemetry Unit

The DTU for SAGE is basically identical to HCMM. The HCMM-developed DTU should be applicable to SAGE.

5.7.10 Tape Recorder

The requirements of the tape recorder and the characteristics of the LCSO magnetic tape recorder are as follows:

Parameter	Requirements	Candidate (NASA Standard)
Record Rate	1200 bps	1700 bps min
Playback Rate	256 kbps	272 kbps max
Total Storage	7×10^8 bits	3.2×10^8 bits
Playback-to-Record Ratio	213.3:1	160:1
Weight	Low	4.5 kg (10 lb)
Power	Low	4 W record 8 W playback

To meet the above requirements, the recorders in the catalog will have to be redesigned; however, a new design is probably a better approach. The magnetic tape recorder described in the LCSO Standard Equipment Announcement will also not meet the requirements as itemized above. The NASA standard recorder has a storage capacity of 1-1/2 days of recording at 1700 bps which exceeds once per day readout requirements. It is suggested that the SAGE requirements be altered to meet the NASA 10^8 magnetic tape recorder capability. The study will assume that the standard recorder will meet the SAGE requirements.

6. SOLAR MAXIMUM MISSION (SMM)

6.1 SMM MISSION

The SMM objective is to investigate the cause and nature of solar flares. The data gathering is to emphasize both the thermal and non-thermal components of the flare, and check the solar magnetic field as a flare-energy source. The secondary objective is to investigate the solar flare effects (References 14 and 15).

The preferred orbital characteristics are a near-circular orbit of 574 $\pm$ 28 km (310 $\pm$ 15 nmi) with a 33 $\pm$ 0.05 deg inclination. Minimum mission lifetime is one year but the desired lifetime is three years. The spacecraft is to maintain a constant sun orientation and no orbital maneuvering capability is required.

The two-stage Delta 2910 is planned as the launch vehicle; it is a modified Thor booster incorporating nine strap-on Thiokol solid rocket motors. To cover the next solar maximum, the launch is scheduled for 1978. The communication link is planned to use both TDRS and STDN where the STDN will provide the pre-TDRS link.

6.2 SMM MISSION EQUIPMENT REQUIREMENTS

The mission equipments will be dedicated to solar observations and consist of many instruments that will be mounted on a plate 1.83 (72 in.) by 1.52 m (60 in.). The specific instruments, yet to be determined, will be limited to seven to nine scientific instruments, mounted on a common plate as shown in Figure 6.2.1. The instrument assembly will be housed in a thermal enclosure as shown in Figure 6.2.2. The spacecraft requirements to satisfy the mission objectives are listed in Table 6.2.1.

6.3 SPACECRAFT DESCRIPTION

The SMM spacecraft is three-axis stabilized with deployable oriented arrays. The estimated gross weight is about 1360 kg (3000 lb) including the mission equipment. The spacecraft is a box structure to

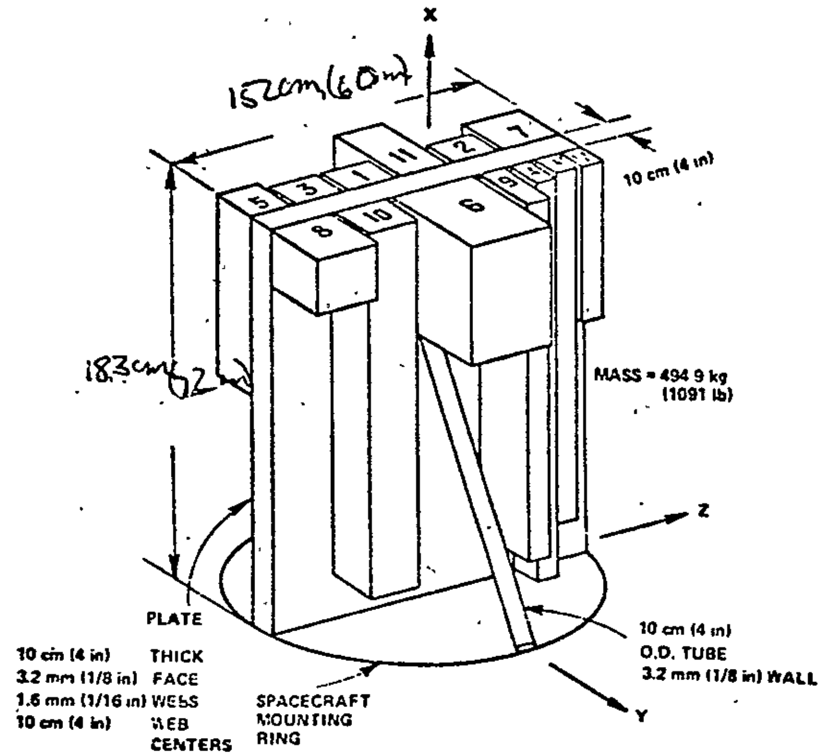


Figure 6.2.1 SMM Scientific Instrument Arrangement

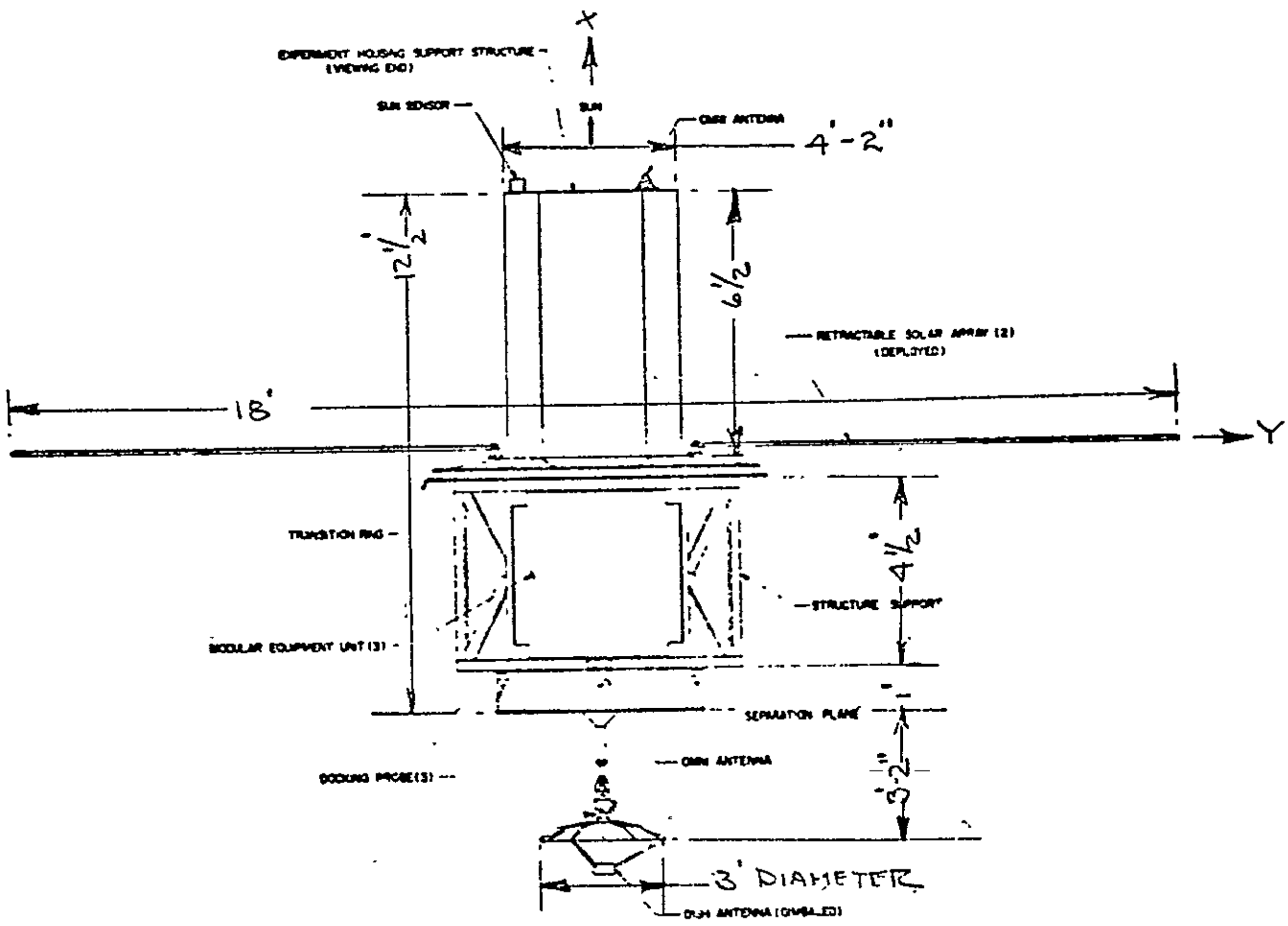


Figure 6.2.2 SMM Orbit Configuration

Table 6.2.1 SMM Instrument Requirements

Weight (instrument structure, support electronics and scientific instruments)	850.5 kg (1875 lb)
Power (peak) (eclipse) (average)	174.0 W 35.0 W 118.4 W
Input Voltage Range	28V ± 25% unregulated
Pointing Accuracy (pitch and yaw) (roll)	±24.2 μrad/s (5 sec/s) ± 1.75 mrad/s (6 min/s)
Pointing Stability (pitch and yaw) (roll)	± 5 μrad/5 min ±0.3 mrad/5 min.
Communication (downlink)	f = 2.283 GHz two channels PCM (split phase)/PSK/PM PCM (split phase)/PM
(uplink)	f = 2.1027 GHz PCM/PSK/PM
Data Handling (data rate) (record/reproduce) (playback rate) (telemetry rate)	8 kbps 1:20 160 kbps 16 kbps

accommodate subsystem modules. The modularized subsystem approach is desired for future Shuttle on-orbit maintenance capability; however, this analysis assumed an integrated spacecraft, i.e., current spacecraft design approach. The SC concept is reaction wheels with magnetic torquers and cold gas to unload the wheels. The communication is via STDN and TDRS. During periods of solar activity, the scientific and housekeeping data are stored on tape recorders. The AP studied only the cold gas propellant method because of its inherent simplicity, low cost, and unconstrained weight limit. The EP considered two configurations: one is to use a similar configuration to the SMM conceptual study and the second is to configure with all components being flight proven. The latter configuration is possible because the bus voltage is unregulated 28V ± 25%. The system weight and power breakdown by subsystems are shown in Table 6.3.1.

Table 6.3.1 SMM Satellite Weight and Power Summary

SUBSYSTEM	WEIGHT		POWER W
	kg	lb	
Stabilization and Control	81.2	179.0	181.0
Auxiliary Propulsion			
Dry Weight	18.1	40.0	0
Nitrogen	4.9	10.8	
Electrical Power	160.5	353.9	0[a]
Communication and Data Handling	78.3	172.7	47.6
Structure and Thermal[b]	158.8	350.0	0
Mission Equipment	850.5	1875.0	118.4
Total	1352.3	2981.4	347.0

[a] Not considered in the load power determination.

[b] Estimated by SDCM computer assuming integrated structure, i.e., not modularized.

6.4 STABILIZATION AND CONTROL

The SC requirements to meet the scientific objectives that are outlined in Section 6.1 and specified in Section 6.2 require a three-axis stabilized control system. The actuators in the SC are reaction wheels with magnetic torquers and thrusters to unload the momentum wheels. The rate and position sensors are inertial gyros, sun and stellar sensors, and magnetometers. The sequence and operation modes of the spacecraft are as follows: (Reference 15).

Initial Stabilization	Initial tumbling sensed by gyros, tumbling removed by thrusters and magnetic torques
Sun Acquisition	Orient to sun with analog sun sensor, digital sun sensor and magneometer data
Attitude Acquisition	Calibrate to determine attitude and provide required stability
Normal Operation	Inertially stabilized using gyros and pointing data provided by fine pointing sun sensor and star sensors

The functional block diagram of the SC subsystem is shown in Figure 6.4.1 and the requirements for the components are provided in the SMM conceptual study report (Reference 15). In some cases the specified requirements are given in terms of characteristics of an existing unit which are indicated to be suitable values. In these instances, it is probable that the candidate components are better than required or other candidates could have been considered if minimum requirements were specified. Because the requirements may not be supplied in terms of minimums, the candidate components were not eliminated for marginal performance. The marginal components are indicated in the cases where performance is below that specified. Also, the power and weight values indicated in Reference 15 were not considered a constraint, since it appears that adequate overall weight margin exists.

The selected components are listed in Table 6.4.1 along with the weight and power. The total estimated SC subsystem weight is 81.2 kg (179.0 lb) and the estimated power is 181 W. The requirements, candidates, characteristics, and remarks for each component are provided in Tables 6.4.2 to 6.4.7.

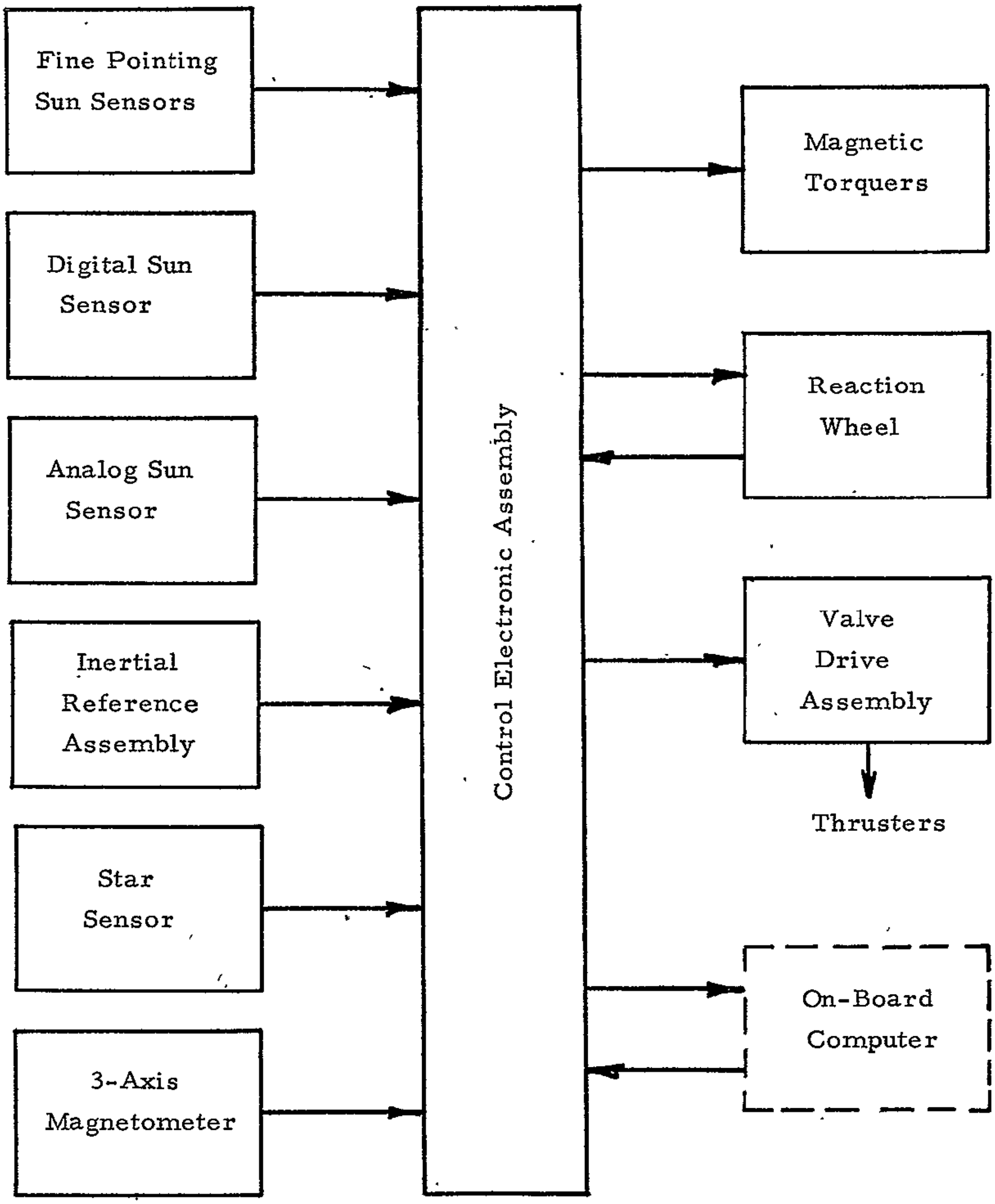


Figure 6.4.1 SMM Stabilization and Control Subsystem Functional Diagram

Table 6.4.1 SMM Stabilization and Control Subsystem Components

COMPONENTS	NO. RQD.	INDEX NO.	WEIGHT kg	WEIGHT lb	TOTAL POWER W
Inertial Reference Assy	4	N7-1-3	22.7	50.0[a]	96
Star Sensor	2	(developed)[b]	10.0	22.0	20
Fine Pointing Sun Sensor	1	N1-1-2	1.5	3.3	2
Digital Sun Sensor	1	D7-1-5[c]	0.9	1.9	1
Analog Sun Sensor	3	N6-1-9	0.3	0.7	0
Magnetometer	2	N3-1-1	0.7	1.6	1
Magnetic Torquer	6	D2-1-4	5.4	12.0	3
Reaction Wheel	4	D1-1-3[c]	22.1	48.8	48
Valve Drive Assembly	1	(nh)	1.5	3.2	0
Control Electric Assembly	1	(nh)	4.5	10.0	10
Solar Array Drive and Electronic	2	(nh)	11.6	25.5	
Total			81.2	179.0	181

[b] Unit has been developed but not listed in the catalog.

[c] Unit performance is marginal.

[a] Weight includes mounting platform.

Table 6.4.2 Inertial Reference Assembly

REQUIREMENTS	CANDIDATES	CANDIDATE CHARACTERISTICS	REMARKS
Configuration: Four SDF gas bearing gyros, one redundant, integral electronics Weight: 13.6-18.1 kg (30-40 lb) Power: 40-60 W Short-term bias stability: 35 μrad/hr (0.002 deg/hr) Torquing rate: 5.2 rad/hr (300 deg/hr)	Requirements within state of art, but no conforming unit known. If developed, recommend using any of following gyros: Bendix: 64-PM-RIG Northrup: GI-K7G Honeywell: GG 334	Configuration: Four SDF gas bearing gyros, one redundant, integral electronics Est. Wt: 15.9 kg (35 lb) Est. Power: 50 W Short-term bias stability: 26 μrad/hr (0.0015 deg/hr) Torquing rate: $\leq$13.1 rad/hr (750 deg/hr)	New development to meet requirements
	Nimbus-E/ERTS-A. (N7-1-3) rate measuring package. Each package contains one GI-K7G gyro and associated electronics	SDF gas bearing gyro, integral electronics Weight: 22.6 kb (50 lb) Power: 130 W Short-term bias stability: 26 μrad/hr (0.0015 deg/hr) Torquing Rate: 13.1 rad/hr (750 deg/hr)	Exceeds weight and power limits and needs mounting structure Assume DDT&E = 50%

Table 6.4.3 Star and Fine Pointing Sun Sensor

REQUIREMENTS	CANDIDATES	CANDIDATE CHARACTERISTICS	REMARKS
<u>STAR SENSOR</u> Accuracy: 48 μrad (10 $\widehat{sec}$) rms Sensitivity: $6m_v$ [a] FOV: 0.14 x 0.14 rad (8 deg x 8 deg) Weight: 4.9 kg (11 lb) Power: 10 W (Requirement based on suitable unit.)	Ball Bros. strapdown star sensor that is used in the mission equipment portion of SAS-C. The (N3-1-3) SAS-C unit in the catalog is used in the SC subsystem and is not suitable	Accuracy: 48 μrad (10 $\widehat{sec}$) rms Sensitivity $6\ m_v$ [a] FOV: 0.14 x 0.14 rad (8 deg x 8 deg) Weight: 4.9 kg (11 lb) Power: 10 W	The star sensor used in the mission equipment meets the requirements. DDT&E should not be expected
<u>FINE POINTING SUN SENSOR</u> Accuracy: 12-39 μ rad (2.5-8.0 $\widehat{sec}$) rms Weight: 4.5 kg (10 lb) Power: 5 W	Exotech PIA Sun Sensor (N1-1-2) used on OSO	Accuracy: 22-39 μrad (4.5-8.0 $\widehat{sec}$) rms Weight: 1.5 kg (3.4 lb) Power: 2.0 W	DDT&E is not expected

[a] m_v is the magnitude based on visual response.

Table 6.4.4 Digital Sun and Analog Sun Sensor

REQUIREMENTS	CONDIDATES	CANDIDATE CHARACTERISTICS	REMARKS
DIGITAL SUN SENSOR Accuracy: 0.3 mrad (1 min) Resolution: 68 μrad (14 sec) FOV: 1.1 x 1.1 rad (64 deg x 64 deg) Weight: 2.3 kg (5 lb) Power: 1 W	Adcole digital solar aspect sensor, used on OAO-Copernicus	Accuracy: 0.3 mrad (1 min) Resolution: 68 μrad (14 sec) FOV: 1.1 x 1.1 rad (64 deg x 64 deg) Weight: 2.3 kg (5 lb) Power: 1 W	DDT&E is not expected
	Adcole sun sensor unit (D7-1-5) used on DMSP	Accuracy: 1.5 mrad(5min) Resolution: NA FOV: 1.74 x 1.74 rad (100 deg x 100 deg) Weight: 0.9 kg (1.9 lb) Power: 0.9 W	Marginal performance
ANALOG SUN SENSOR Accuracy: 0.09 rad (5 deg) Weight: 0.5 kg (1 lb) Power: 0	Adcole 3-eye coarse analog sun sensor (N6-1-9) used on ATS-F	Accuracy: 0.05 rad(3 deg) Weight: 0.3 kg (0.7 lb) Power: 0	DDT&E is not expected
	Adcole 2-eye coarse analog sun sensor (N6-1-10) used on ATS-F	Accuracy: 0.05 rad(3 deg) Weight: 0.3 kg (0.7 lb) Power: 0	DDT&E is not expected

Table 6.4.5 Magnetometer

REQUIREMENTS	CANDIDATES	CANDIDATE CHARACTERISTICS	REMARKS
Accuracy: ±0.035 rad (2 deg) Weight: 9.1 kg (20 lb) Power: 6 W	Schonstedt unit (N3-1-1) used on SAS-C	Accuracy: ±0.035 rad (2 deg) Weight: 0.4 kg (0.8 lb) Power: 1 W	DDT&E is not expected
(Weight and power include magnetometer plus 3 axes-magnetic torquers)	Schonstedt unit (D2-1-3) used on P72-1	Accuracy: 0.022 rad (1.3 deg) Weight: 1.5 kg (3.3 lb) Power: 1 W	DDT&E is not expected
	Schonstedt unit (D4-1-3) used on S3	Accuracy: 0.044 rad (2.5 deg) Weight: 0.5 kg (1.0 lb) Power: 1.1 W	Marginal performance
	Schonstedt unit (N1-1-6) used on OSO.	Accuracy: 0.052 rad (3 deg) Weight: 0.5 kg (1.2 lb) Power: 0.23 W	Marginal performance

Table 6.4.6 Magnetic Torquer

REQUIREMENTS	CANDIDATES	CANDIDATE CHARACTERISTICS	REMARKS
Dipole mom/axis: 10,000 pole-cm Weight: 9.1 kg (20 lb) Power: 6 W (Weight and power include magnetometer plus 3 axes magnetic torquers)	TRW unit (D2-1-4) used on P72-1	Dipole mom/axis: 10,000 pole-cm Weight: 2.7 kg (6 lb) 3 axes Power: 2.9 W, 3 axes	DDT&E is not expected
	Ithaco unit (D3-1-3) used on P72-2	Dipole mom/axis: 10,000 pole-cm Weight: 1 kg (2.3 lb) 3 axes Power: na	DDT&E is not expected
	RCA unit (N2-1-6) used on AE-C	Dipole mom/axis: 13,000 pole-cm Weight: 9.1 kg (20 lb) 3 axes Power: 12.6 W, 3 axes	Exceeds power requirements
	RCA unit (N4-1-6) used on ITOS-D	Dipole mom/axis: 9,500 pole-cm Weight: 1.4 kg (3 lb) Power: 7 W	Marginal performance

Table 6.4.7 Reaction Wheel and Valve Drive Assembly

REQUIREMENTS	CANDIDATES	CANDIDATE CHARACTERISTICS	REMARKS
<u>REACTION WHEEL</u> Torque: 14.2 Ncm (20 oz-in) Weight: 9.1 kg (20 lb) Power: 5 W	Bendix unit used on LES with Vela motor	Torque: 21.3 Ncm (30 oz-in) Weight: 8.8 kg (19.5 lb) Power: 5 W	No modification
	TRW unit (D1-1-3) used used on FLTSATCOM	Torque: 10.7 Ncm (15 oz-in) Weight: 5.5 kg (12.2 lb) Power: 12 W	Marginal performance
<u>VALVE DRIVE ASSEMBLY</u> No. of valves: 6 pri and 6 sec Voltage: 32 V Power: 40 W		Requirements within state of art, but no conforming unit known. Recommend development of new assembly similar to one used on HCMM SAGE mission, but with a capacity for twelve valves instead of only two	New development

6.5 AUXILIARY PROPULSION

The AP requirements as determined by the SDCM computer program and Reference 15 are as follows:

Total impulse	3114 Ns (700 lb sec)
Thrust levels	0.44N (0.1 lbf)
Life	One year, 50,000 pulses
Reliability	No single mode of failure

Cold gas was chosen due to the low total impulse and no weight constraint, and its inherent simplicity and low cost. An average specific impulse of 637 Ns/kg (65 sec) was used for determining the amount of cold gas propellant. The functional diagram of the AP is shown in Figure 6.5.1. Thrusters, pressure regulators, and relief valves are redundant. In the event of any one component failure as detected by telemetry, the entire primary system can be isolated and the backup leg is activated. A single nitrogen tank is used; however, the failure rate for this nonfunctioning component is extremely low.

In Table 6.5.1, the candidate components that were considered are listed along with the key characteristics. The selected components are listed in Table 6.5.2. The isolation valve, fill and vent valve, and filter were selected on minimum weight. The P72-2 (D3-2-4) thruster was selected because of its low weight and redundant valve seat and nozzle. The Nimbus (N7-2-4) pressure regulator was selected on the basis of redundant regulator seats and regulation of 31 N/cm^2 (45 psia) pressure. The selected tank came closest to the required volume and also provided some growth capability. The tank pressure for the design total impulse is 1669 N/cm^2 (2420 psia).

6.6 ELECTRICAL POWER

The requirements of the EP are to provide a primary bus voltage of 28^{+7}_{-5}V and an average load power of 450 W. This power level includes 347 W of identified power load (see Table 6.3.1) and a contingency of 103 W.

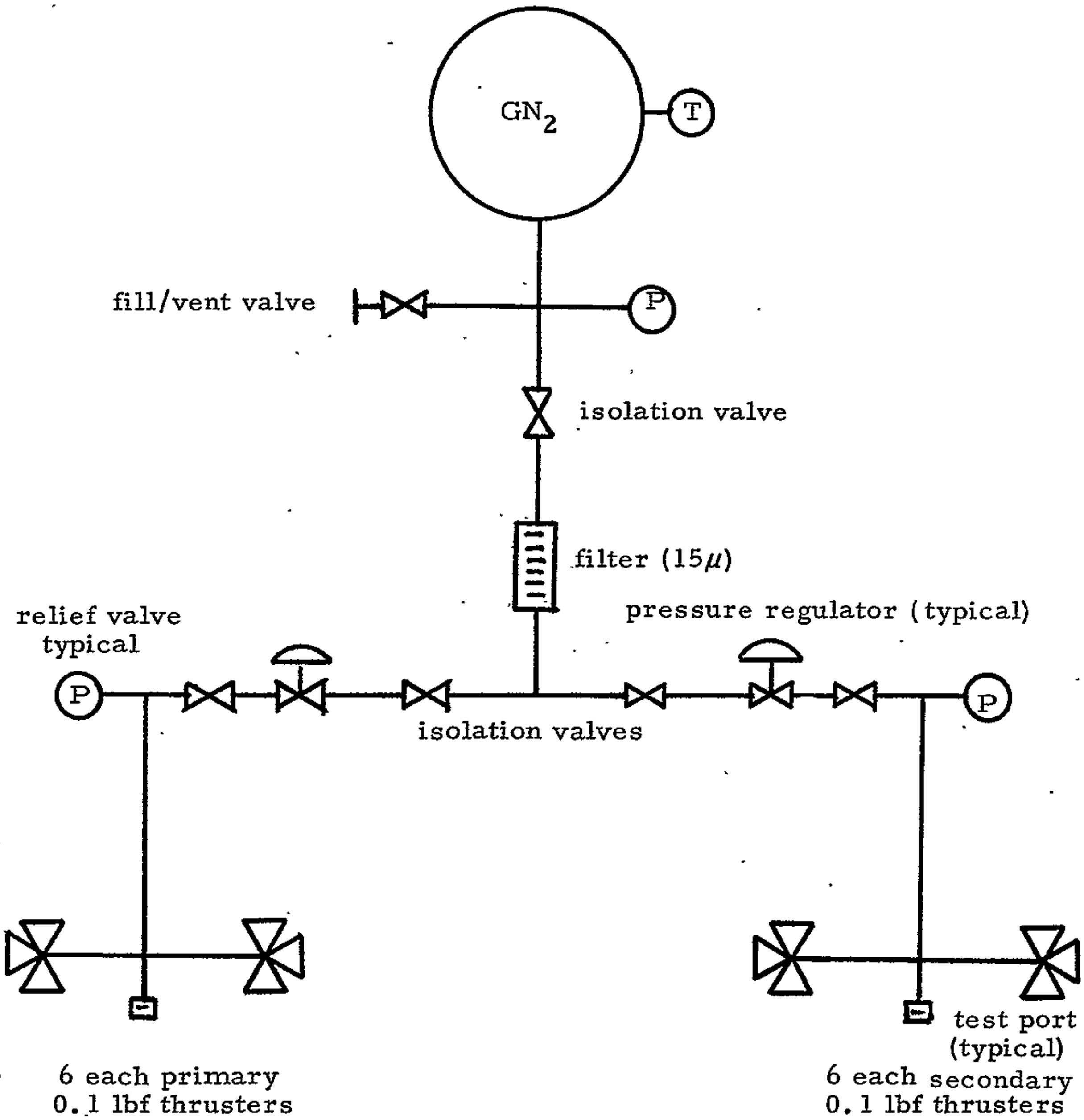


Figure 6.5.1 SMM Auxiliary Propulsion Subsystem, Functional Diagram

Table 6.5.1 Auxiliary Propulsion Component Candidates

COMPONENT	INDEX NO.	REMARKS
0.1 lbf Thruster	N1-2-1	0.5 kg (1.1 lb), 55N/cm^2 (80 psia)
	N7-2-5	0.3 kg (0.7 lb), 41.4 N/cm^2 (60 psia) dual seat, nozzle not included
	D3-2-4	0.4 kg (0.8 lb), 31.0 N/cm^2 (45 psia) dual seat
Tank 17,701 cm^3 (1080 in.^{3}) 2,482 N/cm^2 (3600 psia)	N1-2-2	15,652 cm^3 (955 in.^{3}), 2482 N/cm^2 (3600 psia), 5.2 kg (11.5 lb)
	D3-2-1	14,510 cm^3 (886 in.^{3}), 3172 N/cm^2 (4600 psia), 7.3 kg (16 lb)
	D9-2-3	26,420 cm^3 (1612 in.^{3}), 2482 N/cm^2 (3600 psia), 7.3 kg (16.2 lb)
Pressure Regulator	N7-2-4	0.6 kg (1.3 lb), 10-14 N/cm^2 (15-60 psia) dual seat plus integral relief valve
	D3-2-6	0.5 kg (1.15 lb), 23 N/cm^2 (33 psia), integral relief valve
Isolation Valve	N1-2-4	0.7 kg (1.5 lb)
	D3-2-8	1.1 kg (2.5 lb)
Fill and Vent Valve	N7-2-9	0.1 kg (0.3 lb)
	N7-2-2	0.2 kg (0.4 lb)
	D3-2-7	0.1 kg (0.2 lb)
Filter	N2-2-7	15 μ, 0.14 kg (0.3 lb)
	D8-2-6	15 μ, 0.16 kg (0.35 lb)

Table 6.5.2 SMM AP Subsystem

COMPONENTS	NO. REQ.	INDEX-NO.	WEIGHT	
			kg	lb
0.1 lbf Thruster	12	D3-2-4	4.4	9.6
Tank	1	D9-2-3	7.3	16.2
Pressure Regulator	2	D3-2-6	1.0	2.2
Isolation Valve	3	N1-2-4	2.0	4.5
Fill and Vent Valve	1	D3-2-7	0.1	0.2
Filter	1	N2-2-7	0.1	0.3
Transducers	4		0.4	0.8
Tubing	10m		2.8	6.2
DRY WEIGHT			18.1	40.0
PROPELLANT			4.9	10.8
WET WEIGHT			23.0	50.8

Using these requirements, the SDCM computed the following required characteristics for the shunt discharge voltage regulator configuration:

Array BOL power	1084 W
Array EOL power	1030 W
Total Solar Array Area (Oriented)	10.1m^2 (109 ft^2)
Battery Capacity/Battery	17.5 A-hr
Number of Batteries	2
Number of Cells	17

The functional diagram of the discharge voltage regulator configuration is shown in Figure 6.6.1, and the summary of components is listed in Table 6.6.1.

An alternate configuration is the shunt voltage regulation concept that is shown in Figure 6.6.2. The required characteristics of the shunt voltage are:

Array BOL power	991 W
Array EOL power	941 W
Battery Capacity/Battery	11.6 A-hr
Number of Batteries	2
Number of cells	22

The electrical control unit used on the DSP can be used for the SMM with modifications made to:

a. Power Control Unit (D8-3-1)
   1) Increase shunt regulator drive amplifier to handle eight regulators.
   2) Battery charge controller would have to be adapted to handle the batteries selected for SMM. The DDT&E is estimated at 50 percent.

b. The Solar Array; it would have to be tapped to accept the shunt regulators.

The list of components is shown in Table 6.6.1.

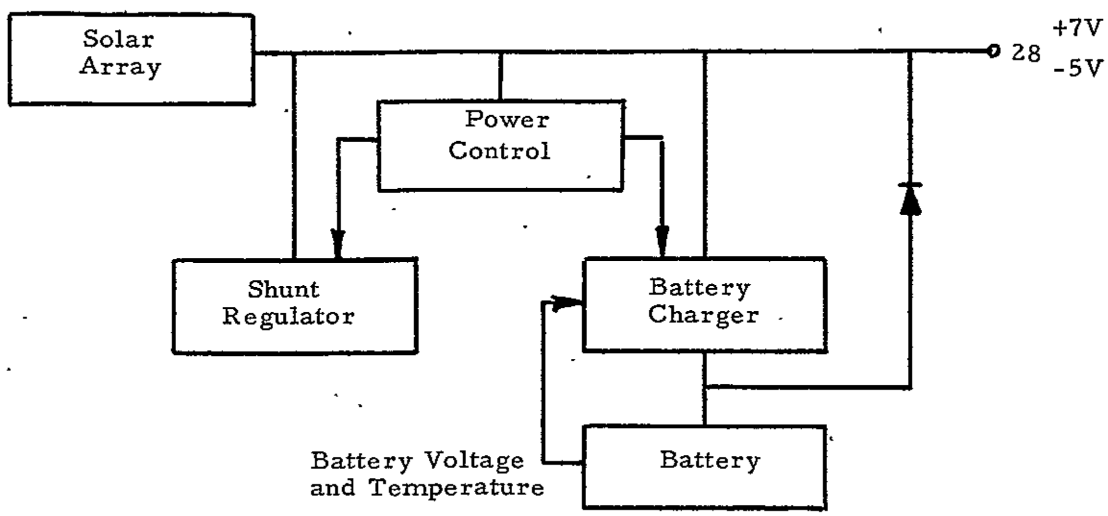


Figure 6.6.1 Shunt Discharge Voltage Regulation

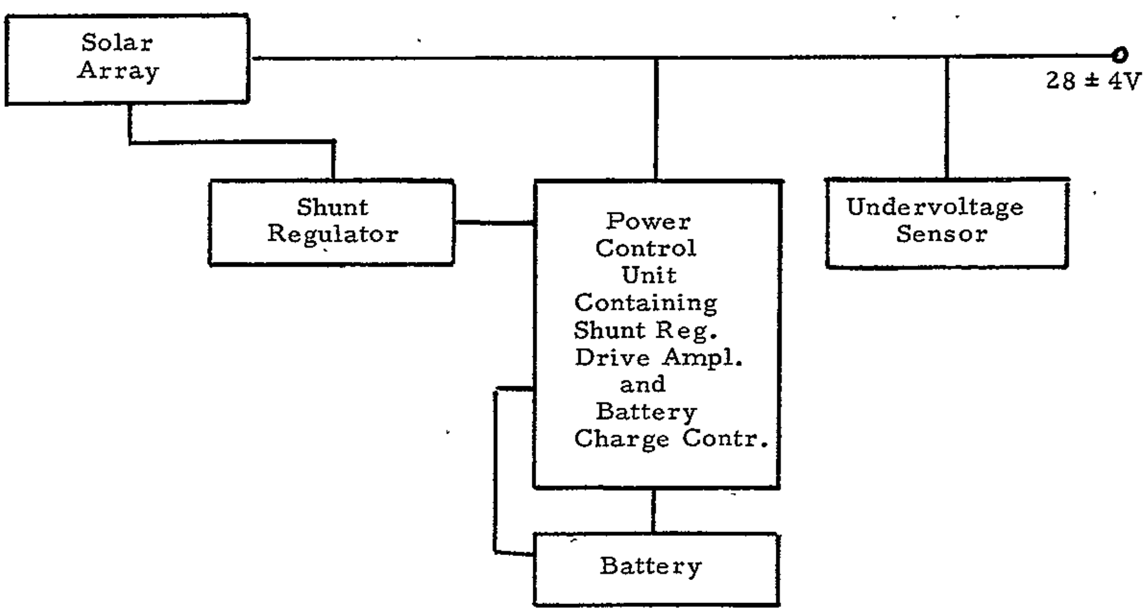


Figure 6.6.2 Shunt Voltage Regulation

Table 6.6.1 SMM Electrical Power Component Summary

COMPONENTS	NO. REQ.	INDEX NO.	WEIGHT	
			kg	lb
DISCHARGE VOLTAGE REGULATOR				
Shunt Regulator	6	D2-3-1	3.1	6.9
Battery Charger	4	(nh)	9.1	20.0
Power Control Unit	1	(nh)	4.5	10.0
Battery	4	D4-3-3	40.8	90.0
Solar Array	1	D1-3-8	44.9	99.0
Harness Weight			58.1	128.0
Total			160.5	353.9
SHUNT VOLTAGE REGULATOR				
Shunt Regulator	9	D8-3-2	17.2	37.8
Power Control Unit	1	D8-3-1	5.5	12.0
Battery	3	D4-3-3	30.6	67.5
Solar Array	1	D1-3-8	44.9	99.0
Harness Weight			58.1	128.0
Total			156.3	344.3

6.6.1 Shunt Regulator

The requirements of the shunt regulator to meet the system needs are:

Type	Series dissipative across the full bus so that it does not modify the array design
Maximum Power Dissipation	634 W
Limiting Voltage When ON	35 V
Special Design Feature	Commandable enable/disable control

The candidates from the catalog are as follows:

Index No.	Input Voltage, V	Voltage Limit, V	Power Diss., W	Number Required
D2-3-1	30.0	30.0	110	6
D4-3-1	31.4	27.7 - 31.2	100	7
N1-3-1	33.0	32.8	66	10
N5-3-2	15.0	29.4	10	64

All of these units are self driven. The prime candidates are D2-3-1 or D4-3-1. The unit will require modifications to limit at the 35V level and incorporate an enable-disable command capability. The DDT&E is estimated at 75 percent.

6.6.2 Battery Charger

There is no battery charger in the catalog that will provide the desired characteristics. These characteristics are:

Type	Current and voltage limited with trickle standby
Input Voltage:	20 to 35 V
Maximum Charge Current	5 A

Charge Voltage Limit	Temperature dependent, linearly decreasing from 30V at 273K (30 $^{\circ}$F) to 28V at 305K (90 $^{\circ}$F)
Trickle Current	0.15A
Special Design Features	Automatic switch from maximum charge rate to trickle rate upon reaching charge voltage limit. Automatic cutoff of all charge current for battery temperature greater than 308K (95 $^{\circ}$F). Commandable enable-disable control

The unit must be developed.

6.6.3 Power Control

The power control unit is a centralized controller for optimizing the use of array energy. It senses the status of the main bus, the charger, and the shunt regulator. The charger is commanded ON immediately after eclipse. If the bus voltage attempts to exceed the 35V limit, the shunt regulator is commanded ON. Under low bus voltage conditions, the power control unit commands non-essential loads OFF in order to protect the battery from overdischarge. The catalog does not contain a candidate.

6.6.4 Solar Array

The requirements of the solar array and the candidate arrays are as follows:

PARAMETERS	Requirements		Candidates	
	Discharge	Shunt	D9-3-8	D1-3-8
BOL, W	1084	991	435	863
Array Area, m^2 (ft^2)	10.1 (109)	8.5 (91.8)	4.2 (45)	10.9 (117)
Weight, kg (lb)			36.7 (81)	44.9 (99)

The array from STP71-2 (D9-3-8) is an assembly of nine flat panels which are deployed by a scissors-type mechanism. Use of this arrangement will require one additional panel per wing. The FLTSATCOM array (D1-3-8) is listed for one wing and is lighter than the STP71-2 array. For this study it will be assumed that one (D1-3-8) array is adequate to handle the identified load power. The DDT&E is expected to be about 10 percent.

6.6.5 Battery

The battery design parameters are provided in Section 6.6. The candidate battery is the unit from STP S3 (D4-3-3). The quantity of batteries should exceed the required capacity. This will result in a higher average state of charge and battery voltage so that the number of cells used (21) will provide adequate voltage despite the calculated requirement of 22 cells for the shunt voltage regulator concept. The DDT&E is expected to be about 10 percent.

6.7 COMMUNICATION AND DATA HANDLING

The SMM will utilize the STDN network and the TDRS for communication. For the TDRS, prime support will be obtained from the single access S-band link. The general CDH requirements are:

a. Commands. 64 power switching commands, 63 magnitude commands. All of these are real-time commands and all are stored in the computer for later execution. Since command rates were not specified in References 14 or 15, a rate of 1000 bps, was assumed. Commands will be received on the omnidirectional antennas from STDN and on the hi-gain antennas via TDRS.

b. Tracking. The unified S-band PRN ranging and range-rate system will be used for tracking and ephemeris determination. Tracking will be from the STDN stations and the TDRS.

c. Communication. Only one telemetry link is required. The signals will radiate from the omnidirectional antenna to STDN and from the hi-gain antenna to TDRS. Data will normally be read out in real-time and recorded at 8 kbps; the record/reproduce ratio will be 1:20 to produce a 160 kbps playback rate. Upon recognition of a flare event by the mission equipment, the telemetry rate will automatically increase to 16 kbps and the record speed will change to maintain the same 160 kbps playback rate. In the read-out mode to STDN, the 8 or 16 kbps real-time data are put on a 768 kHz subcarrier and the 160 kbps playback data are put on a 1.024 MHz subcarrier. Both subcarriers, in turn, phase modulate the carrier. In the TDRS read-out mode the 8 or 16 kbps is modulo-2 added to the PRN and put on the I channel and the 160 kbps is modulo-2 added to the PRN and put on the Q channel. The modulation scheme for the STDN downlink is PCM/PSK/PM and that for the TDRS return link is Staggered Quadriphase Pseudorandom Noise (SQPN).

The CDH functional diagram is shown in Figure 6.7.1 and the candidate components are listed in Table 6.7.1. The link calculation for the downlink portion of STDN is shown in Table 6.7.2. The required STDN transmitter power is 1W to provide a 6 dB margin.

6.7.1 Receiver

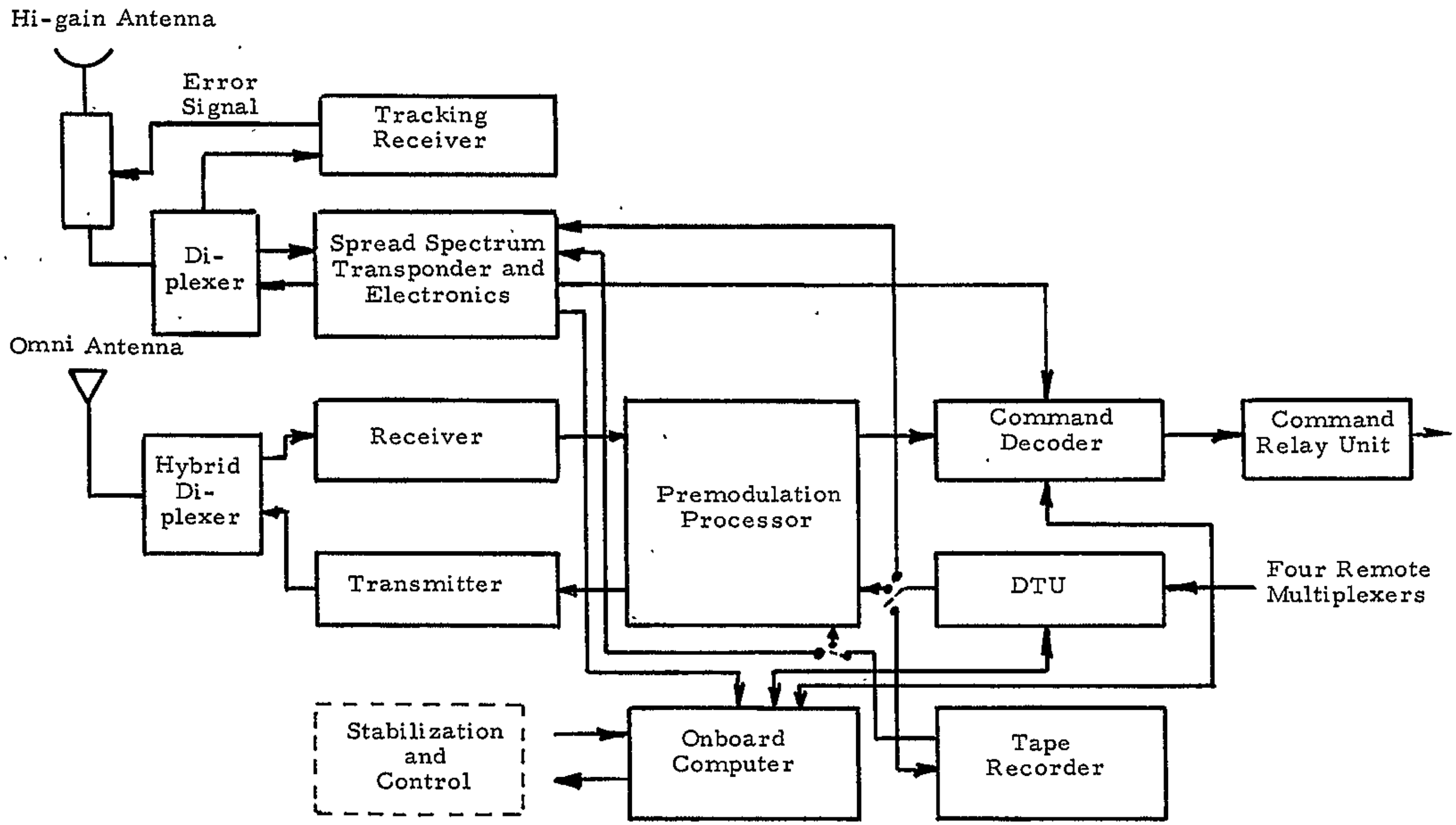
Two receivers meet the requirements as shown in Table 6.7.3. The AEC (N2-4-2) receiver appears a better choice than the SMS (N5-4-5) receiver because (1) it is nearer to the assigned frequency and hence should be easier to tune, (2) the SMS unit will need filter modifications, and (3) the AE-C unit has a better dynamic range. The SMS unit has, however, a lower time delay variation, and although its noise figure is not available, it is probably better than the 13 dB noise figure of the AE-C unit. The DDT&E is estimated at 10 percent.

6.7.2 Transmitter

The two candidate transmitters are compared with the transmitter requirement in Table 6.7.4. Both units will require modifications for coherent operation with the USB receiver. The NATO-III (D6-4-2) unit is recommended over the FLTSATCOM (D1-4-3) unit on the basis that the output better matches the required power. The DDT&E is estimated at 25 percent.

6.7.3 Spread Spectrum Transponder and Electronics

According to the TDRS User's Guide, the forward and return links must be spread spectrum with the modulation being staggered quadriphase PRN.



Note: All units redundant except for antennas, gimbal, and diplexers.

Figure 6.7.1 SMM Communication and Data Handling Subsystem Functional Diagram

Table 6.7.1 SMM Communication and Data Handling Subsystem Components

COMPONENTS	No. Req.	INDEX No.	WEIGHT (kg)	WEIGHT lb	POWER OPERATE W	POWER OPERATE Duty	POWER STANDBY W	POWER STANDBY Duty	POWER TOT. PWR. W
COMMUNICATION									
Receiver	2	N2-4-2	5.4	12.0	6.3	100%			6.3
Transmitter	2	D6-4-2	3.8	8.4	10.0	20%	0		2.0
Spread Spectrym Xponder[a]	2	(nh)	7.3	16.0	10.0	85%	4.0	15%	2.1
Diplexer	1	(nh)	0.7	1.5	0				0
S-Band Antenna	1	(nh)	3.8	8.4	0				0
Hi-gain Gimbal Antenna	1	D8-4-9	1.0	2.1	0				0
Antenna Gimbal & Elect[a]	1	A	5.4	12.0	5.0	85%	0		4.3
Tracking Receiver[a]	1	(nh)	1.8	4.0	3.0	85%	0		2.6
Hybrid Diplexer	1	(nh)	0.7	1.5	0				0
Sub Total			29.9	65.9					17.3
DATA HANDLING									
Premodulation Processor	1	b	5.0	11.0	5.5	20%	1.0	80%	1.1
DTU	2	(nh)	4.5	10.0	5.0	100%			5.0
On-board Computer	2	(nh)	22.7	50.0	14.2	100%			14.2
Command Decoder	2	N1-4-4	4.9	10.8	5.8	20%	1.0	80%	2.0
Command Relay Unit	2	(nh)	2.3	5.0	5.0	20%	1.0	80%	2.0
Tape Recorder	2	(NASA STD)	9.1	20.0	6.0	100%			6.0
Sub Total			48.4	106.8					30.3
Total			78.3	172.7					47.6

[a] TDRS Multiple Access Link

[b] ERTS hardware, internally redundant

Table 6.7.2 Link Calculations - Downlink to STDN

The STDN antenna that will be used is the USB 9.1 m (30 ft) antenna. The modulation index of the PRN ranging on the baseband is assumed to be the standard 0.3 radian. It is assumed that, as in SGLS, the sum of the modulation indices on a link is a maximum of 3 radians. This leaves 2.7 radians for both the 768 kHz and 1.024 MHz subcarriers. The indices are set on the subcarriers such that the difference in modulation loss roughly equals the difference in noise bandwidth between the two subcarriers. This difference in noise bandwidth is 10 dB since the maximum bit rate on the 768 kHz subcarrier is 16 kbps and the bit rate on the 1.024 MHz subcarrier is 160 kbps. The modulation index on the 768 kHz subcarrier is 0.9 radian and on the 1.024 HMz subcarrier it is 1.8 radians. The following are link calculations for the 160 kbps to determine the required transmitter power:

Vehicle Transmitter Power (dBm)	P_t
Vehicle Line Loss (dB)	-2
Vehicle Antenna Gain (dB)	-5
EI RP (dBm)	P_t - 7 dB
Space Loss (dB)	-168
Ground Antenna Gain (dB)	44
Total Received Power (dBm)	-131 + P_t
Ground Station Spectral Noise Density (dBm/Hz)	-176.3
Received Power at Spectral Noise Density (dBm/Hz)	45.3 + P_t
Noise Bandwidth (dB)	52.0
Received Power to Noise Spectral Density (dBm)	-7.3 + P_t
Required Signal to Noise Ratio (dB)	9.6
Modulation Loss (dB)	3.6
Ground Station Degradation (dB)	4
Link Margin (dB)	6

$$-7.3 + P_t = 23.2$$
$$P_t = 30.5 \text{ dBm}$$
$$P_t = 1 \text{ W}$$

Table 6.7.3 Receiver

Parameter	Requirement	Candidates	
		N2-4-2	N5-4-5
Frequency, MHz	2102.722843	2108.247917	2030
Tracking Threshold	Low	-122 dBm	na
Dynamic Range	Good	-122 to -29 dBm	Noise Level to -70 dBm
Demodulation	Phase	Phase	
Noise Figure	Low	≤13 dB	na
Time Delay Vari.	Low	≤40 ns	10 ns
Weight		2.7 kg (6.0 lb)	1.8 kg (4.0 lb)
Power		12.8 W	6 W

Table 6.7.4 Transmitter

Parameter	Requirement	Candidates	
		D6-4-2	D1-4-3
Frequency, MHz	2283.5	2200-2300	2252.5 and 2262.5
Output Power	1 W	1 W	2 W min. 2.8 W max.
Coherency	With uplink	No	No
Stability		±0.003%	±0.003%
Bandwidth		Flat 1 dB between ±2 MHz	na (1.024 MHz subcarrier)
Spurious Output		40 dB dwn with respect to carrier	60 dB dwn from unmod. carrier)
Weight	Low	1.9 kg (4.22 lb)	2.1 kg (4.7 lb)
Power	Low	10 W	18 W
Efficiency	High	10%	11%

The command data is modulo-2 added to the PRN on both the I and Q channels on the forward link. On the return link the 8 kbps real-time data are modulo-2 added to the PRN and put on the I channel, and the 160 kbps recorded data are modulo-2 added to the PRN and put on the Q channel. Also, according to the TDRS User's Guide, the return link must be single access since the maximum data rate that can be sent on the multiple access links is 50 kbps.

The equipment that will be needed to do this job includes a spread spectrum transponder, a correlator for extracting the command data, a modulo-2 adder, and an error correction encoder. None of these equipments are in existence as flight qualified units at present. There are indications that NASA is planning to develop a standard TDRS compatible transponder. The delivery date for the first unit is planned for May 1978.

6.7.4 Diplexer

A diplexer as characterized in Table 6.7.5 is not available in the catalog because the frequency required is USB. The units in the catalog operate in the 1.75 to 1.85 GHz frequency range. This unit will require development.

6.7.5 S-Band Antenna

There are no antennas in the catalog that will meet the USB transmit-receive requirements that are indicated in Table 6.7.5. The antenna that meets the transmit requirement could possibly be modified to meet the receive requirements. The unit is a boom-mounted conical log spiral on STP 72-1 (D2-4-1). Two of these antennas would be needed to obtain the required coverage. The DDT&E should be based on a new development effort.

6.7.6 Hi-gain Antenna System

The hi-gain antenna system consists of the gain antenna, gimbal and electronics, and tracking receiver. In Reference 14 an 0.9 m (3 ft) parabolic dish is indicated; however, link calculations show that an 0.6 m (2 ft) dish will close the return link with about 1.2 W of transponder output power.

Table 6.7.5 Diplexer, S-Band Antenna, Command Decoder and DTU Requirements

Parameters	Requirements
DIPLEXER	
Frequencies	Transmit: 2200 to 2300 MHz Receive: 2025 to 2130 MHz
Isolation	50 dB (transmit to receive port)
Insulation Loss	52 dB (transmit channel)
Bandwidth	2 MHz (transmit and receive chl)
Power Rating	2 W
S-BAND ANTENNA	
Frequencies	Transmit: 2200 to 2300 MHz Receive: 2025 to 2120 MHz
Gain	$\geq$15 dB over 85% of sphere
Polarization	Right hand circular
Power Rating	2 W
COMMAND DECODER	
Number of Commands	64 power switching 63 magnitude, 37 bits each 128 bi-level
Command Execute Rate	20 per sec from ground 20 per sec from computer
DTU	
Bit Rate	8 kbps switchable to 16 kbps
Number of Input Channels	32 analog and 32 digital directly 128 analog and digital from each four submulitplexers
Bit/words	8
Words/Minor Frame	128
Minor Frames/Major Frame	256
Outputs	2 bit stream, one to the transmitter or recorder and one to the computer

With the smaller dish, the candidate antenna can be the unit on the DSP program (D8-4-9). The antenna characteristics are:

Gain on Axis	20 dB
Frequency Band	2200 - 2300 MHz
Polarization	Right-hand circular
Coverage Angle Gain	15.5 dB gain at a subtended angle of ±0.15 rad (8.5 deg) and 10 dB gain at a subtended angle of ±0.21 rad (12 deg).

The antenna feed portion will have to be modified to receive in the 2025 to 2120 MHz band. The DDT&E is estimated at 25 percent.

An antenna gimbal and electronic assembly does not exist in the catalog; however, a special unit has been designed and built at The Aerospace Corporation and successfully operated on an Air Force satellite program. This unit appears suitable for this application. The drawings are not currently in a form for manufacturing an additional unit, but they can be made available within a reasonable time. The unit characteristics are:

Pointing Accuracy	0.02 rad (1 min)
Power	5 W
Weight	5.4 kg (12 lb)

The DDT&E is estimated at 50 percent.

Tracking receivers are also not contained in the catalog. The unit will require development. The pointing accuracy requirement is about ± 0.02 rad (1 deg).

6.7.7 Premodulation Processor

The premodulation processor demodulates the command data and provides suitable subcarriers for phase modulating the transponder transmitter in the STDN link. The only processor is the ERTS unit (Ref. 15) which is not contained in the catalog. The requirements and characteristics of the candidate are compared in Table 6.7.6. This unit will require modification to change the existing 597 kHz oscillator to 1.024 MHz. The DDT&E is estimated at 50 percent.

Table 6.7.6 Premodulation Processor

Parameters	Requirements	Candidate (ERTS)
Discriminator	70 kHz	70 kHz
Subcarrier	768 kHz, PCM/PSK 1.024 MHz, PCM/PSK	768 kHz, PCM/PSK 597 kHz, PCM/PSK
Receive	PSK modulate 8-16 kbps on 768 kHz Subcarrier PSK modulate 160 kbps on 1.024 MHz Subcarrier Linearly sum two subcarrier and PRN ranging	PSK modulates signals on both Subcarrier Linearly sums both subcarrier and IF output of data collection receiver

6.7.8 Digital Telemetry Unit (DTU)

None of the DTUs in the catalog will meet the bit rates, number and types of channels, and format requirements. For this study, it will be assumed that this unit must be developed.

6.7.9 On-Board Computer

The computer requirements are summarized in Table 6.7.7 which is based on a GSFC computer design. No such computer is known to exist in industry. Apparently GSFC will provide the drawings and specifications to the prime spacecraft contractor. The DDT&E will be assumed to be equivalent to a new development.

6.7.10 Command Decoder

From the information supplied in the catalog, none of the listed decoders will meet the requirements shown in Table 6.7.5. The SMM conceptual study (Ref. 15) states that the OSO-I or the IUE decoders could satisfy the requirements. The OSO-I unit is in the catalog (N1-4-4), but the data sheet information does not provide enough to select the unit as a candidate. The study will assume the unit is satisfactory and estimate a DDT&E of 50 percent.

Table 6.7.7 On-Board Computer and Hi-gain Antenna Requirements

Parameters	Requirements
Modules	Processor and Memory
Number of Instructions	55
Number of Words in Memory	8192
Bits per word	18
Number of Input Channels	8
Number of Output Channels	8
Weight	11.4 kg (25 lb)
Power	14.2 W

6.7.11 Command Relay Unit

The catalog does not contain a unit of this type which is used for switching power to various spacecraft components. The unit is to provide 64 relay switches and will require development.

6.7.12 Tape Recorder

There is no tape recorder in the catalog that is capable of recording at the low rates. The required rates are not common with current recorders. The unit that comes closest to meeting the requirements listed in Table 6.7.8 is the recorder that is being used in STP-S3 (D4-4-6). To make this unit meet the requirements, it would have to undergo a major modification. The NASA magnetic tape recorder in the LSC's Standard Equipment Announcements will meet the requirements.

Table 6.7.8 Tape Recorder

Parameter	Requirements	Candidate	
		NASA Std	D4-4-6
Record Rate	8 and 16 kbps	1.7 kbps to 1.088 Mbps	16.384 kbps
Total Storage	10^8 bits	3.2×10^8 bits	2×10^8 bits
Reproduce/ Record	20:1	160:1 to 1:160	8:1
Record Time	210 min	2.2 min to 53 hr	210 min
Weight		4.5 kg (10 lb)	6.6 kg (14.6 lb)
Power		6W	7 W Record 14 W Playback

7. TIROS-N

7.1 TIROS-N MISSION

The spacecraft mission is to (1) provide an economical and stable platform for the advanced instruments to be used in making measurements of the earth's atmosphere, its surface, its cloud and the proton and electron flux near the earth; and (2) receive, process, and retransmit data from free-floating balloons, buoys, and remote automatic observation stations distributed around the globe.

The nominal orbit will be at circular 833 km (450 nmi) altitude and sun synchronous inclination of 98.74 deg. The launch will be from WTR using the Atlas F/TE-M-364-15 booster. The final orbit descending node is to be 0600-1000 or 1400-1800 (Ref. 16).

7.2 MISSION EQUIPMENT

The instrument complement is:

1. Advanced very high resolution radiometer (a five channel imaging line scan sensor) - AVHRR
2. TIROS operational vertical sounder (a 22 channel step scanned spectrometer consisting of three separate units - a basic sounding unit, a stratospheric sounding unit, and a microwave sounding unit). - TOVS
3. Space environment monitor (five units) - SEM
4. Data Collection System - DCS
5. Complement of growth sensors devised in anticipation of future operational requirements.

The description of these instruments are summarized in Table 7.2.1 (Ref. 16).

7.3 TIROS-N SPACECRAFT

The TIROS-N is basically the DMSP 5D spacecraft. The spacecraft size in the launch configuration is 1.87 m (74 in.) diameter by 3.70 m (146 in.) long, and the nominal weight is about 653 kg (1440 lb). An orbital configuration of TIROS-N is shown in Figure 7.3.1.

Table 7.2.1 TIROS-N Instruments Mission Equipment

Unit	IFOV km	IFOV nmi	Number of Channels	WEIGHT kg	WEIGHT lb	Power W	Number of TLM Analog	Commands	Data Rate
AVHRR	1.1	0.59	4	23.1	51.0	25.0	20	28	39.936 k samples/s/chl
TOVS BSU	22.0	11.80	14	28.5	62.8	34.2	12	19	2880 bps
SSU	147.2	79.5	3	12.5	27.6	15.0	8	7	480 bps
MSU	109.1	58.9	4	16.3	36.0	20.0	9	16	320 bps
Power				4.5	10.0	10.0			
DCS Power				2.3	5.1	6.0	16	16	480 bps
Receiver				7.5	16.5	12.0			
Signal Proc.				8.2	18.1	2.5			
SEM									
LEPAT				1.8	4.0	1.0	4	6	160 bps
HEPAT				3.4	7.5	2.0	5	4	
TED				2.0	4.4	0.8	4	4	
POD				1.8	4.0	1.0	4	2	
DPU				0.9	2.0	1.0		2	
Growth MSU			6	27.2	60.0	30.0	14	21	480 bps Replaces MSU
Growth MSUE				5.9	13.0	15.0			
Microwave Imager			2	27.2	60.0	65.0	20	15	300 bps
Pollution Monitor(HIRS)				22.7	50.0	25.0	20	15	
5 Channel AVHRR			5				23	31	Replaces AVHRR

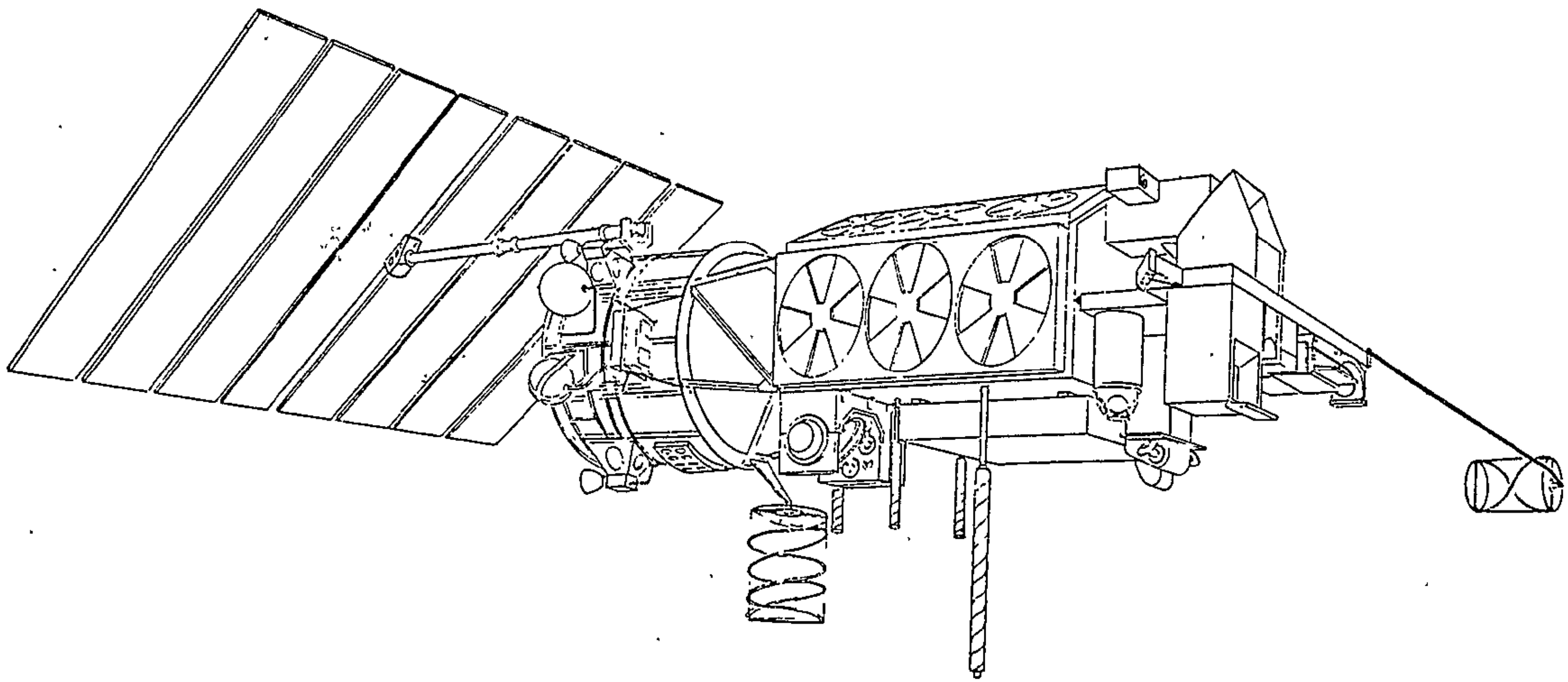


Figure 7.3.1 TIROS-N Orbital Configuration

The changes that were made to DMSP 5D components were to satisfy the TIROS-N requirements or to configure a more cost-effective spacecraft. These changes are summarized in Table 7.3.1 (Ref. 16). The differences are the launch vehicle, fairing, and the orbital nodal crossing times. The DMSP subsystem changes are in the SC, EP, and CDH subsystems and are as follows:

a.	Stabilization and Control	-	Software change, delete celestial sensors and add sun sensors for redundancy
b.	Auxiliary Propulsion	-	No change
c.	Electrical Power	-	Modify power supply electroncis and pulse load regulator for added busses.
d.	Communication and Data Handling	-	Change all components affected by frequencies.

The changes in the SC and EP subsystems are basically limited to software, quantity of components, and modification of DMSP components. The CDH, however, cannot use most of the DMSP components because of the difference in communication frequencies. Thus the TIROS-N analysis is limited to only the CDH subsystem. The CDH component requirements summarized in the following section were obtained from Reference 16. The CDH functional block diagram is shown in Figure 7.3.2.

7.4 COMMUNICATION AND DATA HANDLING

The general requirements of the CDH that can be developed from Reference 16 are as follows:

a. Command. The command uplink frequency is at VHF, 148.56 MHz. The modulation is FSK/AM. The command rate is 1,000 bps ternary FSK. There are 800 command words both stored and in realtime. A command word is 25 bits in length. There is an on-board computer to handle the stored commands.

b. Tracking. The ephemeris determination and periodic orbital updates are obtained from skin tracking with Air Force radars. The Air Force processes the tracking data and transmits it to NOAA. No vehicle equipment (such as a transponder) is required for the tracking function.

Table 7.3.1 DMSP and TIROS-N Comparison

ITEM	5D	5D2	TIROS-N
Launch Vehicle	(Classified/TE-M-364-4/ TE-M-364-15)	SLV-2A/TE-364-4/TE-364-15	Atlas F/TE-M-364-15
Heat Shield	1.7m (67 in.) dia	1.7 m (67 in.) dia	2.1 m (84 in.) dia Metallic Fairing (OV1) and Delta 2.4 m (94 in.) dia Isogrid Fairing.
Orbit	833 km (450 nmi) Sun Synch	833 km (450 nmi) Sun Synch	833 km (450 nmi) Sun Synch
Nodal Times	Any: Ascending or Descending	Any: Ascending or Descending	0600 - 1000 Descending or 1400 - 1800 Ascending
Spacecraft Sun Angle	0 to 1.7 rad (0 to 95 deg)	0 to 1.2 rad (0 to 70 deg) Selectable 1 to 1.7 rad (55 to 95 deg) before launch	0 to 1.2 rad (0 to 68 deg)
Lifetime	2 years	2 years	2 years
Attitude Control	Primary (Classified)	Primary (Classified)	±0.02 rad (±1 deg) Control ±3.5 mrad (±0.2 deg) Prediction for 12 hours
	Backup (Classified)	Backup (Classified)	1.7 mrad (0.1 deg) Knowledge
	(Classified)	(Classified)	0.6 mrad/s (0.035 deg/s) rate (Pitch and Yaw) 0.3 mrad/s (0.015 deg/s) rate (Roll)
Load Power Req. (Orbit Average)	280 W	370 W	330 W Baseline 425 W Growth
Weight	< 467 kg (1030 lb)	< 649 kg (1430 lb)	< 1225 kg (2700 lb) ≈ 680 kg (1500 lb)
Command	S-Band SGLS 1 kbps	S-Band SGLS 1 kbps Additional Redundancy	VHF SGLS 1 kbps
Telemetry Processing	Non-Redundant	Completely Redundant	Completely Redundant
Communication Links	Real Time S-Band 1 Mbps Serial Playback (High Power) S-Band (1-2.7 Mbps) Serial Playback (Low Power) S-Band (1-2.7 Mbps) TLM S-Band (2, 10, or 60 kbps)	Real Time S-Band 1 Mbps Serial Playback (High Power) S-Band (1-2.7 Mbps) Serial Playback (Low Power) S-Band (1-2.7 Mbps) TLM S-Band (2, 10, or 60 kbps) Real Time Sounder UHF 1 kbps	Real Time S-Band 667 kbps Dual Playback S-Band (2.7 Mbps) each Real Time VHF 2 kHz Real Time TLM ≈8 kbps VHF and Low Rate Data
Central Ground Station	Two in Continental U.S.		Two CDA's One European Station
Data Processing	GFE	GFE	Non-Redundant Processor for 5-Channel AVHRR 667 kbps 67 kbps 2 kHz Redundant Processor for Low Rate Sensor Plus TLM 8320 kbps
Recording	GFE Four Recorders at 1.6 x 10^9 bits	GFE Four Recorders at 1.6 x 10^9 bits	10 Minutes - 667 kbps 428 Minutes - 67 kbps 220 Minutes - 8320 bps Four Recorders at 1.6 x 10^9 bits
Instruments	Unique	Unique	Unique
Growth			Growth MSU HIRS Five channels AVHRR ESMR Real Time Temperature Profiles

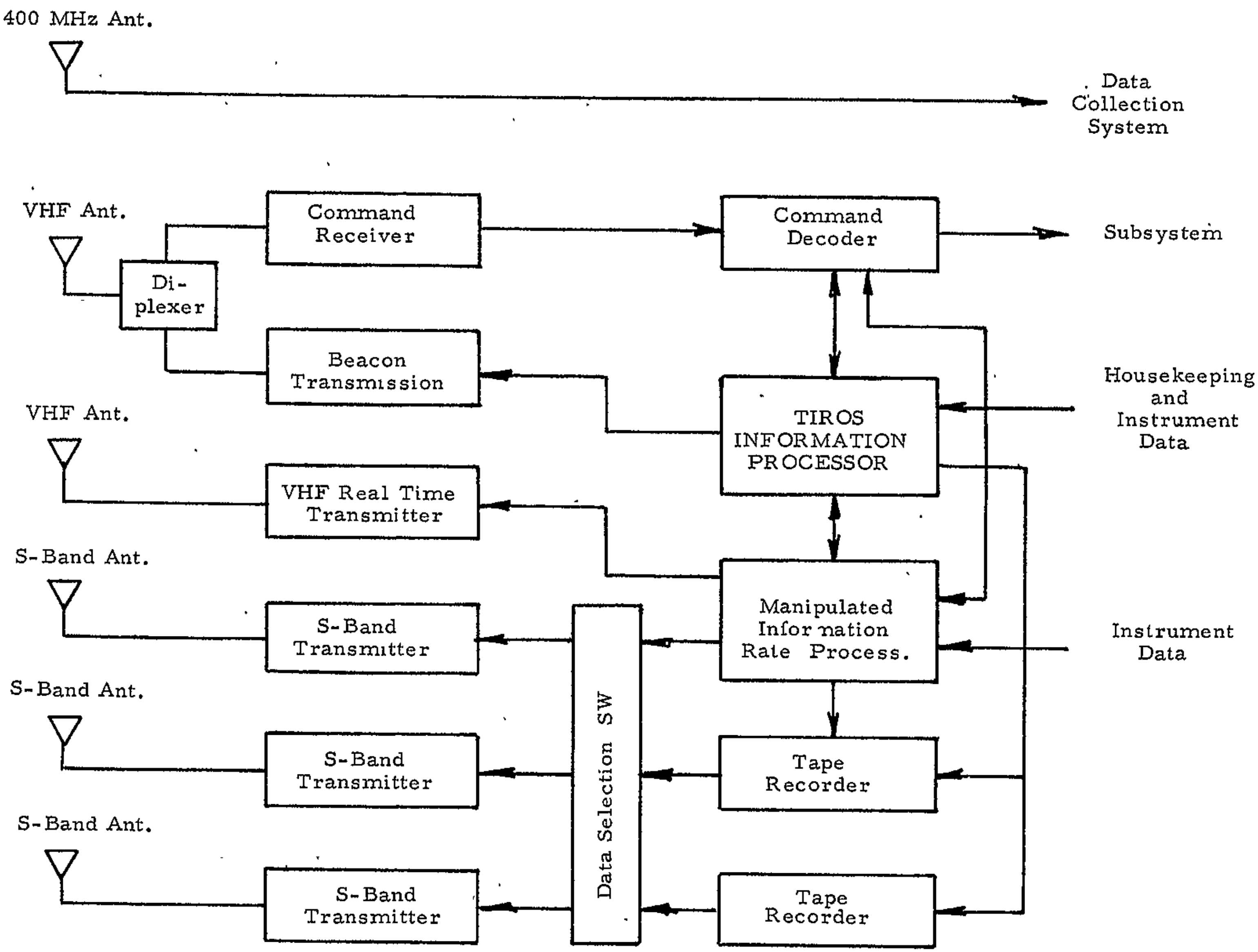


Figure 7.3.2 Communication and Data Handling Subsystem Block Diagram

c. Telemetry. There are five telemetry downlinks on the vehicle. The beacon downlink contains 60 kbps during launch and 8.32 kbps during orbital operations. The information on this link is housekeeping, command verification, and some sounder data. The modulation scheme is PSK/PM. The beacon transmits continuously from launch. The VHF real-time link has a 2.4 kHz subcarrier which is AM modulated. This subcarrier in turn FM modulates the carrier. This link is on continuously after orbit injection. There are three S-band downlinks. One of these transmitters will run continuously and transmit real-time data and the other two will transmit tape recorder dump data. The real-time data will PSK/PM modulate the carrier at a bit rate of 660 kbps. It will be read out at various High Resolution Picture Taking (HRPT) and Automatic Picture Taking (APT) ground stations each of which has about a 3 m (10 ft) and 31 dB gain dish at 1,700 MHz. One of the other links will transmit at a 160 kbps rate to either the HRPT, APT, or the Command and Data Acquisition (CDA) ground stations. The third link will transmit at either 1.33 Mbps or 2.66 Mbps rates to the CDA ground stations at Gilmore Creek, Alaska and Wallops Island, Virginia. The modulation scheme on these two links is PSK/PM also. Actually, the three S-band transmitters will be cross-strapped such that any of the bit streams can be switched by command to any transmitter. The power output from each transmitter is 5 W.

7.4.1 S-Band Transmitters

The requirements are:

a. Frequency band: 1695 - 1710 MHz

b. Frequency Stability: $\pm 2 \times 10^{-5}$

c. Power Output: 5 W

d. Modulation: PSK

e. Bandwidth (with Doppler): ≤ 3 MHz

f. Baseband: 160 kbps, 660 kbps, 1.33 Mbps, and 2.66 Mbps

g. Spurious PM: ≤ 5 deg rms

h. AM Noise: ≤ 5 percent

i. Duty Cycle: 1 unit 100 percent, 2 units 10 percent

j. Number Required: 3

There are no transmitters in the catalog that will meet the above requirements. RCA documentation (Ref. 16) indicates they were planning to modify the DMSP transmitters for this application but in discussions with NASA, it was stated that RCA has abandoned this plan and will go out for a new design. Apparently the modifications necessary, primarily a change from the 2200-2300 MHz band to the 1697-1710 MHz band, would be too extensive.

7.4.2 VHF Real-Time Transmitter

The requirements are:

a. Frequency: 137.5 and 137.62 MHz
b. Frequency Stability: $\pm 2 \times 10^{-5}$
c. Output Power: 5 W
d. Modulation: Carrier FM; Subcarrier AM
e. Bandwidth (with Doppler): ≤ 50 kHz
f. Modulation Index: Carrier 17 kHz, peak; Subcarrier ≤ 92 percent
g. Subcarrier Frequency: 2.4 kHz
h. Residual FM Noise: 340 Hz peak-to-peak
i. AM Noise: ≤ 5 percent
j. Duty Cycle: Continuous
k. Number Required: 2

The ITOS-D (N4-4-3) VHF real-time transmitter is the only one in the catalog that will come near meeting the above requirements and it will require some modifications. The characteristics of this unit are as follows:

a. Frequency: 137.5 and 137.62 MHz
b. Frequency Stability: 5×10^{-5}
c. Output Power: 5 W minimum
d. Modulation: FM
e. Bandwidth: 4.2 kHz
f. Modulation Index: Not Specified
g. Residual FM Noise: 60 Hz
h. AM Noise: Not Specified

The modifications necessary are the bandwidth and frequency stability. The bandwidth modification probably only involves filter changes. The stability requirement may be waived as the 2×10^{-5} may be an arbitrary number. It will depend entirely on the ground station requirement. If the modification is necessary it will require a new crystal which will probably require requalification.

7.4.3 Beacon Transmitter

The requirements are:

a. Frequency: 136.77 MHz
b. Frequency Stability: $\pm 2 \times 10^{-5}$
c. Output Power: 0.5 W
d. Modulation: PSK/PM
e. Bandwidth (with Doppler): $\leq$30 kHz
f. Modulation Index: $\pm 72^{+0}_{-5}$ deg, peak
g. Data Rate: 8.32 and 60 kbps
h. Spurious PM: $\leq$1.5 deg rms
i. AM Noise: $\leq$5 percent
j. Duty Cycle: Continuous
k. Number of Units: 2

There is no transmitter in the catalog that meets the above requirements. A new unit will have to be developed.

7.4.4 Command Receiver

The requirements are:

a. Frequency: 148.56 MHz
b. Frequency Stability: $\pm$2 kHz
c. BER: 10^{-6} at -88 dBm
d. Dynamic Range: -88 to -8 dBm
e. Noise Figure: $\leq$7 dB
f. Unsquelch Level: 9 dB

g. Modulation: Carrier AM
Subcarrier Data 1,000 bps ternary FSK
Clock AM on subcarrier

h. Modulation Index: Carrier 85 ± 5 percent
Clock 50 percent

i. IF Bandwidth: ≥ 42 kHz

j. Clock Rate: 1,000 Hz sinewave

k. "1": 8 kHz

l. "0": 12 kHz

m. "S": 10 kHz

No receiver in the catalog meets the above requirements. None of the NASA programs utilize the ternary system. Several of the receivers meet or nearly meet the requirement from the front end to the IF but none meets the requirements past the IF. This will have to be a new development.

7.4.5 Antennas

There are six antennas on this vehicle. This includes three S-band, one VHF real-time, one beacon/command, and one data acquisition antenna. The requirements for each of these are delineated in the RCA documentation. According to these requirements, there are no antennas in the catalog that can be used for these functions.

7.4.6 Command Decoder

No requirements have been given in the RCA documentation. The DMSP Program Office advises that there are about 800 real-time and 800 stored program commands, each 25 bits in length. RCA states that they are going to use the DMSP Controller Interface Unit (CIU) for the decoder function and a DMSP computer for the stored commands. The data sheet in the catalog on the CIU does not provide sufficient technical data on the capability of the unit. Without requirements or details on the CIU it is not possible to select a candidate for a decoder for this program.

7.4.7 Tape Recorder

The requirements and performance characteristics of the DMSP (D7-4-5) recorder are as follows:

a. Record Rates: 66.56, 665.6, and 1331.2 kbps
b. Input Data Format: NRZ-L
c. Record Time: 400, 40, or 20 min.
d. Total Storage: 1.7×10^9 bits
e. Record/Reproduce: 40:1/2:1
f. Reproduce Time: 20 or 10 min.
g. Reproduce Rate: 1331.2 kbps or 2662.4 kbps

The requirements for TIROS-N correspond to the characteristics of the DMSP recorder (D7-4-5).

7.4.8 Digital Telemetry Unit

Requirements were not provided for a DTU. The TIROS Information Processor (TIP) and the Manipulated Information Rate Processor (MIRP) will handle this function. Both have memory storage and computational capabilities. Stored program commands will be stored in either one or the other of these units. The RCA documentation gives considerable detail as to how the TIP and the MIRP work. As nearly as can be ascertained, both of these units appear to be new development.

8. COST ESTIMATES FOR NEW STARTS

The basic concept used in performing cost analysis in this study is to prepare estimates for a baseline new start spacecraft, assuming that all of the components and subsystems must be fully developed according to normal procedures, and alternatively, for new starts where it is planned that as many components as possible would be used from previously-developed spacecraft. The SCM* is used to produce estimates that cover DDT&E and unit (recurring) cost in terms of constant 1975 dollars for all cases.

DDT&E is taken to include engineering design, development, test (including qualification testing), and evaluation. In addition, it includes tooling, ground support equipment (GSE or AGE), and the manufacture of any qualification units. Recurring unit cost includes fabrication, assembly, inspection and acceptance testing labor as well as materials, subcontract, and production engineering (or sustaining engineering) effort. It has been assumed that only one article for qualification and flight is needed for all new starts. Spacecraft related costs only are included. For example, checkout and testing of spacecraft at the launch site is included in the recurring cost, but launch vehicle costs are excluded. Contractor fee (or profit) is included, but is shown as a separate category. The model treats mission equipment as a throughput (i.e., all mission equipment related costs are estimated outside of the model); hence, output equals input. For purposes of cost analysis, it has been assumed that mission equipment remains unchanged between baseline and alternative cases.

A summary of costs for the baseline case and all alternative cases for each new start is presented in this section. Detail cost breakdowns can be found in the Appendixes D through G. Detail breakdowns include the basic computer output as well as the component-oriented output for each case, examples of which were previously shown in Figures 2.3 and 2.4 respectively.

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* The SCM is described in Section 2.4.

The component-oriented outputs contain listings by subsystem of components that have been selected to meet the requirements of each particular design. Quantities and weights are shown along with cost and other pertinent data; however, it should be noted that certain components in the listings may not be exactly the same as those described in the technical discussion in Section 3 because a few components have not been entered in the SCM data base. Whenever particular components were missing from the data base, a substitution was made that most nearly approximated the desired item. In no case did such substitutions have any appreciable effect on the analysis.

8.1 LST COST ESTIMATES

Table 8.1 contains a summary of costs together with the possible savings that could be realized by using LST alternative concepts to the baseline case. The table presents cost estimates with and without the effect of mission equipment cost. Detail breakdowns are in Appendix D.

Six cases are considered: the baseline and five alternatives. The alternatives deal with differing combinations of components within a particular subsystem. For example, Lo Cost (RW-EP2) covers an LST configuration that uses previously-developed hardware to achieve a Lo Cost design but replaces a control-moment gyro (CMG) with a reaction wheel (RW) type of stabilization and control subsystem and replaces a series load regulation (EPI) with a discharge regulation (EP2) electrical power subsystem.

A comparison of total program costs for the various alternatives presented in Table 8.1 reveals that savings could be approximately 12 to 14 percent compared to a normal satellite program represented by the LST baseline. The fact that total satellite costs form the basis for comparison may obscure a more realistic appraisal of possible savings because mission equipment cost, which is substantial, is included in total cost but plays no part in generating possible savings. Accordingly, a second set of numbers is included in Table 8.1 that shows possible savings when mission equipment cost is excluded from consideration. The second set of numbers produces savings estimates that fall between 30 and 40 percent of spacecraft total

Table 8.1 LST Cost Estimates

Cost Including Mission Equipment

LST Configuration	DDT&E Cost	Unit Cost	Total Cost	Cost Savings	% Savings
LST Baseline	392.1	165.8	557.9		
Lo Cost (CMG-EP1)	346.5	146.2	492.7	65.2	11.7
Lo Cost (RW-EP1)	345.1	139.7	484.8	73.1	13.1
Lo Cost (CMG-EP2)	343.8	143.2	487.0	70.9	12.7
Lo Cost (RW-EP2)	342.4	136.7	479.1	78.8	14.1
Lo Cost (RW-EP3)	341.2	136.7	477.9	80.0	14.3

Cost Excluding Mission Equipment

LST Configuration	DDT&E Cost	Unit Cost	Total Cost	Cost Savings	% Savings
LST Baseline	142.1	65.8	207.9		
Lo Cost (CMG-EP1)	96.5	46.2	142.7	65.2	31.4
Lo Cost (RW-EP1)	95.1	39.7	134.8	73.1	35.1
Lo Cost (CMG-EP2)	93.8	43.2	137.0	70.9	34.1
Lo Cost (RW-EP2)	92.4	36.7	129.1	78.8	37.9
Lo Cost (RW-EP3)	91.2	36.6	127.8	80.1	38.5

cost. If DDT&E and unit cost subcategories are considered separately, potential savings percentages of 32 to 36 for DDT&E and 30 to 44 for unit cost are observed.

The basic conclusion that can be drawn from an examination of the figures in Table 8.1 is that when previously-developed components are used in an LST design, total satellite program costs could possibly be decreased by more than 10 percent; 30 percent for spacecraft only. Additional savings could materialize if the types of alternative subsystems listed for LST were considered in tradeoff studies; however, the relatively minor increases in potential savings must be weighed against any uncertainties and technological risks that such alternatives might entail. Finally, substantial unit (recurring) cost savings appear to be a prospect for the LST (but not for the other satellites considered in this section).

8.2 HCMM COST ESTIMATES

Table 8.2 contains cost estimate summaries for six HCMM cases; Appendix E provides detail cost breakdowns. Of the six alternative cases considered, two include baseline designs--one for the HCMM that uses a single scan wheel and another that substitutes a SAGE type two-scan wheel system in stabilization and control. (The HCMM/SAGE design is overweight from a technical standpoint but is included for cost comparison.) Two electrical power alternatives are also treated. The figures in Table 8.2 show program cost savings of approximately 15 to 20 percent for Lo Cost type designs, i.e., designs that use previously-developed components. Note that cost savings for the 3rd and 5th cases are calculated from the HCMM baseline (with the single scan wheel) and the 4th and 6th cases use the HCMM/SAGE baseline. If only the spacecraft portion of program costs is considered as a base, potential savings are 25 to 30 percent. Unlike the previous LST comparison, DDT&E is the major contributor to cost savings for HCMM.

Table 8.2 HCMM Cost Estimates

Cost Including Mission Equipment

HCMM Configuration	DDT&E Cost	Unit Cost	Total Cost	Cost Savings	% Savings
HCMM Baseline	61.2	14.1	75.3		
HCMM/SAGE Baseln	54.0	15.1	69.1		
Lo Cost - (1 SW)	47.1	13.0	60.1	15.2	20
Lo Cost - (2 SW)	44.9	13.5	58.4	10.7	15
Lo Cost - (1 SW-EP2)	46.6	12.9	59.5	15.8	21
Lo Cost - (2 SW-EP2)	44.4	13.5	57.9	11.2	16

Cost Excluding Mission Equipment

HCMM Configuration	DDT&E Cost	Unit Cost	Total Cost	Cost Savings	% Savings
HCMM Baseline	42.2	10.6	52.8		
HCMM/SAGE Baseln	35.0	11.6	46.6		
Lo Cost -(1 SW)	28.1	9.5	37.6	15.2	29
Lo Cost -(2 SW)	25.9	10.0	35.9	10.7	23
Lo Cost -(1 SW-EP2)	27.6	9.4	37.0	15.8	30
Lo Cost -(2 SW-EP2)	25.4	10.0	35.4	11.2	24

The basic conclusions that can be drawn from the figures in Table 8.2 are that program savings could approximate 20 percent (30 percent for spacecraft only) and that such savings stem principally from the development cost category.

8.3 SAGE COST ESTIMATES

Five alternative cases are considered for the SAGE program. Table 8.3 contains the pertinent data from which approximations of potential cost savings can be made. Appendix F provides detail breakdowns. Cost estimates for all five cases, including the baseline, are based on the assumption that the HCMM program precedes SAGE and that the HCMM stabilization and control and electrical power subsystems can be used on SAGE. Thus, the SAGE baseline may be a misnomer because it includes previously-developed components and potential savings are relatively low compared with those for the other programs. Program savings could be as high as 15 percent; spacecraft savings could be over 20 percent. Again DDT&E contributes the major share of potential savings.

8.4 SMM COST ESTIMATES

Three cases are presented for the SMM as shown in Table 8.4 The detail breakdowns can be found in Appendix G. Program savings appear to be between 15 and 20 percent; spacecraft savings could be approximately 25 percent. Unit cost contributes to total estimated savings but the largest share is attributable to DDT&E.

8.5 OBSERVATIONS

For the satellite programs treated in this section, it appears that a case can be made for expecting cost savings that range from 10 to 20 percent if components from previously-developed spacecraft are used in new start designs. If the spacecraft only is considered, values of 20 to 40 percent may be achievable. The latter figures may represent a more straightforward set of values because they are based on costs that exclude mission equipment, which is not treated in this analysis. It must

Table 8.3 SAGE Cost Estimates

Cost Including Mission Equipment

SAGE Configuration	DDT&E Cost	Unit Cost	Total Cost	Cost Savings	% Savings
SAGE Baseline	39.6	14.3	53.9		
Lo Cost	33.0	13.6	46.6	7.3	14
Lo Cost-(AP/CG)	33.7	14.1	47.8	6.1	11
Lo Cost-(AP/HCMM)	31.9	13.7	45.6	8.3	15
Lo Cost-(EP2)	32.8	13.5	46.3	7.6	14

Cost Excluding Mission Equipment

SAGE Configuration	DDT&E Cost	Unit Cost	Total Cost	Cost Savings	% Savings
SAGE Baseline	23.0	11.9	34.9		
Lo Cost	16.4	11.2	27.6	7.3	21
Lo Cost-(AP/CG)	17.1	11.7	28.8	6.1	17
Lo Cost-(AP/HCMM)	15.3	11.3	26.6	8.3	24
Lo Cost-(EP2)	16.2	11.1	27.3	7.6	21

Table 8.4 SMM Cost Estimates

Cost Including Mission Equipment

SMM Configuration	DDT&E Cost	Unit Cost	Total Cost	Cost Savings	% Savings
SMM Baseline	103.3	40.2	143.5		
Lo Cost	86.0	35.6	121.6	21.9	15
Lo Cost-(EP2)	83.2	35.4	118.6	24.9	17

Cost Excluding Mission Equipment

SMM Configuration	DDT&E Cost	Unit Cost	Total Cost	Cost Savings	% Savings
SMM Baseline	68.9	21.9	90.8		
Lo Cost	51.6	17.3	68.9	21.9	24
Lo Cost- (EP2)	48.8	17.1	65.9	24.9	27

be remembered that the baseline estimates in most cases represent normal full development programs and that many current programs often take advantage of prior developed hardware. Accordingly, the cost saving percentages presented in the tables are thought to represent upward boundaries.

9. CONCLUSIONS

The study has indicated that a very high percentage of the housekeeping components can use flight-proven hardware if a complement of equipments, as provided in the equipment compendium, is available. Furthermore, the usage of developed hardware appears to be attainable with not-too-extensive modifications to the components for most of the selected equipments. Of the components that were selected from the catalog for use in NASA new starts, the distribution between the components that were developed by DoD and NASA were about equal. This strongly suggests that components can be transferred between programs and not be limited to contractors, centers, or agencies.

Significant savings came from applying the catalog of developed components to the baseline. The sensitivity of alternative designs to increase the use of developed components was not productive in providing additional savings. The increase in the use of developed units from those selected in the baseline was very nominal and the added savings were very small. The possible savings were increased from an average of 26 to 30 percent for the alternate.

In the following subsections, the data are summarized to show how the above conclusions were reached. The study excludes structures and thermal control as housekeeping components. The TIROS-N is not included among the cost analyses of LST, HCMM, SAGE, and SMM new starts because no additional flight-proven components could be selected over the contractor-configured spacecraft. The TIROS-N spacecraft is basically the DoD/DMSP spacecraft except for the CDH subsystem. The use of catalog components did not increase the number of flight-proven hardware in the CDH subsystem beyond the contractor study.

9.1 USAGE OF DOD AND NASA COMPONENTS

DoD and NASA flight-proven components that are listed in the equipment compendium (catalog) can provide up to 61 percent of the hardware for the four new starts. Of the selected components, 35 percent were DoD and 26 percent were NASA-developed units. The catalog from which the selections were made contains 202 DoD and 198 NASA components.

The NASA standard equipments that are documented in the LCS Standard Equipment Announcement and equipments from other current programs that have not been cataloged, provided an additional 11 percent of flight-proven components. The balance of 28 percent to complete the housekeeping component is new development hardware. The distribution of components between the four new starts and sources providing the developed hardware are shown in Table 9.1. Also shown in the table is the hardware usage for the alternate configuration. The baseline configuration is the spacecraft design that meets the subsystem requirements in the manner desired by the program, whereas the alternate configuration meets most of the requirements.

It should be recognized that the study intent is to provide data to determine the influence of flight-proven hardware on cost savings; it is not intended to be an optimization effort. As an example, HCMM and SAGE have a weight constraint which has been exceeded slightly when developed components were selected. Design tradeoffs to optimize the system configuration to reduce weight were not conducted in this study.

9.2 COMPONENT MODIFICATIONS

Component selections were made by examining the key technical characteristics as to their ability to provide the required functions. The modifications were identified to the extent of providing the required functions. As an example, a redesign may involve modifying a filter in a receiver, or a repackaging may involve removing one of three sections from a power converter. It was assumed that any changes for environmental criteria, electrical connectors, electrical match up, signal levels, mechanical mountings, and thermal interface can be integrated into the subsystem with no cost impact. Based on this ground rule, the levels of modifications were indicated on each component to provide the information to estimate the component DDT&E cost. The cost schedule to go along with the changes is described in Section 2.5. The method supplied a uniform estimating approach across all of the new starts. A summary of the number of

Table 9.1 Distribution of Developed Component Usage

(A) Baseline Configuration

NEW STARTS	CATALOGED		NASA STD.	OTHER DEV'D HDWE.	NEW DEV.	TOTAL COMP.
	DOD	NASA				
LST	13	5	2	5	10	35
HCMM	8	10	0	2	8	28
SAGE	9	9	1	0	3	22
SMM	12	8	1	3	13	37
Total	42	32	4	10	34	122
Percentage	35	26	3	8	28	100

(B) Alternate Configuration

NEW STARTS	CATALOGED		NASA STD.	OTHER DEV'D HDWE.	NEW DEV.	TOTAL COMP.
	DOD	NASA				
LST	14	5	2	4	9	34
HCMM	9	10	0	2	7	28
SAGE	10	9	1	0	3	24
SMM	13	8	1	3	11	36
Total	46	32	4	9	30	122
Percentage	38	26	3	7	25	100

modifications, according to source of hardware, is shown in Table 9.2. Over 40 percent of the cataloged candidate components can be used with less than 10 percent DDT&E and 18 percent of the cataloged components selected will require modifications greater than 10 percent DDT&E. Based on this distribution, 70 percent of the components from the catalog can be used "as is" and 30 percent will require over 10 percent modification. The data also indicate that 50 percent of the housekeeping components can be employed with less than 10 percent component modification under the definition of this study.

Table 9.2 Component Modifications

NEW STARTS	NO MODIFICATION DDT&E < 10%		SOME MODIFICATION DDT&E. > 10%		NEW DEVELOP.
	Catalog	Other Source	Catalog	Other Source	
LST	12	4	6	3	10
HCMM	12	2	6	0	8
SAGE	13	1	5	0	3
SMM	15	2	5	2	13
Total	52	9	22	5	34
Percentage	43	7	18	4	28

9.3 DEVELOPED COMPONENT DISTRIBUTION

The distribution of developed components between subsystems provides further information on commonality between agencies. In general, the DoD programs are earth-directed missions and NASA programs are space-directed missions. This basic mission difference results in more NASA components in the stabilization subsystem than DoD components for

NASA new starts; however, the other subsystems are not as mission oriented. They are the propulsion, electrical power, and communication which shows more DOD candidates than NASA components. The distribution by subsystems is shown in Table 9.3. The percentage of flight components from the catalog for propulsion, electrical power, and communication is 96, 71, and 51 percent, respectively.

Table 9.3 Developed Components Distribution Between Subsystems

BASELINE	DOD	NASA	TOTAL SELECT.	TOTAL COMPONENTS	%
SC	6	8	14	32	44
AP	13	10	23	24	96
EP	8	4	12	17	71
CDH	15	10	25	49	51
TOTAL	42	32	74	122	61

9.4 COST SAVINGS

The cost savings from using over 70 percent of the developed components have produced an average spacecraft cost reduction of approximately 26 percent for the baseline configuration. The mission equipment cost is not included in the percentage. The baseline cost for "business as usual" is primarily an estimate with all new components. The baseline cost for "Low Cost" is the use of flight-proven hardware as selected candidates in this study from the catalog, NASA standard equipment, and other developed hardware sources. The difference is the baseline cost savings. The major portion of the savings (76 percent) comes from the reduction in component DDT&E and the balance comes from reduction i·

the unit recurring cost (24 percent). Lower unit recurring cost savings result from the learning curve, i.e., production line for the unit exists.

The savings in going from baseline to alternate configuration is relatively low. The alternate configurations did not produce a significant increase in the usage of flight-proven components. This is primarily due to the alternate configurations being limited to varying only the electrical power and stabilization subsystems. Communication subsystems could not be altered because the parameters were such that only one basic configuration could be considered in meeting the network and data rate requirements. There was no advantage in reconfiguring the propulsion since the baseline could be configured with all flight-proven units. Reconfiguring would not increase the percentage but could change the weight.

The cost savings is summarized in Table 9.4. The percent savings is based on one flight unit and total program cost without mission equipment. The total savings for the four new starts which exceeds $100M should be accepted as maximum amount, i.e., optimistic savings. The fifth new start studied was not included in the cost analysis since the spacecraft is basically a DoD configuration except for the CDH subsystem. This approach of using an existing spacecraft maximizes the use of flight-proven hardware.

Table 9.4 Summary of Cost Savings

NEW STARTS	DDT&E		UNIT		TOTAL	
	Savings $M	% Savings	Savings $M	% Savings	Savings $M	% Savings
LST						
Baseline	45.6	32	19.6	30	65.2	31
Alternate	50.9	36	29.2	44	80.1	39
HCMM						
Baseline	14.1	33	1.1	10	15.2	29
Alternate	14.6	35	1.2	11	15.8	30
SAGE						
Baseline	6.6	29	0.7	6	7.3	21
Alternate	7.7	33	0.6	5	8.3	24
SMM						
Baseline	17.3	25	4.6	21	21.9	24
Alternate	20.1	29	4.8	22	24.9	27
Baseline	83.6	30	26.0	17	109.6	26
Alternate	93.3	33	35.8	21	129.1	30

APPENDIX A

SC DESIGN CONSIDERATIONS FOR THE HCMM BASE MODULE

A.1 INTRODUCTION

This analysis addresses preliminary attitude and velocity control system design considerations of the heat capacity mapping mission (HCMM) base module. The base module must accommodate two payloads: (1) the heat capacity mapping radiometer (HCMR), and (2) the stratospheric aerosol and gas mission (SAGM)* sensor.

The HCMM mission requires a 600 km (324 nmi), 89 deg inclined, sun synchronous orbit. It has a 70 m/sec velocity requirement for the purpose of circularizing the orbit and changing the average altitude. These velocity requirements necessitate a propellant with high specific impulse such as hydrazine.

The specification requires that the SC have automatic acquisition capability. Reacquisitions must be performed within one day. The specification demands autonomous control, i.e., "Perform Initial Despin, Acquisition, and Reacquisition in a Closed-Loop Fashion..."; and "Perform Fine Control in a Closed-Loop Fashion..." The specification (Reference 11) suggests a three-axis momentum bias system be used to provide this control.

The solar, aerodynamic, and gravity gradient torques are negligible for this orbit. The primary disturbance torques are: (1) the magnetic dipole of the payload reacting with the earth's magnetic field; and (2) a cooling system failure of the payload producing a torque through one orbit. Other sources of disturbances include various residual angular momentum sources on the payload.

The SAGE mission uses the HCMM base module in a 600 km (324 nmi) 50 deg inclined orbit. The SC requirements for SAGE are similar

*This experiment has the acronym SAGE.

to the HCMM mission with the exception of the delta V requirement. The primary sources of distrubances for SAGE are payload residual angular moments and magnetic dipole.

In the following section, an acquisition sequence is developed that meets the requirements of the specification in that it requires minimal ground base interaction. In Section A. 3 the mass properties and disturbance models are used to size SC subsystem components which meet the specifications.

A. 2 ACQUISITION SEQUENCE

The HCMM vehicle will be launched by a four-stage Scout F launch vehicle into the 600 km (324 nmi) circular, nearly polar, sun synchronous orbit. The injection point will be on the dark side of the earth for this orbit, which has a 30-deg vehicle-earth-sun angle on the ascending node. The vehicle and fourth stage are spin-stabilized at 90 rpm prior, during, and 320 ± 20 sec after the burn. Subsequent to spin-up, the SC is required to provide a spin speed measurement. It is assumed that this measurement can be performed on the light side via a spinning sun sensor.

Due to the mass properties of the payload, the spin axis of the vehicle will be the axis of minimum inertia (prior to solar array development). To avoid a buildup in transverse rate, the despin should be initiated during the first orbit after injection. The despin will be done closed loop via a rate gyro. The gyro, whose range must be limited for subsequent use in acquisition, will be initially saturated and must be capable of withstanding the 9.4 rad/s (540 deg/sec) of the spinning phase. A closed-loop design is desirable, since ground station passes are limited to 5 to 10 min for telemetry and less for commands.

Following despin and subsequent array deployment, the remainder of the mission will require earth pointing for both the HCMM and the SAGE missions. The orbital coordinate frame for these missions has the Z-axis pointing to nadir, the X-axis along the velocity vector, and the Y-axis completing the right-hand triad. The payload is mounted on the +Z vehicle axis. Fine pointing for these missions requires aligning the vehicle coordinate frame with this orbital coordinate frame.

Each mission requires a differing payload FOV. The HCMM mission maps the heat capacity by rotating its scanning sensor head about the X-axis while looking out of the Z-axis. During the SAGE mission, its payload scans the horizon by rotating the scanning head about the vehicle Z-axis. Accommodating both of these FOV requirements necessitates that the base module not have any structure interfering with these FOVs. Since the primary attitude sensing device will be an earth sensor, these FOV requirements necessitate that the sensor be mounted on the base module itself. This assumes that payload mounting of the sensor is structurally impossible and undesirable. A scanning wheel earth sensor can be used to determine earth referenced attitude from a base module mounted location.

A.2.1 HCMM Acquisition

The HCMM mission, due to its sun-stationary orbit, lends itself to an acquisition sequence beginning with a sun acquisition, followed by a transfer to earth point when the vehicle Z-axis is 30 deg relative to nadir. At equinox, this would correspond to the ascending node of the orbit.

After despin, the vehicle will have residual rates and an arbitrary orientation. To acquire the sun from these initial conditions, the sun sensor requires a 4π steradian FOV.

The earth sensor must also have a wide FOV, since its radius at 600 km (324 nmi) altitude is 1.15 rad (66 deg) (horizon-to-horizon half cone angle). But, to stay within the FOV constraints of the payload, the sensor will of necessity be mounted on the base module. Either a conical scan or a radiance-balance sensor would be suitable. However, the radiance balance type would have to be mounted around the periphery of the payload, necessitating rather complex thermal compensation in the processing electronics; hence, the conical scan is favored.

The three-axis controller used for the fine pointing phase of the mission requires a yaw reference to be supplied by momentum bias or a star tracker. The momentum bias approach is favored for its simplicity, ease of acquisition, and flight-proven performance. Hence, the wheel control configuration, consisting of roll/yaw offset thrusters for roll control and variable speed wheel for pitch control, was chosen for the fine pointing phase of the mission.

The conical scanning earth sensor has a large weight penalty associated with it, as does the wheel. The two are combined in the form of a scanning wheel with momentum bias. To obtain earth sensor signals the wheel must be spun up prior to earth acquisition. A single wheel-mounted scanning earth sensor provides only one axis of information unless the earth chord is fixed (i.e., constant altitude). This acquisition sequence is adjusted to accommodate this limitation.

Since the vehicle acquires the earth with an arbitrary yaw error, this yaw error transfers to a roll error in a quarter orbit and is removed by the roll controller at that time. Since the error could be large, the acquisition thrusters rather than the roll/yaw thrusters should be used during the first orbit after earth acquisition.

Table A-1 summarizes the acquisition sequence suggested for HCMM. Reacquisitions would begin at sun acquisition and proceed through to earth fine pointing.

In addition to the operational features given in Table A-1, the HCMM mission requires periodic velocity (delta V) corrections to maintain the orbit. This delta maneuver can be performed using the earth point mode in conjunction with the rate gyro, as described in Section A.3.

A.2.2 SAGE Acquisition

The SAGE mission utilizes a 600 km (324 nmi) circular orbit, inclined 50 deg with respect to the equatorial plane. For this orbit an acquisition sequence beginning with a sun acquisition works rather well when the ascending node coincides with noon spacecraft time. However, for any other times of the year, a single scan wheel/earth sensor would not always be able to determine a unique two-axis earth sensor output while sun pointing. This ambiguity can be overcome by adding an additional scanner wheel, as described in Reference 17. Using a dual scan wheel configuration with a full conical scan FOV also increases the earth range,

Table A-1 HCMM Acquisition Sequence

Step	Mission Phase	Vehicle Situation
1.	Despin	Yaw rate gyro reference despins the vehicle with yaw thrusters from 90 rpm to zero. Rate gyro holds vehicle yaw rate at null.
2.	Solar Array Deployment	Zero yaw rate.
3.	Sun Acquisition	From arbitrary initial conditions vehicle neg Z axis is pointed using pitch and roll thruster control.
4.	Reaction Scan Wheel Run-Up	After sun lock, wheel is run up to provide earth sensor signal.
5.	Earth Acquisition	Switch from sun sensor to earth sensor when the pitch error becomes small.
6.	Earth Point	Earth point for one orbit as yaw error is nulled. Rate gyro no longer controls yaw rate.
7.	Fine Earth Point	Spacecraft controlled in pitch by wheel, in roll by roll/yaw thrusters.

Table A-2 SAGE Acquisition Sequence

Step	Mission Phase	Vehicle Situation
1.	Despin	Yaw rate gyro reference, despin with yaw thrusters from 90 rpm to zero. Rate gyro holds vehicle at zero rate.
2.	Solar Array Deployment	Zero yaw rate.
3.	Reaction Scan Wheel Run-Up	Running up wheels rotates vehicle in pitch and provides earth sensor information
4.	Earth Acquisition	Acquire earth using roll and pitch earth sensor output to drive roll and pitch thrusters.
5.	Earth Point	Earth point for one orbit as the yaw error is nulled. Rate gyro and yaw thrusters are inoperative.
6.	Fine Earth Point	Spacecraft controlled in pitch and roll/yaw by two reaction wheels.

making a sun acquisition unnecessary. A full conical scan can be attained when the scan cone has a FOV which is clear of body structure.

Then the acquisition sequence, subsequent to despin, would begin with running up the two wheels. These wheels would be mounted such that the primary momentum component is along the vehicle pitch axis. Running up the wheels would in turn impart to the vehicle a rate about the pitch axis to maintain total momentum at zero. This rate would cause the vehicle to search for the earth by rotating about its Y axis. When the earth comes into the sensor field of view, the earth would be acquired automatically via commands generated by the control electronics. Fine earth pointing could be established after less than one orbit after the yaw error had been nulled. This acquisition sequence for SAGE is given in Table A-2.

A. 3 DESIGN CONSIDERATIONS

The configuration as defined in Section A. 2 is sized based upon the vehicle mass properties, disturbance torques, and the pointing accuracy requirements. These design considerations follow.

A. 3. 1 HCMM Design

The mass properties for the HCMM vehicle are given in Table A-3. The payload mass properties are taken from the specification while the vehicle is assumed to be a uniformly dense cylinder. Two solar arrays are used as described in the Electrical Power section. The mass properties are given for the vehicle before and after solar array deployment.

Table A-3 HCMM Mass Properties

Vehicle Configuration	Vehicle Inertias, kg ms^2 (slug ft^2)		
	I_x	I_y	I_z
Array Stowed	2.4 (17.5)	2.5 (18.1)	1.2 (8.84)
Array Deployed	5.9 (42.9)	2.2 (16.2)	4.7 (33.6)

Weight = 152 kg (337 lb)

During the spinning portion of the mission, the SC is required to supply a measure of spin speed within 0.5 rpm of the 90 rpm desired spin speed. The specification is not clear regarding the purpose of this measurement so we assume it is telemetry for ground information, and that it can be provided by a spinning sun sensor. The injection occurs on the dark side of the earth. Separation is delayed some 324 sec beyond injection and Scout burnout. Due to the unfavorable inertia ratio, separation and despin should occur within the first orbit to minimize coning burnups. The spin information can be delivered on the first telemetry pass over a station. The spinning sun sensor should have a π rad (180 deg) FOV so that the spin rate can be determined from large sun elevation angles.

The rate gyro used during despin should provide a saturated output during the spinning phase. This output can then be used to drive a bang-bang yaw-thruster control system. This provides an essentially open loop thruster despin command until the gyro comes out of saturation. When the gyro comes out of saturation a derived rate modulation feedback can be used to prevent overshoot of the zero rate point.

This rate gyro serves two other functions: preventing yaw rate build-up during sun acquisition and providing a yaw reference during velocity corrections. The latter places the most stringent requirements on its output characteristics. To maintain the yaw attitude within the specification value of 0.03 rad (2 deg) for 30 sec during delta V, the effects of drift rate and threshold must be less than 0.3 m rad/s (0.0167 deg/sec).

A wheel control type system is proposed for the fine pointing phase of HCMM. For details of this design procedure see Reference 18. For the wheel control system, the yaw error is fixed by the wheel momentum and the disturbance torques. For this orbit the torques generated by aerodynamic, solar, and gravity gradient forces are greatly surpassed by the magnetic dipole moment of the payload. This magnetic moment of 1000 pole cm (= 1000 Gauss - cm^3 = 1. A m^2) interacts with the earth's magnetic field to produce a maximum of 62 μNm (46 μ ft- lb) torque at the earth's magnetic pole. This torque is assumed inertially fixed. A smaller peak torque of 31 μNm (23 μ ft-lb) is obtained at the equator. Using the larger torque, the vehicle accumulates 62 mNms (46 m ft-lb-sec) of momentum per radian of orbital motion. The yaw error then will exceed the roll deadband by the ratio of this disturbance momentum divided by the bias momentum. Hence, a bias momentum of 5.4 Nms (4 ft-lb-sec) will produce a yaw deviation beyond the roll deadband of less than 0.02 rad (1 deg).

The purge transient will act to produce a torque in the roll/pitch plane. It acts 53.3 cm (21 in.) from the center of mass producing 0.17 Nms (0.126 ft- lb -sec) of body-fixed momentum in one orbit. A 10 percent control authority in pitch can easily tolerate the worst case combination of the transient and the magnetic torques.

The rate requirement of 0.17 m rad/s (0.01 deg/sec) for roll can be met by using a momentum correction of 0.01 Nms (0.0075 ft-lb-sec) or less. This momentum requirement can be met using a 0.45 N (0.1 lb) thruster acting on a 30 cm (1.0 ft) moment arm. During fine pointing and in the absence of on-board payload disturbances, yaw and pitch rates will be an order of magnitude below the specification.

The HCMM payload has a 0.4 Nms (0.3 ft-lb-sec) component of momentum along the X axis when the compensation motor is not on. This, of course, is an abnormal condition. When the compensation motor is on it cancels all but 0.02 Nms (0.015 ft-lb-sec) of this momentum. Using a 5.4 Nms (4 ft-lb-sec) pitch wheel results in a yaw error of 0.075 rad (4.3 deg) uncompensated, and 3.5 m rad (0.2 deg) compensated.

The specification requires that attitude measurements during fine control must be known to $\pm$ 8.7 m rad ($\pm$ 0.5 deg) about pitch and roll and $\pm$ 35 m rad ($\pm$ 2.0 deg) about yaw. The scanning earth sensor must provide the roll and pitch attitudes within this accuracy which should include alignment errors, null offsets, and random noise. While yaw has no reference source available directly, the vehicle bias momentum will hold it within 35 m rad (2 deg) of null during normal operation.

The total SC complement of equipment is given in Table A-4.

Table A-4 SC Components HCMM

Item	Accuracy	Comment
Spinning Sun Sensor	90 rpm, $\pm$ 0.5 rpm	π rad (180 deg) FOV
Yaw Rate Gyro	0.35 rad/s (20 deg/sec) $\pm$ 0.3 m rad/s (0.016 deg/sec)	Must withstand 9.4 rad/s (540 deg/sec)
Coarse Sun Sensor	4π steradian, $\pm$ 0.09 rad ($\pm$ 5 deg)	
Earth Sensor	0.79 rad (45 deg) scan cone, $\pm$6 m rad ($\pm$ 0.35 deg)	
Wheel	5.4 Nms (4 ft-lb-sec) nominal	+ 10% speed variation for pitch control

The thrusters required for HCMM include eight 1-lb thrusters for despin, acquisition, wheel unloading, and delta V plus two 0.44 N (0.1-lb) thrusters for fine pointing.

The fuel budget for HCMM includes the despin, an acquisition, four worst case reacquisitions, 70 m/s (230 ft/sec) total delta V, and one year of fine control using roll/yaw thrusters. The fuel required for this mission is calculated assuming a 152 kg (335 lb) spacecraft and a 0.3 m (1 ft) thruster moment arm. Acquisitions and reacquisitions require that 6.8 Nms (5 ft-lb-sec) of momentum be precessed 1.57 rad (90 deg) and zeroed. The results are shown in Table A-5.

Table A-5 HCMM Fuel Budget

Events	Impulse Ns (lb sec)
Despin	370 (83.3)
Acquisition	57 (12.8)
Reacquisition	229 (51.4)
Delta V	10644 (2393.)
Fine Point	7001 (1574.)
Margin	1870 (420.5)
Total	20172 (4535.)

A3.2 Modifications for the SAGE Mission

The mass properties for the SAGE mission are given in Table A-6. They are delivered for a configuration which includes four sun pointing solar arrays.

Table A-6 SAGE Mass Properties

Vehicle Configuration	Vehicle Inertia, $kgms^2$ ($slug\ ft^2$)		
	I_x	I_y	I_z
Array Stowed	2.4 (17.5)	2.5 (18.0)	1.2 (8.8)
Array Deployed	4.0 (28.7)	4.0 (29.1)	4.4 (32.1)

Weight = 161 kg (354 lb)

The disturbance torques for SAGE are due to magnetic dipole and aerodynamic forces. The dipole moment is 100 pole cm^3 producing peak torques of 6.2 Nm (4.6 ft-lb) at the earth's pole and 3.1 μNm (2.3 μ ft-lb) at the equator. The aerodynamic torques are on the order of 2.7 μNm (2 μ ft-lb). Then worst case torques are 8.9 μNm (6.6 μft - lb) in magnitude. There are a few negligible sources of residual angular momentum that are ignored in the following.

The vee wheel configuration suggested for SAGE, as described in Reference 17 has a momentum bias along the body Y axis provided by two reaction wheels. The wheels, mounted at an angle relative to the X-Y plane, each have a component along the Z axis that cancels when the wheels are at identical speeds. Then identical variations in wheel speeds control pitch attitude while differential variations control roll attitude. This method of control is used for fine pointing while thruster control is used to acquire and reacquire the earth.

The use of two scanning earth sensors also eliminates errors in roll due to altitude variations. This is important for SAGE since it has no orbit correction capability.

The disturbance torques for SAGE are much smaller than those of HCMM. As a result, the yaw error can be held to 4.3 m rad (0.25 deg) with a pitch momentum bias of 1 Nms (0.75 ft-lb-sec) from each wheel. A 0.035 rad (2 deg) control authority can be attained about roll by canting the wheels 0.35 rad (20 deg). This maximum authority coincides with one wheel 10 percent fast, the other 10 percent slow. This cant angle can be increased by up to 0.17 rad (10 deg) if need be, to clear body structure from the FOV of the scan wheel.

The disturbance torques have both inertially-fixed and body-fixed components. The body-fixed components require that some form of wheel momentum unloading be available along both the pitch and yaw axes. During periods of unloading, the thrusters are used to transfer momentum from the wheels creating body transients. Rate requirements are not met during unloading but are easily met for the remainder of the fine pointing portion of the mission.

The remainder of the mission SC equipment is the same as that required by HCMM. These are listed in Table A-7.

Table A-7 SC Component - SAGE

Item	Range and Accuracy	Comment
Spinning Sun Sensor	90 rpm, ± 0.5 rpm	rad (180 deg) FOV
Yaw Rate Gyro	0.35 rad/s (20 deg/sec) ± 0.3 m rad/s (0.0167 deg/sec)	Must withstand 9.4 rad/s (540 deg/s)
Earth Sensor	0.79 rad (45 deg) scan cone, ± 6.1 m rad (± 0.35 deg)	
Wheels	1.0 Nm (0.75 ft - lb-sec) nominal	± 10% speed variation for pitch and roll control

The thrusters required for SAGE are two on each of the three axes for use in despin, earth acquisition, and momentum unloading. This mission does not require any orbit corrections. The resulting fuel budget is listed in Table A-8.

Table A-8 SAGE Fuel Budget

Events	Impulse - Ns (lb - sec)
Despin	389 (87.5)
Acquisition	57 (12.8)
Reacquisition	229 (51.4)
Momentum Unloading	1001 (225.)
Margin	179 (40.3)
Total	1855 (417.)

A.4 CONCLUSION AND RECOMMENDATIONS

An acquisition sequence and a set of SC components have been proposed for both HCMM and SAGE missions. These components, when incorporated with a properly programmed control electronics computer, will meet the specifications in the Reference 11 document. The list of SC equipment for HCMM is given in Table A-4, while Table A-7 contains a list of equipment for the SAGE mission.

The HCMM vehicle can be controlled by ten thrusters; eight 4.4 N (1 lbf) for roll, pitch torque and delta V, and two 0.4 N (0.1 lbf) for roll/yaw torque during fine pointing. The SAGE vehicle can be controlled by six thrusters; two 4.4 N (1 lbf) thrusters on each axis. SAGE has no delta V requirements. For SAGE, fine pointing in roll/yaw is controlled using a momentum component from the two canted momentum bias wheels.

The approach used to define these sets of mission equipment was to consider the two missions separately. If the base module is to be used interchangeably for both HCMM and SAGE, then the SAGE system could be modified by using larger wheels to meet the HCMM requirements.

APPENDIX B

DATA BASE

This appendix contains the data base that was used for the SDCM and SCM computer programs. The data base printout relates the computer code to the catalog index number, and provides a few of the component attributes for a quick "look up."

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STABILITY AND CONTROL SUBSYSTEM

CODE	PROGRAM	COMPONENT	QTY PER SAT	UNIT WT (LB)	UNIT VOL (CUFT)	AVG PWR (W)	FAIL RATE (/E9HR)	ACCRCY (DEG)	MOMENTUM (F-LB-S)
101	N 1-1-10	DESPIN BEARING		73.8	.75	6	1147	.009	
103	D 5-1- 3	DESPIN MECH ASSY		30.1	1.07	14	14100	.064	
203	D 5-1- 7	VALVE DRIVER ASSY		1.6	.05	5	23		
206	D 8-1- 6	VALVE DRIVER ASSY		1.6	.05	6	1290		
209	N 3-1- 5	VALVE DRIVER		1.3	.05	33	23		
303	N 5-1- 1	SUN SENSOR		.3	.02	0	45		
306	N 3-1- 7	SUN SENSOR		.2	.00	0	9		
309	D 4-1- 1	SUN SENSOR		.4	.01	0	1370		
312	N 1-1- 3	SUN SENSOR		.6	.02	2	316		
315	N 4-1- 6	SUN SENSOR		1.0	.02	0	3		
318	D 5-1- 2	SUN SENSOR ASSY		2.3	.10	1	5090		
321	N 2-1- 3	SUN SENSOR		36.5	1.28	7	9		
403	N 3-1- 2	NUTATION DAMPER		2.8	.28	0	172		
406	D 1-1- 4	NUTATION DAMPER		2.4	.03		11		
409	N 5-1- 3	NUTATION DAMPER		3.4	.32		50		
412	D 5-1- 5	NUTATION DAMPERS		4.0	.91		230		
415	N 4-1- 3	NUTATION DAMPER		6.5	.71		1		
418	N 2-1- 4	NUTATION DAMPER		8.5	4.40	0	172		
421	N 1-1- 8	NUTATION DAMPER		11.3	.42	0	9		
424	D 4-1- 5	NUTATION DAMPER		13.9	.21		172		
427	D 2-1- 2	NUTATION DAMPER		19.0	.20		172		
503	D 5-1- 6	GIMBAL ELECTRONCS		6.3	.28	31	3150	.030	
603	D 5-1	CONTROL ELECTRNCS		7.4	.37	3	14332	.076	
703	D 5-1- 4	BIAXIAL DRIVE		14.3	.50	28	695	.059	
706	N 1-1- 9	BIAXIAL DRIVE		113.5	4.00	1	587	.368	
803	N 5-1- 2	EARTH SENSOR		1.3	.03	0	2633	.456	
806	D 3-1- 1	EARTH SENSOR ASSY		4.1	.14	1	2100	.262	
809	D 4-1- 2	EARTH SENSOR		1.1	.02	0	3450	.230	
812	N 2-1- 2	EARTH SENSOR		1.4	.05	0	4510	.250	
815	D 2-1- 1	EARTH SENSOR		1.5	.03	1	3500	.119	
818	D 1-1- 2	EARTH SENSOR		1.5	.04	1	4050	.200	
821	D 6-1- 1	EARTH SENSOR ASSY		6.5	.30	4	5350	.088	
903	N 6-1- 5	SUN SENSOR		.6	.00	1	53		
906	N 6-1- 8	SUN SENSOR		.5	.00	1	100		
909	N 3-1- 6	SUN SENSOR		.5	.02	0	9		
912	N 5-1- 7	SUN SENSOR		.5	.01	1	4942		
915	N 5-1-10	SUN SENSOR		.7	.02	1	50		
918	N 6-1- 9	SUN SENSOR		.7	.01	1	50		
921	D 8-1- 5	SUN SENSOR ASSY		.3	.01	0	9		
924	D 7-1- 5	SUN SENSOR		1.9	.03	0	440		
927	N 1-1- 4	SUN SENSOR		2.0	.03	2	0		
933	N 1-1- 2	SUN SENSOR		3.3	.12	2	3475		
1003	D 3-1	CONTROL ELECTRNCS		9.1	.90	4	10000	.103	
1106	N 6-1- 2	RATE GYRO		3.0	.05	16	8736		
1112	N 7-1- 1	RATE GYRO ASSY		3.3	.12	8	1270		
1203	D 3-1- 4	EARTH SENSOR ASSY		5.0	.09	2	6520	.357	
1206	D 1-1- 1	EARTH SENSOR		9.9	.35	5	4250	.102	
1303	N 7-1- 5	REACTION WHEEL		5.1	.07	0	500		.3
1309	N 7-1- 4	REACTION WHEEL		8.5	.10	1	500		1.4
1312	D 7-1- 4	REACTION WHEEL		8.3	.05	1	2270		1.5
1315	D 1-1- 3	REACTION WHEEL		12.2	.59	12	137		7.0

1318	N	6-1- 1	REACTION WHEEL	19.3	.31	10	2386		8.2
1321	N	4-1- 4	REACTION WHEEL	17.2	10.83		500		17.7
1324	N	2-1- 1	REACTION WHEEL	53.8	1.89	4	500		100.0
1327	O	8-1- 2	REACTN WHEEL ASSY	80.6	2.30	70	7410		375.0
1399			REACTION WHEEL	78.3	2.50	19	500		5000.0
1413	O	1-3- 3	POWER CONVERTER	15.9	.43		438		
1461	N	6-1-11	SUN SENSOR ELECTR	6.0	.15	4	2936		
1466	N	6-1- 6	SUN SENSOR ELECTR	2.2	.05	0	1949		
1471	O	7-3- 1	POWER CONVERTER	1.1	.02	12	590		
1483	O	8-3- 3	POWER CONVERTER	5.5	.17	15	4080		
1493	O	9-3- 3	POWER INVERTER	11.5	.17	117	8340		
1494	O	9-3- 4	POWER INVERTER	18.2	.22	75	16300		
1495	O	9-3- 5	POWER CONVERTER	6.5	.09	40	4500		
1501			CONTROL ELECT.	10.0	.10	4	10000	.030	
1601			VALVE DRIVER ASSY	1.6	.16	1	1900		
1602			VALVE DRIVER ASSY	4.2	.42	0	965		
1605			VALVE DRIVE ASSY	4.2	.42	0	965		
1706	O	8-1- 1	RATE INTEGR GYRO	3.3	.05	12	1270	.050	
1709	O	3-1- 2	RATE INTEGR GYRO	3.1	.03	20	4609	.050	
1716	N	7-1- 3	RATE INTEGR GYRO	9.6	.13	32	1270	.050	
1721	N	7-1- 2	RATE INTEGR GYRO	9.6	.19	20	1270	.050	
1724	N	6-1-12	RATE INTEGR GYRO	11.3	.43	30	1270	.050	
1727	N	6-1-13	RATE INTEGR GYRO	18.2	.32	40	6054	.100	
1730	O	9-1- 1	RATE INTEGR GYRO	34.0	1.22	30	15000	.063	
1733	N	1-1- 1	RATE INTEGR GYRO	13.0	.13	12	1147	.154	
1803	O	3-1- 1	EARTH SENSOR	14.6	.20	19	3220	.400	
1809	N	7-1- 6	EARTH SENSOR	22.2	.74	1	5166	.300	
1812	O	9-1- 3	EARTH SENSOR ASSY	15.0	.26	4	125001	.300	
1815	N	6-1- 4	EARTH SENSOR	15.4	.53	15	10770	.081	
1818	O	7-1- 2	EARTH SENSOR	7.3	.30	1	235	.068	
1901			CONTROL ELECT.	10.3	1.03	26	6000		
2003	J	9-1- 2	CONTR MOMENT GYRO	15.7	.14	7	52600		3.3
2006			CTRL MOMENT GYRO	170.0	6.00	30	870		500.0
2103	N	3-1- 3	STAR SENSOR	6.4	.23	6	3000	.083	
2106	N	1-1- 5	STAR SENSOR	11.4	1.65	1	3000	.050	
2109	N	6-1- 3	STAR SENSOR	11.8	.50	6	11400	.050	
2112			STAR SENSOR ASSY	15.5	1.55	5	3300	.050	
2115			STAR SENSOR ASSY	23.0	.49	8	10000	.003	
2203	N	4-1- 5	CONTROL ELECTRNCS	7.1	.13	62	23000		

AUXILIARY PROPULSION SYSTEM

CODE	PROGRAM	COMPONENT	QTY PER SAT	UNIT WT (LB)	UNIT VOL (CUFT)	AVG PWR (W)	FAIL RATE (/E9HR)	PROP TYPE	THRUST (LB)	PRESS (PSI)
106		THRUSTER		.3	.03		300	COLD	.05	100
109		THRUSTER		.4	.04		300	COLD	.05	42
110	N 1-2- 1	THRUSTER		1.1	.02	0	1700	COLD	.50	235
112		THRUSTER		.8	.08		300	COLD	.05	42
113	D 3-2- 4	THRUSTER		.8	.02		1700	COLD	.08	25
114	N 7-2- 5	THRUSTER		.7	.03	0	1700	COLD	.45	60
115	D 3-2- 1	THRUSTER		4.7	.19		1700	COLD	.47	100
118	D 7-2- 3	THRUSTER		.4	.00	0	1700	COLD	2.00	465
121		THRUSTER		.7	.07		300	COLD	3.00	200
124		THRUSTER		1.0	.10		300	COLD	3.00	45
127	D 3-2- 3	THRUSTER		.7	.02	0	32	COLD	3.00	270
130		THRUSTER		1.4	.14		300	COLD	15.00	200
133	D 3-2- 2	THRUSTER		1.4	.03	0	54	COLD	15.00	270
136		THRUSTER		2.8	.30		300	COLD	30.00	3250
139		THRUSTER		2.1	.21		300	COLD	30.00	2000
142		THRUSTER		[illegible]	.20		300	COLD	30.00	3000
203		ISOLATION VALVE		6.0	.60	0	70	COLD		3000
205		ISOLATION VALVE		.5	.05		70	COLD		3500
207		ISOLATION VALVE		.3	.04		100	COLD		3500
212	N 1-2- 4	ISOLATION VALVE		3.3	.04	0	70	COLD		4015
213		ISOLATION VALVE		2.5	.25		70	COLD		4600
215	D 3-2- 6	ISOLATION VALVE		2.5	.04		3	COLD		4615
303	N 7-2- 3	FILTER		.0	.00		10	COLD		2000
306		FILTER		.3	.10		10	COLD		4000
309		FILTER		.3	.10		10	COLD		4000
312	N 1-2- 6	FILTER		.3	.00		11	COLD		4015
399		FILTER		.9	.10		10	COLD		4000
406	D 3-2- 6	PRESSURE REGULATR		1.1	.03		427	COLD		37
409		PRESSURE REGULATR		1.2	.10		5000	COLD		41
411	N 7-2- 4	PRESSURE REGULATR		1.3	.02		5000	COLD		60
412		PRESSURE REGULATR		1.1	.10		5000	COLD		100
413	D 9-2- 4	PRESSURE REG		7.9	.23		5000	COLD		125
415		PRESSURE REGULATR		4.1	.40		5000	COLD		250
418	D 3-2- 5	PRESSURE REGULATR		4.1	.05		228	COLD		239
419	N 1-2- 3	PRESSURE REGULATR		1.2	.01	0	5000	COLD		245
421	D 7-2- 5	PRESSURE REGULATR		2.2	.02		5000	COLD		475
499		PRESSURE REGULATR		4.1	.40		5000	COLD		900
503	D 7-2- 2	TANK		3.8	.15		350	COLD		6750
506		TANK		6.1	.23		360	COLD		3620
507	N 7-2- 1	TANK		6.7	.28		350	COLD		2000
509	D 3-2- 1	TANK		16.0	.59		71	COLD		4600
511	N 1-2- 2	TANK		11.5	.59		1	COLD		3615
512		TANK		12.0	.56		360	COLD		3250
515		TANK		27.8	.77		350	COLD		5175
518	D 9-2- 3	TANK		16.2	1.00		360	COLD		3615
521		TANK		22.0	1.13		350	COLD		3250
524	D 9-2- 2	TANK		21.6	1.44		350	COLD		3615
527		TANK		30.0	1.57		350	COLD		3250
530		TANK		50.0	2.02		350	COLD		4800
533		TANK		55.5	3.36		360	COLD		3500
536		TANK		110.0	4.70		360	COLD		3200

603	D	7-2-	6	FILL + VENT VALVE	.1	.00		70	COLD		900
604	N	1-2-	5	FILL + DRAIN VALV	.3	.00		11	COLD		1000
605	N	7-2-	2	FILL + DRAIN VALV	.4	.00		70	COLD		2600
606				FILL/DRAIN VALVE	.2	.02		70	COLD		4600
609	D	3-2-	7	FILL + DRAIN VALV	.2	.00		200	COLD		4615
612	D	7-2-	6	FILL + DRAIN VALV	.3	.01		70	COLD		5750
701				RELIEF VALVE	.2	.02		70	COLD		285
803	D	3-2-	3	THRUSTER	3.5	.15	0	1700	MONO	.04	35
806				THRUSTER	.6	.07	0	1700	MONO	.10	300
809				THRUSTER	.3	.03	0	1700	MONO	.10	250
811	N	5-2-	2	THRUSTER	.7	.02	0	1700	MONO	.15	500
812	D	1-2-	4	THRUSTER	.7	.03	0	380	MONO	.22	350
813	N	5-2-	2	THRUSTER	.5	.01	0	2665	MONO	.30	300
815				THRUSTER	.5	.07	0	1700	MONO	.30	280
818				THRUSTER	.4	.04	0	1700	MONO	.50	250
821	D	1-2-	3	THRUSTER	.9	.03	0	114	MONO	1.00	365
824				THRUSTER	1.0	.10	0	1700	MONO	1.00	
827				THRUSTER	.7	.07	0	1700	MONO	1.00	375
829	N	7-2-	7	THRUSTER	.5	.01	0	1700	MONO	1.00	500
830	D	8-2-	2	THRUSTER	.4	.03	0	1700	MONO	4.20	600
833	D	5-2-	1	THRUSTER	[illegible]	.03	0	1700	MONO	4.10	150
834	N	2-2-	1	THRUSTER	[illegible]	.02	0	223	MONO	4.10	615
836				THRUSTER	.9	.09	0	1710	MONO	5.00	300
839				THRUSTER	1.2	.10	0	1730	MONO	5.00	230
842	D	6-2-	2	THRUSTER	1.0	.01	0	1700	MONO	5.00	250
843	N	5-2-	1	THRUSTER	1.2	.01	0	2531	MONO	5.30	300
845				THRUSTER	4.5	.45	0	1700	MONO	25.00	360
848				THRUSTER	2.5	.25	0	1700	MONO	25.00	330
851				THRUSTER	2.8	.28	0	1700	MONO	40.00	515
854				THRUSTER	3.0	.50	0	1700	MONO	50.00	
857	D	7-2-	4	THRUSTER	3.9	.09	0	1700	MONO	155.00	450
860				THRUSTER	5.0	.50	0	1700	MONO	300.00	
863				THRUSTER	17.9	1.70	0	1700	MONO	632.00	480
906				ISOLATION VALVE	.7	.07		200	MONO		350
907				ISOLATION VALVE	1.3	.13		200	MONO		360
909	D	1-2-	2	ISOLATION VALVE	.9	.01		285	MONO		460
912	N	3-2-	4	ISOLATION VALVE	.5	.00	0	70	MONO		500
915	N	2-2-	3	ISOLATION VALVE	.2	.00	0	70	MONO		500
918	N	2-2-	4	ISOLATION VALVE	.4	.00	0	11	MONO		900
921	N	2-2-	5	ISOLATION VALVE	.4	.00	0	11	MONO		900
924	N	6-2-	3	ISOLATION VALVE	.5	.01	0	57	MONO		1000
927				ISOLATION VALVE	1.5	.15	0	100	MONO		4000
999				ISOLATION VALVE	1.3	.13		200	MONO		360
1003				FILTER	.5	.05		10	MONO		400
1006	D	1-2-	6	FILTER	.5	.01		2	MONO		460
1009	D	3-2-	4	FILTER	.4	.00		2	MONO		600
1012	D	3-2-	6	FILTER	.3	.04		4	MONO		615
1013	N	2-2-	7	FILTER	.3	.00		114	MONO		900
1015				FILTER	.5	.05		10	MONO		1000
1018	N	6-2-	4	FILTER	.1	.00		10	MONO		1000
1021	N	7-2-	2	FILTER	.1	.00		10	MONO		1000
1101				TANK	2.9	.05		360	MONO		560
1102				TANK	2.5	.24		350	MONO		610
1109	D	7-2-	1	TANK	3.5	.35		350	MONO		900
1112	D	6-2-	1	TANK	2.7	.59		360	MONO		568
1113	N	5-2-	3	TANK	.2	.59		360	MONO		525
1115	D	5-2-	2	TANK	3.5	.64		11	MONO		615

1116	N 2-2- 2	TANK	13.5	1.63	114	MONO		900
1117	N 7-2- 6	TANK	16.3	1.34	360	MONO		660
1118	N 6-2- 1	TANK	10.2	1.34	57	MONO		1000
1119		TANK	10.2	1.35	360	MONO		400
1121		TANK	17.0	1.60	350	MONO		350
1124	D 8-2- 1	TANK	11.5	2.42	23	MONO		615
1127	D 1-2- 1	TANK	16.7	3.23	370	MONO		365
1130		TANK	17.3	3.23	360	MONO		350
1203	D 6-2- 3	FILL + DRAIN VALV	.2	.00	70	MONO		355
1206	D 1-2- 5	FILL + DRAIN VALV	.2	.01	10	MONO		460
1209	D 8-2- 5	FILL + DRAIN VALV	.2	.03	9	MONO		515
1211	N 5-2- 5	FILL + DRAIN VALV	.3	.00	3	MONO		525
1212		FILL/DRAIN VALVE	.2	.02	70	MONO		600
1215	D 5-2- 3	FILL + DRAIN VALV	.2	.01	23	MONO		600
1216	N 2-2- 6	FILL + DRAIN VALV	.2	.00	70	MONO		900
1218	D 7-2- 7	FILL + VENT VALVE	.1	.00	70	MONO		900
1221	N 7-2- 9	FILL VALVE	.3	.03	70	MONO		3600
1224	N 7-2-10	FILL VALVE	.3	.03	70	MONO		3600
1227	N 6-2- 5	FILL + DRAIN VALV	.3	.00	70	MONO		3900
1301		THRUSTER	1.5	.15	1700	BI	5.00	190
1302		THRUSTER	1.2	.12	1700	BI	5.00	300
1303		THRUSTER	2.9	.29	1700	BI	22.00	190
1304		THRUSTER	2.7	.27	1700	BI	23.00	242
1305		THRUSTER	5.8	.58	1700	BI	88.00	
1306		THRUSTER	4.9	.49	1700	BI	100.00	190
1307		THRUSTER	15.5	1.50	1700	BI	300.00	230
1308		THRUSTER	17.4	1.70	1700	BI	600.00	300
1401		ISOLATION VALVE	.6	.05	200	BI		340
1402		ISOLATION VALVE	1.3	.13	200	BI		350
1403		ISOLATION VALVE	2.7	.27	100	BI		360
1404		ISOLATION VALVE	6.0	.60	100	BI		435
1405		ISOLATION VALVE	1.5	.15	100	BI		4000
1501		FILTER	3.0	.30	10	BI		400
1599		FILTER	3.0	.30	10	BI		4800
1601		TANK	5.5	.47	350	BI		820
1602		TANK	17.0	1.77	350	BI		350
1603		TANK	10.5	4.10	350	BI		200
1604		TANK	22.5	7.78	350	BI		300
1605		TANK	150.0	18.50	350	BI		
1701		FILL/DRAIN VALVE	.2	.02	70	BI		540

ELECTRICAL POWER SUBSYSTEM

CODE	PROGRAM	COMPONENT	QTY PER SAT	UNIT WT (LB)	UNIT VOL (CUFT)	AVG PWR (W)	FAIL RATE (/E9HR)	CURRENT RATING (AMPS)	PWR CAPAC (W)	CELL CAPAC (A-H)	EFFI-CIENCY (O/O)
102	D 3-3- 1	SHUNT REGULATOR		5.0	.13		5400		15		
103	D 3-3- 2	SHUNT REGULATOR		4.2	.13		76		65		
106	D 5-3- 2	SHUNT REGULATOR		4.3	.13		7		70		
112	D 4-3- 1	SHUNT REGULATOR		1.4	.01		1140		100		
130		SHUNT REGULATOR		2.2	.03		200		130		
131		SHUNT REGULATOR		4.3	.06		200		260		
132		SHUNT REGULATOR		6.5	.08		200		390		
133		SHUNT REGULATOR		8.7	.11		200		520		
134		SHUNT REGULATOR		10.8	.14		200		650		
135		SHUNT REGULATOR		13.0	.17		200		780		
136		SHUNT REGULATOR		15.2	.20		200		910		
137		SHUNT REGULATOR		17.3	.23		200		1040		
138		SHUNT REGULATOR		19.5	.23		200		1170		
139		SHUNT REGULATOR		21.7	.28		200		1300		
140		SHUNT REGULATOR		23.8	.31		200		1430		
141		SHUNT REGULATOR		26.0	.34		200		1560		
142		SHUNT REGULATOR		28.2	.37		200		1690		
143		SHUNT REGULATOR		30.3	.40		200		1820		
144		SHUNT REGULATOR		32.5	.43		200		1950		
145		SHUNT REGULATOR		34.7	.45		200		2080		
146		SHUNT REGULATOR		36.8	.48		200		2210		
147		SHUNT REGULATOR		39.0	.51		200		2340		
148		SHUNT REGULATOR		41.2	.54		200		2470		
149		SHUNT REGULATOR		43.3	.57		200		2600		
150		SHUNT REGULATOR		45.5	.60		200		2730		
151		SHUNT REGULATOR		47.7	.63		200		2860		
152		SHUNT REGULATOR		49.8	.65		200		2990		
153		SHUNT REGULATOR		52.0	.68		200		3120		
154		SHUNT REGULATOR		54.2	.71		200		3250		
155		SHUNT REGULATOR		56.3	.74		200		3380		
156		SHUNT REGULATOR		58.5	.77		200		3510		
157		SHUNT REGULATOR		60.7	.80		200		3640		
158		SHUNT REGULATOR		62.8	.82		200		3770		
159		SHUNT REGULATOR		65.0	.85		200		3900		
160		SHUNT REGULATOR		67.2	.88		200		4030		
161		SHUNT REGULATOR		69.3	.91		200		4160		
162		SHUNT REGULATOR		71.5	.94		200		4290		
163		SHUNT REGULATOR		73.7	.96		200		4420		
164		SHUNT REGULATOR		75.8	.99		200		4550		
165		SHUNT REGULATOR		78.0	1.02		200		4680		
166		SHUNT REGULATOR		80.2	1.05		200		4810		
167		SHUNT REGULATOR		82.3	1.08		200		4940		
168		SHUNT REGULATOR		84.5	1.11		200		5070		
169		SHUNT REGULATOR		86.7	1.14		200		5200		
170		SHUNT REGULATOR		88.8	1.16		200		5330		
171		SHUNT REGULATOR		91.0	1.19		200		5460		
172		SHUNT REGULATOR		93.2	1.22		200		5590		
173		SHUNT REGULATOR		95.3	1.25		200		5720		
174		SHUNT REGULATOR		97.5	1.28		200		5850		
175		SHUNT REGULATOR		99.7	1.31		200		5980		
176		SHUNT REGULATOR		101.8	1.34		200		6110		

177		SHUNT REGULATOR	104.0	1.36	200	6240		
178		SHUNT REGULATOR	106.2	1.39	200	6370		
179		SHUNT REGULATOR	108.3	1.42	200	6500		
180		SHUNT REGULATOR	110.5	1.45	200	6630		
181		SHUNT REGULATOR	112.7	1.48	200	6760		
182		SHUNT REGULATOR	114.8	1.51	200	6890		
183		SHUNT REGULATOR	117.0	1.53	200	7020		
184		SHUNT REGULATOR	119.2	1.56	200	7150		
185		SHUNT REGULATOR	121.3	1.59	200	7280		
186		SHUNT REGULATOR	123.5	1.62	200	7410		
187		SHUNT REGULATOR	125.7	1.65	200	7540		
188		SHUNT REGULATOR	127.8	1.67	200	7670		
189		SHUNT REGULATOR	130.0	1.70	200	7800		
190		SHUNT REGULATOR	132.2	1.73	200	7930		
191		SHUNT REGULATOR	134.3	1.76	200	8060		
192		SHUNT REGULATOR	136.5	1.79	200	8190		
193		SHUNT REGULATOR	138.7	1.82	200	8320		
194		SHUNT REGULATOR	140.8	1.85	200	8450		
195		SHUNT REGULATOR	143.0	1.87	200	8580		
196		SHUNT REGULATOR	145.2	1.90	200	8710		
197		SHUNT REGULATOR	147.3	1.93	200	8840		
198		SHUNT REGULATOR	149.5	1.96	200	8970		
199		SHUNT REGULATOR	151.7	1.99	200	9100		
202	N 5-3- 4	BATTERY	.4	.01			3	64
203		BATTERY	.3	.00			3	64
204		BATTERY	.3	.00			4	64
205	N 7-3- 2	BATTERY	.7	.00	659		5	64
206	N 3-3- 2	BATTERY	1.1	.00			6	64
207	N 2-3- 3	BATTERY	.8	.01			6	64
208	N 4-3- 4	BATTERY	.9	.01			6	64
209		BATTERY	.6	.00			7	64
212		BATTERY	.6	.00			7	64
215	D 4-3- 3	BATTERY	.7	.00			10	64
218		BATTERY	.8	.01			11	64
221	D 5-3- 4	BATTERY	1.0	.01			12	64
222	N 1-3- 6	BATTERY	1.3	.02			12	64
224		BATTERY	1.1	.01			14	64
227	D 2-3- 5	BATTERY	1.7	.02			15	64
230	D 3-3- 4	BATTERY	1.6	.01			15	64
231	N 6-3- 7	BATTERY	1.3	.02			15	64
233		BATTERY	1.4	.01			17	64
236		BATTERY	1.6	.02			18	64
239	D 6-3- 2	BATTERY	1.3	.01			20	64
242	D 8-3- 6	BATTERY	2.4	.00			20	64
245	D 1-3- 7	BATTERY	.9	.04			24	64
248		BATTERY	2.0	.01			26	64
251		BATTERY	2.0	.01			26	64
254		BATTERY	2.3	.01			28	64
257	D 7-3- 4	BATTERY	3.3	.05			30	64
260		BATTERY	2.4	.01			33	64
263	D 9-3- 7	BATTERY	3.6	.02			36	64
266		BATTERY	2.8	.02			40	64
269		BATTERY	3.6	.02			50	64
272		BATTERY	4.0	.02			60	64
273		BATTERY	2.7	.02			60	64
274		BATTERY	4.5	.02			65	64
275		BATTERY	3.5	.03			100	64

276		BATTERY	5.7	.04				200	54
277		BATTERY	7.8	.05				300	64
278	D 9-3- 6	BATTERY	[illegible].4	.06				325	64
279		BATTFRY	10.0	.08				400	64
280		BATTERY	12.2	.10				500	64
281		BATTERY	14.3	.11				600	64
282		BATTERY	16.4	.13				700	64
283		BATTERY	18.6	.15				800	64
284		BATTERY	20.8	.17				900	64
303	D 4-3- 2	BATTERY CHARGER	3.5	.09	3910	5			85
306	D 5-3- 1	BATTERY CHARGER	12.8	.29	18	7			100
309	D 3-3- 3	BATTERY CHARGER	12.8	.19	260	8			85
312	D 9-3- 2	BATTERY CHARGER	5.0	.13	5400	8			85
315	D 8-3- 1	BATTERY CHARGER	12.0	.34	457	10			100
389		BATTERY CHARGER	5.3	.12	260	35			100
390		BATTERY CHARGER	7.5	.17	260	50			100
391		BATTERY CHARGER	15.0	.34	250	100			100
392		BATTERY CHARGER	22.5	.52	250	150			100
393		BATTERY CHARGER	30.0	.69	260	200			100
394		BATTERY CHARGER	37.5	.85	260	250			100
395		BATTEFY CHARGER	45.0	1.03	250	300			100
396		BATTERY CHARGER	52.5	1.20	260	350			100
397		BATTERY CHARGER	60.0	1.37	250	400			100
398		BATTERY CHARGER	67.5	1.55	250	450			100
399		BATTERY CHAFGER	75.0	1.72	260	500			100
403		DISCHARGE REGLTOR	3.0	.30	250		59		85
406	D 2-3- 2	DISCHGE REGULATOR	9.8	.18	2300		344		85
409	D 6-3- 1	DISCHGE REGULATOR	20.3	1.29	650		400		85
412	D 7-3- 3	DISCHGE REGULATOR	16.4	.37	133		450		85
415	N 6-3- 1	DISCHG REGULATOR	47.[illegible]	.86	573		500		85
503	N 5-3- 2	SHUNT REGULATOR	.3	.02	200		10		
506	N 1-3- 1	SHUNT REGULATOR	.9	.01	366		33		
509	N 6-3- 4	SHUNT REGULATOR	1.4	.02	57		35		
515	D 2-3- 1	SHUNT REGULATOR	2.3	.02	200		110		
598		SHUNT REGULATOR	4.3	.43	200		130		
599		SHUNT REGULATOR	4.3	.43	200		200		
603	D 2-3- 3	BATTERY CHARGER	2.6	.05	250	6			85
609	D 7-3- 2	BATTERY CHARGER	3.6	.03	183	15			85
699		BATTERY CHARGER	7.0	1.50	650	30			85
702	N 5-3- 1	POWER CONTROL	9.4	.60	2107				
803	N 1-3- 4	SERIES LOAD REG	9.3	.13	23		29		89
812	N 2-3- 1	SERIES LOAD REG	23.5	.45	260		384		89
815	N 7-3- 1	SERIES LOAD REG	21.9	1.39	650		500		89
818	D 1-3- 1	SERIES LOAD REG.	13.3	.63	1720		1150		96
902	N 1-3- 2	BATTERY CHARGER	3.0	.07	58	6			85
906		BATTERY CHARGER	8.0	.30	650	22			85
1003		SOLAR POWER DSTRB	1.0	.10	300				
1102	N 1-3- 5	POWER CONTROL	1.7	.20	492				
1202	N 4-3- 1	POWER CONTROL	11.6	.25	460				
1206	D 3-3- 1	POWER CONTROL EQ	21.7	.44	237				

COMMUNICATIONS SUBSYSTEM

CODE	PROGRAM	COMPONENT	QTY PER SAT	UNIT WT (LB)	UNIT VOL (CUFT)	AVG PWR (W)	FAIL RATE (/E9HR)	DATA RATE (KBPS)	MAX FREQ (MHZ)	MIN FREQ (MHZ)	GAIN OF PWR OUTPUT	NO. OF CHNLS
103	D 8-4- 5	BASEBND ASSY UNIT		2.0	.03	0	4050	128				1
106		BASEBND ASSY UNIT					2000	128				1
109	D 5-4- 6	BASEBND ASSY UNIT		2.0	.02	0	23	256				1
112	D 2-4- 3	BASEBND ASSY UNIT		4.0	.05	3	13300	264				2
199		BASEBAND ASSY		.3	.01	0	1147	256				1
202	N 2-4- 6	ANTENNA		8.4	.71		40		2300	2090	-11	
203	D 6-4- 7	ANTENNA		10.4	.13		233		2300	1750	-7	
206	D 2-4- 2	ANTENNA		1.1	.14		40		2300		-6	
212	D 2-4- 1	ANTENNA		.5	.02		40		2300		-0	
213	N 1-4-14	ANTENNA		14.2	2.51		11		2218			
215	D 1-4- 7	ANTENNA		2.6	.03		39		2300	1750	0	
218	D 4-4- 4	ANTENNA		[illegible]	.02		23		2300	1750	0	
221	D 3-4- 5	ANTENNA		5.8	.20		14		2300	1750	2	
227	D 3-4- 8	ANTENNA		.3	.01		15700		2300	1750	2	
230	D 3-4- 9	ANTENNA		1.3	.30		20		2300	1740	3	
233	D 3-4-10	ANTENNA		2.1	.03		400		2300	1750	6	
236		ANTENNA		1.0	1.00		100				10	
239	D 8-4- 9	ANTENNA		2.1	.03		400		2300		20	
303	D 5-4- 3	TRANSMITTER		2.2	.04	10	1950		2311	UNIFIED	1	1
306	D 8-4- 2	TRANSMITTER		2.1	.03	10	3080		2300	UNIFIED	1	1
309	D 6-4-21	TRANSMITTER		1.8	.02	8	1370		2300	UNIFIED	1	1
312	D 8-4- 3	TRANSMITTER		2.2	.03	15	3800	1024	2300		2	0
315		TRANSMITTER		2.4	.04	10	14000		2300	UNIFIED	2	1
318	D 2-4- 4	TRANSMITTER		7.0	.07	30	22000		2300	UNIFIED	2	1
321	D 3-4-11	TRANSMITTER		2.3	.03	22	10000	24	2300	UNIFIED	2	1
324	D 9-4- 1	TRANSMITTER		7.5	.20	37	2500		2300	UNIFIED	2	1
325	N 1-4- 2	TRANSMITTER		3.3	.03	9	376	128	2300		2	0
327	D 1-4- 3	TRANSMITTER		4.7	.05	16	6870		2300	UNIFIED	3	1
328	N 7-4-10	TRANSMITTER		3.0	.04	55	102499		1734	UNIFIED	4	2
333		TRANSMITTER		2.3	.02	20	14000		2300	UNIFIED	5	1
336	D 4-4- 7	TRANSMITTER		2.5	.03	70	2849		2300	UNIFIED	9	2
339		TRANSMITTER		2.5	.02	40	14000		2300	UNIFIED	10	1
342	D 3-4- 7	TRANSMITTER		3.0	.03	70	10001	1024	2300		10	0
345	D 3-4- 3	TRANSMITTER		13.0	.41	130	21700		2300	UNIFIED	10	1
348	D 2-4- 6	TRANSMITTER		3.0	.03	75	12500	256	2300	UNIFIED	11	0
351	D 7-4- 1	TRANSMITTER		1.9	.20	52	5600	2562	2289		12	0
354		TRANSMITTER		2.8	.02	90	14000		2300	UNIFIED	20	1
357	N 7-4- 9	TRANSMITTER		10.3	.12	67	10009	24	2265		20	0
397		TRANSMITTER		1.9	.19	10	2336		2300	UNIFIED	1	1
398		TRANSMITTER		2.1	.21	16	3022	1024	2300		50	0
399		TRANSMITTER		2.1	.21	16	3022	1024	2300		5	0
403	D 3-4-16	RECEIVER		2.3	.03	3	3330	1	1842	1760		
406	D 6-4-26	RECEIVER		2.3	.02	7	3360	1	1840	1760		
409	D 4-4-16	RECEIVER		[illegible]	.03	3	530	1	1850	1750		
415	D 1-4- 5	RECEIVER		3.9	.05	3	5790	1	1840	1760		
418	D 5-4- 4	RECEIVER		4.2	.08	2	511	1	1850	1750		
421	D 8-4- 1	RECEIVER		4.2	.05	1	5180	1	1850	1750		
424	D 7-4- 2	RECEIVER		5.0	.07	3	1150	1	1850	1750		
427	D 3-4-12	RECEIVER		9.0	.21	10	2400	1	1850	1750		
503	D 5-4- 8	COMMD SIG COND		1.5	.02	0	3120	1				
504	D 3-4- 6	COMMD SIG COND		1.5	.01	0	5560	1				

509	D	1-4- 4	COMMD SIGNAL COND	10.7	.30	15	1660	1		
541	D	4-4-15	COMMD SIG CONDIT	0.0	0.00	3	690	1		
603	D	3-4- 1	DIPLEXER	3.1	.04	1	150		2300	1750
606	D	1-4- 1	DIPLEXER	2.9	.06		137		2300	1750
612	D	3-4- 7	DIPLEXER ASSY	3.0	.05		2590		2120	1630
618	D	4-4- 5	DIPLEXER	1.5	.02		223		2300	1750
701			POWER CONVERTER	1.8	.19	13	972			
714	D	1-3- 4	POWER CONVERTER	12.1	.34	29	252			
715	D	1-3- 5	POWER CONVERTER	14.3	.37	22	554			
716	D	1-3- 6	POWER CONVERTER	13.1	.32	17	554			
755	D	5-3- 5	POWER CONVERTER	2.0	.03	11	884			
784	D	8-3- 4	POWER CONVERTER	2.0	.13	19	1840			

DATA HANDLING SUBSYSTEM

CODE	PROGRAM	COMPONENT	QTY PER SAT	UNIT WT (LB)	UNIT VOL (CUFT)	AVG PWR (W)	FAIL RATE (/E9HR)	INSTRUC OR DATA RATE (KBPS)	NO. OF WORDS OR COMNDS	WORD LENGTH (BITS)	STOR CAPAC (KBITS)
103		GEN PURP PROCESR		2.8	.0	15	15000	160			
106	N 2-4- 9	GEN PURP PROCESSR		22.5	.5	20	21700	200			
109		GEN PURP PROCESR		15.0	.1	20	15000	200			
112		GEN PURP PROCESR		15.0	.1	80	15000	250			
115		GEN PURP PROCESR		12.0	.1	40	15000	300			
118		GEN PURP PROCESR		15.0	.1	50	15000	500			
121		GEN PURP PROCESR		25.0	.0	140	15000	750			
124		GEN PURP PROCESR		25.0	.1	40	15000	1000			
127		GEN PURP PROCESR		20.0	.1	100	15000	1200			
203	N 5-4- 1	DIGITAL TELEMETRY		8.9	.2	3	18300	0		9	
206	D 5-4- 7	DIGITAL TELEMETRY		11.4	.1	6	3680	0		8	
209	N 5-4- 1	DIGITAL TELEMETRY		18.5	.4	14	4509	0		9	
212	N 4-4-11	DIGITAL TELEMETRY		9.1	.1	3	18300	0		16	
215	D 1-4- 6	DIGITAL TELEMETRY		12.1	.2	7	1660	1		8	
218	N 7-4- 8	DIGITAL TELEMETRY		18.7	.2	11	18300	8		10	
221	N 2-4- 7	DIGITAL TELEMETRY		9.3	.2	0	2305	16		8	
224	N 2-4- 4	DIGITAL TELEMETRY		8.1	.2	5	2305	16		8	
227	N 1-4- 1	DIGITAL TELEMETRY		4.3	.1	3	5750	32		8	
230	D 3-4- 6	DIGITAL TELEMETRY		5.0	.0	14	16700	32		8	
233	D 9-4- 6	DIGITAL TELEMETRY		15.5	.4	15	2850	32		8	
236	D 7-4- 4	DIGITAL TELEMETRY		6.0	.1	5	16790	60		9	
239	D 2-4- 5	DIGITAL TELEMETRY		6.0	.0	9	18300	64		8	
242	D 9-4- 4	DIGITAL TELEMETRY		4.0	.0	15	42000	65		8	
245	D 8-4- 4	DIGITAL TELEMETRY		9.5	.2	7	18000	128		8	
248	D 6-4- 1	DIGITAL TELEMETRY		7.1	.1	3	3710	250		8	
251	D 9-4- 5	DIGITAL TELEMETRY		20.0	.4	25	42000	256		8	
303		TAPE RECORDER		9.6	.2	3	1600	1			650
306		TAPE RECORDER		11.0	.2	4	1600	8			1600
309	N 3-4- 3	TAPE RECORDER		7.2	.1	0	1600	19			5888
312		TAPE RECORDER		11.0	.2	4	1600	26			7100
315	N 7-4- 3	TAPE RECORDER		13.0	.2	7	1600	25			12600
318	N 1-4-12	TAPE RECORDER		15.5	.4	5	10000	128			84480
~~321~~		TAPE ~~RECORDER~~		15.5	.4	4	1600	128			85000
324		TAPE RECORDER		16.0	.4	6	1600	131			120000
327	D 4-4- 6	TAPE RECORDER		14.6	.3	7	1600	131			200000
330		TAPE RECORDER		20.5	.5	14	1600	189			21000
333		TAPE RECORDER		23.0	.5	8	1600	380			1730000
336	C 2-4- 7	TAPE RECORDER		17.0	.3	30	1600	512			1530000
339	D 9-4-10	TAPE RECORDER		17.0	.3	25	5540	512			1690000
342		TAPE RECORDER		15.5	.3	20	1600	767			2300000
345	D 3-4- 3	TAPE RECORDER		16.8	.4	25	14300	1024			1530000
348	D 7-4- 5	TAPE RECORDER		21.5	.2	10	1600	2662			1670000
351	N 7-4- 4	TAPE RECORDER		72.0	2.3	90	1600	15000			27000000
403	D 9-4- 2	COMMD DECOD+DISTR		2.3	.0	7	15000		39		
406	D 4-4- 2	COMMD DECOD+DISTR		11.0	.1	5	12600		128		
409	D 6-4- 6	COMMD DECOD+DISTR		5.1	.1		1630		159		
412	D 2-4- 8	COMMD DECOD+DISTR		10.0	.2	4	21700		224		
413	N 5-4- 6	COMMD DECOD+DISTR		11.9	.2	20	21700		254		
415	D 5-4	COMMD DISTR UNIT		48.0	1.0	26	6500		256		
418	D 8-4- 8	COMMD DECOD+DISTR		17.4	.3	12	21700		255		

421	D	1-3- 2	COMMD DISTRIB	22.4	.7	0	578	255
424	D	1-4- 8	COMMAND CIST UNIT	19.1	.7	4	160	256
427	D	3-4- 2	COMMD DECOD+DISTR	9.2	.2	10	26700	283
430	D	1-4- 9	COMMAND DIST UNIT	26.0	1.0	4	390	342
433	N	2-4- 8	COMMD DECOD+DISTR	47.2	1.5	66	108500	495
436	N	5-4- 5	COMMD DECOD+DISTR	15.4	.3	51	2926	512
439	N	7-4- 1	COMMD DISTR UNIT	27.0	.3	23	21700	512
442	N	1-4- 6	COMMD DECOD+DISTR	16.3	.3	12	65532	2733

APPENDIX C

An example SDCM printout of the Solar Maximum Mission (SMM), design case number 5.

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SMM
SYSTEM DESCRIPTION - - DESIGN NUMBER   5 * * * *
  STABILIZATION AND CONTROL
    CONFIGURATION - - MASS EXPULSION WITH PITCH MOMENTUM WHEEL
      POINTING ACCURACY =      .400000(DEG.)
  AUXILIARY PROPULSION
    CONFIGURATION - - COLD GAS
      TOTAL IMPULSE =          642.(LB-SEC)
  DATA PROCESSING AND INSTRUMENTATION
    CONFIGURATION - - GENERAL PURPOSE PROCESSOR
      COMPUTER OPERATIONS RATE =       12600.(IPS)
      CDPI TABLE                                          ENGINEERING DATA    MISSION EQUIPMENT DATA
        NUMBER OF COMMANDS                                            128.                        0.
        NUMBER OF MAIN FRAME WORDS                                    256.                        0.
        MAIN FRAME SAMPLE RATE                                        125.                        0.
        MAIN FRAME WORD LENGTH                                          8.                        0.
        NUMBER OF SUBFRAMES                                             9.                        0.
        SUBFRAME RATE                                                    .1250                    0.
        NUMBER OF WORDS PER SUBFRAME                                  128.                        0.0000
  COMMUNICATIONS                                                                                  0.
    CONFIGURATION - - UNIFIED LINK-COMMON ANTENNAS
      PRIMARY DOWNLINK DATA RATE =          256.000(KBPS)
      SEPARATE DOWNLINK DATA RATE =           0.000(KBPS)
  ELECTRICAL POWER
    CONFIGURATION - - SERIES LOAD REGULATION - PADDLE MOUNTED SOLAR ARRAY
      END OF LIFE POWER REQUIREMENT        =   1045.75(WATTS)
      TOTAL SOLAR ARRAY AREA               =    110.65(FT**2)
      MINIMUM INSTALLED BATTERY CAPACITY=        11.55(AMP-HR)
  VEHICLE SIZING
    CONFIGURATION - - BOX
      VEHICLE WEIGHT =     2590.33(LBS)  LAUNCH WEIGHT =     2686.38(LBS)
      EQUIPMENT BAY DIMENSIONS LENGTH        42.05(IN),HEIGHT       42.11(IN),WIDTH       42.11(IN)
      MISSION EQUIPMENT LENGTH       72.00(IN),HEIGHT       60.00(IN), WIDTH       60.00(IN)
      TOTAL SATELLITE LENGTH       114.05(IN)
      MOMENTS OF INERTIA (SLUGS*FT**2) IXX =       554.3    IYY =  2972111.8    IZZ =  4567060.0
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SAFETY

CONFIGURATION - - SINGLE SYSTEM

MEAN MISSION DURATION	10.1(MO)
RELIABILITY	.623
MISSION LIFETIME	12.2(MO)

COSTS (ALL AMOUNTS ARE IN DOLLARS)

	DDT+E		INVESTMENT (RECURRING)
DESIGN ENGINEERING	15712416.3	UNIT ENGINEERING	4712661.1
TEST AND EVALUATION	10422538.3	UNIT PRODUCTION	6764226.5
TOOLING AND TEST EQUIPMENT	0.0	TOOLING AND TEST EQUIP.	0.0
QUALITY CONTROL	1094841.6	QUALITY CONTROL	1017681.6
SYSTEMS ENGINEERING AND INTEGRATION	7642659.2	SYSTEMS ENG. AND INT.	2996181.4
PROGRAM MANAGEMENT	3193810.2	PROGRAM MANAGEMENT	1030690.1

COST CATEGORY	DDT+E	INVESTMENT	OPERATIONS
SPACECRAFT	38865667.6	16521440.8	
MISSION EQUIPMENT	0.0	0.0	
TOTAL PAYLOAD	38865667.6	16521440.8	
QUALIFICATION UNITS	16521440.8		
A.G.E.	9578185.4		
LAUNCH SUPPORT			641640.8
CONTRACTOR FEE	4547570.6	1156500.9	44914.9
PROGRAM TOTALS	69512864.4	17677941.7	686555.6

SCHEDULE

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SMM
SUBSYSTEM DESCRIPTIONS - - DESIGN NUMBER   5 * * * *
  STABILIZATION AND CONTROL
    CONFIGURATION - - MASS EXPULSION WITH PITCH MOMENTUM WHEEL
    EQUIPMENT CODE IDENTIFIER 1601 2203 1815 1309
    EQUIPMENT QUANTITIES        1    2    1    1
              WEIGHT          39.70(LB), VOLUME          1.05(FT**3), POWER REQUIREMENT          141.7(WATT)
              DES. ENG. COST     2740200.0              TEST + EVAL. COST       1124420.0
              UNIT PROD.COST      812281.5              UNIT ENG.    COST        725315.6
              RELIABILITY            .3266
              IERR                0
  AUXILIARY PROPULSION
    CONFIGURATION - - COLD GAS
    EQUIPMENT CODE IDENTIFIER  114  114  203  303  413  530  603  701
    EQUIPMENT QUANTITIES        12    4    4    9    1    1    1    1
              WEIGHT         114.49(LB), VOLUME          4.72(FT**3), POWER REQUIREMENT            0.0(WATT)
              DRY WEIGHT        103.62(LBS), EXPENDABLE WEIGHT      10.86(LBS)
              DES. ENG. COST      735762.6              TEST + EVAL. COST        492919.1
              UNIT PROD.COST      425706.1              UNIT ENG.    COST        460345.0
              RELIABILITY            .8377
              IERR                0
  DATA PROCESSING AND INSTRUMENTATION
    CONFIGURATION - - GENERAL PURPOSE PROCESSOR
    EQUIPMENT CODE IDENTIFIER  103  203  330  406
    EQUIPMENT QUANTITIES         2    1    1    1
              WEIGHT          46.03(LB), VOLUME           .80(FT**3), POWER REQUIREMENT           53.0(WATT)
              DES. ENG. COST     3999350.0              TEST + EVAL. COST       2576790.0
              UNIT PROD.COST     2135521.5              UNIT ENG.    COST       1576755.5
              RELIABILITY            .8510
              IERR                1
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COMMUNICATIONS
  CONFIGURATION - - UNIFIED LINK-COMMON ANTENNAS
   EQUIPMENT CODE IDENTIFIER  112  203  336  403   503  618
   EQUIPMENT QUANTITIES         2    1    1    1     1    1
             WEIGHT          26.26(LB), VOLUME          .32(FT**3), POWER REQUIREMENT          30.4(WATT)
             DES. ENG. COST       444000.0          TEST + EVAL. COST       432800.0
             UNIT PROD.COST       238595.3          UNIT ENG.    COST        90317.3
             RELIABILITY              .9491
             IERR                0
ELECTRICAL POWER
  CONFIGURATION - - SERIES LOAD REGULATION - PADDLE MOUNTED SOLAR ARRAY
   EQUIPMENT CODE IDENTIFIER  812  221  902 1003 1152
   EQUIPMENT QUANTITIES         2    2    2    1    1
             WEIGHT          111.67(LB), VOLUME        1.61(FT**3), POWER REQUIREMENT         596.7(WATT)
             HARNESS WEIGHT       114.2(LBS), SOLAR ARRAY WEIGHT      105.4(LBS)
             DES. ENG. COST      3671197.5          TEST + EVAL. COST      3960530.7
             UNIT PROD.COST      2277953.5          UNIT ENG.    COST      1011389.4
             RELIABILITY              .9930
MISSION EQUIPMENT
             WEIGHT      1875.00(LB), VOLUME       117.75(FT**3), POWER REQUIREMENT         174.0(WATT)
             DDT+E COST               0.0         AVERAGE UNIT COST           0.0
             RELIABILITY             1.0000
             SCHEDULE
               COMPONENT DEVELOPMENT TIME   0.0(MONTH) COMPONENT QUALIFICATION TIME   0.0(MONTH)
               SUBSYSTEM DEVELOPMENT TIME   0.0(MONTH) SUBSYSTEM QUALIFICATION TIME   0.0(MONTH)
               SYSTEM DEVELOPMENT AND FLIGHT READINESS TIME   0.0(MONTH)
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THERMAL CONTROL
  RADIATOR AREA               11.9 (FT**2),  BATTERY RADIATOR AREA                 .7 (FT**2)
                                             TOTAL RADIATOR AREA                 12.6 (FT**2)
  HEATER POWER               652.1(BTU/HR),  BATTERY HEATER POWER                53.3(BTU/HR)
                                             TOTAL HEATER POWER                 907.4(BTU/HR)
  HEAT PIPE                16415.1(WATT-IN), VARIABLE CONDUCTANCE H.P.         1283.1(WATT-IN)
  THERMAL CONTROL WEIGHT         8.5(LBS)
           DES. ENG. COST     530790.3          TEST + EVAL. COST        201563.7
           UNIT PROD.COST      72319.6          UNIT ENG.    COST        106348.1
           IERR      [illegible]
STRUCTURES
  SKIN THICKNESS           .029 (IN)
  STRINGER NO.,THICKNESS,HT.       68.     ,               .156 (IN),              1.719 (IN)
  FRAME    NO.,THICKNESS,HT.        1.     ,              1.952 (IN),               .685 (IN)
  ENDCOVER THICKNESS- FORWARD    .282 (IN), CENTER         .538 (IN), AFT           .282 (IN)
  EQUIPMENT BAY STRUCTURE WT.    73.9 (LBS)
  SOLAR ARRAY BOOM AND DRIVE WT. 15.2 (LBS)
  ADAPTER WEIGHT                 96.0 (LBS)
           DES. ENG. COST    3541117.8          TEST + EVAL. COST       1613494.5
           UNIT PROD.COST     801348.6          UNIT ENG.    COST        707490.3
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SMM

ASSEMBLY DESCRIPTIONS - - DESIGN NUMBER 5 * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG COST
1501	VALVE DRIVER ASSY	1	1.6	.2	1.0	49000.0	30000.0	11493.0	7991.7
2203	CONTROL ELECTRNCS	2	7.1	.1	62.0	636000.0	424600.0	225907.4	304911.3
1815	EARTH SENSOR	1	15.4	.5	15.6	1961800.0	611520.0	540746.5	395949.6
1309	REACTION WHEEL	1	8.5	.1	1.1	82400.0	58300.0	34134.3	16462.9

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG COST
114	THRUSTER	12	.7	.0	0.0	153676.8	89047.5	62243.1	282071.2
114	THRUSTER	4	.7	.0	0.0	119208.8	35427.5	32396.7	103604.9
203	ISOLATION VALVE	4	6.0	.6	0.0	0.0	0.0	0.0	0.0
303	FILTER	9	.0	.0	-0.0	0.0	0.0	0.0	0.0
413	PRESSURE REG	1	[illegible]	.2	-0.0	94000.0	25500.0	11033.3	18780.5
530	TANK	1	50.0	2.0	-0.0	0.0	0.0	0.0	0.0
503	FILL + VENT VALVE	1	.1	.0	-0.0	0.0	0.0	0.0	0.0
711	RELIEF VALVE	1	.2	.0	-0.0	[illegible]	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG COST
103	GEN PURP PROCESR	2	2.3	.5	15.0	2781250.0	1700000.0	1344686.8	1333387.7
203	DIGITAL TELEMETRY	1	8.9	.2	3.0	186400.0	169290.0	106365.1	37241.4
331	TAPE RECORDER	1	20.5	.5	14.9	508000.0	385000.0	459721.0	101494.8
405	COMMD DECOD+DISTR	1	11.0	.1	5.5	523700.0	322500.0	224228.9	104631.6

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG COST
112	BASEBND ASSY UNIT	2	4.0	.0	3.0	29000.0	9000.0	6310.0	13903.2
203	ANTENNA	1	10.4	.1	-0.0	272500.0	256200.0	62293.3	54443.6
336	TRANSMITTER	1	2.5	.0	70.0	35500.0	32500.0	79301.9	7092.6
403	RECEIVER	1	2.3	.0	3.5	53200.0	119400.0	33559.6	11627.9
503	COMMD SIG COND	1	1.5	.0	.9	36000.0	27000.0	28732.6	7192.5
518	DIPLEXER	1	1.5	.0	-0.0	1280.0	870.0	11608.0	2557.3

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG COST
812	SERIES LOAD REG	2	23.5	.5	-0.0	0.0	0.0	0.0	0.0
221	BATTERY	2	28.0	.1	-0.0	995646.6	2132820.0	893699.5	477333.2
902	BATTERY CHARGER	2	3.0	.1	-0.0	0.0	0.0	0.0	0.0
1003	SOLAR POWER DSTRB	1	1.0	.1	-0.0	0.0	0.0	0.0	0.0
1102	POWER CONTROL	1	1.7	.2	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	165.4	355000.0	438590.0	792822.8	70926.5
HARNESS	114.2	580150.8	479622.7	241171.8	115910.0
THERMAL CONTROL	8.5	530790.3	201583.7	72319.6	106048.1
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		418875.1	342944.1	300333.1	83688.3
STRUCTURE	39.1	3541117.8	1613494.8	801846.6	707490.3
POWER CONTROL UNITS	55.7	1740400.1	909498.0	350259.4	347719.6

APPENDIX D

LST

Cost Estimates

SPACECRAFT COST MODEL

LST BASELINE

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E			RECURRING		
	DESIGN ENGINEERING	TEST AND EVALUATION	TOTAL RDT+E	PRODUCTION ENGINEERING	FAB AND ASSEMBLY	TOTAL RECURRING
STRUCTURE	12.2	5.5	17.7	0.0	4.3	4.3
THERMAL CONTROL	7.0	2.5	9.5	0.0	1.2	1.2
ELECTRICAL POWER	23.5	22.4	45.9	7.9	14.0	21.8
COMMUNICATIONS	1.9	1.9	3.9	.5	1.4	1.9
DATA HANDLING	7.8	5.5	13.3	1.5	5.7	7.2
STABILITY AND CONTROL	11.2	7.3	18.5	9.7	11.3	20.9
AUXILIARY PROPULSION	2.6	2.1	4.7	1.7	1.2	2.9
SPACECRAFT	66.2	47.3	113.5	21.2	39.2	60.4
MISSION EQUIPMENT			250.0			100.0
SATELLITE			363.5			160.3
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			19.3			
LAUNCH SITE SUPPORT						1.1
CONTRACTOR FEE			9.3			4.3
TOTAL SATELLITE			392.1			165.8
AVERAGE UNIT COST						165.7
TOTAL SATELLITE DDT+E AND RECURRING COST						557.9

LST BASELINE

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	24	1.8	.1	35.2	242824.7	314722.5	410364.5	891390.1
306	SUN SENSOR	5	.2	.0	0.0	144934.2	231078.7	168193.4	171418.4
503	GIMBAL ELECTRONCS	2	6.3	.3	31.6	0.0	0.0	0.0	0.0
1733	RATE INTEGR GYRO	3	13.0	.1	12.0	1202337.6	1103308.6	645001.8	846135.4
1901	CONTROL ELECT.	2	10.3	1.0	26.5	1172070.0	752440.0	465651.4	468342.6
2006	CTRL MOMENT GYRO	4	170.0	6.0	30.8	2894000.0	2170500.0	5986959.2	2774884.7
2109	STAR SENSOR	3	11.8	.5	8.0	1681386.0	558296.0	497237.8	1183261.8

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
133	THRUSTER	12	1.4	.0	0.0	336434.7	659137.4	224940.1	786368.7
212	ISOLATION VALVE	8	3.3	.0	0.0	0.0	0.0	0.0	0.0
312	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
418	PRESSURE REGULATR	2	4.1	.1	-0.0	740502.2	307487.5	156325.8	295894.2
524	TANK	2	21.6	1.4	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
109	GEN PURP PROCESR	1	15.0	.1	20.0	2676950.0	1664050.0	1847819.0	0.0
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	183045.5	181453.8	207547.5	73142.4
312	TAPE RECORDER	2	11.0	.2	4.0	483298.0	392137.0	947933.2	193119.0
345	TAPE RECORDER	2	16.8	.4	25.0	648545.4	499359.7	245464.8	259149.6
424	COMMAND DIST UNIT	2	19.1	.7	4.6	1141339.3	1121960.4	914672.4	456063.1

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	41384.2	12733.6	29749.9	0.0
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	260460.0	221391.0	106434.6	104076.1
239	ANTENNA	2	2.1	.0	-0.0	150486.0	115760.0	38249.9	60132.9
309	TRANSMITTER	2	1.8	.0	8.8	27058.9	31544.6	109760.7	10812.4
324	TRANSMITTER	2	7.5	.2	37.5	162064.0	95502.0	139695.4	64758.5
351	TRANSMITTER	2	1.9	.2	52.0	39069.0	39069.0	256108.3	15611.4
415	RECEIVER	2	3.9	.1	3.0	107946.2	244253.6	115415.0	43133.8
418	RECEIVER	2	4.2	.1	2.0	109972.0	247437.0	116412.8	43943.3
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6
714	POWER CONVERTER	24	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	BATTERY	6	73.9	.1	-0.0	3728291.1	8243559.0	3266014.8	5161942.5
303	BATTERY CHARGER	6	3.5	.1	-0.0	0.0	0.0	0.0	0.0
902	BATTERY CHARGER	6	3.0	.1	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	820.0	1714809.2	1412959.9	2591551.6	0.0
HARNESS	985.0	3917703.0	2447653.7	1930387.7	0.0
THERMAL CONTROL	300.0	4575811.1	1737802.7	876734.1	0.0
POWER CONVERTERS	290.4	4032336.5	2368754.2	1805767.8	0.0
PROPULSION FEED SYS.		643674.1	504212.9	490054.8	0.0
STRUCTURE	2476.0	7979414.5	3847158.6	3090258.2	0.0
POWER CONTROL UNITS	38.7	2034343.6	1179612.3	527078.5	0.0

SPACECRAFT COST MODEL

LO COST (CMG-EP1)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E			RECURRING		
	DESIGN ENGINEERING	TEST AND EVALUATION	TOTAL RDT+E	PRODUCTION ENGINEERING	FAB AND ASSEMBLY	TOTAL RECURRING
STRUCTURE	12.2	5.5	17.7	0.0	4.3	4.3
THERMAL CONTROL	7.0	2.5	9.5	0.0	1.2	1.2
ELECTRICAL POWER	11.7	8.1	19.8	2.7	12.4	15.1
COMMUNICATIONS	.9	1.1	2.0	.4	1.0	1.4
DATA HANDLING	4.2	3.1	7.3	2.1	4.3	6.4
STABILITY AND CONTROL	2.9	2.1	5.0	4.4	7.6	12.0
AUXILIARY PROPULSION	1.5	.9	2.5	.7	1.0	1.7
SPACECRAFT	40.4	23.3	63.7	10.3	31.9	42.3
MISSION EQUIPMENT			250.0			100.0
SATELLITE			326.4			142.2
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			13.7			
LAUNCH SITE SUPPORT						.9
CONTRACTOR FEE			6.3			3.0
TOTAL SATELLITE			346.5			146.2
AVERAGE UNIT COST						146.1
TOTAL SATELLITE DDT+E AND RECURRING COST						492.7

LO COST (CMG-EP1)

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	24	1.8	.1	35.2	121412.3	157361.3	268618.3	228885.6
306	SUN SENSOR	5	.2	.0	0.0	0.0	0.0	110096.8	63840.2
503	GIMBAL ELECTRONCS	2	6.3	.3	31.6	0.0	0.0	0.0	0.0
1733	RATE INTEGR GYRO	3	13.0	.1	12.0	601168.8	551654.3	422208.2	413383.7
1901	CONTROL ELECT.	2	10.3	1.0	26.5	1172070.0	752440.0	465651.4	468342.6
2006	CTRL MOMENT GYRO	4	170.0	6.0	30.8	0.0	0.0	3918971.0	1143986.2
2109	STAR SENSOR	3	11.8	.5	8.0	0.0	0.0	325484.2	578088.6

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
133	THRUSTER	12	1.4	.0	0.0	0.0	0.0	147242.3	226582.8
212	ISOLATION VALVE	8	3.3	.0	0.0	0.0	0.0	0.0	0.0
312	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
418	PRESSURE REGULATR	2	4.1	.1	-0.0	370251.1	153743.8	102328.5	209145.8
524	TANK	2	21.6	1.4	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
109	GEN PURP PROCESR	1	15.0	.1	20.0	1338475.0	832025.0	1209553.8	540211.0
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	183045.5	181453.8	207547.5	73142.4
312	TAPE RECORDER	2	11.0	.2	4.0	0.0	0.0	620502.4	136501.6
345	TAPE RECORDER	2	16.8	.4	25.0	64854.5	49936.0	160677.5	183173.7
424	COMMAND DIST UNIT	2	19.1	.7	4.6	1141339.3	1121960.4	914672.4	456063.1

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	65115.0	55347.8	69670.4	73563.7
239	ANTENNA	2	2.1	.0	-0.0	0.0	0.0	25037.8	42503.5
309	TRANSMITTER	2	1.8	.0	8.8	2705.9	3154.5	71847.6	7642.5
324	TRANSMITTER	2	7.5	.2	37.5	0.0	0.0	91442.5	45773.0
351	TRANSMITTER	2	1.9	.2	52.0	3906.9	3906.9	167644.5	11034.6
415	RECEIVER	2	3.9	.1	3.0	107946.2	244253.6	115415.0	43133.8
418	RECEIVER	2	4.2	.1	2.0	54986.0	123718.5	76202.1	31060.2
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6
714	POWER CONVERTER	24	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	BATTERY	6	73.9	.1	-0.0	372829.1	824355.9	2137882.9	1794057.3
303	BATTERY CHARGER	6	3.5	.1	-0.0	0.0	0.0	0.0	0.0
902	BATTERY CHARGER	6	3.0	.1	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	820.0	1714809.2	1412959.9	2591551.6	0.0
HARNESS	985.0	3917703.0	2447653.7	1930387.7	0.0
THERMAL CONTROL	300.0	4575811.1	1737802.7	876734.1	0.0
POWER CONVERTERS	290.4	403233.7	236875.4	1805767.8	0.0
PROPULSION FEED SYS.		643674.1	504212.9	490054.8	0.0
STRUCTURE	2476.0	7979414.5	3847158.6	3090258.2	0.0
POWER CONTROL UNITS	38.7	1281636.5	743155.7	527078.5	0.0

SPACECRAFT COST MODEL

LO COST (RW-EP1)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL RDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	12.0	5.4	17.4	0.0	4.3	4.3
THERMAL CONTROL	7.0	2.5	9.5	0.0	1.2	1.2
ELECTRICAL POWER	11.7	8.1	19.8	2.7	12.4	15.1
COMMUNICATIONS	.9	1.1	2.0	.4	1.0	1.4
DATA HANDLING	4.2	3.1	7.3	2.1	4.3	6.4
STABILITY AND CONTROL	3.0	2.3	5.4	3.2	2.9	6.0
AUXILIARY PROPULSION	1.5	.9	2.5	.7	1.0	1.7
SPACECRAFT	40.3	23.5	63.8	9.1	27.2	36.3
MISSION EQUIPMENT			250.0			100.0
SATELLITE			325.1			136.2
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			13.7			
LAUNCH SITE SUPPORT						.8
CONTRACTOR FEE			6.2			2.6
TOTAL SATELLITE			345.1			139.7
AVERAGE UNIT COST						139.6
TOTAL SATELLITE DDT+E AND RECURRING COST						484.8

LO COST (RW-EP1)

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	24	1.8	.1	35.2	121412.3	157361.3	268618.3	228885.6
306	SUN SENSOR	5	.2	.0	0.0	0.0	0.0	110096.8	63840.2
503	GIMBAL ELECTRONCS	2	6.3	.3	31.6	0.0	0.0	0.0	0.0
1327	REACTN WHEEL ASSY	4	80.6	2.3	70.0	83220.6	174942.3	478114.5	328967.5
1733	RATE INTEGR GYRO	3	13.0	.1	12.0	601168.8	551654.3	422208.2	413383.7
1901	CONTROL ELECT.	2	10.3	1.0	26.5	1172070.0	752440.0	465651.4	468342.6
2109	STAR SENSOR	3	11.8	.5	8.0	0.0	0.0	325484.2	578088.6

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
133	THRUSTER	12	1.4	.0	0.0	0.0	0.0	147242.3	226582.8
212	ISOLATION VALVE	8	3.3	.0	0.0	0.0	0.0	0.0	0.0
312	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
418	PRESSURE REGULATR	2	4.1	.1	-0.0	370251.1	153743.8	102328.5	209145.8
524	TANK	2	21.6	1.4	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
109	GEN PURP PROCESR	1	15.0	.1	20.0	1338475.0	832025.0	1209553.8	540211.0
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	183045.5	181453.8	207547.5	73142.4
312	TAPE RECORDER	2	11.0	.2	4.0	0.0	0.0	620502.4	136501.6
345	TAPE RECORDER	2	16.8	.4	25.0	64854.5	49936.0	160677.5	183173.7
424	COMMAND DIST UNIT	2	19.1	.7	4.6	1141339.3	1121960.4	914672.4	456063.1

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	65115.0	55347.8	69670.4	73563.7
239	ANTENNA	2	2.1	.0	-0.0	0.0	0.0	25037.8	42503.5
309	TRANSMITTER	2	1.8	.0	8.8	2705.9	3154.5	71847.6	7642.5
324	TRANSMITTER	2	7.5	.2	37.5	0.0	0.0	91442.5	45773.0
351	TRANSMITTER	2	1.9	.2	52.0	3906.9	3906.9	167644.5	11034.6
415	RECEIVER	2	3.9	.1	3.0	107946.2	244253.6	115415.0	43133.8
418	RECEIVER	2	4.2	.1	2.0	54986.0	123718.5	76202.1	31060.2
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6
714	POWER CONVERTER	24	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	BATTERY	6	73.9	.1	-0.0	372829.1	824355.9	2137882.9	1794057.3
303	BATTERY CHARGER	6	3.5	.1	-0.0	0.0	0.0	0.0	0.0
902	BATTERY CHARGER	6	3.0	.1	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	820.0	1714809.2	1412959.9	2591551.6	0.0
HARNESS	985.0	3917703.0	2447653.7	1930387.7	0.0
THERMAL CONTROL	300.0	4575811.1	1737802.7	876734.1	0.0
POWER CONVERTERS	290.4	403233.7	236875.4	1805767.8	0.0
PROPULSION FEED SYS.		643674.1	504212.9	490054.8	0.0
STRUCTURE	2476.0	7853218.5	3786315.0	3090258.2	0.0
POWER CONTROL UNITS	38.7	1281636.5	743155.7	527078.5	0.0

SPACECRAFT COST MODEL

LO COST (CMG-EP2)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL RDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	11.9	5.4	17.3	0.0	4.3	4.3
THERMAL CONTROL	7.0	2.5	9.5	0.0	1.2	1.2
ELECTRICAL POWER	10.8	7.2	18.0	2.7	9.6	12.4
COMMUNICATIONS	.9	1.1	2.0	.4	1.0	1.4
DATA HANDLING	4.2	3.1	7.3	2.1	4.3	6.4
STABILITY AND CONTROL	2.9	2.1	5.0	4.4	7.6	12.0
AUXILIARY PROPULSION	1.5	.9	2.5	.7	1.0	1.7
SPACECRAFT	39.2	22.4	61.6	10.3	29.1	39.5
MISSION EQUIPMENT			250.0			100.0
SATELLITE			324.3			139.4
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			13.4			
LAUNCH SITE SUPPORT						.9
CONTRACTOR FEE			6.1			2.8
TOTAL SATELLITE			343.8			143.2
AVERAGE UNIT COST						143.1
TOTAL SATELLITE DDT+E AND RECURRING COST						487.0

LO COST (CMG-EP2)

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	24	1.8	.1	35.2	121412.3	157361.3	268618.3	228885.6
306	SUN SENSOR	5	.2	.0	0.0	0.0	0.0	110096.8	63840.2
503	GIMBAL ELECTRONCS	2	6.3	.3	31.6	0.0	0.0	0.0	0.0
1733	RATE INTEGR GYRO	3	13.0	.1	12.0	601168.8	551654.3	422208.2	413383.7
1901	CONTROL ELECT.	2	10.3	1.0	26.5	1172070.0	752440.0	465651.4	468342.6
2006	CTRL MOMENT GYRO	4	170.0	6.0	30.8	0.0	0.0	3918971.0	1143986.2
2109	STAR SENSOR	3	11.8	.5	8.0	0.0	0.0	325484.2	578088.6

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
133	THRUSTER	12	1.4	.0	0.0	0.0	0.0	147242.3	226582.8
212	ISOLATION VALVE	8	3.3	.0	0.0	0.0	0.0	0.0	0.0
312	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
418	PRESSURE REGULATR	2	4.1	.1	-0.0	370251.1	153743.8	102328.5	209145.8
524	TANK	2	21.6	1.4	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
109	GEN PURP PROCESR	1	15.0	.1	20.0	1338475.0	832025.0	1209553.8	540211.0
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	183045.5	181453.8	207547.5	73142.4
312	TAPE RECORDER	2	11.0	.2	4.0	0.0	0.0	620502.4	136501.6
345	TAPE RECORDER	2	16.8	.4	25.0	64854.5	49936.0	160677.5	183173.7
424	COMMAND DIST UNIT	2	19.1	.7	4.6	1141339.3	1121960.4	914672.4	456063.1

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	65115.0	55347.8	69670.4	73563.7
239	ANTENNA	2	2.1	.0	-0.0	0.0	0.0	25037.8	42503.5
309	TRANSMITTER	2	1.8	.0	8.8	2705.9	3154.5	71847.6	7642.5
324	TRANSMITTER	2	7.5	.2	37.5	0.0	0.0	91442.5	45773.0
351	TRANSMITTER	2	1.9	.2	52.0	3906.9	3906.9	167644.5	11034.6
415	RECEIVER	2	3.9	.1	3.0	107946.2	244253.6	115415.0	43133.8
418	RECEIVER	2	4.2	.1	2.0	54986.0	123718.5	76202.1	31060.2
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	BATTERY	6	73.9	.1	-0.0	372829.1	824355.9	2137882.9	1794057.3
303	BATTERY CHARGER	6	3.5	.1	-0.0	0.0	0.0	0.0	0.0
312	BATTERY CHARGER	6	5.0	.1	-0.0	0.0	0.0	0.0	0.0
406	DISCHGE REGULATOR	6	9.8	.2	-0.0	0.0	0.0	0.0	0.0
515	SHUNT REGULATOR	10	2.3	.0	-0.0	0.0	0.0	0.0	0.0
702	POWER CONTROL	1	9.4	.6	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	585.2	1340383.6	1193644.7	2232646.5	0.0
HARNESS	985.0	3917703.0	2447653.7	1930387.7	0.0
THERMAL CONTROL	300.0	4575811.1	1737802.7	876734.1	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		643674.1	504212.9	490054.8	0.0
STRUCTURE	2476.0	7703695.7	3714224.8	3090258.2	0.0
POWER CONTROL UNITS	141.7	1438156.0	575326.7	667515.3	0.0

SPACECRAFT COST MODEL

LO COST (RW-EP2)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL RDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	11.7	5.3	17.1	0.0	4.3	4.3
THERMAL CONTROL	7.0	2.5	9.5	0.0	1.2	1.2
ELECTRICAL POWER	10.8	7.2	18.0	2.7	9.6	12.4
COMMUNICATIONS	.9	1.1	2.0	.4	1.0	1.4
DATA HANDLING	4.2	3.1	7.3	2.1	4.3	6.4
STABILITY AND CONTROL	3.0	2.3	5.4	3.2	2.9	6.0
AUXILIARY PROPULSION	1.5	.9	2.5	.7	1.0	1.7
SPACECRAFT	39.1	22.5	61.7	9.1	24.4	33.5
MISSION EQUIPMENT			250.0			100.0
SATELLITE			323.0			133.4
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			13.4			
LAUNCH SITE SUPPORT						.8
CONTRACTOR FEE			6.0			2.4
TOTAL SATELLITE			342.4			136.7
AVERAGE UNIT COST						136.6
TOTAL SATELLITE DDT+E AND RECURRING COST						479.1

LO COST (RW-EP2)

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	24	1.8	.1	35.2	121412.3	157361.3	268618.3	228885.6
306	SUN SENSOR	5	.2	.0	0.0	0.0	0.0	110096.8	63840.2
503	GIMBAL ELECTRONCS	2	6.3	.3	31.6	0.0	0.0	0.0	0.0
1327	REACTN WHEEL ASSY	4	80.6	2.3	70.0	83220.6	174942.3	478114.5	328967.5
1733	RATE INTEGR GYRO	3	13.0	.1	12.0	601168.8	551654.3	422208.2	413383.7
1901	CONTROL ELECT.	2	10.3	1.0	26.5	1172070.0	752440.0	465651.4	468342.6
2109	STAR SENSOR	3	11.8	.5	8.0	0.0	0.0	325484.2	578088.6

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
133	THRUSTER	12	1.4	.0	0.0	0.0	0.0	147242.3	226582.8
212	ISOLATION VALVE	8	3.3	.0	0.0	0.0	0.0	0.0	0.0
312	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
418	PRESSURE REGULATR	2	4.1	.1	-0.0	370251.1	153743.8	102328.5	209145.8
524	TANK	2	21.6	1.4	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
109	GEN PURP PROCESR	1	15.0	.1	20.0	1338475.0	832025.0	1209553.8	540211.0
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	183045.5	181453.8	207547.5	73142.4
312	TAPE RECORDER	2	11.0	.2	4.0	0.0	0.0	620502.4	136501.6
345	TAPE RECORDER	2	16.8	.4	25.0	64854.5	49936.0	160677.5	183173.7
424	COMMAND DIST UNIT	2	19.1	.7	4.6	1141339.3	1121960.4	914672.4	456063.1

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	65115.0	55347.8	69670.4	73563.7
239	ANTENNA	2	2.1	.0	-0.0	0.0	0.0	25037.8	42503.5
309	TRANSMITTER	2	1.8	.0	8.8	2705.9	3154.5	71847.6	7642.5
324	TRANSMITTER	2	7.5	.2	37.5	0.0	0.0	91442.5	45773.0
351	TRANSMITTER	2	1.9	.2	52.0	3906.9	3906.9	167644.5	11034.6
415	RECEIVER	2	3.9	.1	3.0	107946.2	244253.6	115415.0	43133.8
418	RECEIVER	2	4.2	.1	2.0	54986.0	123718.5	76202.1	31060.2
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	BATTERY	6	73.9	.1	-0.0	372829.1	824355.9	2137882.9	1794057.3
303	BATTERY CHARGER	6	3.5	.1	-0.0	0.0	0.0	0.0	0.0
312	BATTERY CHARGER	6	5.0	.1	-0.0	0.0	0.0	0.0	0.0
406	DISCHGE REGULATOR	6	9.8	.2	-0.0	0.0	0.0	0.0	0.0
515	SHUNT REGULATOR	10	2.3	.0	-0.0	0.0	0.0	0.0	0.0
702	POWER CONTROL	1	9.4	.6	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	585.2	1340383.6	1193644.7	2232646.5	0.0
HARNESS	985.0	3917703.0	2447653.7	1930387.7	0.0
THERMAL CONTROL	300.0	4575811.1	1737802.7	876734.1	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		643674.1	504212.9	490054.8	0.0
STRUCTURE	2476.0	7830377.8	3775302.7	3090258.2	0.0
POWER CONTROL UNITS	141.7	1438156.0	575326.7	667515.3	0.0

SPACECRAFT COST MODEL

LO COST (RW-EP3)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	------DDT+E------ DESIGN ENGINEERING	TEST AND EVALUATION	TOTAL RDT+E	------RECURRING------ PRODUCTION ENGINEERING	FAB AND ASSEMBLY	TOTAL RECURRING
STRUCTURE	11.7	5.3	17.1	0.0	4.3	4.3
THERMAL CONTROL	7.0	2.5	9.5	0.0	1.2	1.2
ELECTRICAL POWER	10.0	6.9	17.0	2.7	9.6	12.4
COMMUNICATIONS	.9	1.1	2.0	.4	1.0	1.4
DATA HANDLING	4.2	3.1	7.3	2.1	4.3	6.4
STABILITY AND CONTROL	3.0	2.3	5.4	3.2	2.9	6.0
AUXILIARY PROPULSION	1.5	.9	2.5	.7	1.0	1.7
SPACECRAFT	38.4	22.2	60.6	9.1	24.4	33.5
MISSION EQUIPMENT			250.0			100.0
SATELLITE			321.9			133.4
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			13.3			
LAUNCH SITE SUPPORT						.8
CONTRACTOR FEE			6.0			2.4
TOTAL SATELLITE			341.2			136.7
AVERAGE UNIT COST						136.6
TOTAL SATELLITE DDT+E AND RECURRING COST						477.9

LO COST (RW-EP3)

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	24	1.8	.1	35.2	121412.3	157361.3	268618.3	228885.6
306	SUN SENSOR	5	.2	.0	0.0	0.0	0.0	110096.8	63840.2
503	GIMBAL ELECTRONCS	2	6.3	.3	31.6	0.0	0.0	0.0	0.0
1327	REACTN WHEEL ASSY	4	80.6	2.3	70.0	83220.6	174942.3	478114.5	328967.5
1733	RATE INTEGR GYRO	3	13.0	.1	12.0	601168.8	551654.3	422208.2	413383.7
1901	CONTROL ELECT.	2	10.3	1.0	26.5	1172070.0	752440.0	465651.4	468342.6
2109	STAR SENSOR	3	11.8	.5	8.0	0.0	0.0	325484.2	578088.6

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
133	THRUSTER	12	1.4	.0	0.0	0.0	0.0	147242.3	226582.8
212	ISOLATION VALVF	8	3.3	.0	0.0	0.0	0.0	0.0	0.0
312	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
418	PRESSURE REGULATR	2	4.1	.1	-0.0	370251.1	153743.8	102328.5	209145.8
524	TANK	2	21.6	1.4	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
109	GEN PURP PROCESR	1	15.0	.1	20.0	1338475.0	832025.0	1209553.8	540211.0
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	183045.5	181453.8	207547.5	73142.4
312	TAPE RECORDER	2	11.0	.2	4.0	0.0	0.0	620502.4	136501.6
345	TAPE RECORDER	2	16.8	.4	25.0	64854.5	49936.0	160677.5	183173.7
424	COMMAND DIST UNIT	2	19.1	.7	4.6	1141339.3	1121960.4	914672.4	456063.1

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	65115.0	55347.8	69670.4	73563.7
239	ANTENNA	2	2.1	.0	-0.0	0.0	0.0	25037.8	42503.5
309	TRANSMITTER	2	1.8	.0	8.8	2705.9	3154.5	71847.6	7642.5
324	TRANSMITTER	2	7.5	.2	37.5	0.0	0.0	91442.5	45773.0
351	TRANSMITTER	2	1.9	.2	52.0	3906.9	3906.9	167644.5	11034.6
415	RECEIVER	2	3.9	.1	3.0	107946.2	244253.6	115415.0	43133.8
418	RECEIVER	2	4.2	.1	2.0	54986.0	123718.5	76202.1	31060.2
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	SHUNT REGULATOR	34	4.2	.1	-0.0	0.0	0.0	0.0	0.0
242	BATTERY	6	73.9	.1	-0.0	372829.1	824355.9	2137882.9	1794057.3
315	BATTERY CHARGER	2	12.0	.3	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	585.2	1340383.6	1193644.7	2232646.5	0.0
HARNESS	985.0	3917703.0	2447653.7	1930387.7	0.0
THERMAL CONTROL	300.0	4575811.1	1737802.7	876734.1	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		643674.1	504212.9	490054.8	0.0
STRUCTURE	2476.0	7703695.7	3714224.8	3090258.2	0.0
POWER CONTROL UNITS	166.8	959173.2	366226.1	687624.8	0.0

APPENDIX E

HCMM COST ESTIMATES

SPACECRAFT COST MODEL

HCMM BASELINE

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL RDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	4.0	1.7	5.8	0.0	1.6	1.6
THERMAL CONTROL	.8	.3	1.1	0.0	.1	.1
ELECTRICAL POWER	2.0	3.6	5.6	.0	2.4	2.5
COMMUNICATIONS	.7	.7	1.4	0.0	.5	.5
DATA HANDLING	1.6	1.1	2.7	.2	.8	1.0
STABILITY AND CONTROL	8.6	4.3	12.9	.7	2.2	2.9
AUXILIARY PROPULSION	1.2	.5	1.8	.6	.3	.9
SPACECRAFT	19.0	12.2	31.2	1.5	8.0	9.5
MISSION EQUIPMENT			19.0			3.5
SATELLITE			50.2			13.0
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			8.2			
LAUNCH SITE SUPPORT						.4
CONTRACTOR FEE			2.8			.7
TOTAL SATELLITE			61.2			14.1
AVERAGE UNIT COST						14.1
TOTAL SATELLITE DDT+E AND RECURRING COST						75.3

HCMM BASELINE

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	108525.0	36175.0	27717.3	0.0
303	SUN SENSOR	2	.3	.0	.0	181584.0	229754.7	94793.3	72558.4
918	SUN SENSOR	4	.7	.0	1.0	387459.6	611849.5	264922.9	371512.0
1106	RATE GYRO	1	3.0	.1	16.0	389677.1	162353.4	89988.8	0.0
1466	SUN SENSOR ELECTR	1	2.2	.1	.7	621052.4	326587.9	19771.7	0.0
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	1	14.6	.2	19.0	2789526.6	855003.4	834290.3	0.0

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
812	THRUSTER	2	.7	.0	0.0	166260.3	166260.3	28936.9	66435.3
829	THRUSTER	8	.6	.0	0.0	181797.5	82925.2	85134.7	316612.2
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1101	TANK	2	2.8	.1	-0.0	0.0	0.0	0.0	0.0
1206	FILL + DRAIN VALV	2	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	157723.0	161933.8	99227.9	0.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	352704.4	292728.1	241806.1	140935.7
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	548268.3	322246.9	249825.1	0.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
218	ANTENNA	1	.8	.0	-0.0	86675.3	62076.3	19586.9	0.0
230	ANTENNA	1	1.8	.3	-0.0	137030.9	106643.9	30489.0	0.0
327	TRANSMITTER	1	4.7	.0	18.0	99843.0	70903.0	86847.5	0.0
351	TRANSMITTER	1	1.9	.2	52.0	39069.0	39069.0	142282.1	0.0
403	RECEIVER	1	2.3	.0	3.5	84215.4	172771.8	53956.3	0.0
618	DIPLEXER	1	1.5	.0	-0.0	18521.6	12588.9	18663.0	0.0
714	POWER CONVERTER	1	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202 BATTERY	2	10.5	.1	-0.0	67611.1	1233885.8	614659.8	27016.4
603 BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	31.0	142347.9	274728.5	622198.8	0.0
HARNESS	11.0	157514.4	176524.3	67822.2	0.0
THERMAL CONTROL	4.3	547824.8	208053.0	79315.9	0.0
POWER CONVERTERS	4.9	320937.5	188531.4	88784.1	0.0
PROPULSION FEED SYS.		464712.6	130349.1	128478.7	0.0
STRUCTURE	58.0	2650162.8	1198743.1	1151383.2	0.0
POWER CONTROL UNITS	5.2	626227.2	644696.5	365783.8	0.0

SPACECRAFT COST MODEL

HCMM/SAGE BASELINE

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL RDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	4.1	1.7	5.9	0.0	1.6	1.6
THERMAL CONTROL	.8	.3	1.1	0.0	.1	.1
ELECTRICAL POWER	1.9	1.8	3.7	.0	2.1	2.2
COMMUNICATIONS	0.0	0.0	0.0	.1	.3	.5
DATA HANDLING	1.3	.9	2.2	.3	.6	.9
STABILITY AND CONTROL	7.1	3.1	10.2	1.9	2.8	4.7
AUXILIARY PROPULSION	.7	.2	.9	.2	.3	.5
SPACECRAFT	15.9	8.0	23.9	2.6	7.8	10.4
MISSION EQUIPMENT			19.0			3.5
SATELLITE			44.4			13.9
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			7.2			
LAUNCH SITE SUPPORT						.4
CONTRACTOR FEE			2.3			.8
TOTAL SATELLITE			53.9			15.1
AVERAGE UNIT COST						15.1
TOTAL SATELLITE DDT+E AND RECURRING COST						69.1

HCMM/SAGE BASELINE

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	108525.0	36175.0	27717.3	0.0
303	SUN SENSOR	3	.3	.0	.0	199946.5	324359.5	133691.3	140710.7
1106	RATE GYRO	1	3.0	.1	16.0	389677.1	162353.4	89988.8	0.0
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	2	14.6	.2	19.0	2789526.6	855003.4	1501725.7	1114655.4

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
812	THRUSTER	2	.7	.0	0.0	0.0	0.0	18941.7	46958.2
829	THRUSTER	8	.6	.0	0.0	0.0	0.0	55727.9	100579.5
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1101	TANK	2	2.8	.1	-0.0	0.0	0.0	0.0	0.0
1206	FILL + DRAIN VALV	2	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	157723.0	161933.8	99227.9	0.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	264528.3	219546.1	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	411201.2	241685.2	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
218	ANTENNA	1	.8	.0	-0.0	0.0	0.0	12821.3	17491.2
230	ANTENNA	1	1.8	.3	-0.0	0.0	0.0	19957.6	27653.0
327	TRANSMITTER	1	4.7	.0	18.0	0.0	0.0	56849.0	20148.4
351	TRANSMITTER	1	1.9	.2	52.0	0.0	0.0	93135.6	7884.2
403	RECEIVER	1	2.3	.0	3.5	0.0	0.0	35319.0	16994.7
618	DIPLEXER	1	1.5	.0	-0.0	0.0	0.0	12216.5	3737.7
714	POWER CONVERTER	1	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202 BATTERY	2	10.5	.1	-0.0	0.0	0.0	402346.8	19095.9
603 BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	31.0	142347.9	274728.5	622198.8	0.0
HARNESS	11.0	157514.4	176524.3	67822.2	0.0
THERMAL CONTROL	4.3	547824.8	208053.0	79315.9	0.0
POWER CONVERTERS	4.9	320937.5	188531.4	88784.1	0.0
PROPULSION FEED SYS.		464712.6	130349.1	128478.7	0.0
STRUCTURE	58.0	2696328.4	1219625.1	1151383.2	0.0
POWER CONTROL UNITS	5.2	626227.2	644696.5	365783.8	0.0

SPACECRAFT COST MODEL

LO COST (ISW)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL RDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	4.0	1.7	5.8	0.0	1.6	1.6
THERMAL CONTROL	.8	.3	1.1	0.0	.1	.1
ELECTRICAL POWER	.7	.7	1.4	.0	2.1	2.2
COMMUNICATIONS	0.0	0.0	0.0	.1	.3	.5
DATA HANDLING	1.3	.9	2.2	.3	.6	.9
STABILITY AND CONTROL	3.5	1.8	5.3	1.2	1.6	2.8
AUXILIARY PROPULSION	.7	.2	.9	.2	.3	.5
SPACECRAFT	11.0	5.6	16.6	1.9	6.7	8.5
MISSION EQUIPMENT			19.0			3.5
SATELLITE			39.6			12.0
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			5.6			
LAUNCH SITE SUPPORT						.3
CONTRACTOR FEE			1.8			.6
TOTAL SATELLITE			47.1			13.0
AVERAGE UNIT COST						13.0
TOTAL SATELLITE DDT+E AND RECURRING COST						60.1

LO COST (1SW)

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	108525.0	36175.0	27717.3	0.0
303	SUN SENSOR	2	.3	.0	.0	0.0	0.0	62050.2	51286.2
918	SUN SENSOR	4	.7	.0	1.0	0.0	0.0	173414.5	153161.2
1106	RATE GYRO	1	3.0	.1	16.0	389677.1	162353.4	89988.8	0.0
1466	SUN SENSOR ELECTR	1	2.2	.1	.7	621052.4	326587.9	19771.7	0.0
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	1	14.6	.2	19.0	0.0	0.0	546113.5	562929.0

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
812	THRUSTER	2	.7	.0	0.0	0.0	0.0	18941.7	46958.2
829	THRUSTER	8	.6	.0	0.0	0.0	0.0	55727.9	100579.5
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1101	TANK	2	2.8	.1	-0.0	0.0	0.0	0.0	0.0
1206	FILL + DRAIN VALV	2	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	157723.0	161933.8	99227.9	0.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	264528.3	219546.1	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	411201.2	241685.2	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
218	ANTENNA	1	.8	.0	-0.0	0.0	0.0	12821.3	17491.2
230	ANTENNA	1	1.8	.3	-0.0	0.0	0.0	19957.6	27653.0
327	TRANSMITTER	1	4.7	.0	18.0	0.0	0.0	56849.0	20148.4
351	TRANSMITTER	1	1.9	.2	52.0	0.0	0.0	93135.6	7884.2
403	RECEIVER	1	2.3	.0	3.5	0.0	0.0	35319.0	16994.7
618	DIPLEXER	1	1.5	.0	-0.0	0.0	0.0	12216.5	3737.7
714	POWER CONVERTER	1	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202 BATTERY	2	10.5	.1	-0.0	0.0	0.0	402346.8	19095.9
603 BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	31.0	71174.0	137364.3	622198.8	0.0
HARNESS	11.0	157514.4	176524.3	67822.2	0.0
THERMAL CONTROL	4.3	547824.8	208053.0	79315.9	0.0
POWER CONVERTERS	4.9	160468.7	94265.7	88784.1	0.0
PROPULSION FEED SYS.		464712.6	130349.1	128478.7	0.0
STRUCTURE	58.0	2650162.8	1198743.1	1151383.2	0.0
POWER CONTROL UNITS	5.2	62622.7	64469.6	365783.8	0.0

SPACECRAFT COST MODEL

LO COST (2SW)

(MILLIONS OF 1975 DOLLARS)

	DDT+E			RECURRING		
SUBSYSTEM COST	DESIGN ENGINEERING	TEST AND EVALUATION	TOTAL RDT+E	PRODUCTION ENGINEERING	FAB AND ASSEMBLY	TOTAL RECURRING
STRUCTURE	4.1	1.7	5.9	0.0	1.6	1.6
THERMAL CONTROL	.8	.3	1.1	0.0	.1	.1
ELECTRICAL POWER	.7	.7	1.4	.0	2.1	2.2
COMMUNICATIONS	0.0	0.0	0.0	.1	.3	.5
DATA HANDLING	1.3	.9	2.2	.3	.6	.9
STABILITY AND CONTROL	2.5	1.4	3.9	1.3	2.0	3.3
AUXILIARY PROPULSION	.7	.2	.9	.2	.3	.5
SPACECRAFT	10.1	5.2	15.3	2.0	7.0	9.1
MISSION EQUIPMENT			19.0			3.5
SATELLITE			37.9			12.5
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			5.3			
LAUNCH SITE SUPPORT						.4
CONTRACTOR FEE			1.7			.7
TOTAL SATELLITE			44.9			13.6
AVERAGE UNIT COST						13.5
TOTAL SATELLITE DDT+E AND RECURRING COST						58.4

LO COST (2SW)

**** ASSEMBLY DESCRIPTIONS ****

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	108525.0	36175.0	27717.3	0.0
303	SUN SENSOR	3	.3	.0	.0	0.0	0.0	87512.3	68744.9
1106	RATE GYRO	1	3.0	.1	16.0	389677.1	162353.4	89988.8	0.0
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	2	14.6	.2	19.0	0.0	0.0	983006.5	787867.5

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
812	THRUSTER	2	.7	.0	0.0	0.0	0.0	18941.7	46958.2
829	THRUSTER	8	.6	.0	0.0	0.0	0.0	55727.9	100579.5
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1101	TANK	2	2.8	.1	-0.0	0.0	0.0	0.0	0.0
1206	FILL + DRAIN VALV	2	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	157723.0	161933.8	99227.9	0.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	264528.3	219546.1	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	411201.2	241685.2	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
218	ANTENNA	1	.8	.0	-0.0	0.0	0.0	12821.3	17491.2
230	ANTENNA	1	1.8	.3	-0.0	0.0	0.0	19957.6	27653.0
327	TRANSMITTER	1	4.7	.0	18.0	0.0	0.0	56849.0	20148.4
351	TRANSMITTER	1	1.9	.2	52.0	0.0	0.0	93135.6	7884.2
403	RECEIVER	1	2.3	.0	3.5	0.0	0.0	35319.0	16994.7
618	DIPLEXER	1	1.5	.0	-0.0	0.0	0.0	12216.5	3737.7
714	POWER CONVERTER	1	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202	BATTERY	2	10.5	.1	-0.0	0.0	0.0	402346.8	19095.9
603	BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	31.0	71174.0	137364.3	622198.8	0.0
HARNESS	11.0	157514.4	176524.3	67822.2	0.0
THERMAL CONTROL	4.3	547824.8	208053.0	79315.9	0.0
POWER CONVERTERS	4.9	160468.7	94265.7	88784.1	0.0
PROPULSION FEED SYS.		464712.6	130349.1	128478.7	0.0
STRUCTURE	58.0	2696328.4	1219625.1	1151383.2	0.0
POWER CONTROL UNITS	5.2	62622.7	64469.6	365783.8	0.0

SPACECRAFT COST MODEL

LO COST (1SW-EP2)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL RDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	4.0	1.7	5.7	0.0	1.6	1.6
THERMAL CONTROL	.8	.3	1.1	0.0	.1	.1
ELECTRICAL POWER	.5	.6	1.1	.0	2.0	2.1
COMMUNICATIONS	0.0	0.0	0.0	.1	.3	.5
DATA HANDLING	1.3	.9	2.2	.3	.6	.9
STABILITY AND CONTROL	3.5	1.8	5.3	1.2	1.6	2.8
AUXILIARY PROPULSION	.7	.2	.9	.2	.3	.5
SPACECRAFT	10.8	5.5	16.3	1.9	6.6	8.4
MISSION EQUIPMENT			19.0			3.5
SATELLITE			39.3			11.9
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			5.5			
LAUNCH SITE SUPPORT						.3
CONTRACTOR FEE			1.8			.6
TOTAL SATELLITE			46.6			12.9
AVERAGE UNIT COST						12.9
TOTAL SATELLITE DDT+E AND RECURRING COST						59.5

LO COST (1SW-EP2)

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	108525.0	36175.0	27717.3	0.0
303	SUN SENSOR	2	.3	.0	.0	0.0	0.0	62050.2	51286.2
918	SUN SENSOR	4	.7	.0	1.0	0.0	0.0	173414.5	153161.2
11C6	RATE GYRO	1	3.0	.1	16.0	389677.1	162353.4	89988.8	0.0
1466	SUN SENSOR ELECTR	1	2.2	.1	.7	621052.4	326587.9	19771.7	0.0
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	1	14.6	.2	19.0	0.0	0.0	546113.5	562929.0

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
812	THRUSTER	2	.7	.0	0.0	0.0	0.0	18941.7	46958.2
829	THRUSTER	8	.6	.0	0.0	0.0	0.0	55727.9	100579.5
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1101	TANK	2	2.8	.1	-0.0	0.0	0.0	0.0	0.0
1206	FILL + DRAIN VALV	2	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	157723.0	161933.8	99227.9	0.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	264528.3	219546.1	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	411201.2	241685.2	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
218	ANTENNA	1	.8	.0	-0.0	0.0	0.0	12821.3	17491.2
230	ANTENNA	1	1.8	.3	-0.0	0.0	0.0	19957.6	27653.0
327	TRANSMITTER	1	4.7	.0	18.0	0.0	0.0	56849.0	20148.4
351	TRANSMITTER	1	1.9	.2	52.0	0.0	0.0	93135.6	7884.2
403	RECEIVER	1	2.3	.0	3.5	0.0	0.0	35319.0	16994.7
618	DIPLEXER	1	1.5	.0	-0.0	0.0	0.0	12216.5	3737.7

ELECTRICAL POWER

IDENT TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
112 SHUNT REGULATOR	2	1.4	.0	-0.0	0.0	0.0	0.0	0.0
202 BATTERY	2	8.9	.1	-0.0	0.0	0.0	402346.8	19095.9
406 DISCHGE REGULATOR	1	9.8	.2	-0.0	0.0	0.0	0.0	0.0
603 BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	24.8	56504.3	122862.3	559224.2	0.0
HARNESS	11.0	157514.4	176524.3	67822.2	0.0
THERMAL CONTROL	4.3	547824.8	208053.0	79315.9	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		464712.6	130349.1	128478.7	0.0
STRUCTURE	58.0	2630508.9	1189853.1	1151383.2	0.0
POWER CONTROL UNITS	16.4	122899.8	91097.5	450830.7	0.0

SPACECRAFT COST MODEL

LO COST (2SW-EP2)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL RDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	4.1	1.7	5.8	0.0	1.6	1.6
THERMAL CONTROL	.8	.3	1.1	0.0	.1	.1
ELECTRICAL POWER	.5	.6	1.1	.0	2.0	2.1
COMMUNICATIONS	0.0	0.0	0.0	.1	.3	.5
DATA HANDLING	1.3	.9	2.2	.3	.6	.9
STABILITY AND CONTROL	2.5	1.4	3.9	1.3	2.0	3.3
AUXILIARY PROPULSION	.7	.2	.9	.2	.3	.5
SPACECRAFT	9.9	5.0	15.0	2.0	6.9	9.0
MISSION EQUIPMENT			19.0			3.5
SATELLITE			37.5			12.4
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			5.2			
LAUNCH SITE SUPPORT						.3
CONTRACTOR FEE			1.7			.6
TOTAL SATELLITE			44.4			13.5
AVERAGE UNIT COST						13.4
TOTAL SATELLITE DDT+E AND RECURRING COST						57.9

C.4

LO COST (2SW-EP2)

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	108525.0	36175.0	27717.3	0.0
303	SUN SENSOR	3	.3	.0	.0	0.0	0.0	87512.3	68744.9
1106	RATE GYRO	1	3.0	.1	16.0	389677.1	162353.4	89988.8	0.0
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	2	14.6	.2	19.0	0.0	0.0	983006.5	787867.5

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
812	THRUSTER	2	.7	.0	0.0	0.0	0.0	18941.7	46958.2
829	THRUSTER	8	.6	.0	0.0	0.0	0.0	55727.9	100579.5
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1101	TANK	2	2.8	.1	-0.0	0.0	0.0	0.0	0.0
1206	FILL + DRAIN VALV	2	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	157723.0	161933.8	99227.9	0.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	264528.3	219546.1	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	411201.2	241685.2	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
218	ANTENNA	1	.8	.0	-0.0	0.0	0.0	12821.3	17491.2
230	ANTENNA	1	1.8	.3	-0.0	0.0	0.0	19957.6	27653.0
327	TRANSMITTER	1	4.7	.0	18.0	0.0	0.0	56849.0	20148.4
351	TRANSMITTER	1	1.9	.2	52.0	0.0	0.0	93135.6	7884.2
403	RECEIVER	1	2.3	.0	3.5	0.0	0.0	35319.0	16994.7
618	DIPLEXER	1	1.5	.0	-0.0	0.0	0.0	12216.5	3737.7

ORIGINAL PAGE IS OF POOR QUALITY

ELECTRICAL POWER

IDENT TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
112 SHUNT REGULATOR	2	1.4	.0	-0.0	0.0	0.0	0.0	0.0
202 BATTERY	2	8.9	.1	-0.0	0.0	0.0	402346.8	19095.9
406 DISCHGE REGULATOR	1	9.8	.2	-0.0	0.0	0.0	0.0	0.0
603 BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	24.8	56504.3	122862.3	559224.2	0.0
HARNESS	11.0	157514.4	176524.3	67822.2	0.0
THERMAL CONTROL	4.3	547824.8	208053.0	79315.9	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		464712.6	130349.1	128478.7	0.0
STRUCTURE	58.0	2677533.2	1211123.6	1151383.2	0.0
POWER CONTROL UNITS	16.4	122899.8	91097.5	450830.7	0.0

APPENDIX F

SAGE COST ESTIMATES

SPACECRAFT COST MODEL

SAGE BASELINE

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL RDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	.4	.2	.5	0.0	1.6	1.6
THERMAL CONTROL	.6	.2	.8	0.0	.1	.1
ELECTRICAL POWER	.6	.8	1.4	.0	2.3	2.4
COMMUNICATIONS	1.3	1.4	2.7	0.0	.6	.6
DATA HANDLING	2.4	1.7	4.0	.2	1.5	1.8
STABILITY AND CONTROL	1.8	1.1	2.9	1.5	2.0	3.5
AUXILIARY PROPULSION	1.1	.3	1.4	.5	.3	.8
SPACECRAFT	8.1	5.7	13.8	2.2	8.5	10.8
MISSION EQUIPMENT			16.6			2.4
SATELLITE			33.5			13.2
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			4.5			
LAUNCH SITE SUPPORT						.3
CONTRACTOR FEE			1.5			.8
TOTAL SATELLITE			39.6			14.3
AVERAGE UNIT COST						14.3
TOTAL SATELLITE DDT+E AND RECURRING COST						53.9

SAGE BASELINE

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	0.0	0.0	18143.3	21900.4
303	SUN SENSOR	5	.3	.0	.0	0.0	0.0	134957.4	104248.4
1106	RATE GYRO	1	3.0	.1	16.0	0.0	0.0	58905.3	78637.2
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	2	14.6	.2	19.0	0.0	0.0	983006.5	787867.5

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
114	THRUSTER	6	.7	.0	0.0	184964.6	70660.6	73460.0	256089.6
604	FILL + DRAIN VALV	2	.3	.0	-0.0	0.0	0.0	0.0	0.0
812	THRUSTER	2	.7	.0	0.0	166260.3	41565.1	28936.9	66435.3
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1109	TANK	1	3.5	.4	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	157723.0	161933.8	99227.9	0.0
312	TAPE RECORDER	1	11.0	.2	4.0	483298.0	392137.0	526628.4	0.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	352704.4	292728.1	241806.1	140935.7
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	548268.3	322246.9	249825.1	0.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	41384.2	12733.6	29749.9	0.0
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
206	ANTENNA	1	1.5	.1	-0.0	125020.8	166115.6	27902.1	0.0
309	TRANSMITTER	1	1.8	.0	8.8	27058.9	31544.6	60978.0	0.0
327	TRANSMITTER	1	4.7	.0	18.0	99843.0	70903.0	86847.5	0.0
406	RECEIVER	1	2.3	.0	7.4	74231.1	144265.9	49336.8	0.0
415	RECEIVER	1	3.9	.1	3.0	107946.2	244253.6	64119.3	0.0
618	DIPLEXER	1	1.5	.0	-0.0	18521.6	12588.9	18663.0	0.0
714	POWER CONVERTER	1	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202 BATTERY	2	10.5	.1	-0.0	0.0	0.0	402346.8	19095.9
603 BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	51.6	213516.6	354444.1	774268.9	0.0
HARNESS	11.0	157514.4	176524.3	67822.2	0.0
THERMAL CONTROL	4.0	396276.9	150498.1	76134.8	0.0
POWER CONVERTERS	4.3	29597.1	17386.5	80625.1	0.0
PROPULSION FEED SYS.		381939.1	111194.7	109780.0	0.0
STRUCTURE	66.0	246184.0	111600.8	1191182.8	0.0
POWER CONTROL UNITS	5.2	0.0	0.0	365783.8	0.0

SPACECRAFT COST MODEL

LO COST

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL RDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	.4	.2	.5	0.0	1.6	1.6
THERMAL CONTROL	.6	.2	.8	0.0	.1	.1
ELECTRICAL POWER	.6	.7	1.3	.0	2.3	2.4
COMMUNICATIONS	.4	.5	.9	.2	.4	.6
DATA HANDLING	0.0	0.0	0.0	.5	1.0	1.5
STABILITY AND CONTROL	1.8	1.1	2.9	1.5	2.0	3.5
AUXILIARY PROPULSION	.6	.2	.7	.2	.2	.5
SPACECRAFT	4.3	2.9	7.1	2.5	7.8	10.2
MISSION EQUIPMENT			16.6			2.4
SATELLITE			29.0			12.6
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			2.9			
LAUNCH SITE SUPPORT						.3
CONTRACTOR FEE			1.1			.7
TOTAL SATELLITE			33.0			13.7
AVERAGE UNIT COST						13.6
TOTAL SATELLITE DDT+E AND RECURRING COST						46.6

LO COST

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	0.0	0.0	18143.3	21900.4
303	SUN SENSOR	5	.3	.0	.0	0.0	0.0	134957.4	104248.4
1106	RATE GYRO	1	3.0	.1	16.0	0.0	0.0	58905.3	78637.2
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	2	14.6	.2	19.0	0.0	0.0	983006.5	787867.5

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
114	THRUSTER	6	.7	.0	0.0	0.0	0.0	48085.8	89005.1
604	FILL + DRAIN VALV	2	.3	.0	-0.0	0.0	0.0	0.0	0.0
812	THRUSTER	2	.7	.0	0.0	0.0	0.0	18941.7	46958.2
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1109	TANK	1	3.5	.4	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	0.0	0.0	64953.0	31828.6
312	TAPE RECORDER	1	11.0	.2	4.0	0.0	0.0	344722.8	97530.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	0.0	0.0	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	0.0	0.0	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	34829.3	31935.3	48745.0	70285.8
206	ANTENNA	1	1.5	.1	-0.0	125020.8	166115.6	27902.1	0.0
309	TRANSMITTER	1	1.8	.0	8.8	2705.9	3154.5	39915.3	5460.5
327	TRANSMITTER	1	4.7	.0	18.0	9984.3	7090.3	56849.0	20148.4
406	RECEIVER	1	2.3	.0	7.4	7423.1	14426.6	32295.1	14979.9
415	RECEIVER	1	3.9	.1	3.0	53973.1	122126.8	41971.5	21783.6
618	DIPLEXER	1	1.5	.0	-0.0	18521.6	12588.9	18663.0	0.0
714	POWER CONVERTER	1	12.1	.3	29.2	0.0	0.0	0.0	0.0

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ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202	BATTERY	2	10.5	.1	-0.0	0.0	0.0	402346.8	19095.9
603	BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SCLAR ARRAY	51.6	213516.6	354444.1	774268.9	0.0
HARNESS	11.0	118135.8	132393.2	67822.2	0.0
THERMAL CONTROL	4.0	396276.9	150498.1	76134.8	0.0
POWER CONVERTERS	4.3	29597.1	17386.5	80625.1	0.0
PROPULSION FEED SYS.		381939.1	111194.7	109780.0	0.0
STRUCTURE	66.0	246184.0	111600.8	1191182.8	0.0
POWER CONTROL UNITS	5.2	0.0	0.0	365783.8	0.0

SPACECRAFT COST MODEL

LO COST (AP/CG)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL RDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	.4	.2	.6	0.0	1.6	1.6
THERMAL CONTROL	.6	.2	.8	0.0	.1	.1
ELECTRICAL POWER	.6	.7	1.3	.0	2.3	2.4
COMMUNICATIONS	.4	.5	.9	.2	.4	.6
DATA HANDLING	0.0	0.0	0.0	.5	1.0	1.5
STABILITY AND CONTROL	1.8	1.1	2.9	1.5	2.0	3.5
AUXILIARY PROPULSION	.7	.4	1.1	.3	.5	.9
SPACECRAFT	4.5	3.1	7.5	2.6	8.0	10.6
MISSION EQUIPMENT			16.6			2.4
SATELLITE			29.6			13.0
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			3.0			
LAUNCH SITE SUPPORT						.3
CONTRACTOR FEE			1.1			.8
TOTAL SATELLITE			33.7			14.1
AVERAGE UNIT COST						14.1
TOTAL SATELLITE DDT+E AND RECURRING COST						47.8

LO COST (AP/CG)

**** ASSEMBLY DESCRIPTIONS ****

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	0.0	0.0	18143.3	21900.4
303	SUN SENSOR	5	.3	.0	.0	0.0	0.0	134957.4	104248.4
1106	RATE GYRO	1	3.0	.1	16.0	0.0	0.0	58905.3	78637.2
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	2	14.6	.2	19.0	0.0	0.0	983006.5	787867.5

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
113	THRUSTER	2	.8	.0	-0.0	0.0	0.0	20901.1	51903.3
114	THRUSTER	6	.7	.0	0.0	0.0	0.0	48085.8	89005.1
212	ISOLATION VALVE	5	3.3	.0	0.0	0.0	0.0	0.0	0.0
411	PRESSURE REGULATR	2	1.3	.0	-0.0	0.0	0.0	48987.0	81839.6
511	TANK	1	11.5	.6	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	0.0	0.0	64953.0	31828.6
312	TAPE RECORDER	1	11.0	.2	4.0	0.0	0.0	344722.8	97530.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	0.0	0.0	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	0.0	0.0	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	34829.3	31935.3	48745.0	70285.8
206	ANTENNA	1	1.5	.1	-0.0	125020.8	166115.6	27902.1	0.0
309	TRANSMITTER	1	1.8	.0	8.8	2705.9	3154.5	39915.3	5460.5
327	TRANSMITTER	1	4.7	.0	18.0	9984.3	7090.3	56849.0	20148.4
406	RECEIVER	1	2.3	.0	7.4	7423.1	14426.6	32295.1	14979.9
415	RECEIVER	1	3.9	.1	3.0	53973.1	122126.8	41971.5	21783.6
618	DIPLEXER	1	1.5	.0	-0.0	18521.6	12588.9	18663.0	0.0
714	POWER CONVERTER	1	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202	BATTERY	2	10.5	.1	-0.0	0.0	0.0	402346.8	19095.9
603	BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	51.6	213516.6	354444.1	774268.9	0.0
HARNESS	11.0	118135.8	132393.2	67822.2	0.0
THERMAL CONTROL	4.0	396276.9	150498.1	76134.8	0.0
POWER CONVERTERS	4.3	29597.1	17386.5	80625.1	0.0
PROPULSION FEED SYS.		488938.4	257911.7	252418.4	0.0
STRUCTURE	66.0	264367.3	119843.7	1191182.8	0.0
POWER CONTROL UNITS	5.2	0.0	0.0	365783.8	0.0

SPACECRAFT COST MODEL

LO COST (AP/HCMM)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL RDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	.4	.2	.5	0.0	1.6	1.6
THERMAL CONTROL	.6	.2	.8	0.0	.1	.1
ELECTRICAL POWER	.6	.7	1.3	.0	2.3	2.4
COMMUNICATIONS	.4	.5	.9	.2	.4	.6
DATA HANDLING	0.0	0.0	0.0	.5	1.0	1.5
STABILITY AND CONTROL	1.8	1.1	2.9	1.5	2.0	3.5
AUXILIARY PROPULSION	0.0	0.0	0.0	.2	.3	.5
SPACECRAFT	3.7	2.7	6.4	2.5	7.8	10.3
MISSION EQUIPMENT			16.6			2.4
SATELLITE			28.3			12.7
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			2.6			
LAUNCH SITE SUPPORT						.2
CONTRACTOR FEE			1.0			.7
TOTAL SATELLITE			31.9			13.7
AVERAGE UNIT COST						13.7
TOTAL SATELLITE DDT+E AND RECURRING COST						45.6

LO COST (AP/HCMM)

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	0.0	0.0	18143.3	21900.4
303	SUN SENSOR	5	.3	.0	.0	0.0	0.0	134957.4	104248.4
1106	RATE GYRO	1	3.0	.1	16.0	0.0	0.0	58905.3	78637.2
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	2	14.6	.2	19.0	0.0	0.0	983006.5	787867.5

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
812	THRUSTER	2	.7	.0	0.0	0.0	0.0	18941.7	46958.2
829	THRUSTER	8	.6	.0	0.0	0.0	0.0	55727.9	100579.5
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1101	TANK	2	2.8	.1	-0.0	0.0	0.0	0.0	0.0
1206	FILL + DRAIN VALV	2	.2	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	0.0	0.0	64953.0	31828.6
312	TAPE RECORDER	1	11.0	.2	4.0	0.0	0.0	344722.8	97530.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	0.0	0.0	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	0.0	0.0	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	34829.3	31935.3	48745.0	70285.8
206	ANTENNA	1	1.5	.1	-0.0	125020.8	166115.6	27902.1	0.0
309	TRANSMITTER	1	1.8	.0	8.8	2705.9	3154.5	39915.3	5460.5
327	TRANSMITTER	1	4.7	.0	18.0	9984.3	7090.3	56849.0	20148.4
406	RECEIVER	1	2.3	.0	7.4	7423.1	14426.6	32295.1	14979.9
415	RECEIVER	1	3.9	.1	3.0	53973.1	122126.8	41971.5	21783.6
618	DIPLEXER	1	1.5	.0	-0.0	18521.6	12588.9	18663.0	0.0
714	POWER CONVERTER	1	12.1	.3	29.2	0.0	0.0	0.0	0.0

ELECTRICAL POWER

IDENT TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	O.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202 BATTERY	2	10.5	.1	-0.0	0.0	0.0	402346.8	19095.9
603 BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	O.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	51.6	213516.6	354444.1	774268.9	0.0
HARNESS	11.0	118135.8	132393.2	67822.2	0.0
THERMAL CONTROL	4.0	396276.9	150498.1	76134.8	0.0
POWER CONVERTERS	4.3	29597.1	17386.5	80625.1	0.0
PROPULSION FEED SYS.		0.0	0.0	128478.7	0.0
STRUCTURE	66.0	248069.2	112455.4	1191182.8	0.0
POWER CONTROL UNITS	5.2	0.0	0.0	365783.8	0.0

SPACECRAFT COST MODEL

LO COST (EP2)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL RDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	8.3	3.6	12.0	0.0	2.6	2.6
THERMAL CONTROL	1.3	.5	1.7	0.0	.2	.2
ELECTRICAL POWER	3.3	2.5	5.8	.1	3.8	4.0
COMMUNICATIONS	1.3	1.3	2.6	.4	.9	1.2
DATA HANDLING	2.4	1.2	3.6	1.1	2.1	3.2
STABILITY AND CONTROL	3.0	1.9	4.9	1.5	1.9	3.4
AUXILIARY PROPULSION	.8	.4	1.1	.3	.6	.9
SPACECRAFT	20.3	11.4	31.7	3.5	12.0	15.5
MISSION EQUIPMENT			34.4			18.3
SATELLITE			71.5			33.7
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			8.6			
LAUNCH SITE SUPPORT						.5
CONTRACTOR FEE			3.2			1.1
TOTAL SATELLITE			83.2			35.4
AVERAGE UNIT COST						35.4
TOTAL SATELLITE DDT+E AND RECURRING COST						118.6

LO COST (EP2)

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
209	VALVE DRIVER	1	1.8	.1	35.2	0.0	0.0	18143.3	21900.4
303	SUN SENSOR	5	.3	.0	.0	0.0	0.0	134957.4	104248.4
1106	RATE GYRO	1	3.0	.1	16.0	0.0	0.0	58905.3	78637.2
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1803	EARTH SENSOR	2	14.6	.2	19.0	0.0	0.0	983006.5	787867.5

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
114	THRUSTER	6	.7	.0	0.0	0.0	0.0	48085.8	89005.1
604	FILL + DRAIN VALV	2	.3	.0	-0.0	0.0	0.0	0.0	0.0
812	THRUSTER	2	.7	.0	0.0	0.0	0.0	18941.7	46958.2
915	ISOLATION VALVE	1	.2	.0	.2	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0
1109	TANK	1	3.5	.4	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
242	DIGITAL TELEMETRY	1	4.0	.0	15.0	0.0	0.0	64953.0	31828.6
312	TAPE RECORDER	1	11.0	.2	4.0	0.0	0.0	344722.8	97530.0
403	COMMD DECOD+DISTR	2	2.3	.0	7.5	0.0	0.0	158282.5	99617.0
409	COMMD DECOD+DISTR	1	6.1	.1	-0.0	0.0	0.0	163531.7	110641.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.0	.5	0.0	0.0	19473.8	8351.4
202	ANTENNA	1	8.4	.7	-0.0	34829.3	31935.3	48745.0	70285.8
206	ANTENNA	1	1.5	.1	-0.0	125020.8	166115.6	27902.1	0.0
309	TRANSMITTER	1	1.8	.0	8.8	2705.9	3154.5	39915.3	5460.5
327	TRANSMITTER	1	4.7	.0	18.0	9984.3	7090.3	56849.0	20148.4
406	RECEIVER	1	2.3	.0	7.4	7423.1	14426.6	32295.1	14979.9
415	RECEIVER	1	3.9	.1	3.0	53973.1	122126.8	41971.5	21783.6
618	DIPLEXER	1	1.5	.0	-0.0	18521.6	12588.9	18663.0	0.0

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
112	SHUNT REGULATOR	2	1.4	.0	-0.0	0.0	0.0	0.0	0.0
202	BATTERY	2	8.9	.1	-0.0	0.0	0.0	402346.8	19095.9
406	DISCHGE REGULATOR	1	9.8	.2	-0.0	0.0	0.0	0.0	0.0
603	BATTERY CHARGER	2	2.6	.0	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	43.4	184714.9	325063.2	717222.7	0.0
HARNESS	11.0	118135.8	132393.2	67822.2	0.0
THERMAL CONTROL	4.0	396276.9	150498.1	76134.8	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		381939.1	111194.7	109780.0	0.0
STRUCTURE	66.0	245869.5	111458.2	1191182.8	0.0
POWER CONTROL UNITS	16.4	0.0	0.0	450830.7	0.0

APPENDIX G

SMM COST ESTIMATES

SPACECRAFT COST MODEL

SMM BASELINE

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E			RECURRING		
	DESIGN ENGINEERING	TEST AND EVALUATION	TOTAL RDT+E	PRODUCTION ENGINEERING	FAB AND ASSEMBLY	TOTAL RECURRING
STRUCTURE	8.3	3.7	12.0	0.0	2.6	2.6
THERMAL CONTROL	1.3	.5	1.7	0.0	.2	.2
ELECTRICAL POWER	5.9	8.8	14.7	.4	4.4	4.8
COMMUNICATIONS	1.9	2.2	4.1	.5	1.1	1.6
DATA HANDLING	4.0	2.2	6.2	1.1	2.9	3.9
STABILITY AND CONTROL	7.1	5.2	12.3	2.5	2.7	5.1
AUXILIARY PROPULSION	1.5	.7	2.2	.9	.7	1.6
SPACECRAFT	30.0	23.2	53.2	5.3	14.5	19.8
MISSION EQUIPMENT			34.4			18.3
SATELLITE			87.6			38.1
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			11.2			
LAUNCH SITE SUPPORT						.6
CONTRACTOR FEE			4.5			1.4
TOTAL SATELLITE			103.3			40.2
AVERAGE UNIT COST						40.1
TOTAL SATELLITE DDT+E AND RECURRING COST						143.5

SMM BASELINE

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	VALVE DRIVER ASSY	1	1.6	.1	5.9	237308.0	21705.0	38804.2	0.0
406	NUTATION DAMPER	6	2.4	.1	-0.0	44766.6	6511.5	31241.6	61980.8
918	SUN SENSOR	3	.7	.0	1.0	354869.5	473689.9	207573.3	249736.6
924	SUN SENSOR	1	1.9	.0	.8	569394.5	308500.4	138586.4	0.0
933	SUN SENSOR	1	3.3	.1	2.0	827539.3	394741.6	184319.9	0.0
1315	REACTION WHEEL	4	12.2	.6	12.0	208825.6	356164.6	223912.3	200230.5
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1718	RATE INTEGR GYRO	4	9.6	.2	32.0	1084383.6	1149236.3	663953.8	1039751.0
2106	STAR SENSOR	2	11.4	1.8	1.9	180779.1	162845.4	193577.9	72236.8

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
113	THRUSTER	12	.8	.0	-0.0	204443.0	78101.8	145907.1	477856.7
215	ISOLATION VALVE	2	2.5	.0	-0.0	0.0	0.0	0.0	0.0
406	PRESSURE REGULATR	2	1.2	.0	-0.0	286542.2	118075.2	74836.8	114498.2
518	TANK	1	16.2	1.0	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
106	GEN PURP PROCESSR	2	22.5	.5	20.0	88860.3	20663.2	203223.6	35507.3
206	DIGITAL TELEMETRY	1	11.4	.1	6.0	820449.0	266682.1	194021.0	0.0
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	494222.9	181453.8	207547.5	197484.5
303	TAPE RECORDER	2	9.6	.2	3.0	441335.0	364644.0	881411.6	176351.2
427	COMMD DECOD+DISTR	2	9.2	.2	10.0	764166.1	709189.2	580733.8	305350.0

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	260460.0	221391.0	106434.6	104076.1
239	ANTENNA	1	2.1	.0	-0.0	150488.0	115760.0	21249.9	0.0
309	TRANSMITTER	2	1.8	.0	8.8	27058.9	31544.6	109760.7	10812.4
324	TRANSMITTER	2	7.5	.2	37.5	162064.0	95502.0	139695.4	64758.5
406	RECEIVER	2	2.3	.0	7.4	74231.1	144265.9	88806.4	29661.7
415	RECEIVER	1	3.9	.1	3.0	107946.2	244253.6	64119.3	0.0
418	RECEIVER	3	4.2	.1	2.0	116157.9	334040.0	164182.3	81745.2
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
215	BATTERY	4	21.6	.1	-0.0	267705.6	3765296.6	955518.7	256687.0
312	BATTERY CHARGER	4	5.0	.1	-0.0	0.0	0.0	0.0	0.0
515	SHUNT REGULATOR	6	2.3	.0	-0.0	0.0	0.0	0.0	0.0
702	POWER CONTROL	1	9.4	.6	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	99.0	698285.4	490953.7	1306676.3	0.0
HARNESS	128.0	910709.2	741835.5	422090.9	0.0
THERMAL CONTROL	10.0	835425.0	317277.9	127884.3	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		506070.8	261003.7	255412.9	0.0
STRUCTURE	365.5	5469870.6	2552827.3	1868433.8	0.0
POWER CONTROL UNITS	36.9	1978255.8	1162821.9	522529.3	0.0

SPACECRAFT COST MODEL

LO COST

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL RDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	8.3	3.7	12.0	0.0	2.6	2.6
THERMAL CONTROL	1.3	.5	1.7	0.0	.2	.2
ELECTRICAL POWER	4.4	3.2	7.7	.2	4.0	4.1
COMMUNICATIONS	1.3	1.3	2.6	.4	.9	1.2
DATA HANDLING	2.4	1.2	3.6	1.1	2.1	3.2
STABILITY AND CONTROL	3.0	1.9	4.9	1.5	1.9	3.4
AUXILIARY PROPULSION	.8	.4	1.1	.3	.6	.9
SPACECRAFT	21.4	12.2	33.6	3.5	12.1	15.6
MISSION EQUIPMENT			34.4			18.3
SATELLITE			73.7			33.9
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			8.9			
LAUNCH SITE SUPPORT						.5
CONTRACTOR FEE			3.4			1.1
TOTAL SATELLITE			86.0			35.6
AVERAGE UNIT COST						35.6
TOTAL SATELLITE DDT+E AND RECURRING COST						121.6

LO COST

**** ASSEMBLY DESCRIPTIONS ****

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	VALVE DRIVER ASSY	1	1.6	.1	5.9	237308.0	21705.0	38804.2	0.0
406	NUTATION DAMPER	6	2.4	.1	-0.0	0.0	0.0	20450.3	21541.7
918	SUN SENSOR	3	.7	.0	1.0	0.0	0.0	135874.3	122010.1
924	SUN SENSOR	1	1.9	.0	.8	0.0	0.0	90716.5	114904.3
933	SUN SENSOR	1	3.3	.1	2.0	0.0	0.0	120653.0	166998.2
1315	REACTION WHEEL	4	12.2	.6	12.0	0.0	0.0	146569.5	82547.9
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1718	RATE INTEGR GYRO	4	9.6	.2	32.0	542191.8	574618.2	434613.9	428652.3
2106	STAR SENSOR	2	11.4	1.8	1.9	0.0	0.0	126713.1	51058.8

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
113	THRUSTER	12	.8	.0	-0.0	0.0	0.0	95508.5	137688.7
215	ISOLATION VALVE	2	2.5	.0	-0.0	0.0	0.0	0.0	0.0
406	PRESSURE REGULATR	2	1.2	.0	-0.0	0.0	0.0	48987.0	80930.3
518	TANK	1	16.2	1.0	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
106	GEN PURP PROCESSR	2	22.5	.5	20.0	88860.3	20663.2	203223.6	35507.3
206	DIGITAL TELEMETRY	1	11.4	.1	6.0	410224.5	133341.1	127003.1	165567.4
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	494222.9	181453.8	207547.5	197484.5
303	TAPE RECORDER	2	9.6	.2	3.0	0.0	0.0	576958.4	124649.7
427	COMMD DECOD+DISTR	2	9.2	.2	10.0	573124.6	531891.9	380139.4	215829.3

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	130230.0	110695.5	69670.4	73563.7
239	ANTENNA	1	2.1	.0	-0.0	37622.0	28940.0	13909.9	30368.6
309	TRANSMITTER	2	1.8	.0	8.8	6764.7	7886.2	71847.6	7642.5
324	TRANSMITTER	2	7.5	.2	37.5	162064.0	95502.0	139695.4	64758.5
406	RECEIVER	2	2.3	.0	7.4	18557.8	36066.5	58131.3	20965.7
415	RECEIVER	1	3.9	.1	3.0	107946.2	244253.6	64119.3	0.0
418	RECEIVER	3	4.2	.1	2.0	11615.8	33404.0	107471.2	39937.0
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	O.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
215	BATTERY	4	21.6	.1	-0.0	26770.6	376529.7	625467.8	105822.9
312	BATTERY CHARGER	4	5.0	.1	-0.0	0.0	0.0	0.0	0.0
515	SHUNT REGULATOR	6	2.3	.0	-0.0	0.0	0.0	0.0	0.0
702	POWER CONTROL	1	9.4	.6	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	O.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	99.0	69828.5	49095.4	1306676.3	0.0
HARNESS	128.0	910709.2	741835.5	422090.9	0.0
THERMAL CONTROL	10.0	835425.0	317277.9	127884.3	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		506070.8	261003.7	255412.9	0.0
STRUCTURE	365.5	5469870.6	2552827.3	1868433.8	0.0
POWER CONTROL UNITS	36.9	1879343.0	1104680.8	522529.3	0.0

SPACECRAFT COST MODEL

LO COST (EP2)

(MILLIONS OF 1975 DOLLARS)

SUBSYSTEM COST	DDT+E			RECURRING		
	DESIGN ENGINEERING	TEST AND EVALUATION	TOTAL RDT+E	PRODUCTION ENGINEERING	FAB AND ASSEMBLY	TOTAL RECURRING
STRUCTURE	.4	.2	.5	0.0	1.6	1.6
THERMAL CONTROL	.6	.2	.8	0.0	.1	.1
ELECTRICAL POWER	.5	.7	1.1	.0	2.3	2.3
COMMUNICATIONS	.4	.5	.9	.2	.4	.6
DATA HANDLING	0.0	0.0	0.0	.5	1.0	1.5
STABILITY AND CONTROL	1.8	1.1	2.9	1.5	2.0	3.5
AUXILIARY PROPULSION	.6	.2	.7	.2	.2	.5
SPACECRAFT	4.2	2.8	7.0	2.5	7.7	10.2
MISSION EQUIPMENT			16.6			2.4
SATELLITE			28.8			12.6
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			2.9			
LAUNCH SITE SUPPORT						.3
CONTRACTOR FEE			1.1			.7
TOTAL SATELLITE			32.8			13.6
AVERAGE UNIT COST						13.5
TOTAL SATELLITE DDT+E AND RECURRING COST						46.3

LO COST (EP2)

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	VALVE DRIVER ASSY	1	1.6	.1	5.9	237308.0	21705.0	38804.2	0.0
406	NUTATION DAMPER	6	2.4	.1	-0.0	0.0	0.0	20450.3	21541.7
918	SUN SENSOR	3	.7	.0	1.0	0.0	0.0	135874.3	122010.1
924	SUN SENSOR	1	1.9	.0	.8	0.0	0.0	90716.5	114904.3
933	SUN SENSOR	1	3.3	.1	2.0	0.0	0.0	120653.0	166998.2
1315	REACTION WHEEL	4	12.2	.6	12.0	0.0	0.0	146569.5	82547.9
1501	CONTROL ELECT.	1	10.0	.1	4.0	1157600.0	766910.0	253151.2	0.0
1718	RATE INTEGR GYRO	4	9.6	.2	32.0	542191.8	574618.2	434613.9	428652.3
2106	STAR SENSOR	2	11.4	1.8	1.9	0.0	0.0	126713.1	51058.8

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
113	THRUSTER	12	.8	.0	-0.0	0.0	0.0	95508.5	137688.7
215	ISOLATION VALVE	2	2.5	.0	-0.0	0.0	0.0	0.0	0.0
406	PRESSURE REGULATR	2	1.2	.0	-0.0	0.0	0.0	48987.0	80930.3
518	TANK	1	16.2	1.0	-0.0	0.0	0.0	0.0	0.0
609	FILL + DRAIN VALV	1	.2	.0	-0.0	0.0	0.0	0.0	0.0
1013	FILTER	1	.3	.0	-0.0	0.0	0.0	0.0	0.0

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
106	GEN PURP PROCESSR	2	22.5	.5	20.0	88860.3	20663.2	203223.6	35507.3
206	DIGITAL TELEMETRY	1	11.4	.1	6.0	410224.5	133341.1	127003.1	165567.4
230	DIGITAL TELEMETRY	2	5.0	.0	14.0	494222.9	181453.8	207547.5	197484.5
303	TAPE RECORDER	2	9.6	.2	3.0	0.0	0.0	576958.4	124649.7
427	COMMD DECOD+DISTR	2	9.2	.2	10.0	573124.6	531891.9	380139.4	215829.3

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
202	ANTENNA	1	8.4	.7	-0.0	348292.9	319352.9	74467.1	0.0
221	ANTENNA	2	5.8	.2	-0.0	130230.0	110695.5	69670.4	73563.7
239	ANTENNA	1	2.1	.0	-0.0	37622.0	28940.0	13909.9	30368.6
309	TRANSMITTER	2	1.8	.0	8.8	6764.7	7886.2	71847.6	7642.5
324	TRANSMITTER	2	7.5	.2	37.5	162064.0	95502.0	139695.4	64758.5
406	RECEIVER	2	2.3	.0	7.4	18557.8	36066.5	58131.3	20965.7
415	RECEIVER	1	3.9	.1	3.0	107946.2	244253.6	64119.3	0.0
418	RECEIVER	3	4.2	.1	2.0	11615.8	33404.0	107471.2	39937.0
618	DIPLEXER	2	1.5	.0	-0.0	20605.3	21401.1	33593.4	8233.6

ELECTRICAL POWER

IDENT TYPE	NO.	UNIT WEIGHT	UNIT VOLUME	UNIT POWER	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103 SHUNT REGULATOR	9	4.2	.1	-0.0	0.0	0.0	0.0	0.0
215 BATTERY	3	21.6	.1	-0.0	24518.8	291506.8	490068.6	84299.8
315 BATTERY CHARGER	1	12.0	.3	-0.0	0.0	0.0	0.0	0.0

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	99.0	69828.5	49095.4	1306676.3	0.0
HARNESS	128.0	910709.2	741835.5	422090.9	0.0
THERMAL CONTROL	10.0	835425.0	317277.9	127884.3	0.0
POWER CONVERTERS	0.0	0.0	0.0	0.0	0.0
PROPULSION FEED SYS.		506070.8	261003.7	255412.9	0.0
STRUCTURE	365.5	5457093.5	2546864.2	1868433.8	0.0
POWER CONTROL UNITS	49.8	1179455.6	636318.2	551832.9	0.0

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