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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SUMMARY REPORT ON POWER GENERATION AND CRYOGENIC GAS STORAGE SYSTEMS STUDY FOR POST AAP 1-4 MANNED MISSIONS

MSC INTERNAL NOTE NO. 67-EP-24

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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SUMMARY REPORT ON POWER GENERATION AND CRYOGENIC GAS STORAGE SYSTEMS STUDY FOR POST AAP 1-4 MANNED MISSIONS

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1.0 SUMMARY

This report represents a summary of MSC Internal Note No. 67-EP-20 titled " Power Generation and Cryogenic Gas Storage System Study for Post AAP 1-4 Manned Missions." The following is the summary extracted from that report:

"This report presents a study of the possible electrical power generation systems (PGS) and cryogenic gas storage systems (CGSS) for the Apollo Applications Program (AAP) missions anticipated after AAP 1-4. Detailed system configuration analyses based on existing, modified, or new hardware are presented for various cluster configurations. Included are a baseline mission, two alternate missions, and one fallback mission.

PGS configurations studied were (1) all solar cell/battery system with fuel cell 14-day fallback capability, (2) solar cell/battery/fuel cell system with the fuel cells operating for 90 days at the water production rate required for crew consumption, and (3) solar cell/battery/fuel cell system with the fuel cells providing CSM power for the full 90-day mission phase. Also evaluated were (1) one-degree-of-freedom array orientation systems, (2) one-degree-of-freedom array orientation systems with β adjust, and (3) operation of these systems with the arrays both perpendicular to and parallel to the orbital plane during the streamline flight mode of APPS operations.

It was determined that a 90-day CGSS is feasible using slightly modified Cluster I hardware. However, a volume limit exists on quantity of cryogenics than can be located in the CSM. This limit included the necessary atmospheric gas but only slightly more H_2 and O_2 than needed for fuel cells to operate at the crew water production rate power level of 1200 watts.

Cluster I fuel cell hardware--1500-hour baseline P and W and 1500-hour backup A-C--will satisfy all fuel cell requirements for Cluster II. Use of the fuel cell fallback capability to operate the CSM during APPS operations is shown to significantly reduce the solar cell/battery PGS weight.

Solar cell/battery PGS analyses show that all mission power requirements can be satisfied using improved SIVB arrays with additional arrays on the AMDA. Both arrays require one-degree-of-freedom orientation systems. The addition of β adjust to the AMDA arrays was shown to significantly reduce PGS weight.

It was also determined that operating the PGS arrays parallel to the orbit plane allows increasingly smaller array area--and PGS weight--as APPS operations are programmed to perform at increasingly higher included β angles.

Orbital storage net continuous power can be 485 watts minimum, based on SIVB array area with an initial sun adjustment."

2.0 INTRODUCTION

This report summarizes a comprehensive report prepared by the Power Generation Branch, Propulsion and Power Division, MSC on a study of possible electrical power generation systems (PGS) and cryogenic gas storage systems (CGSS) for the Apollo Applications Program (AAP) missions anticipated after the Cluster I, AAP 1-4 missions. The study was initiated at MSC by the AAP Program Office in response to a NASA Headquarters request for a composite MSC/KSC/MSFC study to prepare baseline and alternate mission plans and system configurations for low-earth-orbit, post Cluster I missions--referred to hereafter as Cluster II. Study team coordination at MSC was provided by the Advanced Spacecraft Technology Division. Also, a Mission Planning Task Force (MPTF) provided overall study direction and control.

The approach used for this PGS/CGSS study was as follows:

a. Examination of the groundrules and guidelines specifically affecting PGS and CGSS requirements.

b. Review of candidate hardware for Cluster II use from the standpoints of state of the art, discussion of Cluster I hardware and concepts, and potential modifications to Cluster I hardware and concepts.

c. Design and analysis based on (1) the candidate hardware as discussed in b. and, if necessary, (2) improved designs that utilize present technology to the maximum practical extent.

d. Summation and discussion of system comparisons.

e. Discussion of mission/system comparisons.

f. Discussion of programmatic considerations.

g. Conclusions and recommendations.

The order of presentation in this summary report, as in the detailed report, is as outlined above.

3.0 REQUIREMENTS

3.1 PGS/CGSS STUDY GROUNDRULES AND GUIDELINES

The groundrules and guidelines were examined to determine which ones impact the PGS and CGSS designs and analyses. These were then evaluated and discussed with the MSC study coordinator to assure proper interpretation and to provide a firm basis for establishing the PGS/CGSS study direction. These guidelines and groundrules, including MPTF mid-study revisions, were as follows:

Guidelines

a. A new Cluster should be established at approximately 260 n.m. and 50° inclination.

b. The option to fly fall-back missions separate from the cluster should be retained with reduced objectives. The minimum mission is to be 14 days.

c. The ability of baseline sequences to respond to program and in-flight contingencies should be examined and understood.

d. Each manned launch should be planned to be open-ended to 90 days.

e. As a design goal, missions should overlap with sufficient margins to assure continuity of manned operation with reasonable confidence.

f. Planning and design shall include consideration of orbital storage fall-back mode capabilities.

g. The APPS experiments should be designed to be operated with a cluster for long-term operations at 260 n.m. A single launch, separate mission should not be planned.

h. Consider reduced cluster leakage.

Groundrules

a. Intermittent operation of APPS and OWS experiments: APPS, two weeks active + two weeks standby each season. OWS experiment active remainder of year.

b. Control moment gyros (CMG's) on AMDA.

c. OWS and AMDA always liveable.

d. Spacecraft roll for APPS targets of opportunity limited to $\pm 45^\circ$. Time to roll may be as little as 60-90 seconds.

e. Water evaporative cooling discouraged.

f. Water to be used for washing.

g. Service module (SM) reaction control system (RCS) used to desaturate CMG's.

h. Launch a three-months supply of water on first launch sequence.

i. Consider water reclamation where necessary.

j. Stabilization:

CSM/AMDA/OWS/APPS A, B--streamlined mode with APPS tracking either forward or aft (depends on best solar power case) when APPS is active. Sun-oriented rest of time.

k. Hardware to be used: As far as possible, configurations should be derived from those developed for Cluster I as follows:

(1) CSM, as developed for AAP-3, but with integrally carried cryogenics for 75 to 90 days. Block II CSM expendables for a nominal 14 days independent operation should also be carried.

(2) OWS/AMDA - as developed for AAP-2. Improved solar panels should also be investigated. Ability to operate a cluster using only the AMDA should be retained.

l. Docking ports may <u>not</u> be blocked.

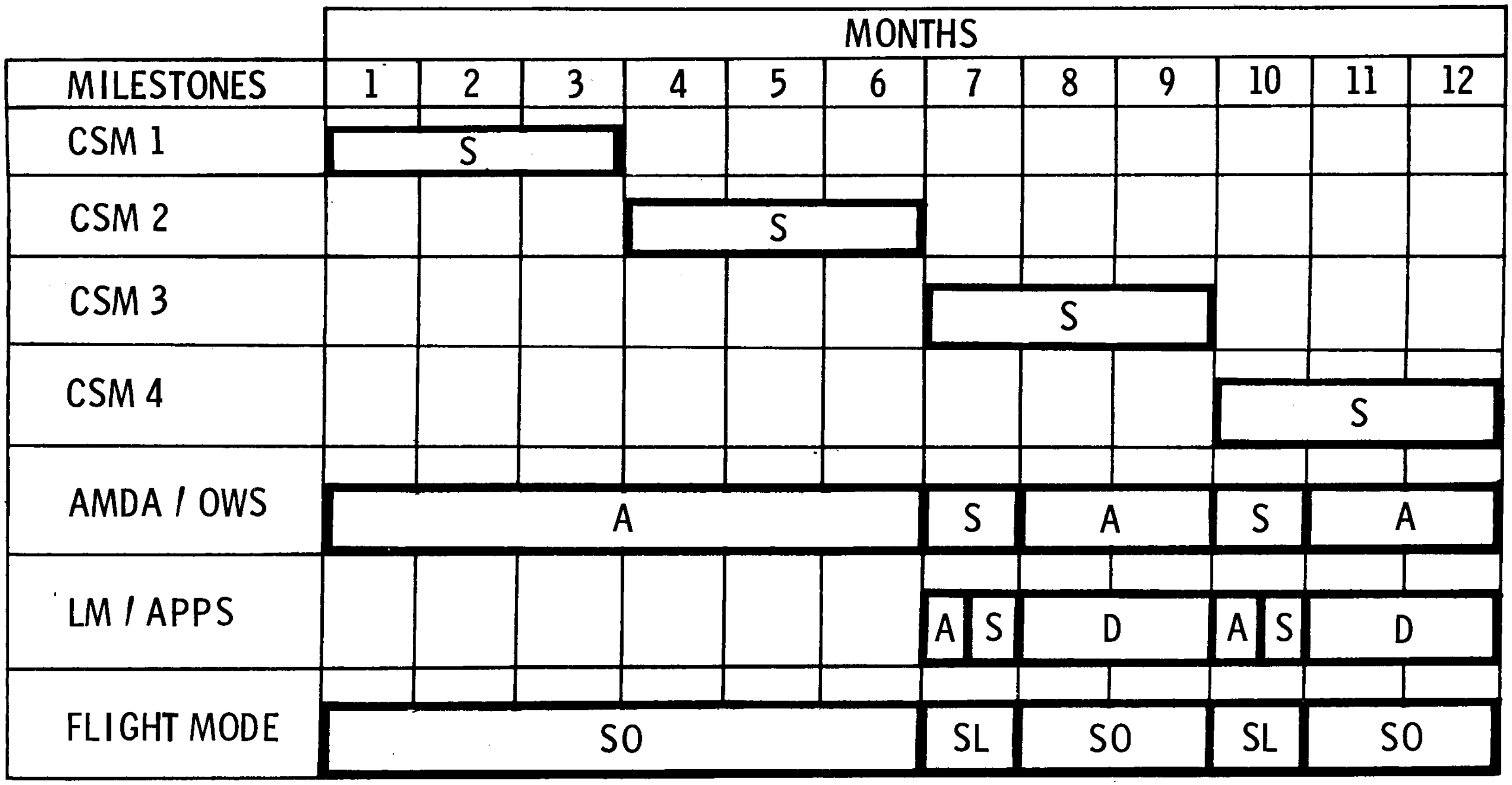
m. Consider initial launch to be January 1, 1970, and latest delivery for KSC installation to be June 1, 1969.

3.2 MISSIONS AND CONFIGURATIONS

The missions studies included a baseline mission, two alternates, and one fall-back mission. The baseline mission launch and operations sequences are presented in figure 1. This mission consists of four manned CSM launches, one unmanned OWS/AMDA launch, and one unmanned launch of APPS in a rack which is on a modified lunar module (LM) ascent stage vehicle. Alternate mission 1 sequences are presented in

FIGURE 1

LAUNCH AND OPERATIONS, BASELINE MISSION



LEGEND: A - ACTIVE (FULL USE)
S - STANDBY (LIVEABLE)
D - DORMANT (SUSTAINING FUNCTIONS ONLY)
SL - STREAMLINED
SO - SUN-ORIENTED

figure 2. This mission consists of four manned CSM launches and only one unmanned launch. The latter is an OWS/AMDA vehicle combination which contains APPS experiments in the MDA and in a special movable MDA nose cone. Alternate mission 2 sequences are given in figure 3. This mission also uses four manned CSM launches and one unmanned launch. It is the same as alternate 1 except that no OWS is included. The fall-back mission considered is applicable only within the baseline mission using a CSM/LM-APPS combination. This mission is to be a minimum of 14 days duration and must be flown in a streamlined mode.

The terms active, standby, and dormant used in the sequence figures mean, respectively, full operation, liveability or capability for immediate response, and minimum function that will insure reuse.

3.3 POWER REQUIREMENTS

The mission power profiles based on these requirements are given in figures 4 - 6. The profiles are straight forward additions of vehicle power requirements with the exception that OWS experiments or their equivalent were considered to be in the AMDA for alternate mission 2. Peak power requirements were assumed to be 150 percent of the average power. This is based on a review of peak power requirements used in previous studies, and is a reasonable factor for vehicle power levels in the 2 Kwe range and above. However, with fuel cells in the CSM for other than 14-day requirements, the peak is assumed to be 3200 watts. This is based on detailed CSM analyses.

Voltage regulation was assumed to be the same as for Cluster I vehicles, as follows:

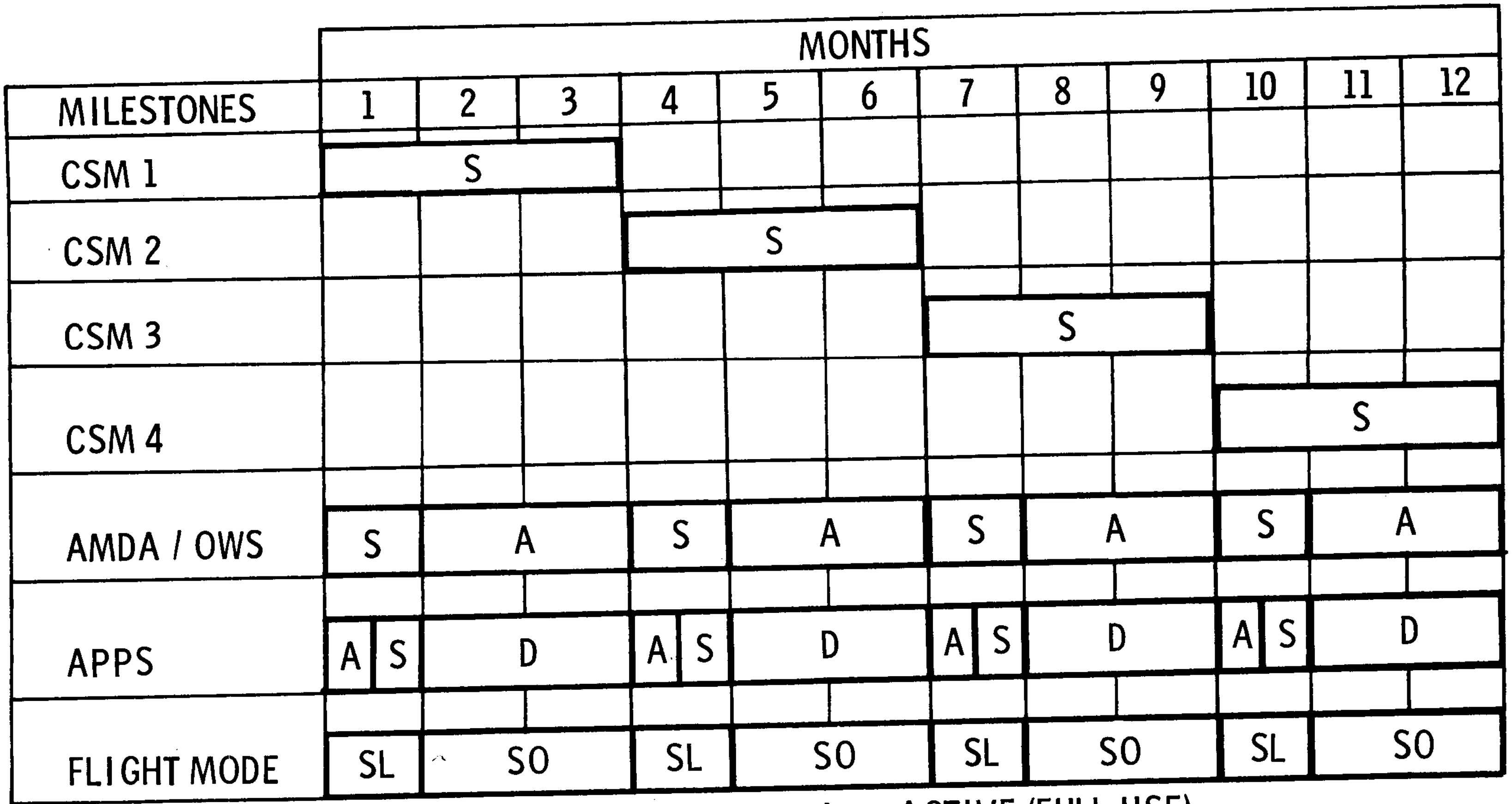
CSM BUS	26.4 to 31.5 volts
AMDA BUS	22.0 to 29.0 volts
LM BUS	27.5 to 32.0 volts

3.4 CGSS REQUIREMENTS

The CGSS must supply the metabolic and vehicle leakage gas for 90 days and fuel cell reactant gas requirements for a 90-day mission or 14-day fall-back mission. Oxygen and nitrogen must be supplied to the crew and oxygen and hydrogen must be supplied to the fuel cells. The gas leakage and metabolic requirements used are given in table 1. They are based on a 5 psi, 70 percent O_2/30 percent N_2 atmosphere. For purposes of operating the fuel cells at a water production rate equal to crew needs, a rate of approximately nine pounds of water per man-day was used.

FIGURE 2

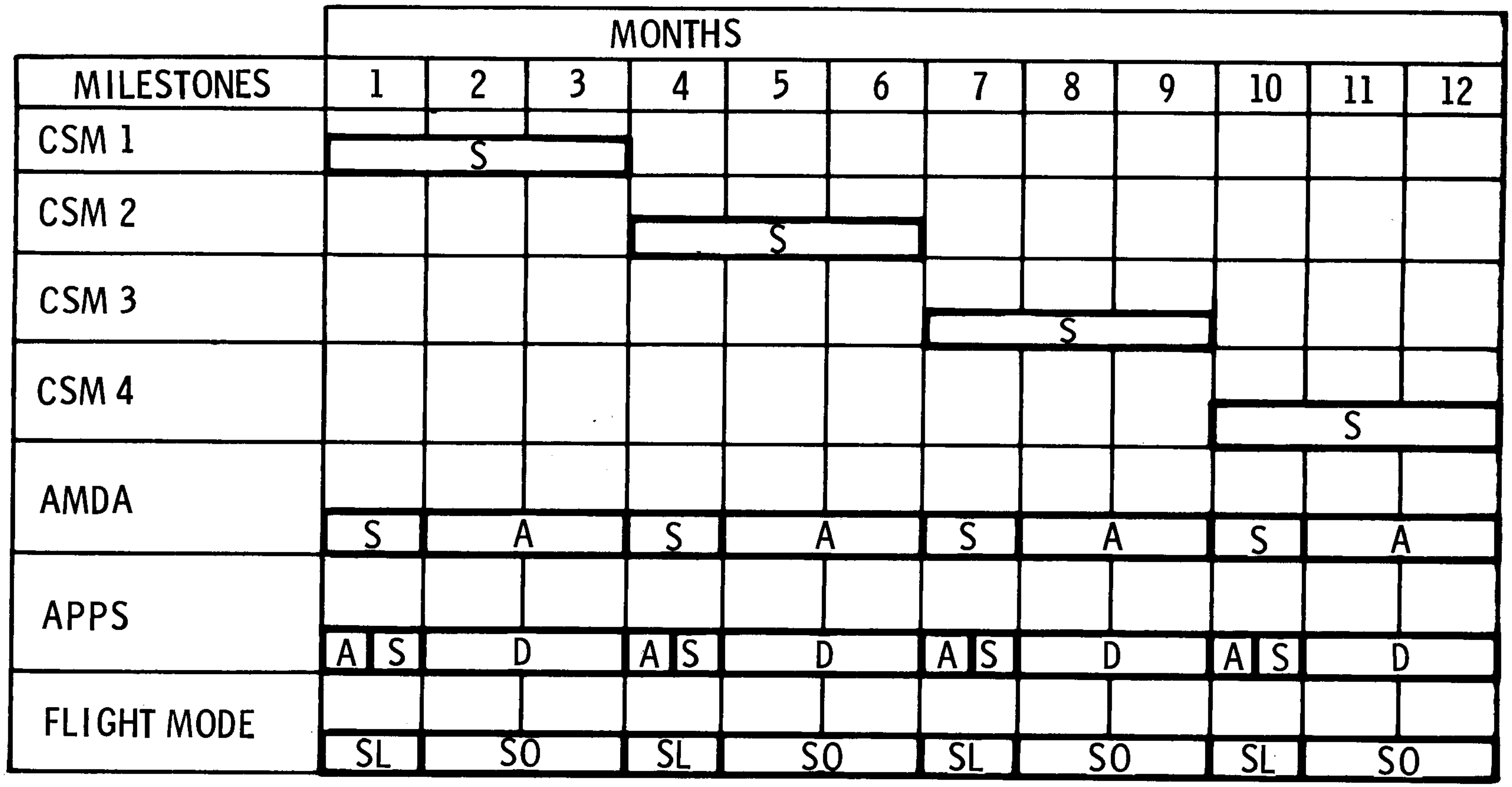
LAUNCH AND OPERATIONS, ALTERNATE MISSION 1



LEGEND: A - ACTIVE (FULL USE)
S - STANDBY (LIVEABLE)
D - DORMANT (SUSTAINING FUNCTIONS ONLY)
SL - STREAMLINED
SO - SUN-ORIENTED

FIGURE 3

LAUNCH AND OPERATIONS, ALTERNATE MISSION 2



LEGEND:
A - ACTIVE (FULL USE)
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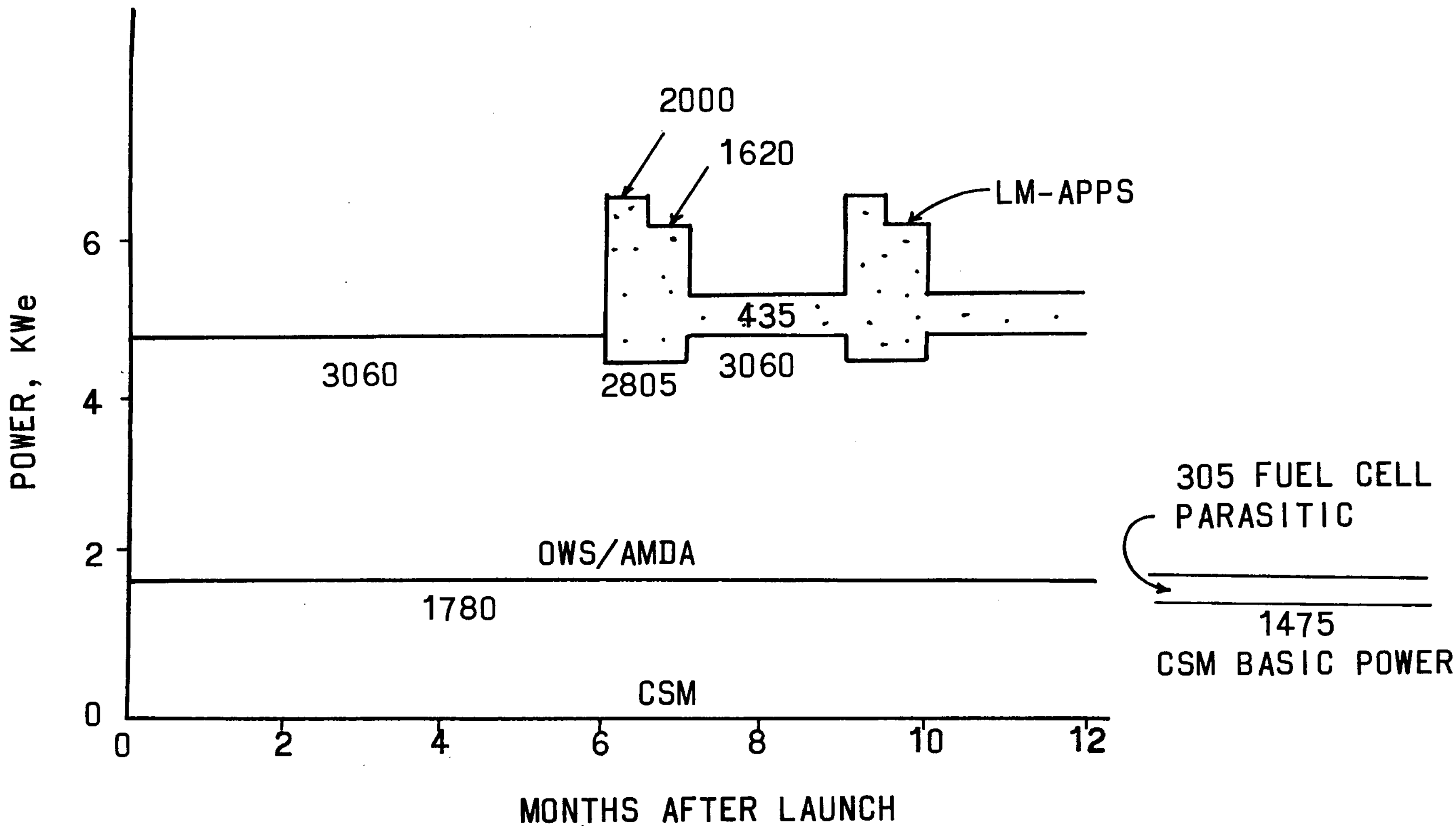


FIGURE 4 BASELINE MISSION AVERAGE POWER REQUIREMENTS

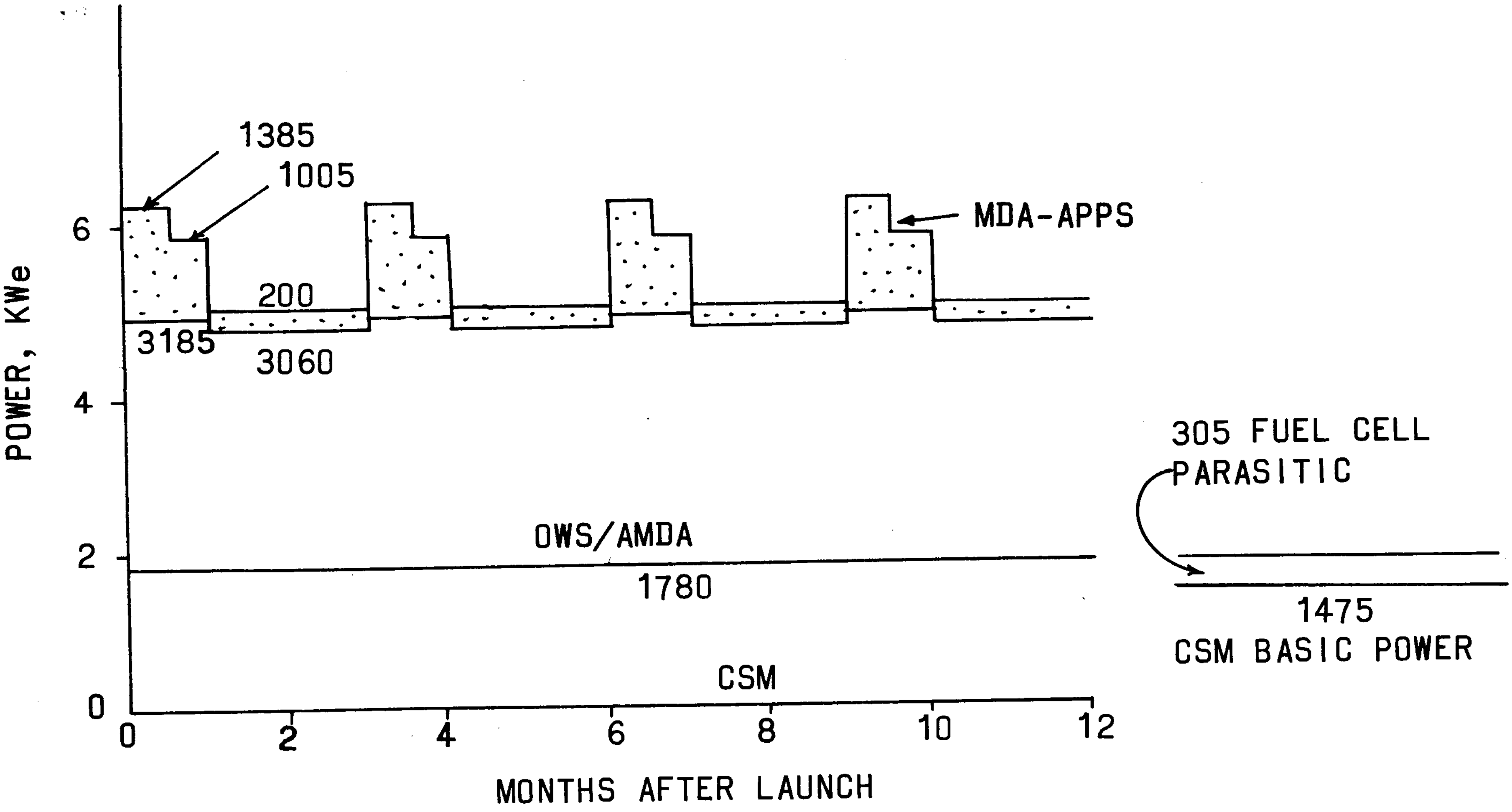


FIGURE 5 ALTERNATE MISSION 1 AVERAGE POWER REQUIREMENTS

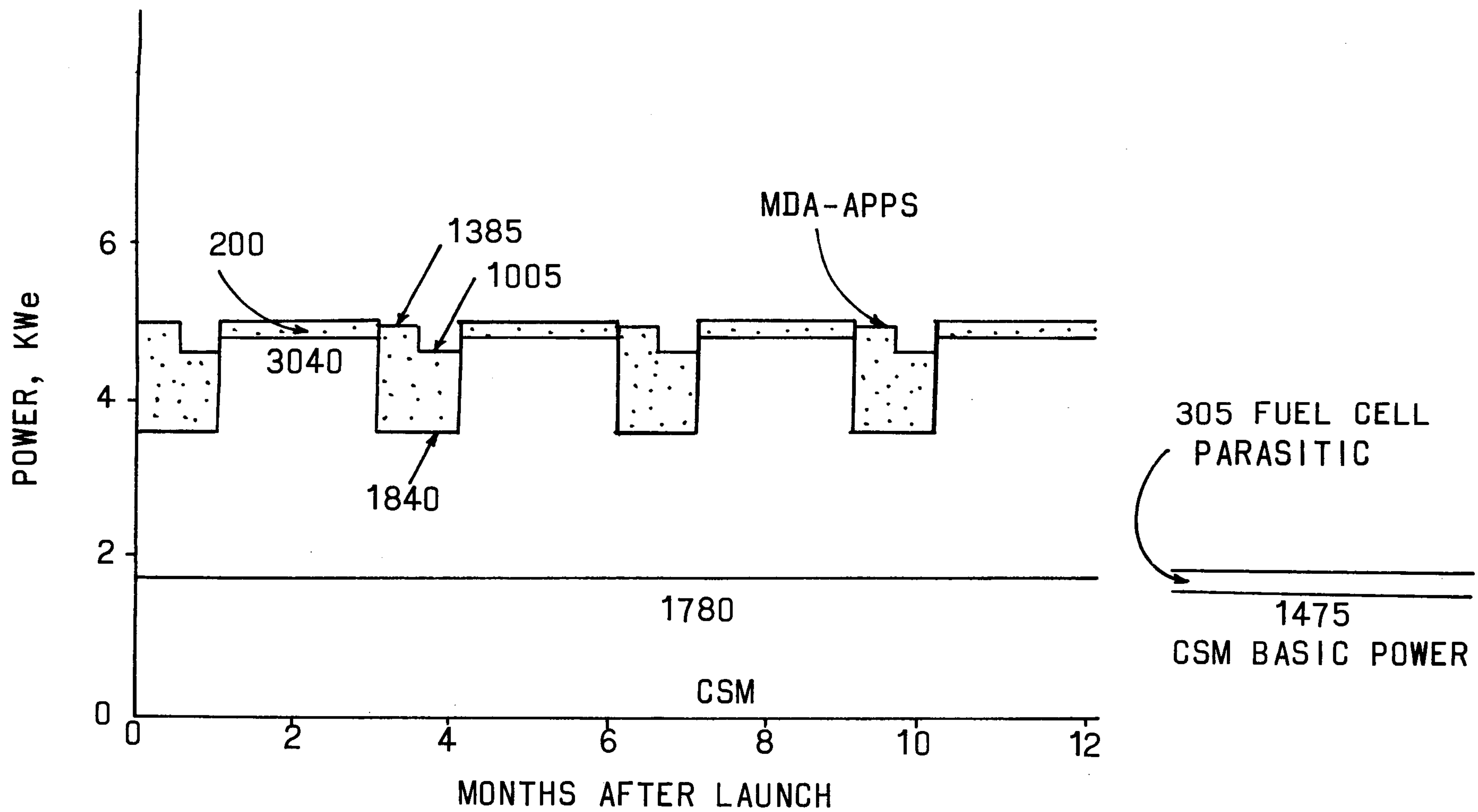


FIGURE 6 ALTERNATE MISSION 2 AVERAGE POWER REQUIREMENTS

3.5 WEIGHTS AND PAYLOAD MARGINS

Table 2 summarizes the launch vehicle capabilities and spacecraft weights assumed. Where applicable, Cluster I vehicle weights are given for reference. The expendables and primary power systems were subtracted from reference weights to establish a common base for system comparisons. Preactivation and descent primary battery systems were retained in the numbers given. The launch margins given are for vehicles with Minuteman strap-on solid rockets. The capabilities with the strap-ons were assumed to be only 7000 pounds more than without.

3.6 GENERAL DESIGN PHILOSOPHY AND CRITERIA

The general design philosophy was as follows:

a. Evaluate Cluster I systems for applicability to Cluster II. If they do not perform satisfactorily, modify or improve them to a reasonable degree. If the latter is not satisfactory, consider new systems or combinations of improved systems.

b. Add 10 percent contingency to all systems.

c. Use three-for-two redundancy for batteries and fuel cells.

d. Use three-for-two redundancy for power conditioning, or derate and provide interconnection capability.

The abort criterion is to initiate abort when one more failure of a single element in a system would jeopardize crew safety.

4.0 CANDIDATE HARDWARE REVIEW

This section presents a review of candidate PGS and CGSS hardware available or potentially available for Cluster II mission application. In the detailed study report, each major PGS and CGSS component is examined and reviewed from the standpoints of state-of-the-art, Cluster I usage, and potential modifications (if used on Cluster I) to satisfy Cluster II mission (s) requirements. The following subsections summarize the results and conclusions of that review.

TABLE I

ATMOSPHERIC GAS REQUIREMENTS

LEAKAGE		
	O_2	N_2
CSM	3.4 LBS/DAY	1.4 LBS/DAY
SIVB	3.5	1.4
AMDA	.7	.4
DOCKING PORT		
1. DOCKED	1.6	.4
2. SEALED	0	0
LM-APPS	2.0	.5
APPS RACK	2.0	.5

METABOLIC
6 LB/DAY ON ALL CONFIGURATIONS

SIVB ACTIVATION
412 LB O_2
106 LB N_2

TABLE 2 LAUNCH VEHICLE CAPABILITIES AND SPACECRAFT WEIGHTS

	MINUTEMAN STRAP-ON CAPABILITY, LBS	HARDWEIGHT, LBS	PGS/CGSS EXPENDABLES MARGIN, LBS
OWS/AMDA, BASELINE MISSION			
AAP-2	NA	28929	NA
Cluster II	31670	17568	14102
LM-APPS, BASELINE MISSION			
AAP-4	NA	32606	NA
Cluster II	31670	19757	11913
OWS/AMDA, ALTERNATE MISSION 1			
Cluster II	31670	22574	9096
AMDA, ALTERNATE MISSION 2			
Cluster II	31670	21052	10618
CSM, ALL MISSION OPTIONS			
AAP-3	NA	39869	NA
Cluster II, 2 Stage	38775	31336	7439
Cluster II, 2½ Stage	40980	31336	9644

4.1 CRYOGENIC GAS STORAGE SYSTEMS

Table 3 presents a summary of the state-of-the-art for cryogenic tankage potentially available for Cluster II applications. The AAP tanks shown for mission durations of 56 days will soon be under development for AAP Cluster I. These new tanks may be uprated to satisfy the 90-day mission requirement by use of external insulation. The feasibility of this approach has been demonstrated by MSC.

In view of the above considerations and development program being initiated, 90-day cryogenics tanks are considered to be feasible and potentially available for the Cluster II mission. Further, other suitable containers are, or will be, available for more-optimum use where long-duration containers are not required.

4.2 FUEL CELLS

Three basic fuel cell concepts have been developed or are being developed: The Pratt and Whitney (P&W) "Bacon" cell for Apollo and other applications, the General Electric (GE) ion-exchange membrane cell for Gemini, and the Allis-Chalmers (A-C) capillary matrix cell under supporting development funding. They are similar in that each consumes H_2 and O_2 and produces electrical power and H_2O. They are different in features such as electrolyte character, materials of construction, system design, and operational parameters such as temperature, pressure, and concentration.

Integration of the GE ion-exchange membrane fuel cell into the Apollo spacecraft is not viable, and life and performance capability are not adequate to meet the mission duration and power requirements of AAP. A major development effort would be required to over-come these deficiencies; therefore, this fuel cell will not be considered further for AAP Cluster II missions.

Life, weight, power levels, and other important specifications of the P&W and A-C fuel cells are given in table 4.

The baseline fuel cell for AAP Cluster I missions is an improved Block II P&W system. The present Apollo Block II fuel cell was eliminated because of its life and power limitations. For the same reason, this fuel cell was eliminated from Cluster II consideration.

TABLE 3

SUMMARY INFORMATION

CRYOGENIC TANKAGE PROGRAMS

Program		USABLE FLUID	PRESSURE VESSEL I.D	MAT'L	OPERATING PRESSURE	TYPE INSULATION	DESIGN DURATION	SYSTEM WEIGHT
		(LBS)	(INCH)		(PSIA)		(DAYS)	(LBS)
Gemini:	RSS O_2	45.0	13.35	Inc. 718	850	Super	2	20.50
	ECS O_2	15.3	9.56	Inc. 718	850	Super	2	13.0
	RSS H_2	5.6	18.65	Ti-5AL-2.5 Sn	250	Super	2	27.5
	RSS O_2	177.4	20.56	Inc. 718	850	Super	14	55.0
	ECS O_2	104.0	17.60	Inc. 718	850	Super	14	38.8
	RSS H_2	21.9	26.25	Ti-5AL-2.5 Sn	250	Super	14	47.3
Apollo:	BL I O_2	320.0	25.06	Inc. 718	900	Super	14	86.5
	BL I H_2	28.0	28.24	Ti-5AL-2.5 Sn	250	Super/Shield	14	79.1
	BL II H_2	28.0	28.24	Ti-5AL-2.5 Sn	250	Super/Shield	14	72.3
LM	He	48.5	27.5	Ti-5AL-2.5 Sn	1250	Super	8	97
BIOS	O_2	115	17.8	Inc. 718	1000	Super	30	54.1
	H_2	11	21.2	Ti-5AL-2.5 Sn	300	Super/Shield	30	54.4
MOL	O_2	700	35	Inc. 718	1000	Super	30	160
	H_2	82	43	Ti-5AL-2.5 Sn	300	Super/Shield	30	110
	He	amb.						
AAP	O_2	1200	39	Inc. 718	1000	Super/Shield	56	300
	H_2	75	39	Inc. 718	1000	Super/Shield	56	300
	N_2	850	39	Inc. 718	1000	Super/Shield	56	300

TABLE 4

BLOCK II FUEL CELL AND OPTIONS FOR AAP

	Apollo Block II	Improved Block II	A-C Capillary Matrix
Average Watts (GROSS)	950	1250	1425
Max. Watts (27V)	1420	1620	2075
Min. Watts (31V)			
Unregulated	470	1160	340
Regulated*	226	226	71
Expected Life at Avg.			
Power (hours)	700	1500	1500
Weight, Pounds	241	246	175
Volume, Cu. Ft.	9.7	9.7	5.0
Energy Density, $\frac{\text{Kw Hr}}{\text{Lb}}$	2.6	7.6	12.2

* Open Circuit Parasitic Power Level

MSC has initiated procurement action for qualification of the improved Block II cell. Specifically, the program will:

a. Qualify one ceria/cobalt fuel cell module for 1500 hours operation to the performance levels described herein.

b. Qualify a suitable pinion gear for the H_2 pump separator for 1500 hours at AAP stress levels.

c. Develop and qualify (with the fuel cell) a voltage regulator (buck-type) for voltage compatibility at low power.

d. Modify thermal functions of the primary by-pass valve to produce a more constant operating temperature, thereby improving transient capability.

The A-C fuel cell development program has been oriented toward maximum flexibility in design for application to a variety of spare missions. The Apollo CSM requirements have been used as a baseline design to achieve maximum compatibility with existing spacecraft. The A-C fuel cell is considered as a potential Cluster I back-up system. Of primary concern in its use are availability and retrofit. It appears likely that the A-C system would be available for Cluster I if the planned Design Verification Test program scheduled for the fall and winter of 1967 is successful. Qualification could be completed in mid-1968. Use of this system for Cluster II does not appear time critical.

Concerning retrofit, it has been a prime goal throughout the A-C program to achieve a configuration that is interchangeable with the present CSM fuel cells. Therefore, this is not considered a major problem.

The improved Block II fuel cell has the potential capability of life extension to 90 days, although at lower power levels than Cluster I. Modifications and improvements in addition to those currently planned may be required predicated on the particular mission and power requirements. As an example, development of an electronic control assembly (ECA) may be necessary to allow in-flight start/stop capability.

The current A-C fuel cell program has an ultimate goal of developing a 2500-hour system. It has the potential to achieve this goal at an early date and with a system capable of sustained high power level.

4.3 SOLAR CELL/BATTERY SYSTEMS

Evaluation of mission requirements with respect to need dates and power levels for Cluster II indicates that existing hardware should be used to the maximum extent. For this study, it was assumed that AAP Cluster I hardware will have been developed and flight-proven by the time Cluster II missions are implemented. Evaluation of the Cluster I (existing baseline) hardware indicates that, for most cases, this hardware can be used with certain modifications. For alternate mission 2, however, "new" solar array hardware must be developed, since the SIVB (and its arrays) is not utilized in the cluster.

Solar array systems of many sizes have been used on unmanned scientific satellites, but for the most part the arrays and associated hardware were of much smaller sizes than are required for AAP applications. Most of the systems were simple, uncomplicated designs employing fixed (non-orientable) one-piece, paddle-type arrays or body-mounted arrays. A small number of systems, however, did utilize deployable arrays with unit assembly (wing) areas of up to 105 square feet and independent orientation. Assemblies of this size have been used on Air Force Agena missions and employ the only technology suitable for consideration in this study (if existing hardware must be used) primarily because the unit sizes and packaging/deployment concepts of other candidate systems are basically incompatible with the mission and spacecraft integration requirements. From an engineering standpoint, an improved array system could be made available in nominally 2 to 2-1/2 years which would be lighter, more efficient, and more reliable than now available. Such a system would make use of recent technology improvements such as lightweight substrates, larger unit solar cells (improved area utilization and lower cost/unit area), thinner solar cells, and increased component efficiencies. For example, substrate weight alone can be improved (using 1967 technology) by at least 25% relative to current Agena wing or LM-ATM array designs. Additionally, the Agena wing design utilizes cells of approximately 10% efficiency, although 10.5% to 10.8% cells are now available in quantity.

The "baseline" array configuration for Cluster I consists of 6 Agena-type, 63-panel wings and 2 Agena-type, 45-panel wings (a total of 468 panels, or 6320 watts gross, full normal array power as shown in figure 7. The two end panels on each side may be capable of limited rotation, as shown in the figure, but this feature has not yet been decided.

The SIVB arrays in the existing baseline configuration are unsatisfactory for Cluster II applications because:

a. Limited power compatibility due to unfavorable array/sun angles during APPS operations.

b. Insufficient array capability to meet load power requirements during sun-oriented flight modes.

Both of these problems, however, can be overcome to a limited extent by incorporating the following modifications:

a. Incorporate single-degree-of-freedom drive system to compensate for off-orientation. This would involve mounting the wings on each side on a common platform and adding a drive motor/linkage system. Possible configurations are shown in figures 8 and 9.

b. Incorporate additional array area (within physical limits) as indicated in figures 8 and 9. This improvement provides an additional 1215 watts gross giving the improved array a maximum power capability of 7535 watts gross normal power. This represents the maximum amount of array that can be reasonably added within the stowage limitations of the array shrouds.

Although these modified and improved arrays still do not meet the requirements of all cases for the missions under consideration, it does effectively minimize the size of solar arrays that must be added elsewhere to fulfill mission power requirements. Although it was assumed that the SIVB arrays would be flight-qualified and proven during Cluster I missions, it should be noted that the "baseline" system at this time is still in the conceptual stage and alternate designs are presently under evaluation. The problems of integrating the arrays are not fully defined, since all the analyses are not completed. The major problems that have been brought out by the studies thus far are summarized below:

a. Array growth is severely limited due to aeroballistic restrictions on pod (envelope) dimensions.

b. Preliminary analyses indicate severe thermal energy interchange problems between the SIVB stage and the deployed arrays.

c. The arrays will probably "frost up" during stage fueling and launch operations. A dry nitrogen purge system is being considered as a possible solution.

d. During stage fueling, the entire stage contracts approximately 4 inches. Array mounting/attachment hardware must be able to compensate for this significant contraction and subsequent expansion in orbital flight.

e. Requalification of the Agena-type wings to SIVB specifications may be necessary.

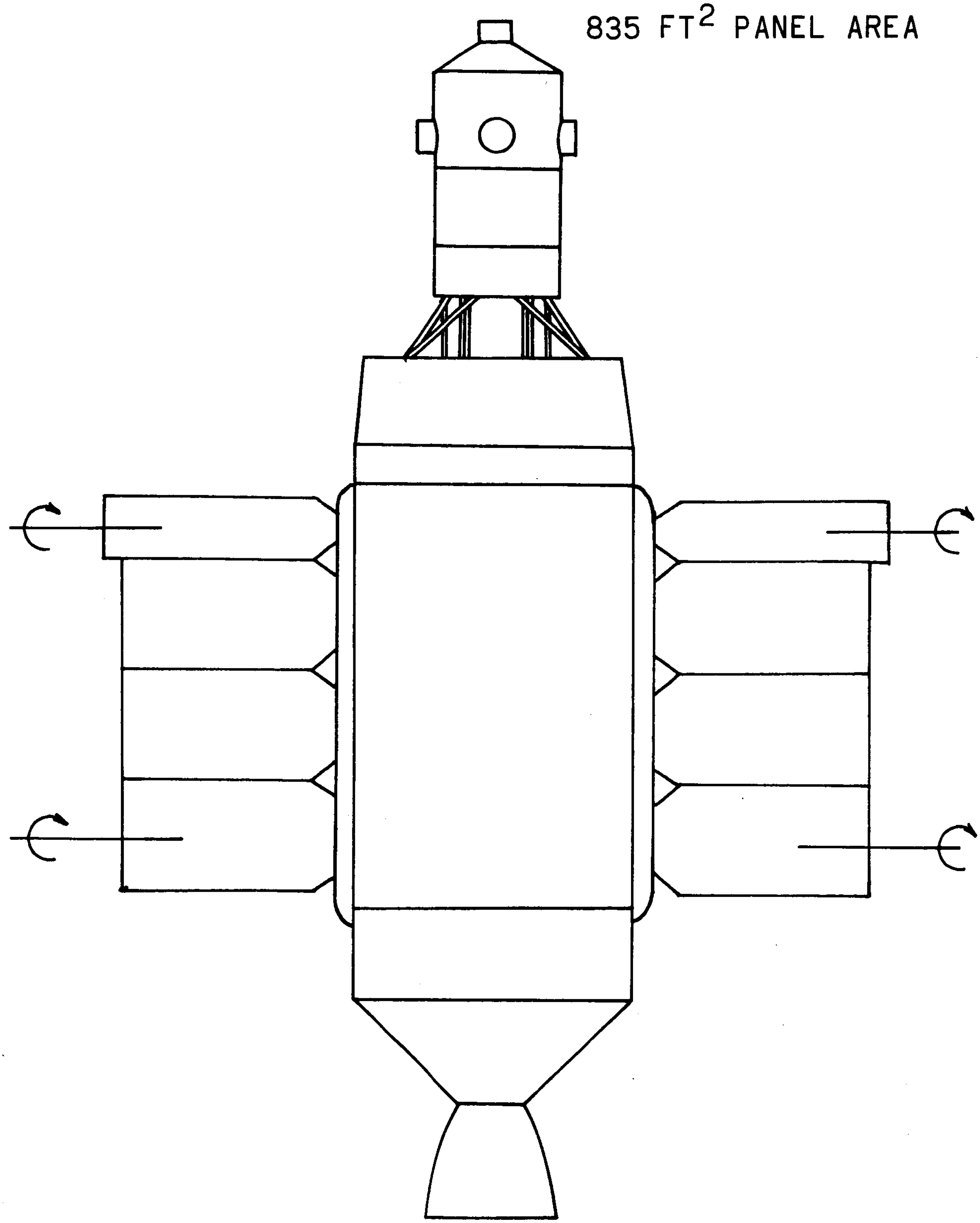
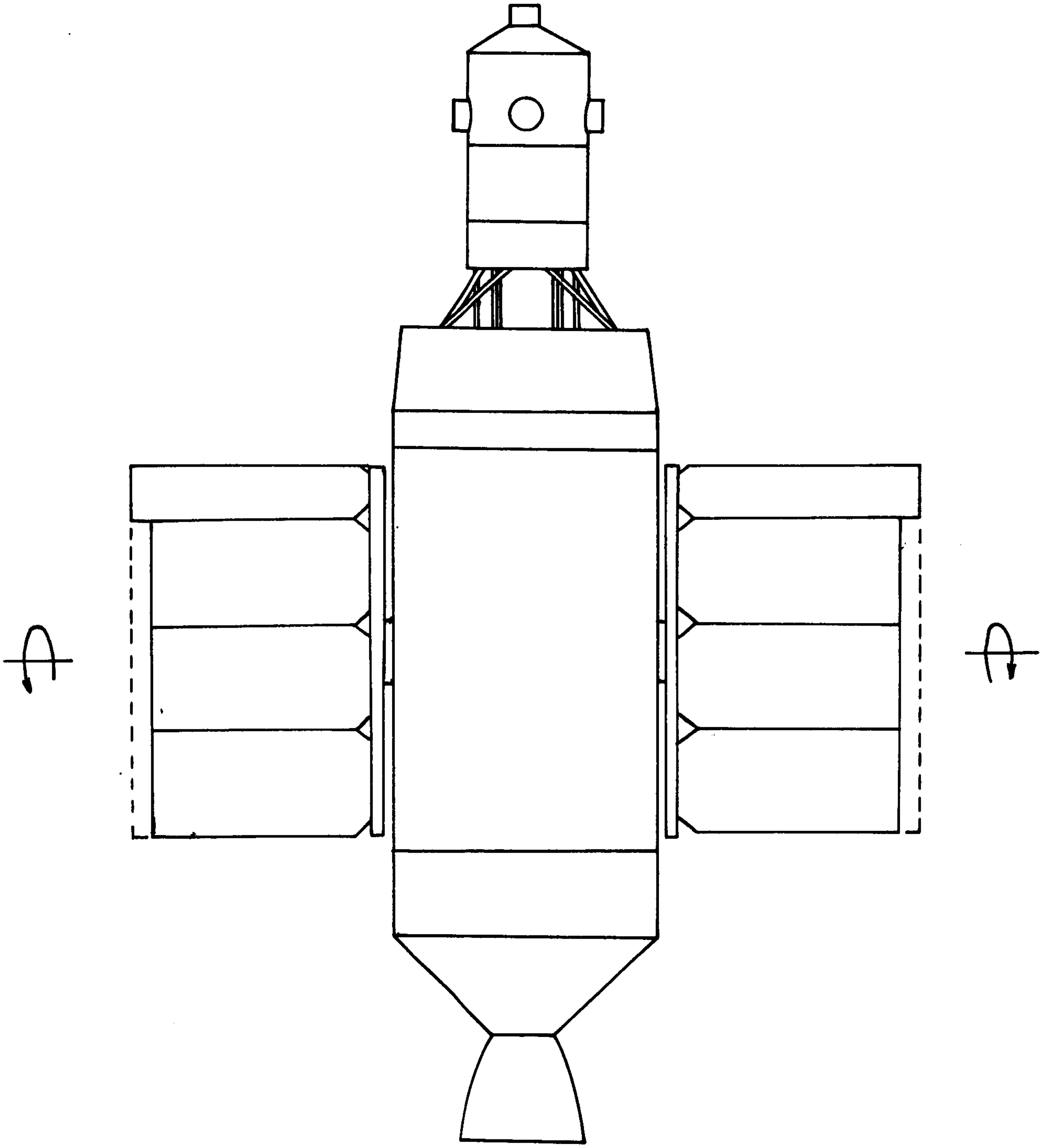
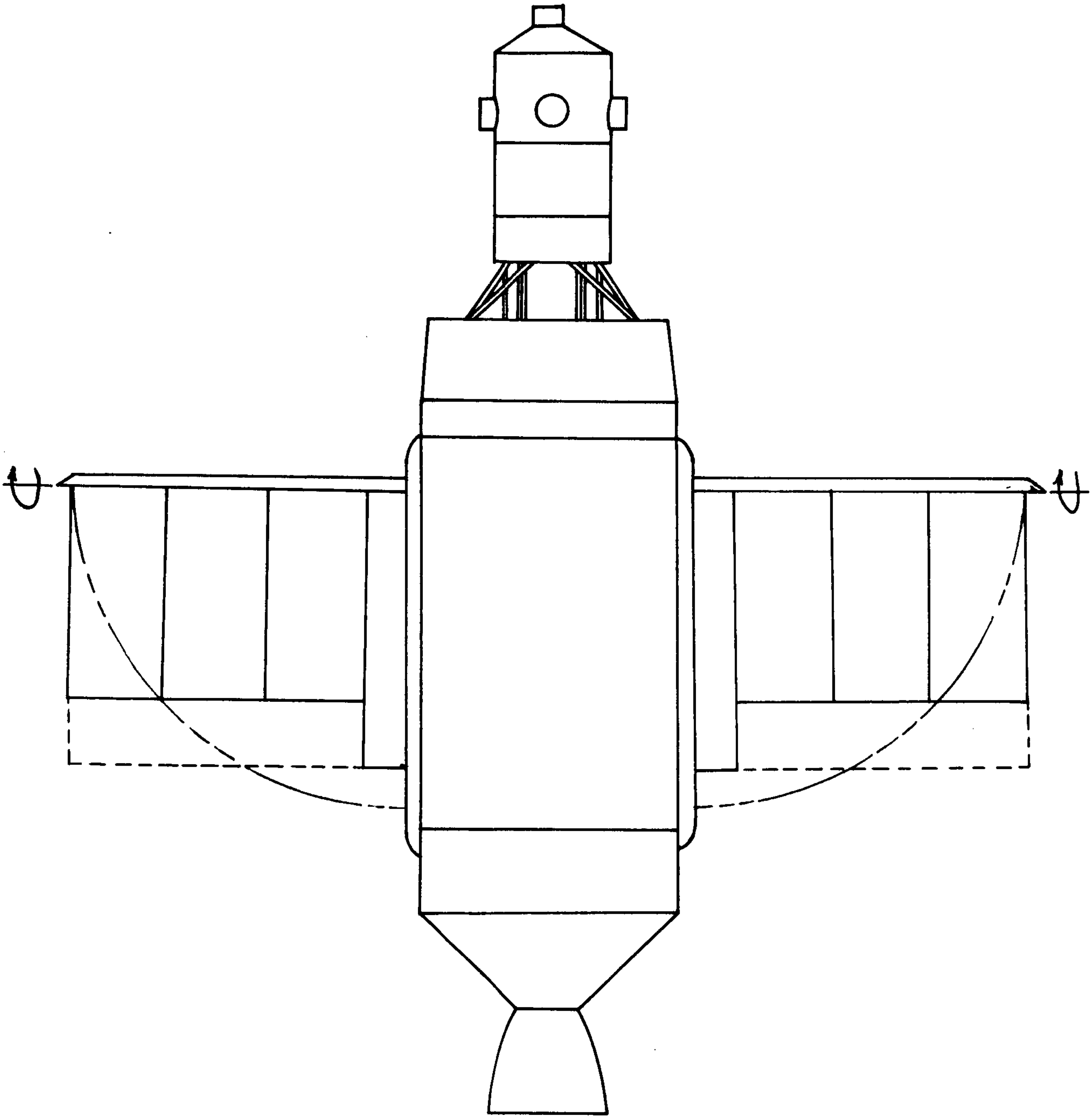


FIGURE 7 BASELINE SIVB ARRAY CONFIGURATION



TYPICAL SINGLE-AXIS ORIENTATION SYSTEM FOR SIVB ARRAYS

FIGURE 8



ALTERNATE SIVB ARRAY DEPLOYMENT/ORIENTATION CONCEPT

FIGURE 9

4.4 SECONDARY BATTERIES

Secondary (rechargeable) batteries are used to provide dark time power and peak power requirements. Solar cell systems charge these batteries during the sun-lit portion of the orbit.

A state-of-the-art review of secondary batteries indicates that the most applicable types for Cluster II purposes are the Ni-Cd and Ag-Cd types. Because of the existence of applicable flight hardware and proven longer life, the Ni-Cd battery is recommended for use. Specifically, the Ni-Cd battery designed for use on the AMDA in support of Cluster I appears at this time to have the performance capability to meet the requirements of Cluster II. No modifications are required; however, real-time testing of at least one year should be performed prior to utilization.

4.5 PRIMARY BATTERIES

Primary batteries are required to provide power for deorbit systems. The largest capacity, flight qualified primary batteries available are the Ag-Zn batteries being developed and qualified for the Apollo LM. Four LM descent stage batteries were recommended (without modification) for Cluster I ascent and deorbit requirements. Present Cluster I ascent and deorbit requirements are being satisfied with CSM fuel cells. Fuel cells will always be used for ascent, rendezvous, and docking in Cluster II missions.

4.6 POWER CONDITIONING AND CONTROL

To obtain high efficiency and reliable performance from a space vehicle electric power system, it is necessary to make a critical inspection of the equipment requirements to establish the parameters of required voltage, power, and tolerance. Preliminary analysis of the power requirements and configurations for Cluster II missions indicate the necessity for power conditioning and control equipment in nearly all of the power system options. The power conditioning and control discussed in the detailed report includes voltage regulators and battery chargers.

Power conditioning equipment being developed in support of Cluster I appears at this time to have the reliability and performance capability to meet the requirements of Cluster II. However, extended test programs and initiation of 2500-hour qualification programs are required prior to utilization of these items of equipment on the Cluster II missions.

5.0 PGS AND CGSS DESIGN AND ANALYSIS

The approach to satisfying the mission requirements was to first examine Cluster I hardware and hardware concepts for applicability to Cluster II. If Cluster I hardware could not satisfy the requirements, the next step was to modify or improve that hardware. If this was not sufficient, the next step was to consider combining improved hardware with new systems that maximize use of present technology and to consider all new systems that maximize use of present technology. The candidate concepts and/or technology (as required for new systems) were discussed in section 4. This procedure was used for PGS and CGSS design and analysis for each mission. Additionally, it was necessary to consider all of these steps for three uses of fuel cells: (1) 14-day CSM/LM-APPS fall-back mode, (2) fuel cell power for 90 days at the crew water-use rate, and (3) power for the CSM for the 90-day mission. The potential combinations are given in figure 10.

5.1 CGSS DESIGN AND ANALYSIS

The CGSS provides storage for gases required for fuel cell power, cabin atmosphere (including leakage), and metabolic consumption.

The AAP tanks discussed in section 4.1 are selected to store and supply these gases.

All CGSS must be located in the Apollo CSM except for special cases such as the CGSS required for initial OWS or LM-APPS activations. The CSM payload is volume-constrained in Bays III and VI by RCS and SPS components. This limits the number of cryogenic tanks to eight and the 90-day fuel cell power capability of the CSM to about 1.2 KW. The water production rate at this power level, however, is adequate to meet the daily water requirements of a 3-man crew (about 27 pounds).

The total wet system weights under the above conditions for the baseline and alternate missions 1 and 2 are 6573, 6399, and 5940 pounds, respectively. In each case, three O_2 tanks, four H_2 tanks, and 1 N_2 tank are employed.

This combination will supply reactants for 1.2 KW fuel cell power for all three missions and is based on leakage and metabolic rates given in section 3.0. There is essentially no O_2 or H_2 contingency for the baseline mission requirements. About 3 to 13 percent contingency is available for these reactants for the alternate missions. Approximately 406, 432, and 568 pounds of N_2 may be added for the baseline, alternate 1 and alternate 2 missions, respectively, if needed.

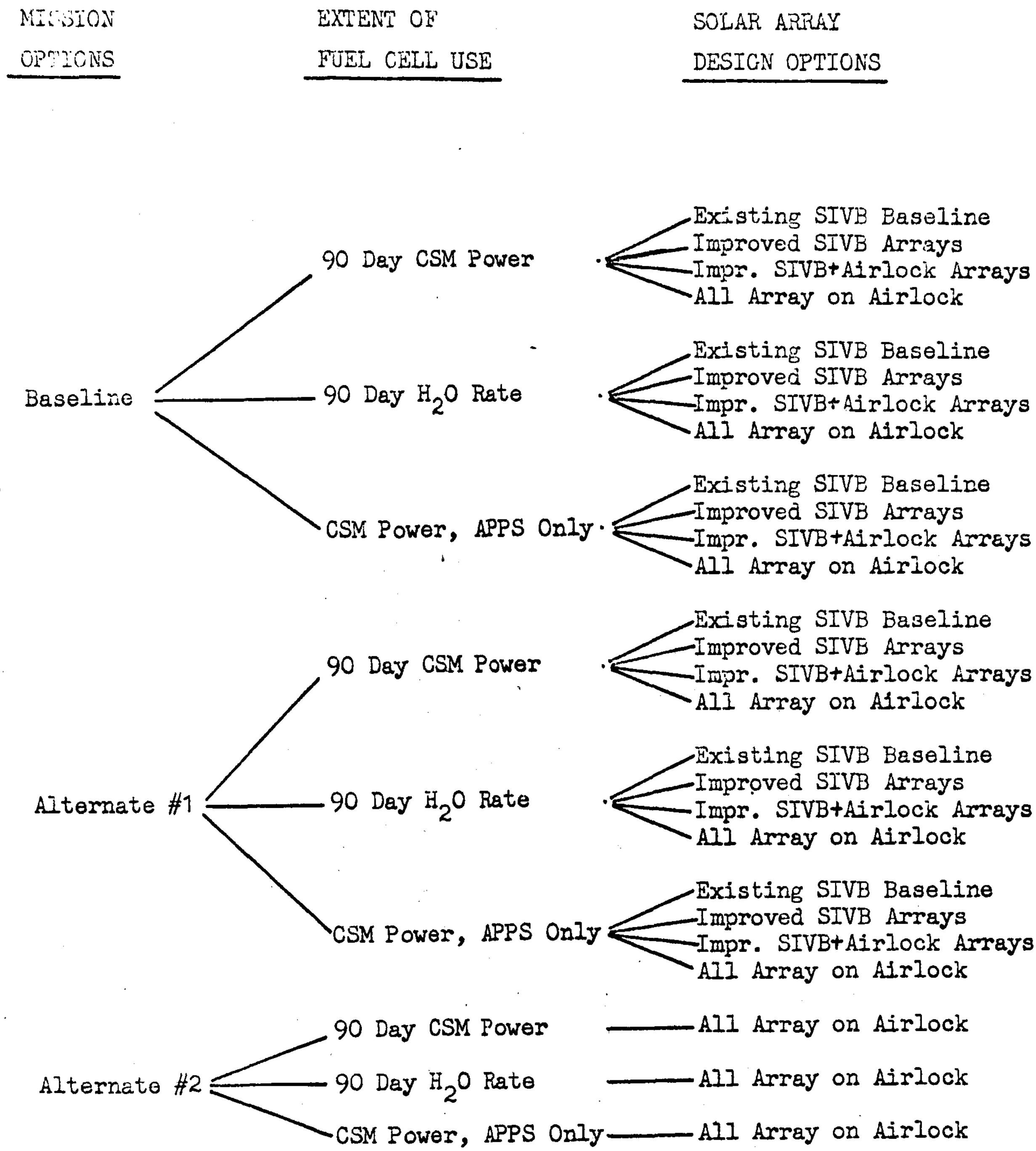


Figure 10 Potential PGS/CGSS Systems

The cryogenic tanks are located in the CSM as follows:

Bay IV	-	2 tanks H_2
Bay I	-	3 tanks O_2
Bay III	-	2 tanks H_2
Bay VI	-	1 tank N_2

This CSM configuration will supply the mission requirements for the baseline mission and also alternate missions 1 and 2. Basically, the CSM becomes a standard vehicle for all the mission possibilities.

Parametrically, the power capabilities of this configuration are as follows:

90 days	-	1.2 KW
30 days	-	3.75 KW
14 days	-	8.0 KW

These power levels are such that the combined CSM and LM-APPS could have independent operation using a 3.78 KW power level for 29.7 days. If the staggered LM-APPS power level of 2.00 KW for 15 days and 1.62 KW for the remainder of the time is used, the CSM/LM-APPS combination could operate for 31.4 days.

For the case where a 14-day fuel cell system is considered with an all solar cell/battery PGS, the CGSS weight totals for the baseline, alternate 1 and 2 missions are 5025, 4851, and 4305 pounds, respectively. In this case three O_2 tanks*, two H_2 tanks, and one N_2 tank are employed.

This case satisfies launch, ascent, rendezvous, and docking requirements as well as the required CSM/LM-APPS fall-back mission. It includes one additional day of power capability as a contingency factor. However, a <u>complete</u> 10 percent contingency factor may be applied to the CGSS, if this case is selected, because volume is available.

The OWS/AMDA must carry enough gas supplies to provide for activation. These supplies are not included on the CSM. This requirement can be met by using one oxygen tank and one nitrogen tank. The weight breakdown for the OWS is as follows:

Oxygen	412 lbs.
2 Block I Oxygen Tanks	173 lbs.
Nitrogen	106 lbs.
1 Nitrogen Tank	87 lbs.
	778 lbs.

*Two O_2 tanks for alternate mission 2.

These supplies will not allow a second activation.

5.2 FUEL CELL DESIGN AND ANALYSIS

The design requirements for candidate fuel cell powerplants for the Cluster II missions are (1) water production requirements, (1200 watts) (2) 1475 watts net average continuous power with a daily peak of 2900 watts net, and (3) use of a fuel cell system for launch, ascent, rendezvous, docking, and supplying CSM loads during high power demands on the solar array, when primary cluster power is furnished by an all solar cell/battery system. All three criteria must provide for a 14-day minimum fallback mission capability.

Fuel cell utilization to satisfy the above criteria was determined as outlined below (pertains equally to baseline and alternate missions).

<u>Criteria 1</u>

a. Use either three improved P&W Block II fuel cells or three A-C fuel cells.

b. One fuel cell operates at 1200 watts for 45 days or until failure or excessive degradation occurs, then switches to second standby fuel cell.

c. Provides high reliability due to three-for-one redundancy and derated power level.

d. Provides potential of 135 days operation based upon the 1500-hour qualification planned for mid-1968.

e. In-flight start must be developed for the improved P&W fuel cell and minor modification incorporated.

<u>Criteria 2</u>

a. Use three A-C fuel cells.

b. With A-C fuel cells, operate two at 875 watts each average and hold the third in reserve.

c. Criteria could be met with improved P&W Block II fuel cells; however, about 330 pounds of H_2 are required and only 250 pounds are available due to SM volume limits.

Criteria 3

Use either improved P&W Block II fuel cells or A-C fuel cells.

The fallback mode assumes the lack of solar array power, with the LM-APPS being entirely dependent on the CSM fuel cell system.

This can be accomplished with any of the fuel cell systems previously recommended herein. However, with the maximum available energy of 112.5 KW-days (cryo-limited) on the CSM, the fuel cells could supply the requirements for the CSM and LM-APPS for 28 days with an excess of 4.4 KW-days (73 watts continuous for 28 days). This assumes a constant umbilical loss in transferring the power from the CSM to the AMDA bus of 300 watts, continuous, for 28 days.

This fallback mode of operation lends credance to the possibility of reducing the solar array size requirement by utilizing the fuel cells to power the CSM during LM-APPS operation. This is further exemplified by the requirement that the vehicle be earth oriented during the LM-APPS experiment phase, thus placing it in a non-optimum attitude for array sun orientation, therefore further increasing the solar array panel size. This is particularly true for fixed and single-axis oriented arrays. This mode of operation would require that water storage capability during the first 28 days of operation be sufficient for the crew requirements for the entire mission, since all the water would be generated during this time. It further requires that the solar array furnish all CSM power requirements and LM-APPS standby power for the remaining 62 days of the mission. The CSM power requirement during this phase would be reduced by the parasitic requirement of the fuel cells (315 watts).

5.3 SOLAR CELL/BATTERY SYSTEM DESIGN AND ANALYSIS

5.3.1 General

In most preliminary studies of this nature, it is sufficient to design solar cell/battery systems to worst case orbit use. This is usually either with flight in the ecliptic plane for equatorial orbits or a midnight (or noon, depending on launch time) plane for polar orbits--cases where minimum light/dark time ratios occur. However, with the combination of high Cluster II power levels and the high inclination "equatorial" orbital requirement, such an approach would result in excessive array areas and battery weights. A more refined approach was therefore necessary in this study.

The performance of a solar cell/battery system in orbital flight is a function of several geometrical and time-related variables, which in turn depend on launch conditions such as time of day, day of year, etc. For this study, the following launch conditions were assumed:

a. January launch

b. Time of day of launch is chosen to provide maximum sunlight (100 percent) during initial orbits.

c. 50° orbit inclination and 260 nautical miles altitude.

If condition a. were different, condition b. could still be satisfied on any other day of the year by choosing the appropriate time of day for launch. Condition b., however, gradually changes to a minimum sunlight condition (58 minutes light) due to orbital plane regression as illustrated in figure 11. To account for this orbital regression in performing solar array performance analyses, it is necessary to consider an angle (beta), defined as follows:

$\beta \equiv 90^{\circ}$ minus the angle between the perpendicular to the orbit plane and the earth-sun line.

The angle β varies not only because of orbital plane regression, but also because the earth is orbiting the sun in a direction opposite to that of the regression, thus effectively decreasing the rate of change of β. Figure 12 shows the variation of β as a function of time and includes the effects of regression and the earth orbiting the sun.

The variation of β not only causes a change in the percent sunlight per orbit with time, but also affects the angle of solar incidence with respect to a plane (such as solar arrays) fixed on the spacecraft. The percent sunlight variation is shown in figure 13.

Other geometrical considerations include solar array position relative to the orbit plane and spacecraft flight mode. For each case, the following solar array installation options were considered:

a. Fixed arrays

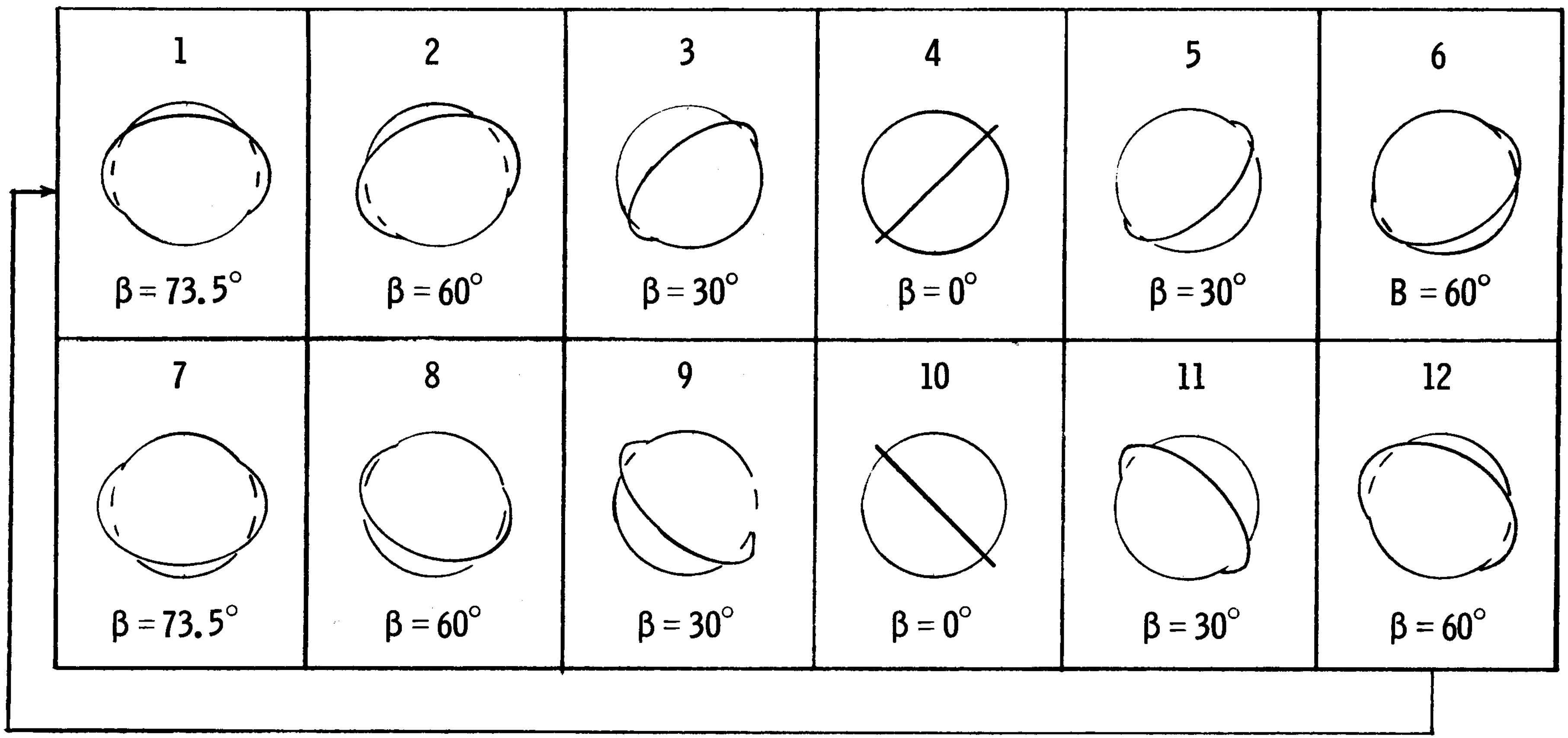
b. Arrays with one degree of freedom

c. Arrays with two degrees of freedom: rotation about array centerline and β-adjust (correction for undesirable β).

In addition, for each of the three missions (baseline and two alternates) two solar array power options were considered in conjunction with the cell operation:

FIGURE 11

ORBITAL REGRESSION (TYPICAL)



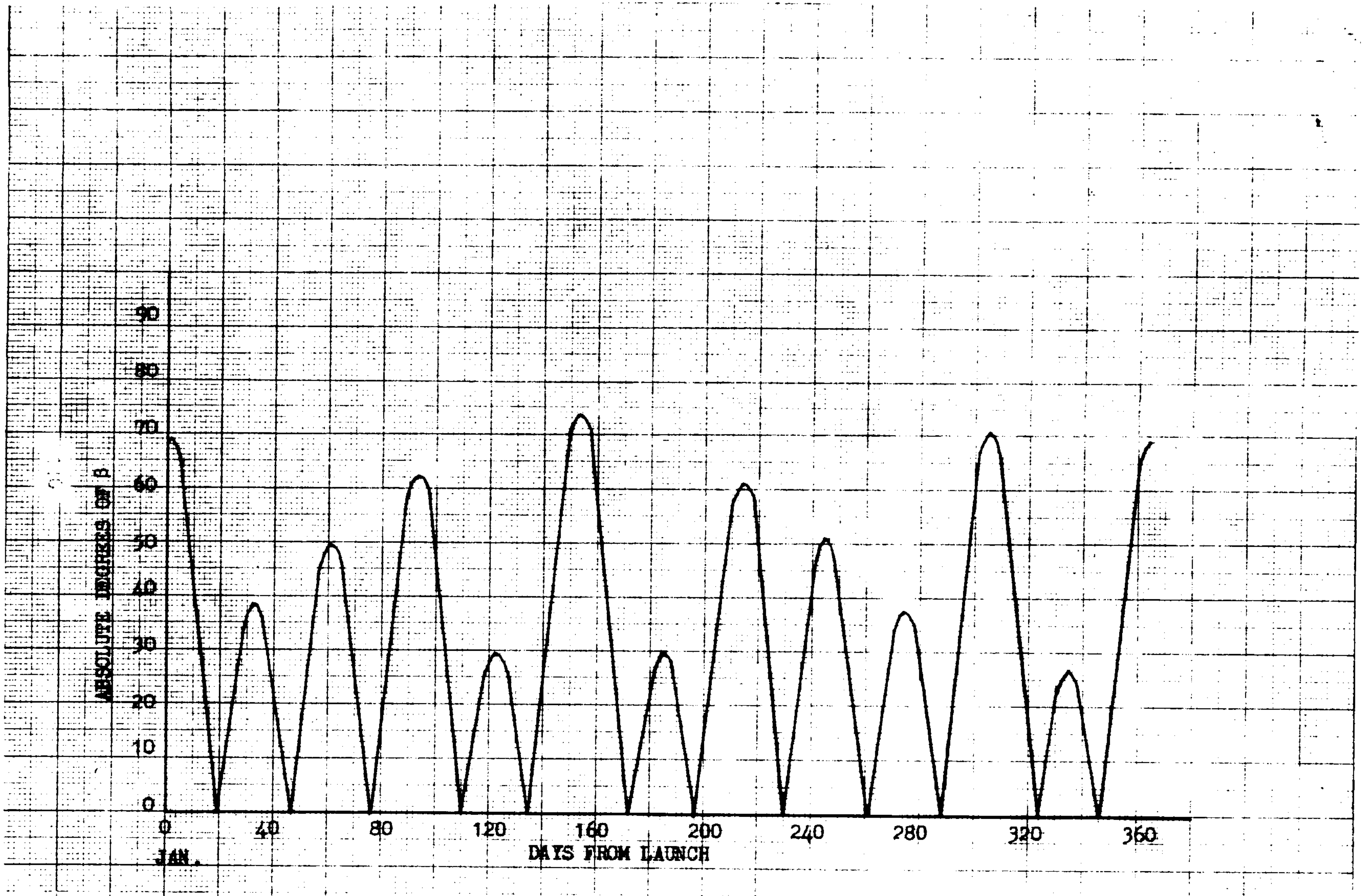


FIGURE 12 VARIATION OF β WITH MISSION DAY

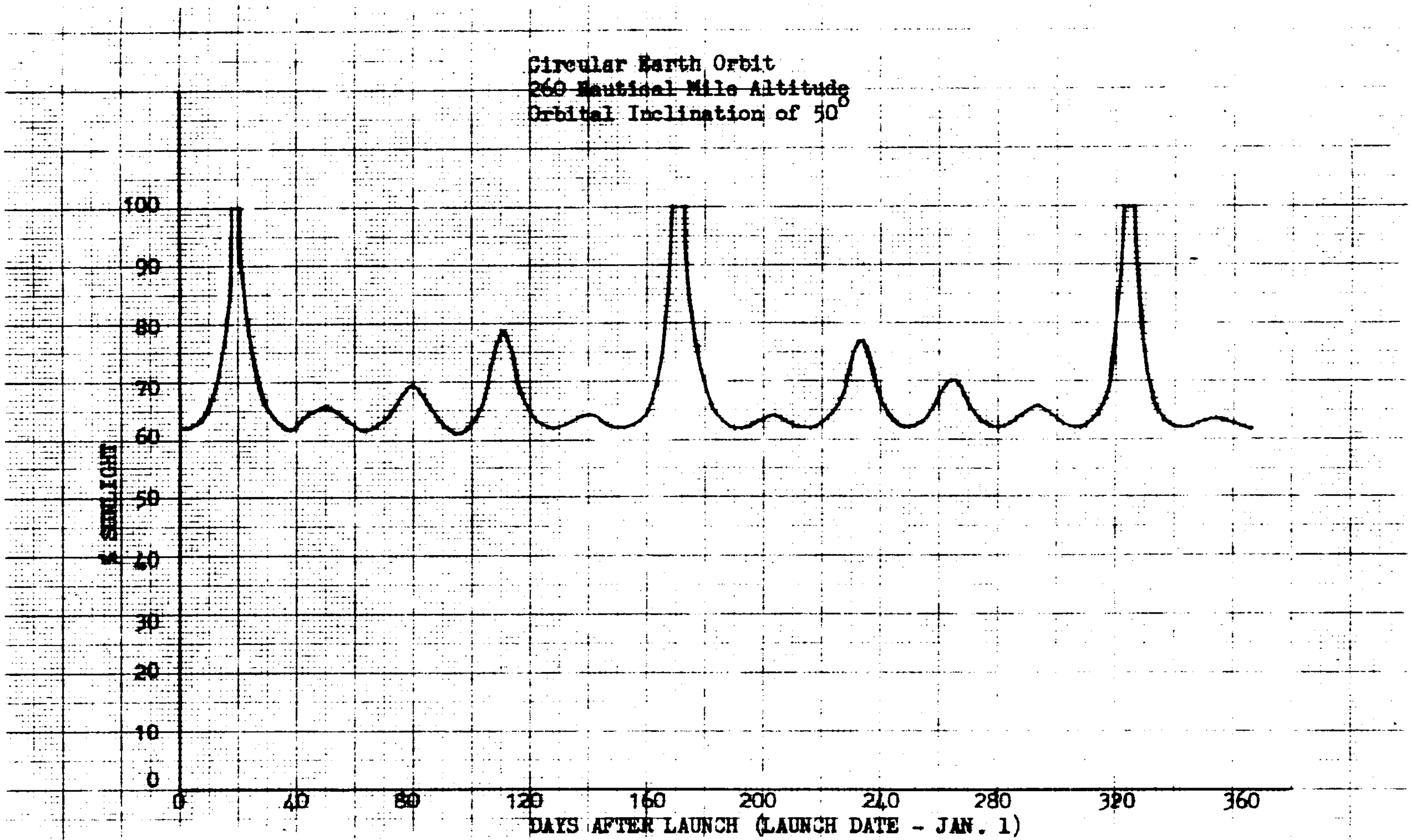


FIGURE 13 % SUNLIGHT VS. DAYS AFTER LAUNCH

a. Fuel cells operating at water use rate power level (about 1200 watts). This case is termed CSMW.

b. CSM fully dependent on the solar cell/battery system. However, the 14-day minimum CSM/APPS fuel cell fall-back capability (56 KW-DAY of energy) is used to power the CSM during APPS operations when fall-back is not incurred. This case is termed CSMD.

Except for the power level differences, all orbital conditions, array attitude options, and analytical procedures were identical for the CSMW and CSMD cases.

Solar array integration and deployment locations considered were (1) along the sides of the SIVB as in Cluster I, except with one degree of freedom as well as fixed and (2) on the AMDA (deployed from the Airlock truss).

Array performance calculations showed that fixed arrays are generally unsatisfactory. Excessively large arrays would be required to provide the required power outputs. One degree of freedom arrays provide considerable improvement over fixed arrays; however, power availability during certain flight periods is low. For example, at $\beta = 73.5^{\circ}$ and with the array axis of rotation perpendicular to the orbit plane, only 15 percent of the average normal power output is available. Two-degree-of-freedom arrays (one degree of freedom in rotation about the array centerline and the second degree of freedom in β-adjust) perform essentially as a solar-oriented arrays, since all misorientation angles are removed by the orientation system. This is, of course, the most efficient system for use during streamline flight modes, since it provides 100 percent of the array capability.

As stated in section 4, the secondary battery selected for Cluster II is the Ni-Cd battery currently planned for use on the Cluster I AMDA.

Battery requirements for the various Cluster II mission options were based on the following for the Ni-Cd system:

a. 25 percent depth of discharge for one year operation.

b. Three for two redundancy factor

c. Available energy of 1300 W-H per battery

d. Weight per battery (including cold-plating) of 110 pounds.

In addition, battery requirements are determined by mission power profile, maximum orbital dark time, solar array output power, power conditioning and (distribution) efficiencies, and battery charge/discharge efficiencies.

5.3.2 Baseline Mission PGS Design

The PGS design for the baseline mission was accomplished parametrically taking into account the various options, flight modes, orbital parameters, and solar array configurations previously discussed. Solar cell/battery system sizing data for the CSMD and CSMW fuel cell options, one degree of freedom SIVB and AMDA arrays, one degree of freedom SIVB arrays with one degree of freedom plus β-adjust AMDA arrays, and new arrays with one degree of freedom plus β-adjust were computed. The data consist of solar array and battery design characteristics (weight, area, total power, etc.) corresponding to the worst and best angles. The cases considered included parallel, perpendicular, and solar oriented (inertial) array flight modes.

Shown in table 5 is an example of the solar cell/battery system sizing data for the baseline mission. The example is for the CSMW case (CSM fuel cells operating at water use rate 1200 watts) with one degree of freedom solar arrays on both the SIVB and AMDA. The data produced in this manner show that:

a. Using the fall-back fuel cell capability to provide CSM power during APPS operations reduces the solar cell/battery system weights by 5 to 15 percent from the CSMW weights for both parallel and perpendicular array flight modes. However, the CSMD weights are approximately 20 percent more than CSMW weights for the solar oriented (inertial) cases, that is, operation between APPS.

b. The perpendicular array flight mode weights are higher in all cases than the parallel mode weights. However, adding β-adjust to the additional or "new" Airlock arrays reduces the difference from a maximum factor of about 110 percent to a maximum factor of about 15 percent. These data illustrate the merits of both array flight modes.

c. Adding β-adjust to Airlock arrays allows weights to be reduced between about 250 percent and 20 percent from cases without β-adjust. Using only "new" arrays on the Airlock reduces weight an additional 25 to 75 percent.

d. The minimum weights for the parallel flight modes are dictated by the solar-oriented flight modes that occur between APPS operations. This is because the best orbit for the parallel case is a 100-percent sunlight orbit that does not require battery charging and thus significantly reduces weight.

TABLE 5 BASELINE MISSION SC/B SIZING - ONE DEGREE FREEDOM ON SIVB AND AMDA ARRAYS (ROTATION)

CASE CSMW - CSM FUEL CELLS RUNNING AT WATER USE RATE (1200 WATTS TOTAL)

ARRAY FLIGHT MODE	β (DEGREES)	"F" RATIO NORMAL ARRAY PWR CONT. SYSTEM PWR	CONTINUOUS SYSTEM PWR 10% CONTINGENCY INCLUDED (WATTS)	TOTAL NORMAL ARRAY POWER WATTS	TOTAL ARRAY AREA (FT^2)	"IMPROVED" SIVB ARRAY AREA (FT^2)	ADD'L ARRAY AREA REQ'D (FT^2)	TOTAL ARRAY WEIGHT (LB)	BATTERY ENERGY REQ'D W-H	BATTERY AND POWER COND. WEIGHT (LB)	BATTERY AND POWER COND. VOLUME (FT^3)	APPLICABLE PERIOD
PERPENDICULAR TO ORBIT PLANE	73.5	8.25	6280	51,800	6860	995	5865	20,227	none	304	4.40	APPS OPER
PERPENDICULAR TO ORBIT PLANE	0	2.26	6280	14,200	1880	995	885	6,417	4050	2869	31.64	APPS OPER
PARALLEL TO ORBIT PLANE	0	3.5	6280	22,000	2915	995	1920	9,087	5700	3926	41.54	APPS OPER
PARALLEL TO ORBIT PLANE	73.5	1.14	6280	7,150	950	995	-45	3,642	none	416	6.04	APPS OPER
SOLAR ORIENTED (INERTIAL)	0	2.26	4525	10,250	1360	995	365	4,977	2920	2114	22.36	SOLAR INERTIAL BETWEEN APPS
SOLAR ORIENTED (INERTIAL)	73.5	1.14	4525	5,150	685	995	-310	2,820	none	224	3.25	SOLAR INERTIAL BETWEEN APPS

In addition, the tabular data discussed above are presented in the detailed report in the form of plots of β versus solar cell/battery system weights. These plots show the percent orbit time at which the cluster is between $\beta = 0$ and $\beta =$ a selected angle. The curves thus presented illustrate the effect of APPS operations on solar cell/battery system weights and show the value of programming APPS operations in reducing weight. Figure 14 is an example of this type of plot for the data given in table 5.

5.3.4 Alternate Missions 1 and 2 PGS Design

For alternate missions 1 and 2, the same orbital conditions and operations prevail. However, for alternate mission 2 there is no OWS and therefore no SIVB solar array. Hence, any solar array for that mission is of necessity new, although the components may be based on present technology.

The same type of parametric design data as produced for the baseline mission were produced for the two alternate missions. In general, the options considered showed basically the same relationships as indicated in the baseline mission analysis.

5.3.5 Design of Additional Arrays Required

Detailed examination of the OWS and AMDA shows that the additional or new arrays are most logically stowed around the lower part of the AMDA and deployed from the top airlock trusses. This selection is supported by previous MSC in-house studies, McDonnell Corporation airlock studies, LMSC studies, and NAA studies. Installation of solar arrays on the LM-APPS vehicle was not considered for two primary reasons: (1) arrays on the LM-APPS would of necessity have to be actively oriented in two axes and would therefore present potentially severe view factor interference problems for the earth-looking APPS experiments and (2) arrays on the LM-APPS would be in a poor location with respect to the entire cluster and would experience, at best, partial shadowing from the sun in most orbits, particularly during APPS operations when power is needed most.

The two fixed constraints to the total array area that can be stowed are (1) number of stowed wings that can be placed side by side around the AMDA and (2) package length as related to fitting within the minimum SLA clearance for launch.

Integration studies showed that:

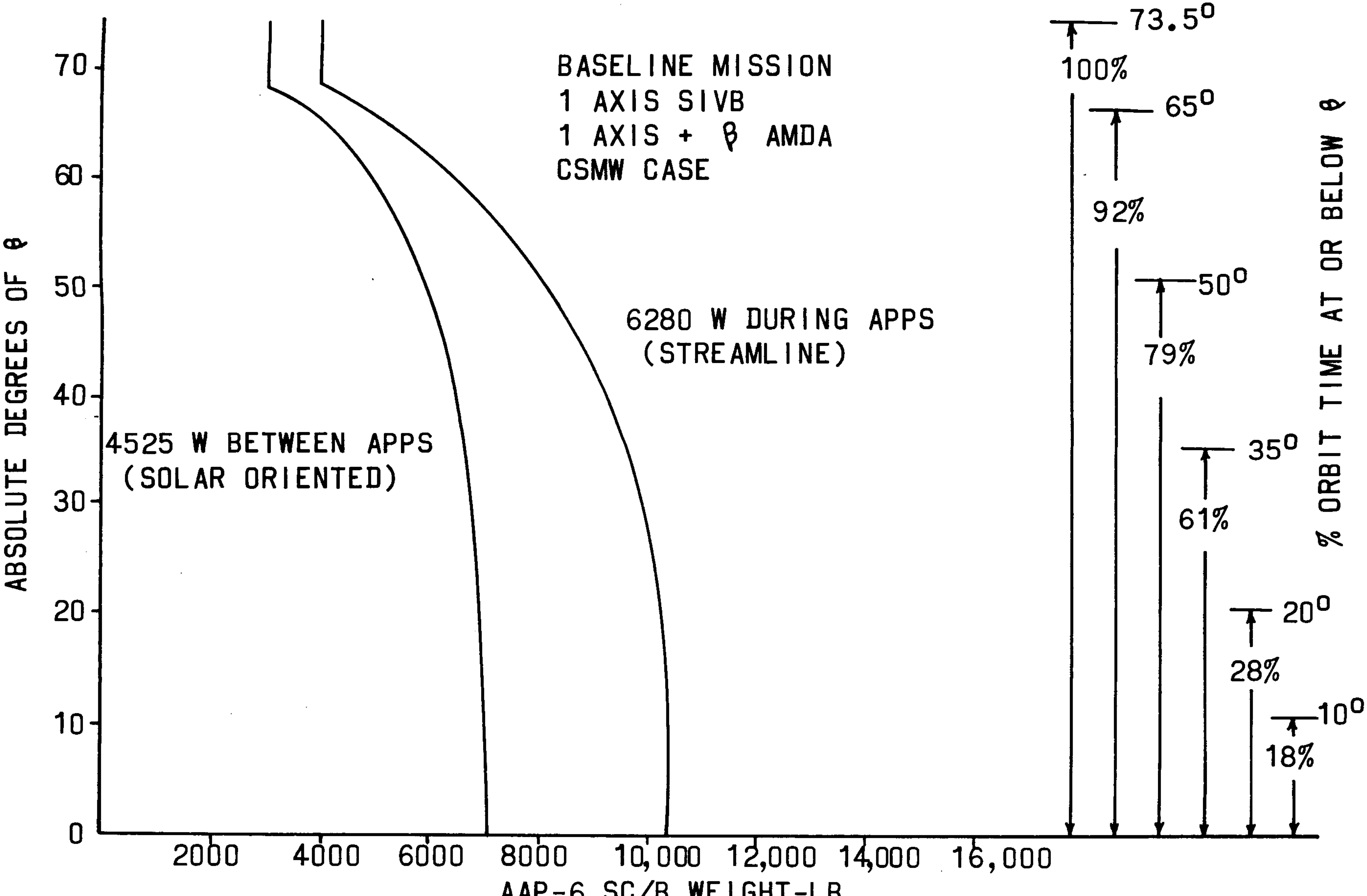


FIGURE 14 BASELINE MISSION, SC/B WEIGHT VS β

a. Package length is satisfactory for SLA clearance.

b. Single-stack, overlap arrangement is selected as stowage mode (see detailed report for integration drawings).

c. Arrays to be deployed in the same plane as are the Cluster I LM-ATM arrays, thereby minimizing RCS plume impingment problems.

d. Partial blocking of docking ports may be a problem if AMDA array is near the maximum size considered.

e. Without the OWS, the AMDA arrays may be deployed at an oblique angle to increase vehicle docking cone angle clearance.

For those cases where SIVB array power is available, standard 63-panel Agena type wings were used as a design point for additional arrays on the AMDA if sufficient area could be obtained by this approach. However, for those cases where more than 650 square feet of additional array was required, the new array design was incorporated.

5.4 PRIMARY BATTERY DESIGN AND ANALYSIS

The only potential requirement for primary batteries aside from the CM reentry batteries is for deorbit when no fuel cell system is available. As discussed in section 4 the LM descent AgZn battery is the logical choice with some additional development. Total capacity required is about 7.5 kw-hr at the end of 90 days wet-stand storage while maintaining a terminal voltage of not less than 27 volts.

5.5 HYBRID POWER SYSTEM CONSIDERATIONS

The Cluster I study report considered and discussed in detail the requirements, configurations, advantages, and disadvantages of several hybrid modes of power transfer and interchange. Some of the same criteria exist for power interchange in the Cluster II vehicles; however, since the requirement for a solar array/battery/fuel all cross-feed hybrid power source is not present in Cluster II, the power interchange is greatly simplified. It is further simplified by the fact that the use of fuel cells is cryo-limited to the water production rate of 1.2 kW.

The baseline Cluster II mission presents two options for power interchange between the CSM and AMDA resulting from the CSM power requirement of 1780 watts. As previously noted, the water production rate mode of operation requires continuous fuel cell operation 1.2 kW (cryo-limited).

This then requires that 580 watts be supplied to the CSM from the AMDA.

Operational option 1, predicated on a CSM isolated-bus ground rule, offers the most direct method of power interchange in that critical CSM loads can be placed on a fuel cell bus and less critical or nonvoltage-sensitive loads, such as heaters, can be placed on a CSM solar cell/battery bus.

Option 2, which is load sharing in the CSM from parallel CSM busses, requires that the source voltages, fuel cells and solar cell/batteries, be paralleled on common busses. This requires that both systems be closely regulated to assure the proper ratio of load sharing. Since the solar cell/battery system is already regulated, the additional requirement is for installation of fuel cell regulators on the CSM.

The major disadvantage in option 1 is the potential for a fuel cell bus failure. This would require that the fuel cell loads be switched to the solar cell/battery bus. Reaction time for switching critical loads in the event of such a failure might have to be extremely rapid to preclude system damage or degradation. Option 2 has no specific operation disadvantages. Before selecting either of these options, detailed study is required. However, all of the system sizing calculations in this study are applicable to either method of load sharing.

5.6 CSM FUEL CELL/RADIATOR HEAT REJECTION SYSTEM

Three modes of fuel cell operation and heat rejection must be considered:

a. Average continuous operation at 1780 watts.

b. Water production level of 1200 watts.

c. Intermittent or fall-back use of the fuel cells.

Mode a. is within the capabilities of the present Block II heat rejection system (maximum capability about 3500 watts). Some heat rejection system modifications may be required to accomplish mode b. in which the radiator fluid temperature could reach the minimum allowable ($-35^{o}F$). To accomplish mode c., some method of flowing the radiator fluid after it has stagnated is required.

This could require complete redesign of the radiators, addition of heaters, and possibly selection of a new fluid.

5.7 ORBITAL STORAGE

Study in this area showed that the minimum orbital storage power can be 485 watts, continuous, considering as a minimum the SIVB array area with an initial sun adjustment. This is based on a gravity-gradient stabilized mode of flight.

6.0 SYSTEM SUMMARY

The purpose of this section is to consolidate and summarize complete mission PGS/CGSS combinations as to the options available. The option matrix presented as figure 10 is repeated as figure 15 with a comments section added.

In the detailed study report, all PGS/CGSS configuration options are presented in the form of curves of β angle versus solar cell/battery system installed weight with payload limits super-imposed and in the form of detailed configuration data sheets upon which the curves are based.

Two cases are given here as examples of the above design information, both for the baseline mission:

a. CSMD case, one degree of freedom SIVB solar array plus two degree of freedom AMDA solar array and a two degree of freedom array on the AMDA only.

b. CSMW case, one degree of freedom SIVB array plus one degree of freedom AMDA array.

Figures 16 and 17 show the curves representing case a. above and figure 18 shows the curves for case b.

Shown in table 6 is a typical configuration data sheet. The sheet shown is for the CSMD case with one degree of freedom arrays on the SIVB and AMDA ($\beta = 0^{\circ}$ case).

All configuration data sheets were summarized in tabular form showing installed weight, payload margin, volume requirements, and total system cost (nonrecurring plus recurring) for best and worst cases for all mission/design options. This information is given in table 7 for AAP-6 and table 8 for AAP 7/8/9/10.

7.0 SCHEDULING, COSTS, AND PROGRAMMATIC CONSIDERATIONS

The detailed report provides discussions of recent progress made toward implementing the various hardware programs supporting Cluster I

MISSION OPTIONS	EXTENT OF FUEL CELL USE	SOLAR ARRAY DESIGN OPTIONS	REMARKS
Baseline	90 Day CSM Power	Existing SIVB Baseline	Insufficient CSM Volume for Cryo
		Improved SIVB Arrays	Insufficient CSM Volume for Cryo
		Impr. SIVB+Airlock Arrays	Insufficient CSM Volume for Cryo
		All Array on Airlock	Insufficient CSM Volume for Cryo
	90 Day H_2O Rate	Existing SIVB Baseline	Insufficient CSM Volume for Cryo
		Improved SIVB Arrays	Insufficient CSM Volume for Cryo
		Impr. SIVB+Airlock Arrays, 1 & 2 Axis	Detailed Study
		All Array on Airlock	Detailed Study
	CSM Power, APPS Only	Existing SIVB Baseline	Insufficient Power Capability from Array
		Improved SIVB Arrays	Insufficient Power Capability from Array
		Impr. SIVB+Airlock Arrays, 1 & 2 Axis	Detailed Study
		All Array on Airlock	Detailed Study
Alternate #1	90 Day CSM Power	Existing SIVB Baseline	Insufficient CSM Volume for Cryo
		Improved SIVB Arrays	Insufficient CSM Volume for Cryo
		Impr. SIVB+Airlock Arrays	Insufficient CSM Volume for Cryo
		All Array on Airlock	Insufficient CSM Volume for Cryo
	90 Day H_2O Rate	Existing SIVB Baseline	Insufficient Power Capability from Array
		Improved SIVB Arrays	Insufficient Power Capability from Array
		Impr. SIVB+Airlock Arrays, 1 & 2 Axis	Detailed Study
		All Array on Airlock	Detailed Study
	CSM Power, APPS Only	Existing SIVB Baseline	Insufficient Power Capability from Array
		Improved SIVB Arrays	Insufficient Power Capability from Array
		Impr. SIVB+Airlock Arrays, 1 & 2 Axis	Detailed Study
		All Array on Airlock	Detailed Study
Alternate #2	90 Day CSM Power	All Array on Airlock	Insufficient CSM Volume for Cryo
	90 Day H_2O Rate	All Array on Airlock	Detailed Study
	CSM Power, APPS Only	All Array on Airlock	Detailed Study

Figure 15 Potential PGS/CGSS Systems

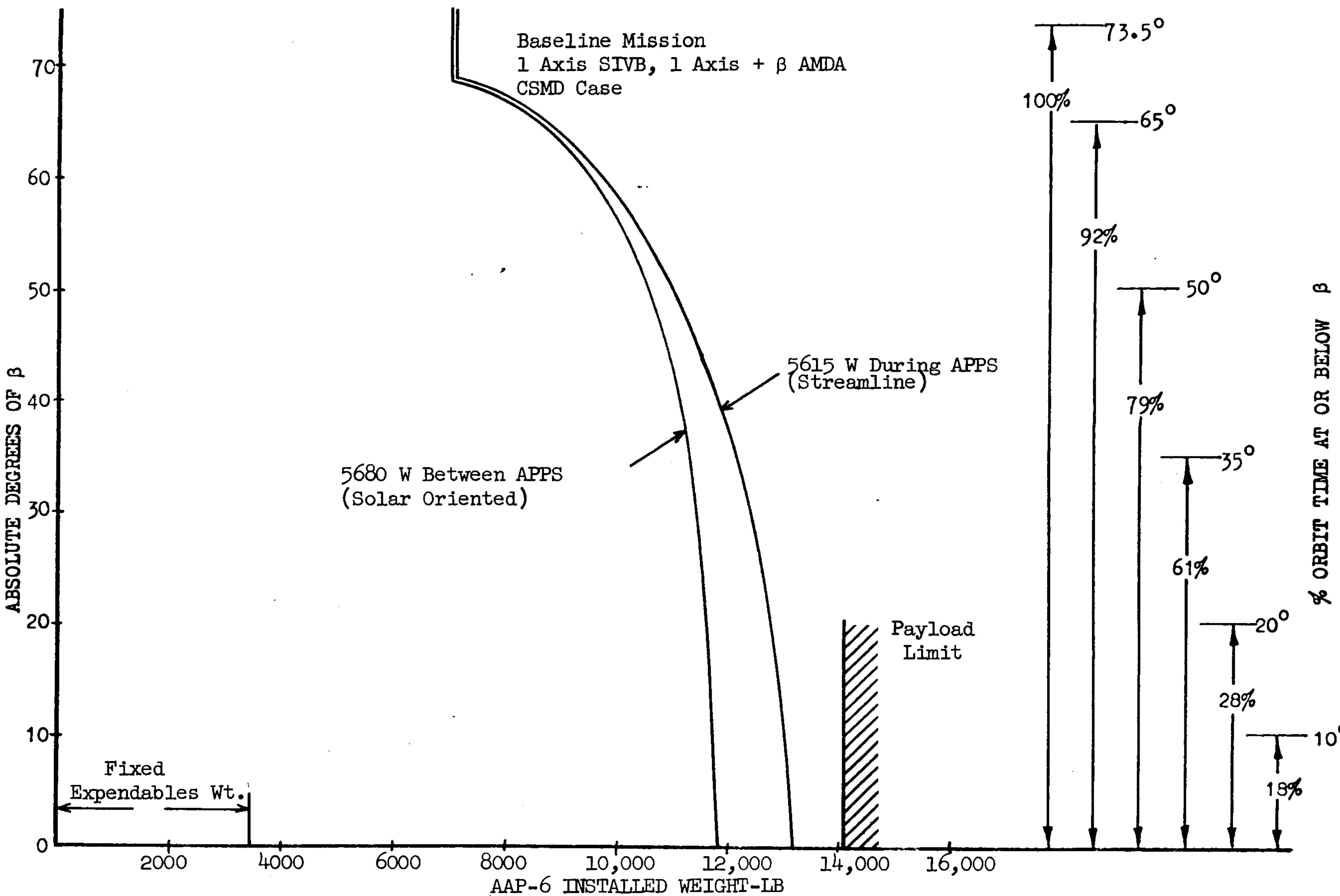


FIGURE 16 BASELINE MISSION, INSTALLED WEIGHT VS β

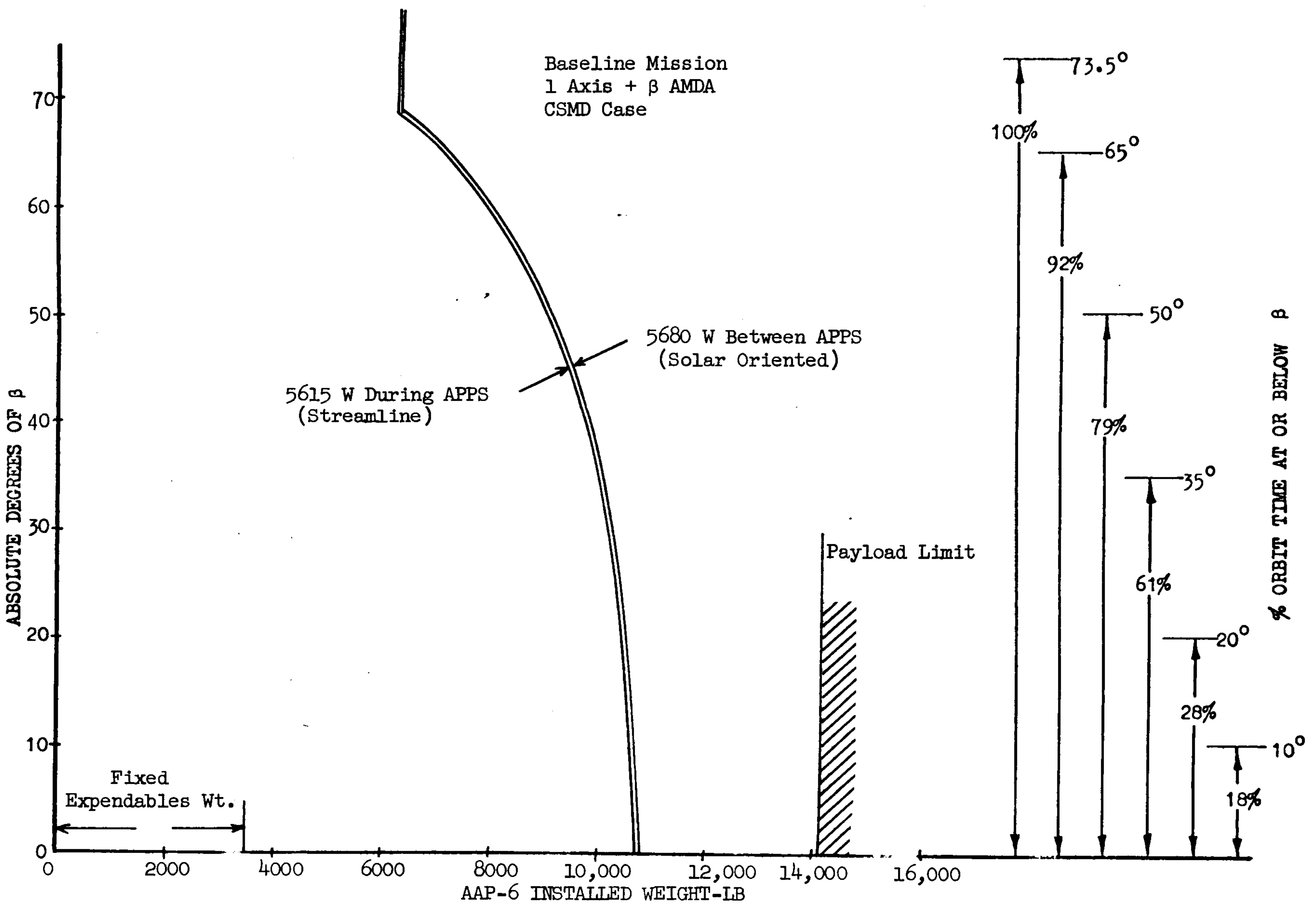


FIGURE 17 BASELINE MISSION, INSTALLED WEIGHT VS β

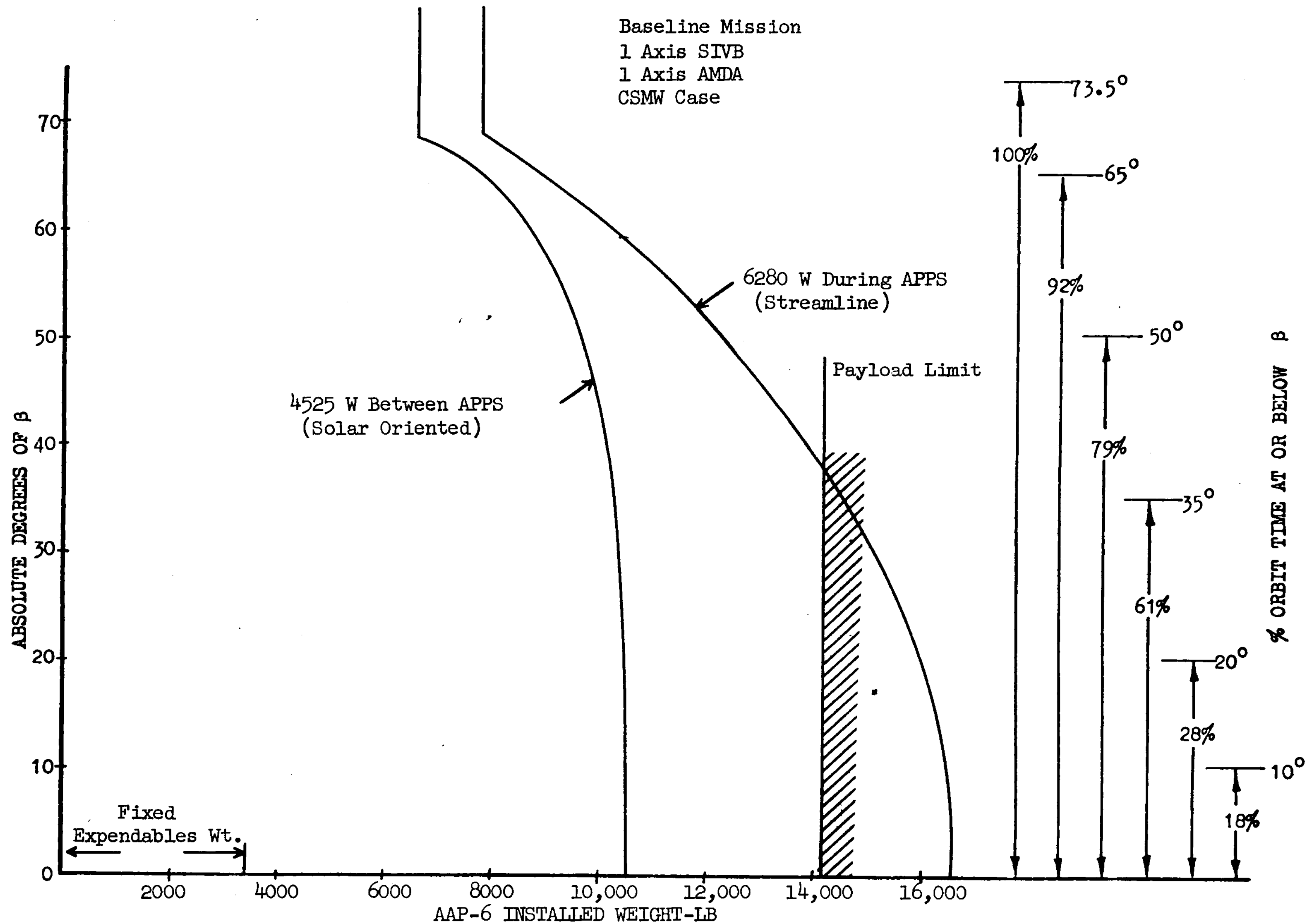


FIGURE 18 BASELINE MISSION, INSTALLED WEIGHT VS β

TABLE 6 CONFIGURATION DATA SHEET

MISSION: Baseline

DESIGN: SIVB and AMDA Arrays

FLIGHT MODE: APPS Operation, Arrays 11 to Orbit Plane

FUEL CELLS: Provide CSM Power During APPS

SOLAR ARRAYS: 1 Axis SIVB, 1 Axis AMDA, $\beta = 0°$

ITEM	TYPE	NO. UNITS	TOTAL CAPACITY	INSTALLED WEIGHT, LB.	SIZE FACTOR	COST $ x 10^6 REC	COST $ x 10^6 NONREC
AAP-6							
SOLAR ARRAYS	SIVB AGENA WINGS	8	7.5 kW	3760	995 ft^2 on SIVB	3.37	0.91
	AMDA AGENA WINGS	8	12.15 kW	4547	1605 ft^2 on AMDA	5.32	2.31
BATTERIES	36 AMP-HR NiCd	24	31 kWh	2640	Vol. 23.0 ft^3	0.12	0.29
BATTERY CHARGERS	60 AMP BUCK	24	68 kW PK	600	Vol. 9.7 ft^3	0.96	
VOLTAGE REGULATORS	60 AMP BUCK	24	43 kW PK	384	Vol. 5.7 ft^3	0.60	
H_2O RESERVE	---	---	2445 lb usable	2690	Vol. 45 ft^3	0.04	0.20
SIVB PRESSURIZATION O_2	BLK I O_2 TANKS	2	412 lb usable	585	Vol. 30 ft^3	0.39	---
SIVB PRESSURIZATION N_2	BLK I O_2 TANK	1	106 lb usable	193	Vol. 15 ft^3	0.29	0.10
TOTAL			6.3 kW NET	15399 lb	128.4 ft^3	\$14.9 × 10^6	
AAP-7/8/9/10						(2)	
FUEL CELLS	UPRATED P&W BLK II	3	4.7 kW PK	738	Vol. 28 ft^3	2.40	---
VOLTAGE REGULATORS	100 AMP BUCK	2	6.0 kW PK	50	Vol. 4 ft^3	0.20	---
N_2 SYSTEM	AAP TANK	1	450 lb usable	759	Vol. 25 ft^3	1.40	---
H_2 SYSTEM	AAP TANKS	2	150 lb usable	756	Vol. 50 ft^3	2.20	---
O_2 SYSTEM	AAP TANKS	3(1)	2768 lb usable	3510	Vol. 65 ft^3	2.68	---
H_2O SYSTEM	MAKEUP STORAGE	---	1184 lb usable	1302	Vol. 22 ft^3	0.16	---
RETURN BATTERIES	300 AMP-HR AgZn	2	19 kW-hr	Incl in CSM wt	Vol. 2 ft^3	0.06	---
FOOD, CLOTHING, & SPARES	---	---	90-day supply	695	---	---	---
TOTAL				7810 lb	196 ft^3	\$9.1 × 10^6	

AAP-6:		AAP-7/8/9/10:	
TOTAL	15399	TOTAL	7810
PAYLOAD	14102	PAYLOAD	9644
MARGIN	-1297	MARGIN	+1834

(1) Includes 1 Blk I O_2 Tank

(2) Totals for 4 CSM Flts

TABLE 7

CONFIGURATION DATA SHEET SUMMARY, AAP-6

MISSION / DESIGN OPTION	INSTALLED WT, LB		PAYLOAD MARGIN, LB		VOLUME, FT^3		TOTAL COST, $\$ \times 10^6$	
	WORST CASE	BEST CASE	WORST CASE	BEST CASE	WORST CASE	BEST CASE	WORST CASE	BEST CASE
BASELINE / CSMD								
SIVB, 1 AXIS AMDA	15 399	7399	-1297	6703	128	95.7	14.9	5.7
SIVB, 1 AXIS + β AMDA	13 137	7000	965	7102	121	93.9	12.6	5.4
1 AXIS + β AMDA	10 660	6340	3422	7762	117	93.9	10.3	6.8
BASELINE / CSMW								
SIVB, 1 AXIS AMDA	16 481	7526	-2379	6576	131	96.0	16.0	5.9
SIVB, 1 AXIS + β AMDA	13 836	7463	266	1550	123	94.9	13.5	5.8
1 AXIS + β AMDA	11 417	6592	2685	7510	121	94.4	11.0	7.2
ALTERNATE 1 / CSMD								
SIVB, 1 AXIS AMDA	14 464	6889	-5368	2207	125	93.7	14.1	5.25
SIVB, 1 AXIS + β AMDA	12 776	6884	-3680	2212	118	93.7	12.2	5.2
1 AXIS + β AMDA	10 294	6214	-1198	2882	115	93.7	10.0	6.65
ALTERNATE 1 / CSMW								
SIVB, 1 AXIS AMDA	15 730	7415	-6634	1568	129	95.8	15.4	5.7
SIVB, 1 AXIS + β AMDA	13 358	7335	-4262	1761	121	94.6	12.9	5.6
1 AXIS + β AMDA	10 775	6390	-1679	2706	117	93.9	10.5	6.95
ALTERNATE 2 / CSMD								
1 AXIS + β AMDA	10 294	6214	324	4404	115	93.7	10.0	6.5
ALTERNATE 2 / CSMW								
1 AXIS + β AMDA	9 111	5796	1507	4822	110	93.0	8.8	6.2

TABLE 8

CONFIGURATION DATA SHEET SUMMARY, AAP- 7/8/9/10

MISSION / DESIGN OPTION	INSTALLED WT, LB		PAYLOAD MARGIN, LB		VOLUME, FT^3		TOTAL COST, $\$ \times 10^6$	
	WORST CASE	BEST CASE	WORST CASE	BEST CASE	WORST CASE	BEST CASE	WORST CASE	BEST CASE
BASELINE / CSMD	7855	7810	1789	1834	199	196	11.6	9.1
BASELINE / CSMW	8094	8094	1550	2550	216	216	13.2	13.2
ALTERNATE 1 / CSMD	7681	7636	1963	2008	199	196	11.6	9.1
ALTERNATE 1 / CSMW	7920	7920	1724	1724	216	216	13.2	13.2
ALTERNATE 2 / CSMD	7135	7090	2509	2554	184	181	11.1	8.6
ALTERNATE 2 / CSMW	7461	7461	2183	2183	216	216	13.2	13.2

missions. Also, development schedules and costs are provided for Cluster II hardware.

8.0 CONCLUSIONS

The following conclusions are made based on the mission/PGS/CGSS analyses conducted in this study:

a. Operating the PGS solar arrays parallel to the orbit plane allows increasingly smaller array area, and associated PGS weight, as APPS operations are programmed to perform at increasingly higher included β angles.

b. Cluster I baseline (fixed) SIVB arrays will satisfy Cluster II power requirements during the solar-oriented mission phases (between APPS operations) at high β angles.

c. All mission power requirements can be satisfied using improved SIVB arrays and AMDA arrays. The former uses all of the SIVB pod volume that is available. Both use one-degree-of-freedom orientation systems.

d. The AMDA arrays can use existing technology for the basic panel, but require a new design structure, deployment, and orientation system.

e. A β adjust capability on the AMDA arrays significantly reduces PGS weight by at least 25 percent depending on the specific PGS option selected with accompanying reductions in cost.

f. If fall-back does not occur, using the fall-back fuel cell capability to supplement the solar cell/battery system during APPS operations results in lower initial launch weight than operating fuel cell continuously at the crew water production rate.

g. The 90-day CGSS operation is feasible using only minimum modifications to Cluster I hardware.

h. The volume available in the CSM for CGSS limits fuel cell operation to the 90-day crew water consumption rate.

i. Both the A-C fuel cell system and the uprated P&W fuel cell system may be used if the 90-day water production approach is selected. The mode would be to use the present 1500-hour capability and operate the fuel cells in timed-series.

j. Both the A-C and uprated P&W fuel cells are satisfactory for fall-back CSM/LM-APPS operation if an all solar cell/battery system approach is selected. These fuel cell systems are also satisfactory for use as described in f.

k. Minimum orbital storage power can be 485 watts, continuous, considering as a minimum the SIVB array area with an initial sun adjustment.

l. PGS development/manufacture/qualification programs are time critical for all systems except fuel cells for Cluster II.