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(NASA-CR-68822) APCLIO EXTENSION SYSTEMS FOR CONTINUOUS EARTH ORBITAL MISSIONS, CASE 218 (Bellcomm, Inc.) 17 p

N75-75653

Unclas

00/98 27445

FACILITY FORM 602

X66 50196 (ACCESSION NUMBER)

(THRU)

17 (PAGES)

2A (CODE)

CR 68822 (NASA CR OR TMX OR AD NUMBER)

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TITLE – Apollo Extension Systems for Continuous Earth Orbital Missions (U)

TM – 65-1013-2

FILING CASE NO(S) – 218

DATE – August 18, 1965

FILING SUBJECT(S) – (ASSIGNED BY AUTHOR(S) – AES Missions

AUTHOR(S) – P. W. Conrad

ABSTRACT

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Five separate modes of operation are discussed for keeping men, spacecraft, and some arbitrary discretionary payload continuously in a low altitude, high inclination earth orbit using standard and/or uprated Apollo equipment. Spacecraft weights, lifetimes, station-keeping requirement, and launch vehicle performance have been estimated for typical missions. The payload is left arbitrary but is restricted to the 5,000 to 10,000 lb range. Author ~~(conf)~~

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BA-146 (8-64)

BELLCOMM, INC.

SUBJECT: Apollo Extension Systems for Continuous Earth Orbital Missions - Case 218 (U)

DATE: August 18, 1965

FROM: P. W. Conrad

TM-65-1013-2

TECHNICAL MEMORANDUM

I. Introduction

It has been suggested that a desirable growth area for the Apollo Extension Systems (AES) missions might be a continuous earth orbital program. This program would consist of several launches which would enable the nation to maintain a manned spacecraft plus some arbitrary descretionary payload (experiments or operational equipment and support) in orbit at all times during a given year. The operations may consist of many similar launches repeated throughout the year or a few large-payload launches with many smaller resupply missions. If necessary, uprated spacecraft and Sa-IB launch vehicles are assumed available for these missions. A rapid study of various possible approaches to accomplish these missions was carried out for NASA-MSF.

To provide a common basis for comparison of the several methods for achieving continuous coverage, a typical orbit was chosen. For long duration flights, one would desire a very large area of total ground coverage, making a high inclination orbit desirable. Also, to accommodate any earth sensing equip- that might be aboard, a low altitude orbit would be desirable. However, air drag causes extreme station-keeping requirements as the altitude is lowered. A 120 NM altitude 83.5° retrograde orbit, although rather difficult to achieve, was selected as a reasonable compromise among the conflicting requirements. The 83.5° retrograde orbit has the added advantage of being sun synchronous, thus providing constant subsatellite earth lighting.

The purpose of this memorandum is to discuss ways of accomplishing the operational missions and to give first order estimates of the required weight, fuel, etc. Definitive estimates are not possible with data now available. Five separate modes of operation chosen from a larger selection given orally to NASA Headquarters are discussed. Only those modes of operation which minimize the number of required Sa-V launches or maximize the use of any uprated vehicles are considered in this memorandum. For schemes involving uprating of the Sa-IB, sufficient uprating was assumed to make the costs worthwhile by eliminating all Saturn V launches in that mode of operation.

II. Building Blocks

All of the spacecraft types used in the operational missions studied and the assumed performance of launch vehicles are given in Table 1.

Launch Vehicles

The launch vehicle performance data are for injection into the 120 NM 83.5° retrograde orbit from the Eastern Test Range on a dog-leg trajectory which will suborbitally overfly Cuba and Panama. The Sa-V case is a two-stage launch with the payload including everything which is carried above the S-II stage. The first standard Sa-IB case includes suborbital ignition of the Service Propulsion System (SPS); hence, no LEM or lab module can be carried. The payload includes anything carried above the LEM adapter. The second standard Sa-IB case is a direct injection into orbit.

The two uprated Sa-IB forms, called Sa-IB-A and Sa-IB-B, are classified only by their capabilities. Possible uprating methods for attaining these capabilities are as follows:

Sa-IB-A (47,000 lb payload)

(1) 80% flox, methane in S-IB stage

(2) Stage zero (four 120" UTC strap-ons); delayed S-IB ignition.

(3) Two 120" strap-ons; high pressure engine in a lengthened S-IB stage.

Sa-IB-B (68,000 lb payload)

(1) 80% flox, methane in lengthened S-IB stage; 30% flox in S-IVB with an uprated J-2 engine.

(2) Stage zero (four 120° strap-ons); uprated H-1 and J-2 engines in lengthened stages.

The payloads using these uprated Sa-IB's in a due-east launch to 100 NM orbit are 70,000 lbs and 100,000 lbs respectively.

Spacecraft Configurations

The first spacecraft listed in Table I is a Block II Apollo CSM with a lifetime of 14 days in Earth orbit. As used in this study, its weight includes minimum life support expendables (to allow for launch, rendezvous, and return only) but not retro fuel. This CSM will be used only with the experiment module which will carry the expendables and SPS fuel. The experiment module is the result of a short Boeing Company study which was concerned with maintaining many experiments in orbit for one year. This module is basically the Boeing lab coupled to a gutted S-IVB stage and S-II adapter. The S-IVB shell and S-II adapter are used to house experiments and to store expendables and spare parts needed for a one-year mission.

The configuration "D" CSM and lab module weights were estimated from the NAA, Boeing, and Grumman AES studies (Ref. 1, 2 and 3). The "D" CSM is essentially a Block II CSM whose lifetime is extended beyond 14 days with supplies carried in the lab module. The configuration "D" lab module which supplies the CSM can be either a Boeing lab module or a Grumman LEM lab. Configuration "D" CSM weight includes retro fuel and life support expendables for 14 days with the remainder of the expendables carried in the lab.

The configuration "C" CSM is a completely independent 45-day CSM similar to the NAA Apollo-X (Ref. 4). It is further defined in the AES studies. The lab module used in conjunction with this CSM is similar to the "D" configuration but is not required to give any support to the CSM.

The Concept "O" is a major uprating of the CSM which was also studied by NAA (Ref. 5). Its lifetime is extended to 90 days using no new subsystem concepts but by adding redundancy and life support. Its weight was estimated from the NAA study. Changes were approximated for the removal of experiments and the two-gas cabin atmosphere which Concept "O" included, and for the addition of the docking hatch, a third astronaut and his life support supplies which had been excluded. Both Concept "O" and configuration "C" CSM weights include retro fuel and life support expendables for their entire lifetime.

The discretionary payload is left completely arbitrary. However, since externally mounted experimental equipment affects the orbital lifetime, two drag cases which put upper and lower bounds on the station-keeping requirements are considered. In the first case no external equipment is appended to the spacecraft while in the other case the effects of the huge external experiments of the Boeing study are calculated. The ballistic coefficients W/C_DA for the latter case are estimated from the Boeing study.

III. Operational Modes

The various schemes (which will be called modes) for carrying out the mission objectives are shown in Table II. Each mode consists of an initial launch of a spacecraft with payload and subsequent resupply launches. The duration of the mode will conform to the lifetime of the spacecraft used in the initial launch. In most cases, the mode must be repeated to maintain continuous operation for a full year or more.

Mode 1

In Mode 1 all expendables needed for one year (including cryogenic hydrogen and oxygen, food, LiOH, Reaction Control System (RCS) propellant, SPS propellant, and spare parts to extend CSM life) in a highly modified S-IVB stage and S-II adapter are orbited on a two stage Sa-V with a Block II CSM and a lab module. Every 90 days a new Block II CSM must be launched on a Sa-IB and rendezvous with the lab. This mode was studied by Boeing, and they concluded that there is room enough to store all the expendables needed.

The discretionary payload is about 30,000 lbs instead of the arbitrarily chosen 9,000 lbs used in all the other modes. The total weight of the initial payload into orbit is estimated to be about 179,400 lbs, which includes 23,000 lbs of SPS propellant stored in the S-IVB. This propellant would be pumped as required into any of the CSM's used during the year. The launch vehicle capability of 190,000 allows 10,600 lbs of SPS fuel to be carried in the initial SM. The resupply missions would carry a Block II CSM (spare parts to extend its life to 90 days are carried in the lab) weighing 19,755 lbs. The remainder of the payload will be station-keeping SPS fuel.

The station-keeping requirements for the lab and spacecraft plus the resupply mission spacecraft weights are given in Table III for three orbital altitudes. (The large antennas of the experiments considered reduce the W/C_DA to about 26, causing the huge station-keeping requirements.)

All resupply missions rendezvous at the lower altitude before propelling the spacecraft (kicking) back up to the initial altitude. The standard Sa-IB can handle only the case where the altitude is maintained between 150 and 160 NM. The initial altitude would be 160 NM, and after decaying to 150 NM, the spacecraft would be propelled back up to 160 NM. The case for 120 NM with continuous station-keeping is just about impossible, as now configured, since the required SPS propellant exceeds tank capacity on resupply missions. However, by reducing the discretionary payload and replacing it with more fuel stored in the lab, the resupply fuel load for this case could be reduced enough that an uprated Sa-IB could be used for resupply. Flying between 140 and 150 NM would require a Sa-IB capable of injecting 39,820 lbs into the 120 NM 83.5° retrograde orbit. This would require a Sa-IB-A.

The advantages of this mode are that it uses only four launches (one Sa-V and three Sa-IB) during the year and does not require uprated launch vehicles or CSM, if flown at 160 NM. Also, the discretionary payload is quite large. The disadvantages are that if the antennas are used, the orbital altitude must be higher than 120 NM and that the discretionary payload must last one year since no equipment would be brought up on the resupply missions.

Mode 2

Mode 2 requires no resupply missions but does require both an uprated Sa-IB and uprated spacecraft. This case requires four launches per year for continuous operation and consists of integral launches of a 90-day CSM and lab, 90 days apart. Estimates of the spacecraft weight, performance, and orbit-keeping requirements are given in Table IV. The W/C_DA for the case with antennas is estimated from the Boeing 360-day-experiment-module study with adjustments for the reduced weight and reduced area due to the removal of the S-IVB stage and the S-II adapter. The basic orbit considered is the 120 NM 83.5° retrograde. When higher orbits are desired to reduce station-keeping requirements, the SPS propellant needed for a Hohmann transfer from 120 NM is given. All altitudes considered will require an uprating to Sa-IB-B if 9,000 lbs of discretionary payload are to be carried.

The advantages of this mode are that the discretionary payload need only last for 90 days and that the altitude can be as low as 120 NM while still requiring only four launches per year, all on uprated Sa-IB's. The disadvantages are the upratings required for both launch vehicle and spacecraft.

Mode 3

The third mode of operation is similar to Mode 2 except that each mission is 45 days and uses AES configuration "D" equipment. This requires eight launches per year, but they are all possible on the "lesser" uprated Sa-IB-A. Performance, orbit-keeping requirements, and weights are given in Table V.

The chief advantage in this mode is that it does not require uprated spacecraft. The discretionary payload must last only 45 days and then is renewed. This mode requires eight launches of uprated Sa-IB's per year.

Mode 4

In order to perform the mission with no uprating and without the drastic modifications of the S-IVB, Mode 4 is suggested. A 45-day configuration "C" CSM, a 135-day LEM lab and up to 65, 000 lbs of discretionary payload can be put up on the first launch with a standard Sa-V. Then, using the standard Sa-IB, two resupply missions are flown at 45-day intervals carrying only a "C" configuration CSM and station-keeping fuel. If no antennas are used, there can be additional payload on the resupply missions. The spacecraft weights are given along with performance and orbit-keeping requirements in Table VI. The orbit-keeping is based on a 9,000 lbs discretionary payload only. Without antennas ($W/C_DA = 105$) the station-keeping fuel is reduced to 600 lbs for 45 days, which reduces the total weights to 41,400 lbs and 23,600 lbs for initial launch or resupply respectively, allowing 1,900 lbs extra payload on the resupply mission. This mode has the advantage of using all non-uprated equipment but requires extra launches. In a three-year period it requires eight Sa-V's and sixteen Sa-IB's at a combined rate of eight launches per year.

Mode 5

To eliminate the Sa-V launches while using only standard Sa-IB's, a multiple-launch initial mission can be substituted for the Sa-V in the previous mode. On the first launch the lab module, discretionary payload, and an aerodynamic protective shroud are put up unmanned. The protective shroud should weigh less than 3,000 lbs. In this case, the capability of the Sa-IB is reduced to 21,000 lbs because the suborbital SPS burn is eliminated. The second launch is a manned CSM identical to the resupply missions of the previous mode. For the case with no antennas, this mode is capable of flying at 120 NM, but, with antennas, it must fly between 150 and 170 NM. The weights, performance, and orbit-keeping requirements are given in Table VII. The added advantage of no Sa-V launches might be offset by the necessity of two extra launch operations per year and the difficulty of rendezvous with an unmanned lab.

The station-keeping fuel estimates in the above examples are not the results of any optimization. Since a low altitude is desirable for earth sensing missions, it seemed reasonable to allow some orbital decay when unable to fly at 120 NM. This would enable the spacecraft to be at a fairly low altitude part of the time, rather than be constantly at some intermediate altitude using continuous station-keeping.

IV Conclusion

The five modes considered have been presented to show first-order feasibility only. No choice as to which would be most desirable is made. Important factors governing this choice, such as cost, operational difficulties, lead times of uprated components, interference with other concurrent space programs, and the actual nature of the payload to be flown, are beyond the scope of this study. It has been shown that such a mission could be flown using AES equipment and existing or modified launch vehicles. However, it may prove to be more efficient and worthwhile to employ the longer duration schemes which use uprated equipment. This question is left entirely open.

V Acknowledgement

The author would like to acknowledge the assistance of H. S. London, who contributed the launch vehicle uprating schemes and performance data.

P. W. Conrad

1013-PWC-plf P. W. Conrad

TABLE I

Launch Vehicles	Payload*
Sa-V	190,000
Sa-IB (SPS suborbital ignition)	25,500
Sa-IB (direct injection)	21,000
Sa-IB-A	47,000
Sa-IB-B	68,000

Spacecraft Modules	Orbit Duration (Days)	Estimated Wt. (lbs)
Apollo CSM Block II	14	19,755
AES CSM Config. "D"	45	21,513
AES CSM Config. "C"	45	23,000
Concept "O" CSM	90	28,830
Lab Module Config. "D"	135	9,476
Lab Module Config. "C"	135	8,800
Experiments Module	360	126,400

*In 120 NM 83.5° retrograde orbit

SPS: Service Propulsion System in the Service Module
CSM: Command/Service Module

TABLE II

Mode	Initial Mission		Resupply		No of Resupplies	Resupply Interval	Duration of Mode	No of Modes/year	Launches per year	
	S/C	L/V	S/C	L/V					Sa-V	Sa-IB
1	Block II CSM + Boeing Experiment Module	Sa-V	Block II CSM	Sa-IB	3	90 days	360 days	1	1	3
2	"O" CSM "C" LAB	uprated Sa-IB	None		--	--	90	4	0	4
3	"D" CSM "D" LAB	uprated S-IB	None		--	--	45	8	0	8
4	"C" CSM "C" LAB	Sa-V	"C" CSM	Sa-IB	2	45	135	8 in 3 years	8 in 3 years	16 in 3 years
5	"C" LAB "C" CSM nonintegral launch	Sa-IB Unmanned Sa-IB rendez	"C" CSM	Sa-IB	2	45	135	8 in 3 years	0	32 in 3 years

TABLE III

MODE 1

Sa-IB RESUPPLY REQUIREMENTS

	Case 1	Case 2	Case 3
Initial Altitude, (NM)	160	140	120
Altitude before Kick, (NM)	150	130	120
Time between Kicks	5 days	2-1/2 days	continuous
SPS Propellant per Year for Kicks, (lbs)	43,600	88,000	162,000
Extra SPS Propellant Required to Resupply at Decayed Altitude, (lbs)	250 per resupply	165	0
Extra SPS Propellant Needed to Bring Lab to Initial Altitude, (lbs)	2,400	1,300	0
SPS Needed for 4 Retros, (lbs)	4,000	4,000	4,000
Total SPS Propellant Needed for 1 Year, (lbs)	50,710	93,795	166,000
SPS Propellant Carried Initial Mission, (lbs)	33,600	33,600	33,600
SPS Propellant to be Carried on Each Resupply Flight, (lbs)	5,713	20,065	44,133*
Resupply CSM Weight, (lbs)	19,755	19,755	19,755
Resupply Mission Weight at 120 NM, (lbs)	25,468	39,820	63,888

*Too large for Block II tanks

TABLE IV

MODE 2

Station-Keeping Requirements

90-day Concept "O" CSM	28,830 lbs	(includes retro fuel and life support for 90 days plus spare parts for added reliability)
90-day lab (135 day lab used for 90 days) Configuration "C"	8,800	
Discretionary payload	9,000	
	46,630 lbs	

Without large antennas $W/C_DA = 120$

160 NM	No station-keeping required. 600 lbs SPS prop. for Hohmann from 120 NM. Total weight in 120 NM orbit	47,230 lbs
140 decay to 120 NM	2 kicks (one every 30 days), 600 lbs SPS propellant (total) required. 300 lbs SPS prop. for Hohmann from 120 NM. Total weight in 120 NM orbit	47,530 lbs
125 decay to 120 NM	18 kicks (one every 5 days), 1400 lbs SPS propellant (total) required. 70 lbs SPS prop. for Hohmann from 120 NM. Total weight in 120 NM orbit	48,100 lbs

With large antennas $W/C_DA = 8.6$

270 NM	No station-keeping required. 2250 lbs SPS prop. for Hohmann from 120 NM. Total weight in 120 NM orbit	48,880 lbs
170 decay to 160 NM	18 kicks (every 5 days), 3000 lbs SPS propellant (total) required. 750 lbs SPS prop. for Hohmann from 120 NM. Total weight in 120 NM orbit	50,380 lbs
120 NM continuous	20,000 lbs SPS prop. required. Total weight in 120 NM orbit	66,430 lbs

TABLE V (MODE 3)

45-day CSM Config. "D"	21,513 lbs	(Includes retro fuel and life support for 45 days)
45-day lab Config. "D"	9,476 lbs	
Discretionary payload	9,000 lbs	
	39,989 lbs	

Without antennas, $W/C_DA = 103$

150 NM	No station-keeping needed for 45 days. 1,090 lbs SPS prop. for Hohmann from 120 NM. Total weight in 120 NM orbit	40,279 lbs
120 NM	Kick every day. 580 lbs SPS prop. (total) required. Total weight in 120 NM orbit	40,569 lbs

With antennas, $W/C_DA = 7.3$

205 NM	No station-keeping needed for 45 days 1090 lbs SPS prop. for Hohmann from 120 NM. Total weight in 120 NM orbit	41,079 lbs
150 decay to 140 NM	Kick 18 times (every 2.5 days), 2300 lbs SPS prop. (total) required. 390 lbs SPS prop. for Hohmann from 120 NM. Total weight in 120 NM orbit	42,679 lbs
120 NM continuous	7,000 lbs SPS prop. required. Total weight in 120 NM orbit	46,989 lbs

TABLE VI

MODE 4

Initial mission with large antennas: $W/C_DA = 7.5$

45-day CSM Config. "C"	23,000 lbs	(includes retro and life support for 45 days)
135-day lab for Config. "C"	8,800 lbs	
Station keeping fuel	16,000 lbs	
Discretionary payload	9,000 lbs	
	56,800 lbs	

Resupply mission with large antennas:

45-day CSM Config. "C"	23,000 lbs
Station keeping fuel	2,500*lbs
	25,500 lbs

*(The actual requirment is 7,000 lbs for each 45 day period. The additional 4,500 required is included in the 16,000 lbs carried in the initial CSM. Upon rendezvous the remaining SPS propellant is to be transferred to the new CSM).

TABLE VII

MODE 5

Without antennas - 120 NM: $W/C_DA = 105$

Initial unmanned launch:

135-day lab	8,800 lbs
Discretionary payload	9,000
Shroud	3,000
	20,800 lbs

Second launch and resupply missions

45-day CSM Config. "C"	23,000 lbs
Station-keeping fuel	600
Additional payload	1,900
	25,500 lbs

With antennas - 150-140 NM: $W/C_DA = 7.5$

Initial unmanned launch same as above.

Second launch

45-day CSM Config. "C"	23,000 lbs
Station-keeping fuel	2,300
Hohmann to 150 NM	200
	25,500 lbs

Resupply missions

45-day CSM Config. "C"	23,000 lbs
Station-keeping fuel	2,300
Additional payload	200
	25,500 lbs

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