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Standard Spacecraft Economic Analysis, Volume 1 Executive Summary

E. D. Harris, J. P. Large

A report prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

This report is an executive summary of the final report on a study of the comparative program costs associated with use of various standardized spacecraft for Air Force Space Test Program missions to be flown on the space shuttle during the 1980-1990 time period. The first phase of the study considered a variety of procurement mixes composed of existing or programmed NASA standard spacecraft designs and a new Air Force standard spacecraft design. The results were briefed to a joint NASA/Air Force audience on July 11, 1976. The second phase considered additional procurement options using an upgraded version of an existing NASA design. The results of both phases are summarized in this report. The final report of the study, R-2099/2-NASA, *Standard Spacecraft Economic Analysis, Vol. 2: Final Report of Findings and Conclusions*, is available from The Rand Corporation as a companion report.

The results of the study should be useful to NASA and Air Force space program offices involved in operational or experimental missions. They should also be of interest to those concerned with the determination of the shuttle tariff rate structure or with shuttle operations, because the impact of a variety of tariff rates is examined.

Although the study examines procurement options that affect both NASA and Air Force programs, the results should not be interpreted as representing official views or policies of NASA or the Air Force.

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CONTENTS

I. INTRODUCTION

The purpose of this study was to examine the relative costs of using one or more of several possible standard spacecraft for Air Force Space Test Program missions during the initial 10-year operational period of the space shuttle. During the first phase of our study we considered the Space Test Program Standard Satellite (STPSS)--a design proposed by the Space Test Program Office of the Air Force Space and Missile Systems Organization (SAMSO), and two NASA candidates--the Applications Explorer Mission spacecraft (AEM) and the Multimission Modular Spacecraft (MMS). After the initial study phase was completed a fourth candidate was introduced--a larger and more capable AEM (L-AEM) configured by the Boeing Company under NASA sponsorship to meet specifications jointly agreed upon by NASA and the Air Force. The evaluation of that spacecraft is also included in the results of this study and procurement options derived using all four spacecraft are compared for the Space Test Program missions. The study was funded by NASA and conducted with the full cooperation of both NASA and the Air Force.

In the past the Space Test Program Office has procured spacecraft as required for specific missions. Generally, that has meant that a new spacecraft was designed and developed for each new mission. The Space Test Program Office has tried to reduce the cost of these spacecraft by requiring that: (1) the contractor use flight-proven components whenever possible; (2) a minimum amount of demonstration testing be done; (3) high technology solutions be avoided; and (4) the institutional aspects of the program, e.g., program office size, be minimized. To date the Space Test Program Office has been very successful in developing spacecraft at a cost substantially lower than the experience of more traditional programs would lead one to expect.

Recognizing that a standard spacecraft produced in accord with these principles could generate substantial savings, the Space Test Program Office contracted for a spacecraft configuration study by TRW[1] which was used as the baseline configuration for this study. Associated studies of other aspects of the STPSS operation and design were also available.[2-4]

Concurrent with the Air Force activity, NASA has for the past six years been working on another standard spacecraft configuration, the MMS.[5] Many of the low-cost aspects of the Space Test Program concept are a part of the MMS design and operational philosophy as well. The principal distinction is an emphasis by NASA on spacecraft modularity, retrieval, and on-orbit servicing that would be possible with a space shuttle. The resulting spacecraft design has capabilities exceeding those necessary for the Air Force Space Test Program missions. The MMS program is ahead of the STPSS chronologically--some of its components have been developed, the design is firm, and contractor bids have been received. Thus the MMS will be developed at no cost to the Air Force, and it is reasonable to ask whether both the MMS and STPSS are needed.

The availability of the AEM further complicates the issue. The AEM is the furthest along in the development cycle. Boeing is under contract to NASA to develop and build AEM spacecraft for the Heat Capacity Mapping Mission (HCMM) and the Stratospheric Aerosol Gaseous Experiment (SAGE), and again, NASA is emphasizing low-cost spacecraft design.[6] Although the AEM is designed specifically for two missions, it uses a modular concept that makes it suitable as a standard spacecraft.

An additional complication is that the AEM can be upgraded to perform some or all projected Space Test Program missions, depending on the kind of attitude control subsystem used. The question, then, of which spacecraft would enable the Space Test Program Office to meet its mission responsibilities at the lowest cost requires a comparative analysis of program costs. This report presents an executive summary of such an analysis. Section II presents study objectives and guidelines, and Sec. III discusses the Space Test Program mission model. The results of the cost analysis are summarized in Sec. IV, where estimates of spacecraft nonrecurring and recurring costs and the costs of the various launch options are presented. Section V summarizes the program costs, and the results of the sensitivity analyses conducted and the conclusions of the study are presented in Sec. VI.

II. OBJECTIVES AND GUIDELINES

The two objectives of this study were to develop internally consistent cost estimates for the AEM, L-AEM, STPSS, and MMS spacecraft and, using these estimates, to determine the variation in program cost for a variety of spacecraft procurement options capable of performing the Space Test Program missions during 1980-1990. The emphasis is on relative, not absolute, accuracy in the estimates developed.

The study guidelines directed that we use the spacecraft configurations as determined by Goddard Space Flight Center (GSFC) for the MMS, TRW for the STPSS, and Boeing for the L-AEM and AEM. Of the four, the AEM has the least capability. It is about 3 ft in diameter, has a 150 lb payload capability, and is limited to operating altitudes of less than 1000 n mi. The L-AEM design is a derivative of the AEM that is larger (5 ft in diameter) and has greater data rate, power, and payload capabilities.(7) The nominal payload of the L-AEM is the same as the STPSS, 1000 lb. Both the L-AEM and STPSS can be procured in three different configurations--a spinning version (L-AEM-S or STPSS-S), a baseline or low-cost three-axis stabilized version (L-AEM-BL or STPSS-LC), and a three-axis stabilized precision version (L-AEM-P or STPSS-P). The MMS is the most sophisticated of the four standard spacecraft considered in the study. It has a modular design that allows on-orbit servicing and reuse, while the AEM, L-AEM, and STPSS are expendable. The MMS has a payload capability of about 4000 lb and can be operated up to geosynchronous altitude.

Space Test Program payloads described in *Current STP Payloads* (the so-called "bluebook")(8) are considered representative of those that would be flown during the period 1980-1990.

All spacecraft are compatible with the use of solid rockets for orbit translation, which usually requires spin stabilization. The AEM, L-AEM, and STPSS are designed with that in mind. The MMS normally uses a hydrazine propulsion module or the Interim Upper Stage (IUS) for orbit translation in a three-axis stabilized attitude, but according to GSFC it can also be spin stabilized for orbit translation.

Space Test Program missions are intended to be flown as secondary payloads, which implies that Space Test Program payloads would rely on solid rocket kick stages, other than the IUS, for orbit translation from the nominal shuttle parking orbit (150 n mi) rather than change the shuttle orbit altitude and inclination to meet the payload requirements.

Nominally, two Space Test Program flights per year would be flown with a minimum of one flight per year. All missions in the study are launched using the space shuttle with no on-orbit servicing or payload retrieval.

III. SPACE TEST PROGRAM MISSION MODEL

As indicated in Table 1, the Space Test Program missions[8] are divided into eight different orbits that distinguish among orbit altitude, inclination, and spacecraft orientation. The first orbit (1-S and 1-E) is a low earth orbit with an altitude of about 250-300 n mi. The missions of this orbit are categorized according to whether they are sun-oriented or earth-oriented. Forty-five percent of the Space Test Program payloads fly in this orbit. The second orbit is a highly elliptical one (7000 by 200 n mi) in which 28 percent of the Space Test Program payloads fly. The missions in both of these orbits are launched from the Western Test Range (WTR). The missions flown from the WTR (orbits 1, 2, and 8) represent about 75 percent of the

Table 1

SPACE TEST PROGRAM MISSION CATEGORIES

Number	Type	Orbit (n mi)	Inclination (deg)	Launch Range	Percentage of Payloads	No. of Payloads
1-S	Sun-synchronous, sun-oriented	250-300 circular	98.4	Western	17	20
1-E	Sun-synchronous, earth-oriented	250-300 circular	98.4	Western	28	32
2	Elliptical	7000 × 200	Polar	Western	28	32
3	Geosynchronous, sun-oriented	19,372 circular	Low (28.5)	Eastern	8	9
4	--	10,000 circular	Low (28.5)	Eastern	4	5
5	12 hr	21,000 × 900	63.4	Eastern	7	7
6	Geosynchronous, earth-oriented	19,372 circular	Low	Eastern	2	3
7	--	3200 × 150	30	Eastern	2	3
8	--	180 circular	Polar	Western	2	3

Space Test Program payloads. The missions flown out of the Eastern Test Range (ETR) all require large orbit translations, e.g., up to geosynchronous. The last column of Table 1 shows the number of Space Test Program payloads that will fly in each of the orbits during the 1980-1990 period. The total number of payloads in the nominal case is 114.

Table 2 lists the number and percentage of the Space Test Program missions that each of the eight standard spacecraft configurations can accommodate. The measures of spacecraft capability used in making this assignment include: payload weight, pointing accuracy, power availability, stability, orientation, and data transmission rate.

Table 2

SPACECRAFT MISSION CAPABILITY

Spacecraft	Number of Payloads	Percentage of Total Payloads
AEM (150 lb, <1000 n mi)	10	22
L-AEM-S	12	26
L-AEM-BL (<1000 n mi)	13	28
L-AEM-P	46	100
STPSS-S	12	26
STPSS-LC	41	89
STPSS-P	46	100
MMS	46	100

The number of payloads accommodated by the AEM and L-AEM-BL is limited primarily by altitude limitations. The spinning configurations are limited by the number of Space Test Program payloads that can be spin stabilized. The three precision spacecraft configurations (L-AEM-P, STPSS-P, and MMS) can accommodate all of the Space Test Program missions.

IV. SPACECRAFT AND LAUNCH COSTS

RECURRING COSTS

The estimated unit 1 costs for each of the spacecraft considered in the study are shown in Table 3. The intent was to provide estimates that would reflect relative differences in the size, complexity, and capability of the spacecraft as currently specified, while remaining consistent with the current cost experience of programs actually underway, i.e., the AEM and MMS. The method adopted was to develop a model calibrated to reflect AEM experience and to use conventional scaling techniques for extrapolation from that base. The estimates shown in Table 3 include integration of the components into subsystems, system integration and test, program management, reliability and quality assurance, etc. No allowance for profit was included.

Table 3

ESTIMATED UNIT 1 COST

(In millions of 1976 dollars)

AEM	2.3
L-AEM	
Spin	3.9
Baseline	4.8
Precision	5.7
STPSS	
Spin	4.6
Low-cost	5.7
Precision	6.9
MMS	
Basic	8.9
SPS-I	9.4

In deriving these unit 1 costs for the AEM and MMS configurations we assume: that the AEM uses the SAGE attitude control system and a

SGLS-compatible S-band communications system; and that the MMS also has an SGLS-compatible communications package as well as a solar array. The area and cost of the array on the L-AEM and STPSS three-axis spacecraft and the MMS are varied according to mission requirements. Spacecraft unit costs are also varied for different production rates and quantities.

NONRECURRING COSTS

Nonrecurring costs were estimated for the STPSS and L-AEM only; for the other spacecraft those costs would not be borne by USAF and therefore would be irrelevant in comparisons of USAF outlays. The SAMSO cost model[9] provided the basic estimating equations, which were derived from a sample of up to 28 space programs over the period 1959-1972. Some spacecraft were deleted from the sample because they were developed "under tight monetary constraints and under a philosophy that required the use of proven technology." STPSS is precisely such a program, so the output of the SAMSO model was modified to fit the Space Test Program Office philosophy. In addition, it has been assumed that a qualification test model would be desirable, and the nonrecurring cost estimates for both the STPSS and L-AEM reflect that assumption.

For the L-AEM nonrecurring costs the basic estimate by Boeing was scaled up to include a test model, but as shown in Table 4 the difference

Table 4

SPACECRAFT NONRECURRING COSTS
(In millions of 1976 dollars)

Spacecraft	Estimates Based on SAMSO Model		Estimates Based on Boeing Study
	STPSS	L-AEM	L-AEM
Spin	15.9	--	--
Low-cost (baseline)	20.7	18.0	8.6
Precision	23.4	19.6	9.1
Spin + low-cost	25.3	--	--
Spin + precision	28.1	23.0	11.3
Low-cost + precision	26.1	25.3	11.9
Spin + low-cost + precision	30.9	28.7	14.5

between the L-AEM and STPSS nonrecurring costs is striking. When estimated in the same manner as the STPSS, the differences are far less. The impact of the discrepancy between the estimates on the issue of spacecraft selection is examined in the sensitivity analysis (Sec. V).

LAUNCH COSTS

Launch costs are an important component of total program cost, and it was essential to determine whether their inclusion would affect the rank ordering of spacecraft alternatives. Since both the cost per shuttle launch and the way in which that cost will be allocated among users are still uncertain, several possibilities were considered (Table 5). A nominal cost of $15.4 million was assumed for most cases but the effect of an increase to $30 million was also considered.

Launch costs could be allocated among missions sharing a space shuttle flight in a variety of ways, e.g., on the basis of weight or by preliminary tariff schedules formulated by NASA. The NASA tariff schedule available for the first phase of the study allocated the shuttle cost on the basis of length, weight, inclination, and altitude. In this equation, weight is the least important variable and for the Space Test Program missions, inclination is the most important. A modified NASA tariff schedule (Table 5), proposed since the earlier phase, prorated the launch costs on the basis of either weight or length, whichever gives the higher cost.

Another possibility is that the primary user might pay the entire cost and a secondary user traveling on a space-available basis might pay only a service charge--shown here as $1 million. All of these possibilities were included in the analysis.

Table 5

LAUNCH COSTS

Shuttle Launch Cost Allocation	Formula for Allocating Shuttle Launch Costs
By weight	\$1 million + $\frac{\text{Mission payload weight}}{\text{Shuttle payload weight}}$ (\$15.4[a] million)
Using service charge only	\$1 million per launch
Using the NASA tariff[b]	$SRU = .00215L + 0.238L^2 + .000203W - .00000000169W^2 - .000122I + .00422I^2 + .00109A + .000232A^2$
Using the modified NASA tariff	$\frac{\text{Mission payload weight}}{\text{Shuttle payload weight}}$ (\$15.4[a] million) or $\frac{\text{Mission payload length}}{\text{Shuttle bay length}}$ (\$15.4[a] million) whichever gives the higher cost

NOTE: The IUS cost is assumed to be \$4.3 million per launch whenever it is used as a kick stage.

[a]Space shuttle costs of \$30 million per launch were also used.

[b]SRU stands for service rendered units, which may exceed 100 for some combinations of inputs, but when it does it is truncated at 100. It represents a percentage of the shuttle cost that is charged for a specific launch. The units of the equation are: L, length in ft; W, weight in lb; I, inclination in deg; and A, altitude in n mi.

V. PROGRAM COST

Program cost for a variety of procurement options, each capable of performing all of the Air Force Space Test Program missions, is used as the principal measure for distinguishing among these procurement options. The analysis was done in two phases. In the first phase, procurement options using the AEM, STPSS, and MMS spacecraft were compared. In the second phase, additional procurement options using the L-AEM spacecraft design, which became available partly as a result of the outcome of the first phase, were evaluated.

NOMINAL CASE

We defined a nominal case as a baseline for estimating the cost to carry out the Space Test Program missions during the 1980-1990 period, and a number of excursions from that baseline were made to test the sensitivity of the results to assumptions about the number of payloads, payloads per spacecraft, etc. The nominal case includes all three versions of the STPSS. The nominal program size is 114 payloads with a maximum of 6 payloads per spacecraft. In keeping with the Space Test Program Office philosophy that its payloads always have secondary status, all missions are launched by the shuttle to a 150 n mi parking orbit; solid rocket kick stages are used to translate the Space Test Program payloads into the proper orbits. Both ETR and WTR launches of the shuttle are considered. For the nominal case, it is assumed that the shuttle cost of $15.4 million is prorated by weight and that a service charge of $1 million per launch is imposed.

The number of spacecraft that would need to be procured for each of four different procurement options is shown in Table 6. The four options are an all-STPSS case, an all-MMS case, and two mixed cases--AEM/STPSS and AEM/MMS. An option consisting of all three types of spacecraft was considered, but it would not be cost-effective to have both the STPSS and MMS in the same option. Either spacecraft alone can provide the full range of capability necessary for the Space Test Program missions but at different costs.

Table 6

NUMBER OF SPACECRAFT
(Nominal case)

Spacecraft Type	Procurement Options			
	STPSS	MMS	AEM/STPSS	AEM/MMS
AEM	0	0	3	4
STPSS-S	0	0	0	0
STPSS-LC	19	0	16	0
STPSS-P	5	0	5	0
MMS	0	24	0	20
Total	24	24	24	24

The STPSS-S configuration is not procured in the nominal case, because there are only a few payloads that can be spin stabilized, and they are distributed over the eight different orbits in such a way that it is always more costly to use the STPSS-S than to place more payloads on the STPSS-LC or STPSS-P. When larger programs are considered, the STPSS-S configuration is included in the procurement mix.

The costs associated with these procurement options are shown in Table 7, broken out by spacecraft, kick stages, and launch operations.

Table 7

PROCUREMENT COSTS IN NOMINAL CASE
($ millions)

Cost Item	Procurement Options			
	STPSS	MMS	AEM/STPSS	AEM/MMS
Spacecraft	167	190	155	172
Kick stages (solids)	4	6	4	5
Launch (100% prorated)	51	67	51	63
Total	222	263	210	240

The cost of the all-solid kick stages is nearly insignificant (about 2 percent of the total). Launch cost represents about 25 percent of the total cost.

The lowest-cost procurement option is the AEM/STPSS combination, but the pure-STPSS option is within 10 percent of its cost. Given the uncertainties of the various spacecraft in this study, *we consider program options having costs within 10 percent of each other as indistinguishable.* Consequently, for the nominal case both the AEM/STPSS and pure STPSS are preferred alternatives. The pure MMS is not a good option for the Space Test Program missions, because it offers more capability than is needed for most missions and that capability must be paid for.

PAYLOAD VARIATIONS

The results of the nominal case can be considered valid only if they obtain for conditions other than those established somewhat arbitrarily. To test their sensitivity to the original assumptions, several other cases were examined as illustrated in Table 8. Of the cases shown, maximum number of payloads per spacecraft, payloads in the Space Test Program, allocation criteria for launch costs, and shuttle costs were found to be the most important in terms of program cost.

Table 8

SENSITIVITY EXCURSIONS

(Nominal case)

Using Current Spacecraft Configurations

1. Maximum number of payloads per spacecraft: 6-13
2. Size of the Space Test Program: 92-228 payloads
3. Type of kick stage: solids, IUS-solids combination
4. Percent of the shuttle costs prorated: 0-100 percent
5. Criteria for allocating the shuttle costs: weight-NASA tariff
6. Shuttle cost: \$15.4 million-\$30 million
7. STPSS nonrecurring cost: nominal costs (Table 4)--30 percent lower

The variation of total program cost with maximum number of payloads per spacecraft is illustrated in Fig. 1, where it can be seen that as the maximum number of payloads increases above 10, the ability to distinguish between the procurement options on the basis of program cost disappears. *The total program cost is about 30 percent lower than in the nominal case (maximum number of payloads of 6) when the number of payloads is allowed to increase to 13.* This trend was found to be true across a wide number of excursions.

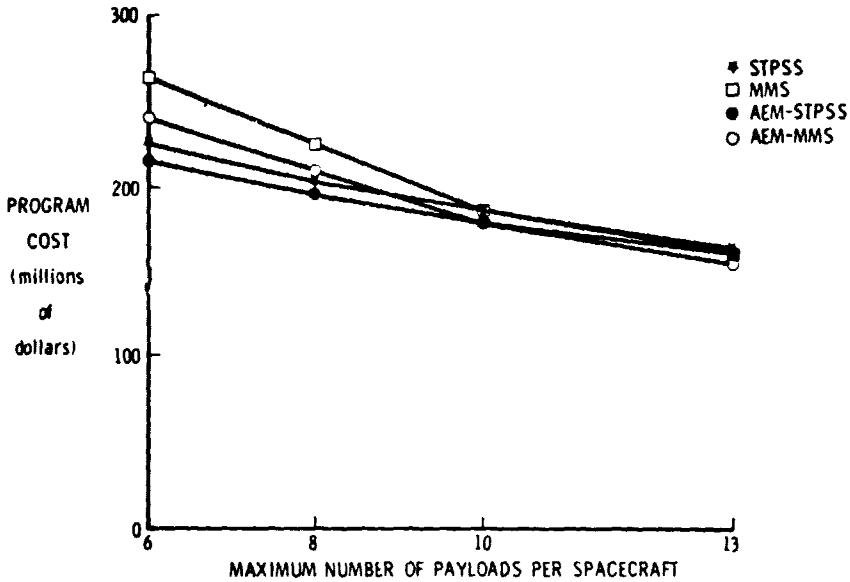

Fig. 1—Effect of the maximum number of payloads per spacecraft (nominal case)

Figure 2 illustrates the variation in program cost as a function of the Space Test Program size. Here we have allowed the program size to double for a total of 228 payloads to see if economies of scale might preferentially benefit the MMS and thereby alter the ordering of the procurement options. As shown, no such effect was found. The ordering of the various procurement options remained unchanged while the program cost increased nearly linearly.

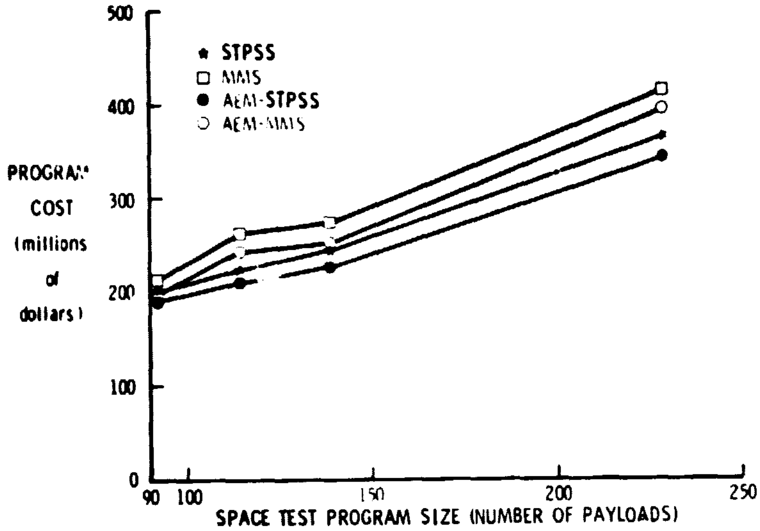

Fig. 2—Effect of Space Test Program size (nominal case)

LAUNCH COST VARIATIONS

Table 9 displays the program costs for the nominal case where the shuttle launch cost is assumed to be $15.4 million prorated among users on the basis of payload weight. Excursions were performed to test the sensitivity of the rank ordering of program costs to shuttle launch cost and the procedure adopted for allocating shuttle costs among users. These results are also shown in Table 9, where for ease of reading all costs more than 10 percent above the lowest cost in each row are in parentheses.

In looking at the other cases, it is clear that increasing the shuttle cost to $30 million per launch has no effect on the relative results. Assuming that Space Test Program payloads get a free ride on the shuttle and pay only a service charge of $1 million per launch does not change the results either.

The effect of the two NASA-proposed tariff schedules is also shown. In the case called *NASA tariff*, where launch cost is allocated on a basis of payload length and weight, altitude, and orbital inclination, relative costs are unchanged from the first two cases. The results for the *modified NASA tariff* case were somewhat different; both the MMS and AEM/MMS options have relatively higher program costs because the average length of the spacecraft-payload combinations for these options is greater than for the options using the STPSS.

Table 9

EFFECT OF SHUTTLE COST AND TARIFF SCHEDULES[a]

Case	No. of Payloads in Programs	Max. No. of Payloads per Spacecraft	Program Cost ($ millions)			
			STPSS	MMS	AEM/STPSS	AEM/MMS
Shuttle cost = $15.4 million	114	13	160	162	157	156
	114	6	222	(263)	210	(240)
	228	13	244	247	244	240
	228	6	373	(418)	342	(392)
Shuttle cost = $30 million	114	13	181	189	178	183
	114	6	249	(306)	237	(279)
	228	13	279	290	279	284
	228	6	424	(489)	391	(461)
Service charge of $1 million only	114	13	139	135	136	129
	114	6	195	(220)	183	201
	228	13	209	204	209	196
	228	6	322	(347)	293	(323)
NASA tariff	114	13	202	204	199	198
	114	6	297	(342)	286	(321)
	228	13	315	316	333	321
	228	6	514	(558)	490	538
Modified NASA tariff	114	13	161	(181)	156	(173)
	114	6	226	(277)	210	(258)
	228	13	244	(267)	240	(265)
	228	6	(376)	(454)	339	(432)

[a]For a given row, program costs within 10 percent of the lowest value are *not* in parentheses.

The implications of the foregoing analysis for spacecraft selection that has included the AEM, STPSS, and MMS may be summarized as follows:

1. When the upper limit on the number of payloads that can be assigned to a spacecraft is ten or more, program costs are essentially the same in all cases.
2. When the number of payloads per spacecraft is limited to 6, the STPSS and AEM/STPSS offer lowest program costs in virtually all cases.
3. When shuttle charges are determined largely by payload length, as is the case when the modified NASA shuttle tari rate is used, the AEM-STPSS combination has the lowest program cost.

4. Given the stipulated AEM, STPSS, and MMS capabilities, the uncertainties in the Air Force Space Test Program mission model, and the uncertainties in the shuttle tariff schedule, none of the alternatives considered offers a clear-cut advantage over the others, although those options that include the STPSS are generally preferred.

UPGRADED AEM

As an additional excursion, the possibility of modifying some spacecraft designs to give them greater capability was considered. Specific modifications considered include: increasing the STPSS payload capability to 1500 lb; increasing the AEM payload capability to 300 lb, and changing the AEM capability to allow sun orientation and/or geosynchronous altitude operation. Of these, only the last promised a sizable impact on program cost because of the increased number of payloads that could be captured (from 22 to 72 percent of the total) even with the AEM's limited power, data rate and payload weight capabilities. To obtain this improved performance, the reaction control system of the AEM needs to be upgraded. As a first-order approximation, the cost of the AEM was increased sufficiently to allow the use of the STPSS cold-gas reaction control system. This configuration is referred to henceforth as the *upgraded AEM*.

Table 10 compares the cost of the upgraded AEM/STPSS and upgraded AEM/MMS options with those considered in the previous nominal case. In

Table 10

EFFECT OF THE UPGRADED AEM[a]

Case	No. of Payloads in Program	Max. No. of Payloads per Spacecraft	Program Cost ($ millions)					
			STPSS	MMS	AEM/STPSS	AEM/MMS	Upgraded-AEM/STPSS	Upgraded-AEM/MMS
Nominal	114	13	(160)	(162)	(157)	(156)	(148)	99
	114	6	(222)	(263)	(210)	(240)	(172)	146
	228	13	(244)	(247)	(244)	(240)	(233)	175
	228	6	(373)	(418)	(342)	(392)	298	294
Increased estimates of upgraded AEM cost	114	13	(160)	(162)	(157)	(156)	(175)	121
	114	6	(222)	(263)	(210)	(240)	(215)	183
	228	13	244	247	244	240	(281)	231
	228	6	373	(418)	342	(392)	368	371

[a]For a given row, program costs within 10 percent of the lowest value are *not* in parentheses.

that excursion the upgraded AEM/MMS option has program costs about 20 percent less than those of the other procurement options. Increasing the cost estimates for the upgraded AEM by doubling the recurring cost and adding a $10 million nonrecurring cost also resulted in the upgraded AEM/MMS being the preferred procurement option. The principal reasons for this are: (1) with the additional performance capabilities, the relatively low-cost upgraded AEM is a substitute for the more expensive STPSS on nearly all missions that do not require precision accuracy, and (2) when the upgraded AEM is used in combination with the MMS, the nonrecurring cost of the STPSS is not incurred.

In this case, an upgraded AEM spacecraft with costs of that magnitude would probably be a redundant design having greater payload weight, power, and data rate capabilities. *Because of the potential value of such a spacecraft it seemed highly desirable that an upgraded AEM having many of the above characteristics be designed and evaluated for use in the Air Force's Space Test Program.*

LARGE-DIAMETER SHUTTLE-LAUNCHED AEM (L-AEM)

Under NASA sponsorship, Boeing undertook a configuration and cost study for a 5 ft diameter AEM that would be designed for shuttle launch and would include the capabilities ascribed above to the upgraded AEM.[7] Using the same approach for comparing alternative procurement options that was used earlier, Table 11 presents the program costs for four procurement options including the L-AEM and compares them with the other options for the nominal case. It is shown that all of the procurement options that use the L-AEM are preferred over those made up of the three original spacecraft. The lowest-cost L-AEM option is about 15-20 percent less costly than the lowest-cost non-L-AEM option, and that assumes that the nonrecurring cost of the L-AEM would be paid for by the Air Force. If the L-AEM is developed by NASA, the L-AEM options are even more attractive.

Table 11 also shows the effect of higher nonrecurring costs for the L-AEM than that assumed in the nominal case. For this excursion, the AEM/STPSS option is also attractive for some conditions, but overall the L-AEM options are preferred.

Table 11

EFFECT OF THE L-AEM[a]

Case	No. of Payloads in Program	Max. No. of Payloads per Spacecraft	Program Cost ($ millions)							
			STPSS	MMS	AEM/STPSS	AEM/MMS	L-AEM	AEM/L-AEM	L-AEM/MMS	AEM/ L-AEM/MMS
Nominal	114	13	(160)	(162)	(157)	(156)	135	133	139	132
	114	6	(222)	(263)	(210)	(240)	186	181	187	186
	228	13	(244)	(247)	(244)	(240)	198	208	212	199
	228	6	(373)	(418)	(342)	(392)	306	297	(373)	323
Higher L-AEM nonrecurring cost	114	13	(160)	(162)	157	156	148	146	150	143
	114	6	(222)	(263)	210	(240)	199	195	200	197
	228	13	(244)	(247)	(244)	(240)	212	222	223	211
	228	6	(373)	(418)	342	(392)	320	311	(384)	335

[a]For a given row, program costs within 10 percent of the lowest value are not in parentheses.

Earlier it was shown that an upgraded AEM/MMS procurement option provided the lowest program cost. The upgraded AEM differs from the L-AEM in that it has the payload weight, power, and data rate limitations of the original AEM, while the L-AEM capabilities are greater in all of these areas. Table 12 compares the program costs for the four L-AEM options and the two upgraded AEM options. Again, the upgraded AEM/MMS procurement option is preferred but by less of a cost margin than before. This result occurs for the same reason as stated earlier (p. 18) except in this case the cheaper, upgraded AEM displaces the L-AEM rather than the STPSS. The limited capability of the upgraded AEM makes

Table 12

COMPARISON OF THE L-AEM AND UPGRADED AEM[a]

Case	No. of Payloads in Program	Max. No. of Payloads per Spacecraft	Program Cost ($ millions)					
			L-AEM	AEM/ L-AEM	L-AEM/ MMS	AEM/ L-AEM/ MMS	Upgraded- AEM/STPSS	Upgraded- AEM/MMS
Nominal	114	13	(135)	(133)	(139)	(132)	(148)	99
	114	6	(185)	(181)	(187)	(186)	(172)	146
	228	13	(198)	208)	(212)	(199)	(233)	175
	228	6	306	297	(373)	322	298	294
With AEM redundancy	114	13	(135)	(135)	(139)	(134)	(167)	113
	114	6	185	186	187	(196)	(209)	175
	228	13	198	217	212	217	(275)	(224)
	228	6	306	318	(373)	337	(363)	(369)

[a]For a given row, program costs within 10 percent of the lowest value are not in parentheses.

this a tenuous conclusion in view of the possibilities of growth in the payload power and weight requirements of the Space Test Program mission model; that growth could quickly decrease any program cost advantage that the upgraded AEM/MMS option might have.

Current Air Force requirements for new spacecraft include minimizing single-point failure modes. The L-AEM has a redundant design, while the AEM and upgraded AEM do not. Illustrated in Table 12 are the results of an excursion where it was assumed that whenever an AEM or upgraded AEM is included in an option, two spacecraft would be flown.* This would make the AEM and upgraded AEM more comparable to the L-AEM in terms of the redundancy. For the case of 114 payloads and 6 payloads per spacecraft, a number of the L-AEM options are within the lower ten percent cost category; for a mission model with 228 payloads, the L-AEM options are clearly preferred over the upgraded AEM/MMS option.

Considering that the program cost advantage indicated for the upgraded AEM/MMS option over the L-AEM options could be lost in either of the two ways mentioned above (that is, by growth in the power and/or weight requirements of the Air Force Space Test Program mission model, or by the spacecraft desigh requirements for minimizing single-point failure modes), *we conclude that the L-AEM spacecraft, or some very similar design, would provide a basis for minimizing the Air Force's Space Test Program costs.* The L-AEM could be used individually or in combination with the AEM and/or the MMS.

The procurement results for the nominal case that include the L-AEM are shown in Table 13. A comparison of these options shows that the L-AEM-P configuration comprises about 75 percent of the buy with the balance being shared by the AEM, L-AEM-BL and/or MMS; the L-AEM-S is never used in the nominal case.

The distribution of the program costs for the pure L-AEM option is shown in Fig. 3. The most significant factor is the large launch costs for WTR launches when the *NASA tariff* schedule is applied. The use of the *modified NASA tariff* schedule redresses this drastic cost imbalance.

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*This idea was suggested by Boeing as a way of achieving the desired level of redundancy without redesigning the entire spacecraft. Physically it is possible to have two AEM spacecraft side by side within the envelope of the L-AEM.

Table 13

PROCUREMENT RESULTS USING L-AEM

(Nominal case)

Spacecraft Type	Number of Spacecraft			
	L-AEM	AEM/L-AEM	L-AEM/MMS	AEM/L-AEM/MMS
AEM	--	1 / 3	--	1 / 4
L-AEM-S	--	--	--	--
L-AEM-BL	4 / 6	3 / 3	-- / 6	--
L-AEM-P	12 / 18	12 / 18	10 / 18	10 / 18
MMS	--	--	4 / --	3 / 2
Total	16 / 24	16 / 24	14 / 24	14 / 24

NOTE: 13 / 6 maximum number of payloads/spacecraft.

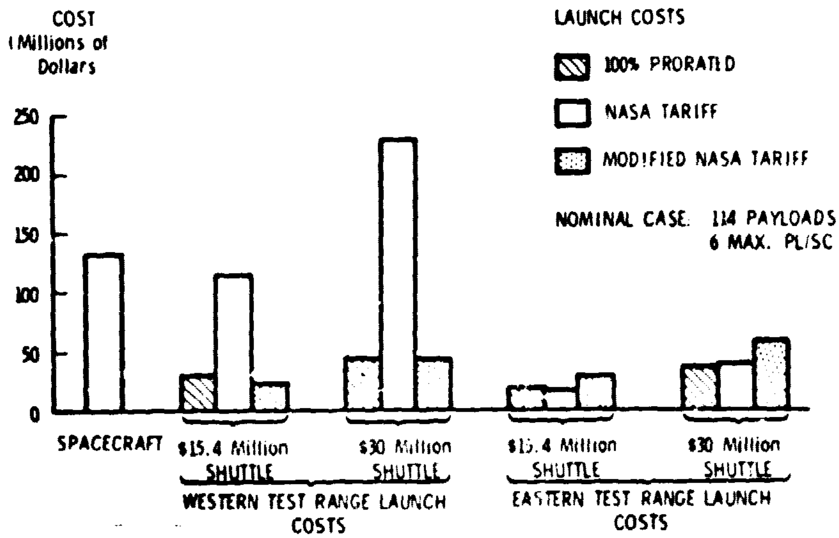

Fig. 3—Distribution of program costs
(L-AEM option)

VI. CONCLUSIONS

Four major conclusions have been drawn from this study. *First, program cost does not provide a basis for choosing among the AEM, STPSS, and MMS spacecraft given their present designs.* Only when the modified NASA tariff schedule was used for allocating the shuttle launch cost did the STPSS options become preferred; with the uncertainty in the appropriateness of this tariff schedule, this case does not provide sufficient basis for recommending development of the STPSS.

Second, the availability of the L-AEM spacecraft, or some very similar design, would provide a basis for minimizing the cost of the Air Force's Space Test Program. The L-AEM could be used individually or in combination with the AEM and/or MMS as the missions require. The *upgraded AEM* options, although having program costs similar to the L-AEM options, provide less capability for handling growth in the Air Force Space Test Program mission model.

Third, the program costs are very sensitive to the maximum number of payloads flown per spacecraft. An increase from 6 to 13 in the maximum number of payloads per spacecraft would result in about 30 percent lower program cost; the major portion of this savings occurred by increasing the maximum number of payloads to 10. An analysis of this potential should be undertaken.

Fourth, launch costs, as determined by a variety of formulas, generally did not affect the preferred procurement option, although they substantially change the total program costs. The modified NASA shuttle tariff rate structure considered during the second phase of the study corrects the drastic cost imbalance that the original NASA tariff imposed on Air Force launches from the Western Test Range. Secondary payload status, an underlying assumption for the Air Force's Space Test Program, is not yet accounted for in any of the NASA tariff rate structures for the shuttle. Incorporation of the concept of a secondary payload could reduce the total program costs presented in this report, but it probably would not affect the spacecraft procurement decision.

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