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R-2619-RC
May 1980

Standard Spacecraft Procurement Analysis: A Case Study in NASA-DoD Coordination in Space Programs

Elwyn D. Harris

(R-2619-RC) STANDARD SPACECRAFT PROCUREMENT ANALYSIS: A CASE STUDY IN NASA-DOD COORDINATION IN SPACE PROGRAMS Ph.D. Thesis - Rand Graduate Inst. (National Aeronautics and Space Administration) 224 p   N81-14915
G3/81   Unclas 11239

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PREFACE

This report was prepared as a dissertation in partial fulfillment of the requirements of the doctoral degree in policy analysis at The Rand Graduate Institute. The faculty committee that supervised and approved the dissertation consisted of Bruce Goeller, Chairman, R.V.L. Cooper, and L. V. Scifers.

The repo ` includes comparative program costs associated with the 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 original study was completed under the joint sponsorship of the National Aeronautics and Space Administration and the Department of Defense). 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 of which were briefed to a joint NASA/Air Force audience in July 1976. The *second* phase considered additional procurement options using an upgraded version of an existing NASA design; this phase was presented to the clients in November 1976.

For this report, the results of the two-phase study are cast in the broader policy context of NASA-DoD cooperation in space activities by examining the experience gained by NASA and DoD during the 1958-1965 time period. Also analyzed are the organizational interactions surrounding the case study, as well as the problems and prospects of applying the lessons learned from the NASA-DoD cooperation experience to other situations.

The study results should be useful to NASA and Air Force space program offices involved in operational or experimental missions and to those concerned with the NASA-DoD coordination and cooperation in space activities. Because the impact of various tariff rates is examined, the results should also be of interest to those concerned with determining the shuttle tariff rate structure or with shuttle operations.

Although the study examines procurement options affecting both NASA and Air Force programs, the results should not be interpreted

as representing the official views or policies of NASA or the Air Force. Preparation of this report was supported by The Rand Corporation from its own funds.

SUMMARY AND CONCLUSIONS

This dissertation presents a case study that analyzes some of the procurement considerations involved in selecting an unmanned standard spacecraft for the Air Force Space Test Program missions to be flown during the space shuttle's initial ten-year operational period.* The selection process included a comparative evaluation of a number of procurement options derived from four candidate Air Force and National Aeronautics and Space Administration (NASA) standard spacecraft designs. The case study is placed within the broader policy context of the Congressional requirement, embodied in the National Aeronautics and Space Act of 1958, that "close cooperation among federal agencies [will be maintained] to avoid unnecessary duplication of effort, facilities, and equipment."

The case study examined in this dissertation was accomplished in two phases. During the first phase, the Space Test Program Standard Satellite (STPSS)--a design proposed by the Air Force--and two NASA candidates--the Applications Explorer Mission spacecraft (AEM) and the Multimission Modular Spacecraft (MMS)--were considered. During the second phase, a fourth candidate was introduced--a larger, more capable AEM (L-AEM), configured by the Boeing Company under NASA sponsorship to meet the specifications jointly agreed upon by NASA and the Air Force. Total program costs for a variety of procurement options, each of which is capable of performing all of the Air Force Space Test Program missions during the 1980-1990 time period, were used as the principal measure for distinguishing among procurement options.

Four major conclusions have been drawn from this case study. *First*, program cost does not provide a basis for choosing among the AEM, STPSS, and MMS spacecraft, given their present designs. *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 Space Test Program. The L-AEM could be used individually or in combination with the AEM or MMS as

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*See footnotes, pp. 2 and 5.

the missions required. *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. *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 case study, corrects the drastic cost imbalance that the original NASA tariff imposed on DoD launches from the Western Test Range.*

Some observations have been made concerning organizational features of NASA-DoD cooperation during the case study. The study was funded by NASA and conducted with the full cooperation of both NASA and the Air Force; it was done with the approval and acknowledgment of the Aeronautics and Astronautics Coordination Board. Because of a variety of motivational factors, the cooperation and support of the two NASA program offices and the Air Force Space Test Program Office involved in the study were exemplary.

Between the first and second phases of the study, the Air Force initiated a memorandum of agreement that: (1) supported the development by NASA of a Small Multimission Modular Spacecraft (SMMS) that would meet the Air Force requirements, (2) agreed to procure the SMMS, and (3) offered advance payment of $1 million to accelerate the SMMS development schedule. NASA declined to undertake the SMMS until it could be justified by NASA missions and suggested that the Air Force procure the MMS (in accordance with the first phase results of this study), but declined to support the upgrading of the AEM.**

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*For a discussion of the economic framework for determining the price of a space shuttle launch, see C. Wolf et al., *Pricing and Recoupment Policies for Commercially Useful Technology Resulting from NASA Programs*, The Rand Corporation, R-1671-NASA, January 1975.

**The results of the first phase of this case study showed that the preferred procurement option consisted of a combination of the MMS and an upgraded AEM. Without the upgraded AEM, the Air Force faced a $100 million higher program cost.

The introduction of the L-AEM spacecraft during the second phase of the study led to a superior procurement option that did not necessarily include the MMS or AEM. The L-AEM spacecraft is very similar to both the Air Force STPSS and the proposed SMMS. Since NASA had declined to proceed with the SMMS development in response to the Air Force-proposed memorandum of agreement, the results of the second phase of this case study provided the Air Force Space Test Program Office with justification for developing its own standard spacecraft, i.e., the L-AEM. At the present time, the Air Force is requesting bids from industry for designs of the spacecraft to support its next two missions. Whether or not the resulting spacecraft designs will represent the beginning of an Air Force standard spacecraft design must await the outcome of a number of future Air Force decisions. In any event, it appears that the possibility of procuring NASA spacecraft for the Air Force Space Test Program will be determined case by case.

Finally, some observations are presented concerning the prospects and problems of applying the NASA-DoD cooperation experience to other situations. This is done in recognition of the increasing interest in interdepartmental and international cooperation as a means of either achieving economic efficiency or of undertaking projects that one agency or country cannot support on its own. The two principal underlying factors that were essential to the ultimate success of the NASA-DoD cooperation experience are: (1) a common subset of missions and resources--manpower, data, spacecraft, launch vehicles, facilities, etc.--where cooperation was possible and desirable, and (2) a common organizational responsibility to the Executive Branch (the President and the Bureau of the Budget), which in turn was responsible to Congress. But even given these two principal factors, it took four to five years before successful cooperation and the formal organizational machinery became a reality for NASA and DoD. The principal impediment to establishing coordination earlier was the open disagreement between President Eisenhower and the Congress over the need for NASA-DoD coordination and their respective space missions. However, during the Kennedy Administration, cooperation between NASA-DoD became institutionalized after the Soviets' first manned orbital flight.

ACKNOWLEDGMENTS

I gratefully acknowledge the guidance, direction, and support from my dissertation committee--B. Goeller (chairman), R. Cooper, and L. V. Scifers--during the preparation of this manuscript. In addition, I received considerable technical and administrative support in the case study by my Rand colleagues--M. M. Balaban, E. Bedrosian, P. A. CoNine, S. H. Dole, D. Dreyfuss, N. E. Feldman, T. B. Garber, W. D. Gosch, J. R. Hiland, L. N. Rowell, and G. A. Sears. Individual contributions are identified on the opening pages of Appendixes A through H. Also, I want to thank F. Cepollina, S. Smith, C. White, and R. E. Davis (NASA Goddard Space Flight Center), Majors C. F. Jund and W. Nieman (SAMSO), F. Wang (Aerospace Corporation), A. Fenwick and L. McMurtrey (Boeing), and J. Taber (TRW) for making data available in a timely manner and for their interaction throughout the case study. Their cooperation contributed greatly to the completion of the study.

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ACRONYMS

AACB	-	Aeronautics and Astronautics Coordinating Board
ABMA	-	Army Ballistic Missile Agency
ACS	-	Attitude Control and Stabilization
AEM	-	Applications Explorer Mission
AFSCF	-	Air Force Satellite Control Facility
AM	-	Amplitude Modulation
ARPA	-	Advanced Research Projects Agency
BoB	-	Bureau of the Budget
BOL	-	Beginning of Life
C&DH	-	Communications and Data Handling
CMLC	-	Civilian-Military Liaison Committee
CMOS/RAM	-	Complementary Metal Oxide Substrate/Random Access Memory
DDR&E	-	Director of Defense, Research and Engineering
EOL	-	End of Life
ETR	-	Eastern Test Range
FCM	-	Frequency Control Modulation
FM	-	Frequency Modulation
FRUSA	-	Flexible Roll Up Solar Array
FSK	-	Frequency-Shift Keying
FSS	-	Flight Support System
GFE	-	Government Furnished Equipment
GN_2	-	Cold Gas (gaseous nitrogen)
GSE	-	Ground Support Equipment
GSFC	-	Goddard Space Flight Center
HCMM	-	Heat Capacity Mapping Mission
HEAO	-	High Energy Astronomical Observatory
ICBM	-	Intercontinental Ballistic Missile
ICSU	-	International Council of Scientific Unions
IGY	-	International Geophysical Year
IRBM	-	Intermediate Range Ballistic Missile
IUE	-	International Ultraviolet Explorer
IUS	-	Interim Upper Stage

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L-AEM	-	Large Diameter Applications Explorer Mission
L-AEM-BL	-	Baseline Configuration of L-AEM
L-AEM-P	-	Precision Configuration of L-AEM
L-AEM-S	-	Spinning Configuration of L-AEM
LHCP	-	Left-Hand Circular Polarization
MMS	-	Multimission Modular Spacecraft
MOA	-	Memorandum of Agreement
MODS	-	Manned Orbital Development System
MOL	-	Manned Orbiting Laboratory
N_2H_4	-	Hydrazine
NACA	-	National Advisory Committee for Aeronautics
NASA	-	National Aeronautics and Space Administration
NASC	-	National Aeronautics and Space Council
NiCd	-	Nickel Cadmium
PCM	-	Pulse Code Modulation
PMP	-	Premodulation Processor
PROM	-	Programmable Read Only Memory
PRU	-	Power Regulation Unit
PSK	-	Phase-Shift Keying
RCS	-	Reaction Control System
RFP	-	Request for Proposal
RHCP	-	Right-Hand Circular Polarization
SAGE	-	Stratospheric Aerosol Gaseous Experiment
SAMSO	-	Space and Missile Systems Organization
SGLS	-	Space Ground Link System
SIRE	-	Solar Infrared Experiment
SMM	-	Solar Maximum Mission
SMMS	-	Small Multimission Modular Spacecraft
SPS	-	Space Propulsion System
SRU	-	Service Rendered Units
STACC	-	Standard Telemetry and Command Components
STDN	-	Space Tracking and Data Acquisition Network
STP	-	Space Test Program
STPSS	-	Space Test Program Standard Satellite
STPSS-LC	-	Low Cost Configuration of STPSS

STPSS-P	-	Precision Configuration of STPSS
STPSS-S	-	Spinning Configuration of STPSS
STS	-	Space Transportation System
TBD	-	To Be Determined
TDRSS	-	Tracking and Data Relay Satellite System
TRW	-	Thompson Ramo Woolridge
VHF	-	Very High Frequency
WTR	-	Western Test Range

I. INTRODUCTION

The National Aeronautics and Space Act, enacted on July 29, 1958, requires that NASA and DoD "avoid unnecessary duplication of effort, facilities, and equipment" in performing their portions of the U.S. space program. Although the Congressional justification for this requirement was to minimize expenditures on duplicative space-related activities, the requirement has created other kinds of problems. It has compelled NASA, DoD, the Executive Branch, and Congress to deal with a wide variety of policy problems related to the establishment and maintenance of two separate organizations for carrying out the civilian and military portions of the U.S. space program. Many of these policy problems associated with NASA and DoD interagency cooperation have varied throughout the nineteen-year history of NASA. Some have involved role and mission issues, such as the delineation of NASA and DoD unique mission areas; the identification of common requirements for services, data, and space equipment; and the determination of responsibilities for joint programs. Others have been concerned with the development of organizational arrangements for interagency cooperation.

As the U.S. space program matured within the context of a changing political and economic environment, many such policy problems kept recurring. The expected advent of the space shuttle early in the 1980s as the standard launch vehicle for both NASA and DoD payloads, for example, has again raised a NASA-DoD roles and missions policy problem. In this instance, there are two parts to this issue: the shuttle's suitability (i.e., responsiveness and survivability) for launching operational DoD payloads and the separation of civilian and military space programs. The latter problem centers on the use of a NASA launch vehicle for placing classified military payloads into orbit. The space shuttle era also brought with it a renewed interest in *standard spacecraft designs* that can be used for a variety of mission payloads. Use of this type of spacecraft with the space shuttle offers operational cost savings over the use of specialized spacecraft because of the standardized interface between the spacecraft and the launch vehicle. However, the use of standardized spacecraft necessitates an assessment of the commonality of NASA and DoD mission and spacecraft needs in keeping with the requirement that they cooperate to minimize duplication.

This dissertation examines the issues surrounding NASA-DoD cooperation for a specific case study--DoD use of NASA standard spacecraft. Using this case study, the primary purpose of this dissertation is to examine some of the procurement considerations involved in an Air Force decision to develop its own standard spacecraft or to use NASA standard spacecraft designs.* In addition, this dissertation (1) places the above decision within the broader policy context of the overall evolution of NASA-DoD cooperation in space programs; (2) analyzes the NASA-DoD organization interactions surrounding the case study; and (3) discusses some of the problems and prospects of applying the NASA-DoD experience with interagency cooperation to other situations where cooperation may be an important ingredient.

The policy context of this dissertation is the development of the NASA-DoD interagency cooperation that has taken place during the nineteen-year history of NASA. A review of this cooperative experience helps reveal the organizational problems that arose from NASA's conflicting goals of both competing with and cooperating with DoD, an organization that had similar objectives and, in some instances, greater capabilities. This review also illustrates the sensitivity of successful organizational arrangements for interagency cooperation to (1) the political environment, (2) the intentions of the agencies and their decisionmakers, and (3) the availability of adequate time for organizational

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*This analysis examines only some of the economic considerations concerned with the Air Force's standard spacecraft procurement decision. It deals mainly with the direct cost and benefits associated with the development, procurement, and operation of the spacecraft needed to accomplish the Space Test Program missions. A number of assumptions limiting the extent of the economic analysis are made to keep the study context, as defined by the client's (Air Force's Space Test Program Office) organizational responsibility, the study budget, the status of related studies, and the expected impact of the spacecraft procurement decisions on other areas, within practical limits. These assumptions are summarized in the footnote, p. 5.

development. Finally, the policy context provides not only the underlying rationale for the case study examined in this dissertation, but also the basis for understanding the organizational interactions surrounding the case study.

The case study used in this dissertation examines the relative costs of using one or more of several possible unmanned standard spacecraft for Air Force Space Test Program* missions during the initial ten-year operational period of the space shuttle. During the first phase of this case study, 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)--were considered. After completion of the initial study, 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 case study, and procurement options derived using all four spacecraft are compared for the Space Test Program missions. The case 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 procured specialized spacecraft as required for specific missions, which generally meant designing and developing a new spacecraft 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.

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*The Air Force Space Test Program, a triservice activity under the management of the U.S. Air Force, is discussed in detail in Sec. III. It is responsible for providing the spacecraft and launch vehicle, for placing the spacecraft in orbit, and for collecting the required data from space experiments derived from the military service and other operating agencies.

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 is used as the baseline configuration for this case study. Associated studies of other aspects of the STPSS operation and design were also available.[(2-4)]

Concurrent with the Air Force activity, for the past six years NASA has 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 retrieval and on-orbit servicing that would be possible with a space shuttle, resulting in design of a spacecraft more capable than 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 more advanced 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 in the spacecraft design. Although the AEM is designed specifically for two missions, it has a modular design 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. To answer the question

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*These cost savings are in addition to those realized because of the standardized interface between the space shuttle and the standard spacecraft mentioned earlier.

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 for alternative procurement options.* This dissertation describes such an analysis and places it within the broader policy context of the evolution of NASA-DoD cooperation in space activities since the Space Act of 1958 established NASA. Section II

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*The following assumptions are used in this analysis:

(1) A constant performance comparison is made of alternative spacecraft procurement options, i.e., an inelastic demand curve for Space Test Program payloads is assumed over the relevant range of total program costs. Although this was one of the client's ground rules for the case study (Sec. III), a sensitivity analysis is made varying the number of payloads included in the mission model to determine the effect on selection of the preferred procurement option.

(2) A mission model consisting of only Space Test Program payloads is used, i.e., no NASA payloads are included. As indicated in Sec. III, this was a client's ground rule, but insofar at the overall performance requirements as derived from the Space Test Program payloads are representative of NASA performance requirements, the above sensitivity analysis illustrates the effect of including NASA payloads.

(3) Only standard spacecraft launched by the space shuttle are included in the study, i.e., zero cross price elasticity is assumed for both spacecraft and launch vehicle. This ground rule stems from the U.S. policy to phase out expendable boosters once the space shuttle is operational and the client's interest in evaluating only standard spacecraft designs for use with the space shuttle (Sec. III).

(4) No estimate is made of the employment impact in the geographical location where the standard spacecraft would be manufactured. This is ignored because the manufacturers of most of the spacecraft under consideration in this case study have not been selected.

(5) A fixed price is assumed for an Air Force-dedicated space shuttle launch over the relevant number of launches. This assumption is based on the preliminary output provided by NASA from their parallel study to establish the price of a space shuttle launch for various users: U.S. commercial firms, foreign users, NASA, and other U.S. government agencies. As discussed in Secs. III and IV, a sensitivity analysis is used to evaluate the effect of the price of a dedicated shuttle launch on the selection of the preferred procurement option.

(6) A fixed tariff formula is used to allocate the cost of a dedicated shuttle launch to Air Force Space Test Program missions flown in proportion to the services rendered, e.g., percentage of total shuttle payload weight-capacity used. A parallel NASA study evaluating various tariff formulas for allocating the cost of a shuttle launch to users of partial shuttle capacity (weight or volume) provided inputs for a sensitivity analysis to evaluate the effect of the various tariff formulas on the selection of a preferred spacecraft procurement option. (See Secs. III and IV.)

traces the development of NASA-DoD cooperation in the U.S. space program from the establishment of the Eisenhower space policies through the mid-1960s. It deals with the creation of the National Aeronautics and Space Act, the organizational arrangements to ensure coordination between NASA and DoD, and the resulting NASA-DoD relationship as it evolved over the years. Section III presents the case study objectives and guidelines, describes the spacecraft configurations and the necessary modifications needed for use by the Air Force for the Space Test Program missions, analyzes the mission model, and presents the estimates for the spacecraft nonrecurring and recurring costs, as well as the costs of the various launch options. Section IV summarizes and compares the program costs of alternative spacecraft procurement options, the results of the sensitivity analyses conducted, and the conclusions of the case study. Section V presents a discussion of the organizational interactions between NASA and DoD during the case study. Section VI briefly examines some of the prospects and problems of applying the NASA-DoD cooperation experience to other situations where interagency or international cooperation may be an important ingredient.

Separate appendixes briefly discuss the spacecraft and program cost analyses, and the technical assessments of the relative state of the art of the major spacecraft subsystems in the AEM, STPSS, and MMS. Also included is some correspondence about NASA and DoD joint participation in providing a standard spacecraft to satisfy the Air Force Space Test Program Office requirements.

II. U.S. SPACE PROGRAM: DEVELOPMENT OF NASA-DOD COOPERATION IN SPACE

In this section, the evolution of NASA-DoD cooperation in the U.S. space program will be traced from the pre-Sputnik era through the mid-1960s. First, factors that may have influenced the passage of the National Aeronautics and Space Act will be reviewed. These include the role that the DoD played in Project Vanguard and the ICBM program, the impact of the Soviets' launch of Sputnik, and the expected decline in importance of the manned bomber for the Air Force. These factors will be cast within the context of the Eisenhower space policy. Next, the main features of the National Aeronautics and Space Act dealing with NASA-DoD relationships will be presented along with some of the background organizational behavior of leading power groups that attempted to influence legislation. Following this, the formal and informal organizational arrangements that were made to ensure coordination of the NASA and DoD space programs will be outlined. Finally, the NASA-DoD relationships during the early years of the national space program will be discussed.

EISENHOWER SPACE POLICIES

During the early 1950s, the problem of distinguishing between peaceful and military uses of outer space was not nearly as complex or important as it became later in the decade, with the mutual and simultaneous requirements of civilians and the military for improving communications, weather predictions, navigation, and the mapping and scientific study of the surfaces of the earth. In 1951, the International Council of Scientific Unions (ICSU), a nongovernmental organization, appointed the Comité Special de l'Année Geophysique International to take charge of the worldwide cooperative effort that resulted in the International Geophysical Year (IGY). During the IGY, individual countries were invited to cooperate in carrying out space-related research with international dissemination of the results. In February 1953, the United States organized the National Committee for the International Geophysical Year, which proposed to launch a peaceful scientific satellite into orbit during the IGY.[6] In approving this project in 1955, President Eisenhower first articulated what was to become the basic policy for the U.S. space program, i.e., that it is essential to maintain a clear separation between civilian and military space-related activities.(7)

All three military services proposed satellite programs for the IGY; these were evaluated by the DoD committee called the Committee on Special Capabilities, chaired by Dr. Homer J. Stewart. The Air Force proposal assumed the use of the Atlas missile, the Army's assumed use of the Redstone rocket with clustered Loki solid propellant upper stages, and the Navy's assumed use of the Viking research rocket with the Aerobee second stage. The Navy's proposal was accepted, as it did not interfere with the top priority ballistic missile programs of the Army and Air Force. Thus began the Vanguard satellite project. U.S. military achievements in the development of the ballistic missile just before the Vanguard decision were not at all spectacular.* For example, the Atlas had two unsuccessful flights, four of the five Thor flights were unsuccessful, and only two of the four Jupiter flights had been successful.(8)

The orbiting of Sputnik I on October 4, 1957, was a dramatic technical achievement that brought immediate repercussions. It was clear that the Soviets had made no distinction between "military" and "scientific" projects. The four tons of total payload of Sputnik I (including 184 lb of instruments) contrasted drastically with the U.S. plans for the Vanguard satellite with a total weight of only 3 lb in orbit. The Soviet success revealed that their competence in rocket technology was much greater than generally believed. It also tended to confirm the Soviet claim of August 1957 that they had the capability to build an intercontinental ballistic missile, and thus the Soviets were a much more immediate threat to U.S. national security than had generally been

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*Before the Vanguard decision, U.S. interest in ballistic missiles as a means of delivering thermonuclear warheads peaked when it was demonstrated that lightweight warheads could be developed. Significant funds began to flow into the ballistic missile programs in 1955. All of the services were involved: The Air Force was developing the Atlas and Titan ICBMs and the Thor IRBM; the Army, the Redstone and Jupiter IRBMs; and the Navy, the Polaris IRBM.

thought.[8] The launching of Sputnik contributed further to the declining credibility of the massive retaliation defensive posture of the U.S. "New Look" strategy of 1953. It was evident that "massive retaliation" had become a two-way street.[9]

The prestige that the Soviets gained from their spectacular Sputnik success helped magnify their worldwide image. The fact that the Soviet Union was first in space tarnished the world image of the United States as a technological leader. To make matters worse, before any significant U.S. actions were made public, Sputnik II (weighing over 11,000 lb with 1120 lb of scientific instruments and carrying a dog) was orbited (November 5, 1957).[7]

For the U.S. military, and especially the Air Force, the successful launches of Sputniks I and II introduced considerable uncertainty about the continued viability of the manned jet bomber as a global nuclear weapon delivery system. This concern led many in the military to emphasize and champion the military space program and especially the potential of manned space systems. To support the Air Force's continued role, they argued in terms of a continuum of space that included everything above the earth.

The United States achieved its first space success by drawing directly upon military resources. The Army Ballistic Missile Agency (ABMA), using a Jupiter C booster, placed Explorer I into orbit on January 31, 1958, 84 days after the Army project was approved in the wake of Sputnik. Subsequently, the Vanguard project was successfully completed within its original time schedule and made significant scientific and technological contributions;* and the Air Force launched Project Score on December 18, 1958. The fact that all these projects were carried out reflects the dramatic impact the Soviets' Sputnik I had on the U.S. satellite program. Fault, therefore, cannot be attributed to the Vanguard system or its developers but to the decisions, priorities, and organizational structures that represented the meager American space effort before Sputnik.[10]

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*After two successful test shots out of four, the first Vanguard satellite was orbited on March 17, 1958, 5-1/2 months after Sputnik and 1-1/2 months after Explorer I. Observation of the orbit of Vanguard I resulted in the discovery that the earth was somewhat pear-shaped.

> The fundamental effect of the concern generated by the Russian success was recognition within the U.S. Government that the entire spectrum of space technology had to be given the same high priority afforded the ballistic missile program. A high priority space program in turn called for strong, new government organizations.(11)

Although President Eisenhower allowed the military to assume a larger role in launching the first U.S. satellite than that originally planned, and never apparently really grasped the international political significance of the Soviet technological successes, he steadfastly held to the policy that the U.S. space program should be scientific, peaceful, and under civilian control. President Eisenhower's view was that space provided no military significance and that it was important to maintain a clear separation Furthermore, he was determined not to disturb the balance between military expenditures and a healthy nondefense economy, which meant that the space program would not be fully supported.(9) This position was maintained even in the face of the negative recommendations of the Gaither Committee that were published before the launching of Sputnik. The Gaither Committee had been appointed by Eisenhower in the spring of 1957 to evaluate proposals for a $40 billion program of civil defense shelters. The committee broadened its charter to produce an overall assessment of the state of national defense. The committee concluded that "...if the United States did not change its policies, it was in danger of becoming a second-class power ...," a conclusion that President Eisenhower chose to ignore until forced to consider it by the Sputnik launches.(12)

Although attempts by Eisenhower to contain the political losses* because of Sputnik were strongly motivated by his personal judgment of its limited significance, it is also likely that:

> Eisenhower's position resulted from careful deliberation--Sputnik I was convincing evidence of the Soviet breakthrough in long-range missile power. If Eisenhower

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*For example, the President told an October 9, 1957, press conference that "The Russians have only put one small ball in the air." Repeatedly, the President and his associates asserted that the United States would not become involved in a "space race" with the Soviets.

> had shown great alarm or acknowledged a serious reduction of American prestige, he would have tended to undermine confidence at home in the security of the country and belief abroad in its power, and this would have been disconcerting to friends and allies. Moreover, Eisenhower would have made himself even more vulnerable to charges that he and his administration were at fault for not having pressed the development of missile and space capabilities sooner and more vigorously.(7)

Within this context, the Eisenhower Administration, Congress, and the DoD began to organize to redress the U.S.-Soviet space imbalance. A lengthy recounting of the specific decisions and actions is outside the scope of this study but are recounted elsewhere in great detail.(7,8,13) In the next subsection, many of the events that directly affected the formulation of the National Aeronautics and Space Act will be discussed. However, in considering the formulation of NASA, it should be recognized that perhaps the most important and lasting impact of the Eisenhower space policy was his insistence on separating civilian and military space efforts and on giving primary emphasis to civilian efforts. This decision later came under repeated and intense attacks from the military services, but Eisenhower was able to prevail in his view that the American space program should be conducted openly, not behind the cloud of military secrecy. The dissent sprang from a variety of expected sources: Congress, the space-oriented positions of the Army and Air Force, defense and aircraft contractors anxious to see an ambitious space program, and space-oriented professional societies and organizations.

THE NATIONAL AERONAUTICS AND SPACE ACT

In response to the obvious lead over the United States in space capabilities that the Soviet Sputnik launches had demonstrated, active Congressional investigations into the U.S. ballistic missile and space programs, DoD's rapidly expanding space program,* and pressure from the

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*The only attempt by the Eisenhower Administration to provide immediate direction to the U.S. space program after the Sputnik launches was the establishment of the Defense Advanced Research Projects Agency (ARPA), on February 12, 1958, for the purpose of providing coordination civilian scientific community, President Eisenhower, on March 5, 1958, approved a memorandum recommending the establishment of a space agency using the National Advisory Committee for Aeronautics (NACA) structure as the core. The memorandum declared that "...an aggressive space program will produce important civilian gains in general scientific knowledge and the protection of the international prestige of the U.S....," and the "...long-term organization for federal space programs ... should be under civilian control."(8) The memo acknowledged DoD's competence and leadership in space activities but recommended against DoD because of the desire for civilian emphasis and DoD's deep involvement in the missile programs. The memo indicated that relationships between NASA and DoD would have to be worked out.

Subsequently, the administration's draft legislation establishing NASA was submitted to Congress on April 2, 1958. This bill was drafted by the Bureau of the Budget (BoB) with assistance from the National Advisory Committee for Aeronautics and Dr. Killian's office.* The DoD was not brought into the picture until the end of March 1958, when the draft bill was sent to various agencies for comment.(7) The Eisenhower schedule for introducing this legislation was driven by his interest in getting it to Congress before the Easter recess, which left insufficient time for a thorough department review.(7) The administration described this draft legislation as a "...bill to provide for research into problems of flight within and outside the earth's atmosphere and

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and leadership not only for the U.S. antimissile missile research programs, but also for space projects already under way or envisioned in DoD. ARPA's mission, as prescribed by law, was to cut across the traditional levels of authority of the military services and to fund and manage outerspace projects. At the time ARPA was established, it was viewed by the administration as an emergency and temporary agency because of the anticipated Congressional resistance of setting up DoD as an operating agency for space programs.(6,11)

*One Eisenhower Administration reaction to Sputnik I was to grant American scientists increased access to the highest echelon of national policymaking. In the two weeks following Sputnik, more scientists met with the President than in the previous 10 months.(14) This access was institutionalized by Eisenhower's announcement in his November 7, 1957, speech that he was establishing the position of Special Assistant to the President for Science and Technology and appointed Dr. James R. Killian, president of Massachusetts Institute of Technology, as his first science advisor.

for other purposes."[15] It would conduct research in these fields through its own facilities or by contract, and would also perform military research required by the military departments. Interim scientific space projects that were under the direction of ARPA would be transferred to the new civilian space agency. A National Aeronautics and Space Board, consisting of members both outside the government and from government agencies, was to assist the President and the Director of NASA.

The most significant differences between the Space Act that was passed by Congress and signed into law by President Eisenhower on July 29, 1958, and the administration's draft legislation centered around the relationship between space and national defense and the issue of NASA-DoD coordination. The administration's proposals had an overwhelming civilian emphasis, whereas Congressional concern following Sputnik was largely in the area of military security.[15] To reconcile these differences, changes in the Space Act, specifically pertaining to the Statement of National Policy and Coordination Machinery, were made.

Statement of National Policy

The dominant issue throughout the Congressional Committee hearings and deliberations was not so much overall policy determination as it was the specific problem of determining the civilian and military jurisdictions. The initial view of this issue as one of "civilian versus military control" soon proved to be a gross oversimplification and not a meaningful statement of the problem. Without exception, ultimate civilian control was supported by both military and civilian activities. However, concern was evident that the concentration on civilian space might hamper activities concerned with national defense; Congress was interested in avoiding this problem because the need for military preparedness in this field was obviously all too vital.[11]

There was considerable feeling that a sharp legislative line should not and could not be drawn. This view came largely from military officials who feared undue restrictions on space activities of the DoD. This view is exemplified by Secretary of the Army Wilbur Brucker:

> It is possible that the bill under consideration could be interpreted so as to restrict unduly the activities of the Department of Defense in the astronautics and space field. It is frequently difficult to determine as we embark on so vast and unknown an enterprise as space exploration just what facets of this exploration will have application to weapons systems and military operation. I do not believe it to be the intent of the administration or of the Congress to prohibit research in this area by the agencies of the DoD.(15)

> The legislative line should not be drawn too sharply between what the DoD and its agencies can do and what they cannot do in the field of space development. That is a matter which ought, in my opinion, to be dealt with administratively between the DoD and the NASA. It should also be clearly emphasized that the NASA, like the Atomic Energy Commission, is a part of the Executive Branch. It is imperative that the character of the NACA, an executive agent of which the NASA will be the successor, should be preserved. If the U.S. is to cope with the fast-changing conditions, and kaleidoscopic developments in the field of space, full discretion in the planning and operations of such an important agency should be left to the President.(15)

After all of the effort in attempting to clarify this jurisdictional problem, the Space Act declares that the policy of the United States is "...that activities in space should be devoted to peaceful purposes for the benefit of all mankind...," and sets forth the jurisdictions of NASA and the DoD as follows:

> The Congress declares that the general welfare and security of the United States require that adequate provision be made for aeronautical and space activities. The Congress further declares that such activities shall be the responsibility of, and shall be directed by, a civilian agency exercising control over aeronautical and space activities sponsored by the United States, except that activities peculiar to or primarily associated with the development of weapon systems, military operations, or the defense of the United States (including the research and development necessary to make effective provision for the defense of the United States) shall be the responsibility of, and shall be directed by, the Department of Defense;

> and that determination as to which agency has responsibility for and direction of any such activity shall be made by the President in conformity with section 201(e).*(15)

Having divided major space responsibilities between NASA and the Department of Defense, the Act provides for the most effective use of U.S. scientific and engineering resources and close cooperation among federal agencies "...to avoid unnecessary duplication of effort, facilities and equipment...." U.S. space activities are to be conducted so that they will materially contribute to the objective of "...making available to agencies directly concerned with national defense of discoveries that have military value or significance, and furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities of information as to discoveries which have value or significance to that agency...."

Coordination Machinery

The existence of a "grey area" in military and civilian interests and difficulty in demarcating jurisdictions made all the more necessary the establishment of machinery for resolving disputes. It has been noted that the administration bill not only failed to provide for overall policy determination, but also made no provision for either solving jurisdictional disputes or for coordination and cooperation between NASA and DoD.

The House and Senate committees dealt with the problem of coordination machinery in different ways; the Conference Committee reconciled these differences and called for the establishment of a nine-member National Aeronautics and Space Council (NASC). The function of the Council was to advise the President in their performance of the following duties: surveying aeronautical and space activities, developing a comprehensive program of such activities to be carried out by the U.S.

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*Section 201(e) refers to the functions of the National Aeronautics and Space Council, *National Aeronautics and Space Act of 1958*, Public Law 85-568 (72 Stat. 426; 42 U.S.C. 2451). The only significant change made in the draft legislation was a general "tightening" of the language concerning the space role of DoD.(8)

government, allocating responsibility for major aeronautical and space activities, providing for effective cooperation between NASA and DoD, and resolving differences arising among departments and agencies of the United States. These duties represented the primary means for carrying out the mandate to devise a comprehensive and integrated policy in this field.[16] (The draft legislation provided for a Space Board advising the NASA Director; the Space Act provided for a Space Council advising the President. The two provisions bear almost no resemblance to each other.)[17]

In the original wording of this provision, Congress intended that the appointment of the executive secretary of the NASC be mandatory, but because of White House pressure "shall" was changed to "may." Throughout the Eisenhower Administration no appointment was made and the Council never really functioned as Congress had intended. This was consistent with the administration position that there was no need for a coordinated national space policy because the civilian and military functions in space development are separate responsibilities requiring no coordinating body.[18]

The Congress also provided machinery for direct day-to-day military-civilian coordination by providing that a Civilian-Military Liaison Committee (CMLC) be established (Sec. 204). A chairman appointed by the President, together with at least one representative from DoD and each of the three services, matched by an equal number from NASA, would serve as a means by which NASA and DoD could "advise and consult with each other on all matters within their respective jurisdictions relating to aeronautical and space activities" and keep each other fully and currently informed with respect to such activities. If DoD or NASA could not come to an agreement on some matter, either agency head was explicitly authorized to refer the matter to the President for a final decision. (No provision for such a liaison committee was included in the draft legislation and the push for it came largely from the House of Representatives.)[8]

ORGANIZATIONAL ARRANGEMENTS

As mentioned previously, the Space Act required the formulation of two groups to facilitate both the formulation of the U.S. national space program and the coordination of DoD-NASA programs. These were the NASC and the CMLC. In addition to these two organizations, other organizations influenced the formulation of the DoD and NASA space programs and hence the degree of cooperation needed between the two agencies. These included the Bureau of the Budget and Congressional committees.

National Aeronautics and Space Council

The Space Act provided for the formulation of the Space Council. It was to consist both of statutory members (the President as Chairman, the Secretary of State, the Secretary of Defense, the Administrator of NASA, and the Chairman of the Atomic Energy Commission) and of not more than four others appointed by the President. Its formal purpose was to advise and assist the President, as he might request. President Eisenhower chose to make little use of the Space Council. He convened it only eight times; and he did not create a staff for it, allowing other agencies (NASA and the Office of the Special Assistant to the President for Science and Technology) to provide successive acting executive secretaries.(17) In January 1960, he recommended to Congress that the Space Council be abolished. Before this was done, the Kennedy Administration took office and revived the Space Council and appointed Vice President Johnson as its Chairman. The Space Council continues to exist for the purpose of advising the President concerning the U.S. space program.

Civilian-Military Liaison Committee

The Space Act also provided for the formation of the CMLC, consisting of representatives of NASA and DoD, plus a Chairman who was to be an independent third party. Congress, unfortunately, did not grant the Chairman or Committee any power; the Committee was bypassed with impunity. In an attempt to make the CMLC work, the part-time chairmanship was changed to a full-time position and President Eisenhower redefined its function to allow the CMLC to initiate actions involving NASA and DoD programs rather than dealing only with those problems brought by either NASA or DoD. These changes did not cure the organizational problem with the CMLC, and it ceased to operate.

Aeronautics and Astronautics Coordination Board

As it turned out, rather than submitting problems to the CMLC, informal arrangements between a number of different organizational levels within both NASA and DoD were used for day-to-day coordination. This informal organization was formalized by an administrative agreement in 1960 between NASA and DoD establishing the Aeronautics and Astronautics Coordinating Board (AACB). The agreement laid down the principle that liaison should be maintained "in the most direct manner possible" at the various bureaucratic levels. To do this, officials having the authority and responsibility for day-to-day decisions within their respective offices are assigned to the AACB. Initially, the Deputy Administrator of NASA and the Director of Defense Research and Engineering served as Co-Chairmen, but each side has come to delegate this responsibility.

The Board is supported by six panels dealing with the following specific areas of the space program: (1) manned spacecraft, (2) unmanned spacecraft, (3) launch vehicles, (4) spacecraft ground equipment, (5) supporting space research and technology, and (6) aeronautics. These panels and the Board itself serve as forums for the exchange of information and for the discussion and resolution of problems. Much of the preparation of the written formal agreements between NASA and DoD concerning a variety of subjects, e.g., launch vehicles, were the responsibility of the AACB. This Board has been effective primarily because it is in the self-interest of both NASA and DoD to settle issues between themselves, especially if issues fall totally within their jurisdictions. If they fail to reach a settlement, the result could be worse for both, because of the uncertainty about the view of the third party that would be drawn into the decision.

Congressional Committees

The initial select committees established by the Senate and the House for creating legislation for the Space Act have been replaced by permanent standing committees. In the Senate, the *Committee on Aeronautical and Space Sciences* was formed on July 24, 1958. All proposed legislation, messages, petitions, memorials, and other matters related to the following subjects are to be referred to this Committee:

1. Aeronautics and space activities, as that term is defined in the National Aeronautics and Space Act of 1958, except those peculiar to, or primarily associated with, the development of weapons systems or military operation.
2. Matters relating generally to the scientific aspects of such aeronautical and space activities, except those peculiar to, or primarily associated with, the development of weapons systems or military operations.
3. National Aeronautics and Space Administration.

In addition, the Committee was given jurisdiction to survey and review the aeronautical and space activities--including activities peculiar to, or primarily associated with, the development of weapons systems or military operations[19]--of all agencies of the United States and to prepare studies and reports of such activities.

In the House, the *Committee on Science and Astronautics* was established in 1958. The jurisdiction of this Committee was delegated to the following five major subcommittees:

1. Aeronautics and Space Technology--deals with legislation and other matters relating to the Office of Aeronautics and Space Technology and the Office of Tracking and Data Acquisition.
2. International Cooperation in Science and Space--deals with all international agreements and activities of NASA, the National Science Foundation, and the National Bureau of Standards, including other international matters of astronautical research and development, outer space, and scientific research.
3. Manned Space Flight--deals with legislation and other matters relating to the Office of Manned Space Flight.

4. Science, Research and Development--deals with legislation and other matters relating to the National Science Foundation, National Bureau of Standards, and scientific research and development.
5. Space Science and Applications--deals with legislation and other matters relating to the Office of Space Science and the Office of Applications.[20]

In addition to the formation of these two standing committees to specifically handle legislation for the space program, the *Armed Services Committee* holds hearings relating to military aspects of the space program. Also, the *Committee on Government Operations* of the House has taken particular interest in the civilian-military roles and relationships in carrying out the U.S. space program.[11,21]

Bureau of the Budget

Normally, the military space program is in competition with all the other military programs for funds. This competition has tended to keep the military space program realistic relative to DoD's other priority requirements. NASA, however, because it is strictly associated with space, generally does not have to subject its program to such severe competition for agency funds. The BoB regularly judges the recommendations made by the various departments and agencies. For NASA, convincing the BoB is where the battle begins for its space program appropriations, whereas for DoD, the competition occurs within the department as well as at the BoB because of the DoD's narrower range of ends and means. As a consequence, the military space programs are generally well defined and justified to survive the internal DoD review process.

NASA-DOD RELATIONSHIP

1958-1960

As noted earlier, the Eisenhower space policy was very conservative. It did not recognize the importance of the political implications of the continuing Soviet accomplishments in space. Because of the multiplicity of motivations underlying opposition to the Eisenhower space policy, his administration was able to withstand all challenges. Supporters of an aggressive, coordinated space program were not able to agree on the specific features of such a program. Rivalry between the Air Force and the Army, within DoD, and between the military services and NASA, helped to fragment the opposition. The administration's attempt to keep the space budget at a low level meant that the governmental space agencies were not able to win significant support from the industrial constituency, especially in comparison with the industrial support for the Air Force and Navy strategic missile programs.

The DoD had the initiative in space activities during the early part of this period, primarily because 90 percent of the U.S. space competency was based on military systems. While NASA was busy organizing itself and deciding on which projects to pursue, the DoD continued to support big projects with funds much larger than those available to the new agency. ARPA and Air Force work was in part related to missile activities, such as that involving solid rockets, launch facilities, and test ranges. Other work combined both space and missile activities, including satellite identification, antisatellite defense and the missile early warning satellite Midas. Beyond this, the list of 1958 military space projects was impressive: orbital gliders, new boosters, and satellites for reconnaissance, communications, weather forecasting, and navigation. In addition, manned spaceflight was considered to be a priority project for the DoD, with all three services vying for ARPA support.[11]

In March 1958, three weeks after the establishment of ARPA, that agency acknowledged that the "Air Force had a long-term development responsibility for manned spaceflight capability, with the primary objective of accomplishing satellite flight as soon as technology permits."[21] In the manned spaceflight area, the Air Force plan included not only earth-orbiting satellites, but also lunar circumnavigation and lunar-landing missions. Because of the urgency surrounding the Soviet Sputnik II launch, the manned earth-orbiting satellite project, "Man-in-Space-Soonest," had top priority. In addition to the Air Force project, there were two other manned military space systems seeking ARPA approval in the summer of 1958. The Army's proposal was put forward by Wernher Von Braun's team at the Redstone Arsenal. It had a faster time schedule than the Air Force "Soonest" program but involved only a suborbital flight. The Navy also proposed a manned satellite study called Manned Earth Reconnaissance I.[22]

Following the establishment of NASA, the DoD, ARPA, and NASA agreed upon divesting the DoD of many of the above-mentioned space-related projects, facilities, and personnel. By Executive Order, issued in December 1958, NASA acquired the Jet Propulsion Laboratory and the Air Force transferred to NASA its contract and funds to develop a 1.5 million lb thrust, single-chamber engine.* By these and other moves, NASA quickly gained competence in electronics, guidance, tracking, propulsion, and systems analysis. Through the years, NASA and DoD reached agreement on numerous cooperative efforts involving, for example, launch sites, tracking stations, and launch vehicle development.** At this level the cooperation was exemplary. From the outset, however, there were numerous projects in a gray area between military and civilian, including the very important man-in-space project. NASA and DoD initially attempted one solution to this problem by making the project a joint one. The Bureau of the Budget, however, frowned on jointly managed projects; consequently, this approach was dropped. By August 1958, the Eisenhower Administration clearly assigned NASA specific responsibility for the manned spaceflight mission, thereby cancelling the "Soonest" project and leaving the Air Force with Project Dyna-Soar as its only near-term manned-spaceflight opportunity.

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*NASA actually wanted part of the ABMA (Wernher Von Braun's team) transferred to give the agency an in-house capability for large rocket engine and booster development. This transfer was delayed until July 1, 1960, by DoD objections that the ABMA group was needed for Army missile development. To support this transfer, NASA and DoD endorsed a memorandum for President Eisenhower declaring "...there is, at present, no clear military requirement for superboosters, although there is a real possibility that the future will bring military weapon systems requirements...."[7]

**A list of 88 joint NASA-DoD agreements made during the 1958-1964 time period are presented in Appendix D of Ref. 11.

Subsequently, the Director of ARPA, Roy Johnson, implied that NASA would concentrate on scientific space explorations and DoD on military applications. Specifically, he said that the NASA manned-spaceflight program (Mercury) was a continuation of NASA projects like the X-series of aircraft, but that after early experiments, the military would do the follow-on work in near-earth space systems:[21] That is, NASA would *develop* the manned system and DoD would *operate* it. This was the DoD's new stance on the manned-spaceflight issue.

During this time period, there were two NASA policy problems that affected the NASA-DoD relationship. The first policy stemmed from the general guidelines for NASA's program as authorized by the Space Act. Not only was NASA concerned with defining its own role in the nation's space program, but there was evidence that Congress intended that NASA have a special role in formulating the space program for the nation as a whole. In a prepared statement, Dr. Keith Glennan said:[8]

> A most important duty placed on the President by the Space Act is to develop a comprehensive program of aeronautical and space activities to be conducted by agencies of the United States.
>
> Preparation of such a program for ultimate approval by the President has been delegated by him to NASA with assistance and cooperation of the Department of Defense.
>
> Very substantial progress has been made in developing national space programs...the national booster program--the national tracking and communication program--the national space science program.[23]

Eleven days later, Glennan retracted the statement that the President had "delegated" to him the responsibility for preparing the national space program. Rather, NASA had been asked "to initiate and bring together, with the assistance of DoD, a total program which would then be submitted to the President."[21] No such integrated space program ever emerged, partly because of the Eisenhower Administration view, supported by DoD, that NASA and DoD space activities should be treated separately, and not as a comprehensive national space program.

Another NASA policy problem that affected its relationship with DoD centered around the realization that the Soviet challenge was the most important factor shaping U.S. space policy. From NASA's point of view, it was absolutely essential that the American public realize that space superiority should not be confused with military superiority and that the U.S. space program should not be construed as the leading edge in the cold war. NASA felt that it must be free to move ahead on a vigorous course of action without having to worry about its every move being thought of in national security terms.(8) The DoD and much of Congress, however, continued to view the U.S. space program in national security terms, especially when the Soviets continued to accomplish spectacular space feats* while the United States was slowly progressing with a variety of earth-orbiting satellite programs.**

During this period, the machinery set up in the Space Act for coordination between the DoD and NASA fell into disuse. After two years, the *Space Council* showed little sign of life. No full-time staff or Executive Secretary were appointed by the Eisenhower Administration, despite provisions made for them in the Space Act. As mentioned above, the comprehensive, integrated space program for the United States, also called for by the Space Act, was not forthcoming. The operation of the *Civilian-Military Liaison Committee* was affected by delays in appointing its membership, some of whom were not directly associated with the management of space projects. In July 1959, President Eisenhower revised the CMLC charter to allow it to take the initiative in dealing with jurisdictional differences between NASA and DoD rather than waiting

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*The spectacular Soviet achievements in space continued after the original Sputnik launches. In the Lunik program, the Soviets first hit the moon on September 13, 1959, and then photographed the lunar far side on October 18, 1959. In August 1960, the Soviets succeeded in recovering a 5 ton satellite containing two dogs, which was obviously developed for eventual manned flight.(11)

**After Explorer and Vanguard, the United States program consisted of the orbiting of the Tiros weather satellite on April 1, 1959; the navigational satellite, Transit 1-B, on April 13; the Midas missile detection satellite on May 24; the passive communication satellite, Echo I, on August 12; and the communication satellite, Courier, on October 4. Tiros and Echo were NASA projects; Transit, Midas, and Courier were DoD projects.(11)

to be asked by one of the agencies. But this alteration did not correct the situation. The Chairman, Mr. W. M. Holaday, called the Committee "nothing more than a post office."(21)

On January 4, 1960, President Eisenhower asked Congress to enact amendments to the Space Act "to clarify management responsibilities and to streamline organizational arrangements...."(8) Basically, the President declared that the Act should be purged of the concept that a comprehensive program for both civilian and military space interests needed to be prepared. Without the need for a comprehensive plan, the Space Council was not needed and he asked that it be abolished along with the Civilian-Military Liaison Committee.

In subsequent Congressional Hearings, Senator Johnson blocked the disestablishment of the Space Council in the Senate and it became known that an informal arrangement had evolved to coordinate DoD-NASA interactions that bypassed the CMLC. The Space Act was amended, institutionalizing this informal coordinating structure called the *Aeronautics and Astronautics Coordinating Board.**

In contrast with the CMLC, the substantive power of the AACB and its panels was based on the inherent power of the individual members. With top-level officials serving on the Board and panels, the number of unresolved problems was small; normal decisionmaking channels were to be used for resolving disagreements.

Perhaps the best evidence that the AACB system worked was that the responsibility for accomplishing interagency planning for the very important national launch vehicle program was entrusted to the AACB and this arrangement was confirmed by the new NASA-DoD leadership that came into being with the Kennedy Administration.(8)

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*The AACB was to be responsible for facilitating (1) the planning of NASA and DoD activities so as "to avoid undesirable duplication and ...achieve efficient utilization of available resources"; (2) "the coordination of activities in areas of common interest"; (3) the "identification of common problems"; and (4) the "exchange of information."(8) The AACB was to be supported by six subboard organizations called panels, each dealing with a different aspect of the space program--manned spaceflight, unmanned spacecraft, launch vehicles, spaceflight ground environment, supporting research and technology, and aeronautics.

1961-196?

At the start of 1961, the situation with regard to the future of any manned-spaceflight program, much less one intended to land man on the moon, was extremely gloomy. President Eisenhower and his advisors remained unconvinced that the country needed, or should invest in, an expensive manned-flight program for propaganda or military purposes. This conviction led them in late 1960 to refuse approval of NASA's Project Apollo.*

It was generally assumed, in view of the Kennedy-Johnson campaign statements, that space matters would receive greater emphasis in the new administration. There was no assurance that NASA's civilian-oriented programs would be expanded or even maintained. Many Kennedy statements stressed the military and national security aspects of space. The military services argued that the Soviets were concentrating on the development of a "near-earth" operational capability for military purposes, something which NASA's civilian-scientific program could not counter.

In the power vacuum following the November election, the military services not only asserted their point of view, but they also announced unilaterally a number of new starts. For example, on December 6, 1960, the Air Force announced plans for orbiting a monkey into the Van Allen radiation belts; on December 8 the Air Force announced plans for orbiting a communication satellite; the Navy also announced its intention to start a new space satellite project.(8)

Within this context, President Kennedy appointed an Ad Hoc Committee on Space (headed by Jerome Wiesner of MIT) to evaluate the nation's space program. Both NASA and DoD were found to be inefficient in the administration and management of their space programs. The Committee recommended the reestablishment of the National Aeronautics and Space Council for improving the coordination between NASA and DoD. Another consequence of this review was the reorganization of DoD space activities, making the Air Force responsible for all of DoD's R&D for

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*At this time, Project Apollo was much less ambitious than the one later approved by President Kennedy.

space systems; operational systems were assigned to services individually. While this reorganization followed the Committee's observation that "...each of the military services has begun to create its own independent space program...," it created considerable interservice concern for its own requirements for space systems.(24)

In accepting the Wiesner Committee recommendations for the reinstatement of the Space Council, President Kennedy indicated that he wanted the Council to advise him on how the nation could overtake the lead of the Soviet Union. He also appointed Vice President Johnson as Chairman of the Council.

On April 12, 1961, Major Yuri Gagarin of the Soviet Union became the first man to travel in space when he successfully orbited the earth in his Vostok space capsule weighing over 5 tons. This feat focused immediate attention on American manned space efforts. The President had already committed himself to gaining space superiority; Project Mercury no longer would suffice.* On May 25, 1961, President Kennedy called for the nation "to commit itself to achieving the goal, before the decade is out, of landing a man on the moon and returning him safely to the earth."(25)

The significance of the Gagarin flight and President Kennedy's selection of a manned-lunar-landing mission as the means of challenging the Soviets in space exploits is that it conclusively ended DoD's challenge for leadership of the U.S. space program. To accomplish the manned lunar landing before 1970 meant much larger budgets for both NASA and DoD, increased cooperation between DoD and NASA on a wide variety of projects, and, for the short range, increasing reliance of NASA on DoD's competency. For a while this pattern obscured the fact that NASA was becoming the *dominant* space agency. As it gained a position of dominance, NASA began to acquire autonomous capabilities;

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*As of April 1961, Project Mercury had nearly completed the unmanned flight portion of its schedule. The remaining schedule called for two manned suborbital flights (accomplished in May and July of 1961--18 months behind the original schedule) and four manned orbital flights (February, May, and October 1962 and May 1963). The total program was completed nearly three years behind the original schedule, with the first orbital flight 14 months after the Gagarin flight.(22)

it also began to exercise its increasing bargaining power by asking for a voice in military-managed projects needed by both DoD and NASA. NASA also asserted its identity in the DoD complex by establishing independent field installations at both the Pacific and Atlantic missile launch sites.(11)

<u>1963-1965</u>

During this period, both NASA and DoD faced the problem of rapidly increasing program costs and the resulting program reviews, cancellations, and realignment. For the DoD, their last remaining connection with the manned spaceflight program, Project Dyna-Soar, faced ultimate cancellation because of technical problems, increasing cost, and competition with NASA projects. Nevertheless, with NASA concentrating mainly on the lunar-landing mission, the Air Force surfaced a variety of manned space projects for operation in low earth orbit. These included the Manned Orbital Development System (MODS) and Blue Gemini. These projects were returned to the Air Force for further study.

In 1963, Defense Secretary McNamara stated the following criteria for DoD space programs:

> First, it must mesh with the efforts of the NASA in all vital areas.... Second, projects supported by DoD must promise, insofar as possible, to enhance our military power and effectiveness.(11)

As a consequence, DoD joined forces with NASA on a number of projects, one of which contained the agreement "that the DoD and NASA will initiate major new programs or projects in the field of manned spaceflight aimed chiefly at the attainment of experimental or other capabilities in near-earth orbit only by mutual agreement."(11) These agreements effectively blocked all DoD manned space projects until Secretary McNamara unilaterally assigned the Air Force a new program for the development of a near-earth manned orbiting laboratory (MOL) on December 10, 1963, at the same time that he cancelled the Dyna-Soar program. In justifying his decision on MOL, Secretary McNamara said: "Their [NASA] program is related to the lunar program ... they have no near-earth orbit manned operations planned comparable to this."(11) It was further recognized that the MOL was a necessary first step in developing military operational systems in near-earth orbit.

The Department of Defense had found that joint NASA-DoD projects have their limitations. There is generally a dispersion of authority and responsibility. If an agency regards its share of this work as merely a service for another agency, or if full agency prestige is not on the line, support tends to diminish--"buckpassing" develops. These potential weaknesses are not limited to joint projects between agencies but also apply to those carried on within agencies. For example, the split responsibility between defense-civil agencies, the Air Force, the Army, and NASA in the advent military communications satellite projects contributed to the troubles and later demise of that project.

Subsequently, MOL ran head-on into competition with NASA space station plans. In 1964, separate DoD and NASA efforts appeared to be subject to only a minimum of coordination. Demands for coordination resulted in a joint DoD-NASA agreement that study information would be exchanged at the conclusion of the respective space station studies.

1965-Present

After 1965, DoD's MOL program was cancelled, NASA successfully completed Project Apollo and the near-earth-orbit Skylab program using Apollo hardware, and NASA began to develop the Space Shuttle. Concentration has been on international cooperation and arms agreements banning the basing of weapons of mass destruction in outer space. The DoD has been concentrating its space activities on the use of unmanned spacecraft for its traditional missions of surveillance, communication, command and control, and early warning.

III. STANDARD SPACECRAFT ACQUISITION FOR THE AIR FORCE: STUDY BACKGROUND AND OBJECTIVES, SPACECRAFT DESCRIPTION, MISSION MODEL, AND COST ESTIMATES

As discussed in Sec. I, changes in the political, economic, and technological environment of the country often affect the policy problems faced by the organizational machinery set up to ensure continued NASA-DoD cooperation. In Sec. II, the evolution of that organizational machinery is traced through the mid-1960s, at which time its institutionalization was assured. Since that time, a number of important developments have taken place involving the ongoing NASA-DoD relationship, including: (1) the successful completion of Project Apollo and the concomitant NASA expansion; (2) the demonstration of the long-duration capability of the manned Skylab; (3) the increasing sophistication of unmanned spacecraft and their mission successes; and (4) the recent national commitment to the space shuttle as the principal launch vehicle for both NASA and DoD beginning in the early 1980s. One of the objectives of this dissertation is to evaluate a current case study involving NASA-DoD cooperation in the procurement of a standard spacecraft. That evaluation also demonstrates the NASA-DoD cooperation process as it now exists, nineteen years after NASA's founding.

The advent of the space shuttle as the only operational launch vehicle for the 1980s (and thereafter) has provided the context for the case study selected for this dissertation. In the shuttle era, standard spacecraft designed to support a wide variety of payloads are expected to receive greater attention from NASA and DoD because of their potential cost savings (mainly recurring costs) over the use of specialized spacecraft designs. The case study evaluated in this dissertation deals with an Air Force decision about the possible use of NASA standard spacecraft designs.

The Air Force decision is whether to design and develop its own standard spacecraft or to procure NASA designs for accomplishing its Air Force Space Test Program missions during the initial ten-year operational period of the space shuttle. In this section and the one that follows, the detailed analysis is presented to support the evaluation of the relative costs of several procurement options for accomplishing the

Air Force missions. Here, the case study background and objectives are presented along with a description of the four unmanned standard spacecraft used in the case study and the necessary modifications needed for use by the Air Force for the Space Test Program missions. The Air Force mission model is also presented and analyzed with respect to the capabilities of the four standard spacecraft. Finally, the estimated nonrecurring and recurring spacecraft costs are presented, as well as the costs for the various launch options considered in the analysis discussed in Sec. IV.

STUDY BACKGROUND AND OBJECTIVES

As mentioned above, all of the missions to be examined in this case study involve the Air Force Space Test Program and are to be flown on the space shuttle. To provide a context for the cost-benefit analysis that follows in Sec. IV, the Air Force Space Test Program is briefly described in terms of its origin, mission, organizational links, operating philosophy, kinds and types of payloads (experiments) flown, and rationale for the standard spacecraft. Following this, the case study objectives and guidelines are presented. Finally, the operation of the space shuttle, as it affects this case study, is described.

Air Force Space Test Program

The Space Test Program, formerly known as the Space Experiments Support Program, was organized in July 1966 as the central flight-support project for all DoD experimental payloads.* It is a triservice activity under the management of the U.S. Air Force. Organizationally, it is associated with the USAF Space and Missile Systems Organization's Advanced Space Programs. As currently organized, the Space Test Program provides the following services:[27]

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*Payload, as used here, could consist of a single experiment or a number of related experiments. As will be discussed later in this section, the Space Test Program Office mission model is composed of a number of different experimental groupings and each of these groupings--distinguished by being on a single page of Ref. 26--is referred to as one payload.

1. A method for collecting, reviewing, and assigning priorities to potential payloads (experiments).
2. A system for defining the number and method of securing spaceflight for these payloads.
3. An agency for managing and funding of booster and spacecraft procurement, payload integration, and launch and orbital support.

The Space Test Program Office has provided these services for over 100 different payloads derived from the three military services and other operating agencies. These payloads have ranged from alpha-particle detectors to x-ray monitors. Some have weighed less than a pound, while others have weighed over a thousand pounds.

The selection process for payloads to be included in the Space Test Program originates with a request from a DoD laboratory, or some other agency, for a spaceflight of a specific experiment. The Director of Space, USAF Headquarters, processes these requests and, with the concurrence of the Office of the Director of Defense, Research and Engineering (DDR&E), and interested military services, determines which payloads will be included in the Space Test Program. The Space Test Program Office defines the spaceflight for as many payloads as possible, given funding limits, and submits the program to the Director of Space and DDR&E for approval. When the plan is approved, the Space Test Program Office contracts for the necessary spacecraft, launch vehicle, and payload integration.

To increase the proportion of the funds available for payload development, the Space Test Program Office has followed a low-cost strategy consisting of:

1. Using "secondary" space on spacecraft and launch vehicles of other programs, i.e., piggybacking.
2. Using existing space vehicle designs whenever possible.
3. Using backup spacecraft designed and built for other programs.
4. Using selective redundancy in Space Test Program-procured spacecraft.

5. Using off-the-shelf, space-qualified hardware whenever possible.
6. Staffing a project with a small, responsible team (about ten individuals per major project).

The type and number of payloads flown on a Space Test Program mission vary widely. For example, one upcoming mission consists of experimental payloads from the Army, Navy, Air Force, and ARPA. The mission includes seven payloads having a total weight of 700 lb. Three of the payloads require a sun-pointing orientation, while the remainder require earth scanning. The spacecraft therefore must be three-axis stabilized with the capability of scanning the earth. Another mission includes twelve small payloads to investigate the same phenomenon--spacecraft charging at altitude--having a total weight of 200 lb.

As will be discussed later in this section, a Space Test Program mission model consisting of descriptions of a number of experiments proposed by various agencies and departments was used in the evaluation of the standard spacecraft acquisition decision. These payloads can be arrayed in a variety of dimensions, as discussed later, but for the sake of providing some understanding of the nature of the problem that these payloads present to the Space Test Program Office, the following ranges of requirements are included in the 1980-1990 Space Test Program mission model:[26]

Operating Parameters	Typical Range of Requirements
Weight	1 to 525 lb
Electric power	0.001 to 100 W
Data rate	0.001 to 64 kbps
Stabilization	Three-axis or spinning
Orientation	Sun-pointing or earth-pointing
Pointing accuracy	$\pm$ 0.5 to $\pm$ 15 deg
Apogee altitude	100 to 20,000 n mi
Perigee altitude	100 to 20,000 n mi
Inclination	Equatorial to polar

The approach used by the Space Test Program Office in the past to satisfy the heterogeneous array of payload requirements on the spacecraft has consisted of minimizing the interaction of one experiment with another. However, with the recent availability of a new fault-tolerant, general-purpose spacecraft computer, it is possible to consider coupling two or more payloads. Information may be extracted from individual payloads and computationally reduced on board, thereby lowering the bandwidth of information transmitted to the ground.[27]

The Space Test Program Office became interested in the standard spacecraft concept because of the possibility of combining this capability with the possibility of further reducing the spacecraft cost by procuring a fairly large number of spacecraft at a given time. This concept was especially interesting with the advent of the space shuttle, where the match between launch vehicle and mission is not as critical as it has been when expendable boosters were used as launchers.* As a consequence, the Space Test Program Office sponsored the design of a modularized standard spacecraft (STPSS) that has the capability of meeting all of its payload requirements, while also conforming to their low-cost design philosophy.

Objectives and Guidelines

The two objectives of this case study are 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 conclusions that are drawn concerning the various procurement options, although discussed in terms of total program costs, are dependent upon the relative costs of the various spacecraft (see Sec. IV). They are not affected if the magnitude of the total program costs is underestimated or overestimated.

The study guidelines are summarized below:

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*Before the space shuttle, the Space Test Program had the option of selecting the launch vehicle to fit the particular mission requirements, e.g., in 1976, both the Titan III and Scout launch vehicles were used.

1. Spacecraft configurations are based on descriptions provided by Goddard Space Flight Center (GSFC) for the MMS, by TRW for the STPSS, and by Boeing for the AEM and L-AEM.
2. Space Test Program payloads described in *Current STP Payloads*[26] (the so-called "Bluebook") are considered representative of those that would be flown during the period 1980-1990.
3. All spacecraft are compatible with the use of solid rockets for orbit translation, which usually requires spin stabilization. The 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.
4. 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* for translation from the nominal shuttle parking orbit to the desired mission orbit rather than on changing the shuttle orbit altitude and inclination to meet the payload requirements.
5. Nominally, two Space Test Program flights per year are scheduled; the minimum is one.
6. All payloads are launched using the space shuttle.
7. Servicing of payloads in orbit or retrieval of spacecraft for reuse is not considered.

Space Shuttle Operations

As just mentioned, this study is restricted to consideration of the space shuttle for the primary launch vehicle. As currently envisioned, the space shuttle will have the capability of placing 65,000 lb of payload into a 150 n mi earth orbit with an inclination of 28.5 deg when operating out of the Eastern Test Range (ETR). To place payloads in

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*Although the IUS uses solid rockets, its use by the Space Test Program is considered a special case because of the high cost of that design.

either higher orbital altitudes or inclinations will degrade the on-orbit space shuttle payload. For example, to increase the orbit altitude to 300 n mi (with an inclination of 28.5 deg), the payload decreases from 65,000 lb to about 53,000 lb; an increase in the orbital inclination to 56 deg results in a similar payload reduction. For a polar orbit with an altitude of 150 n mi, the space shuttle payload is about 39,000 lb.

In addition to the payload weight constraints, the shuttle payload bay is also limited in size. The main cargo bay is 15 ft in diameter and 60 ft long. As will be discussed later in this section, the method of allocating the cost of a space shuttle launch to the various users has not yet been determined, but payload length and weight and orbital altitude and inclination are being considered by NASA as parameters for determining the shuttle tariff schedule.

Because of the Space Test Program Office's interest in retaining the option of operating as a secondary payload status,* nominal shuttle parking orbits with an altitude of 150 n mi and an inclination of 28.5 and 90 deg are used for this study. Nearly all of the Space Test Program missions require orbital translations from the shuttle parking orbit to the desired mission orbit. To accommodate this translation, solid propellant rockets sized for the specific velocity requirements and mission payloads are used. Generally, two rockets are required--one for apogee and one for perigee. In this study, all of the solid rockets are drawn from the inventory of existing solid rocket motors.

In special cases where large velocity increments are required and the Space Test Program payload is large, the IUS is used as the translation stage. This stage is being developed by the Air Force to support the space shuttle operations. It consists of two solid rocket stages and an instrument module capable of guiding the payload into orbit. The translation is accomplished in a three-axis-stabilized mode as compared to a spin-stabilized mode when the smaller solid rocket motors are used.

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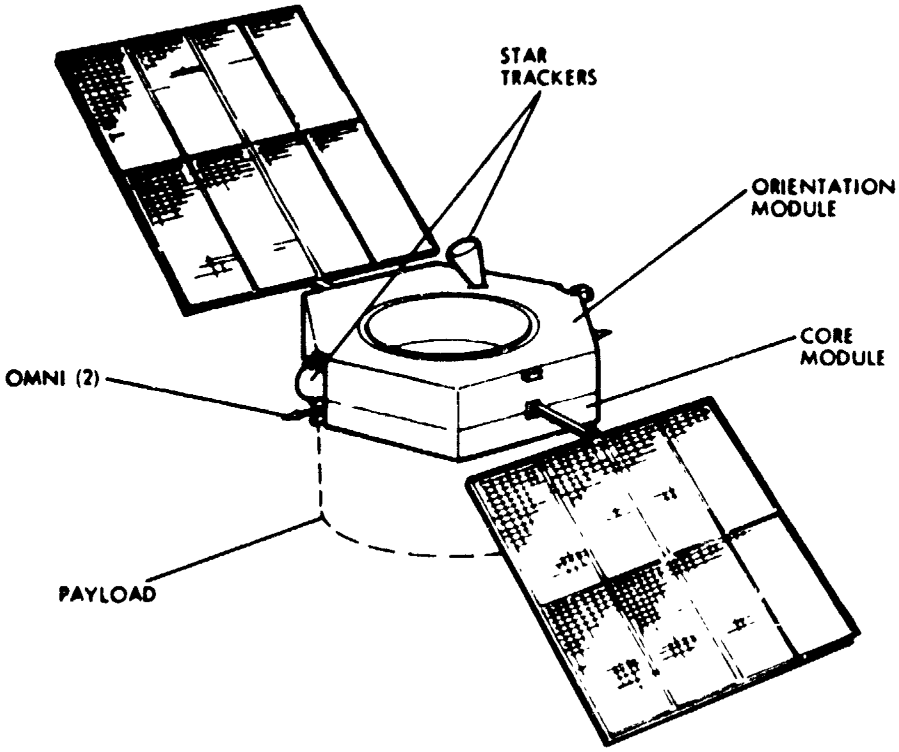
*Secondary payload status refers to the case where the Space Test Program mission does not determine the shuttle altitude, inclination, or launch schedule and flies on a space-available basis.

STANDARD SPACECRAFT DESCRIPTIONS

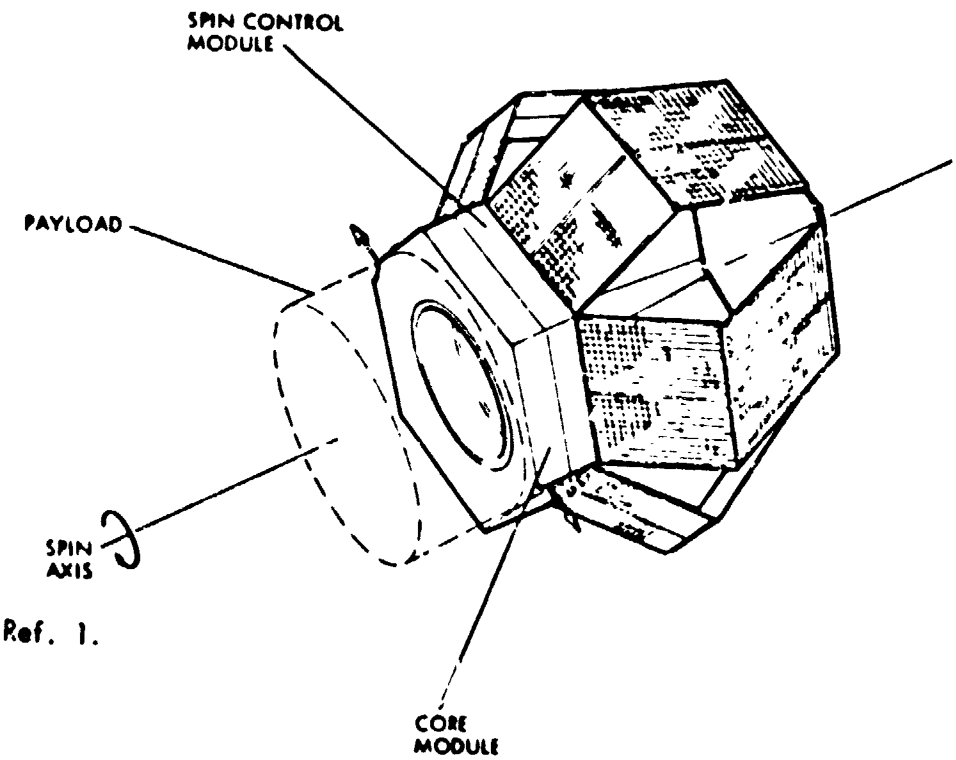
Four unmanned standard spacecraft designs are involved in this case study. As mentioned in Sec. I, during the first phase of this case study, the Space Test Program Standard Satellite--a design proposed by the Space Test Program Office of the Air Force Space and Missile Systems Organization--and two NASA candidates--the Applications Explorer Mission spacecraft and the Multimission Modular Spacecraft--were considered. 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. In the material that follows, each of the spacecraft configurations is described, then a comparison is made of the spacecraft requirements, followed by a detailed description of the modifications needed for their use by the Air Force Space Test Program missions.

The purpose of a standard spacecraft is to provide all of the housekeeping functions for the Space Test Program payloads during the life of the mission. For example, once in orbit, the spacecraft stabilizes the payload and points it in the correct direction, it provides the necessary power and power conditioning to run the experiments and provide thermal protection to the payload, and it provides the communication and data handling equipment necessary to control the experiments and transmit the data back to earth. In most of the cases examined in this study, the spacecraft also provides the guidance and control necessary to translate the payload from the shuttle parking orbit to the mission orbit.

The STPSS design (Fig. 1) consists of four modules: core, orientation, propulsion, and payload cluster. The core module is common to all missions, regardless of whether the spacecraft is spin- or three-axis stabilized. Two types of orientation modules provide for the two stabilization modes. The propulsion module, which fits into the circular space of the core and orientation modules, is tailored for the specific mission weight, final orbital parameters (perigee and apogee altitude and inclination), and the shuttle parking orbital parameters. The STPSS is designed in a hexagonal, torus-shaped configuration, which surrounds the solid propellant propulsion modules.



Three-axis version



SOURCE: Ref. 1.

Spinning version

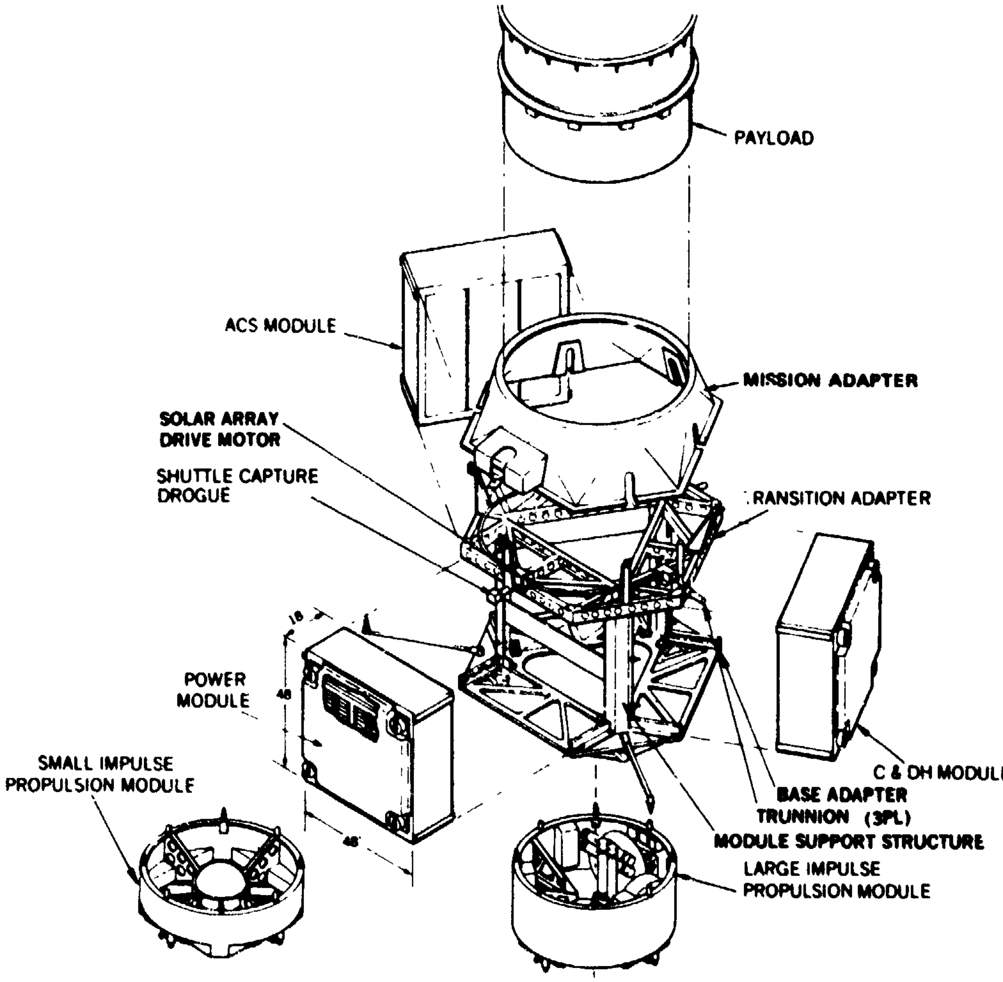
Fig. 1—STP standard spacecraft

The payload cluster, while unique for each set of payloads, has a common mechanical, thermal, and electrical interface with the STPSS. As can be seen in Fig. 1, the configuration of the solar cells is different for the three-axis- and spin-stabilized versions of the STPSS. These panels are also modular, thereby allowing the electrical power generated by the spacecraft to be tailored to the payload demand.

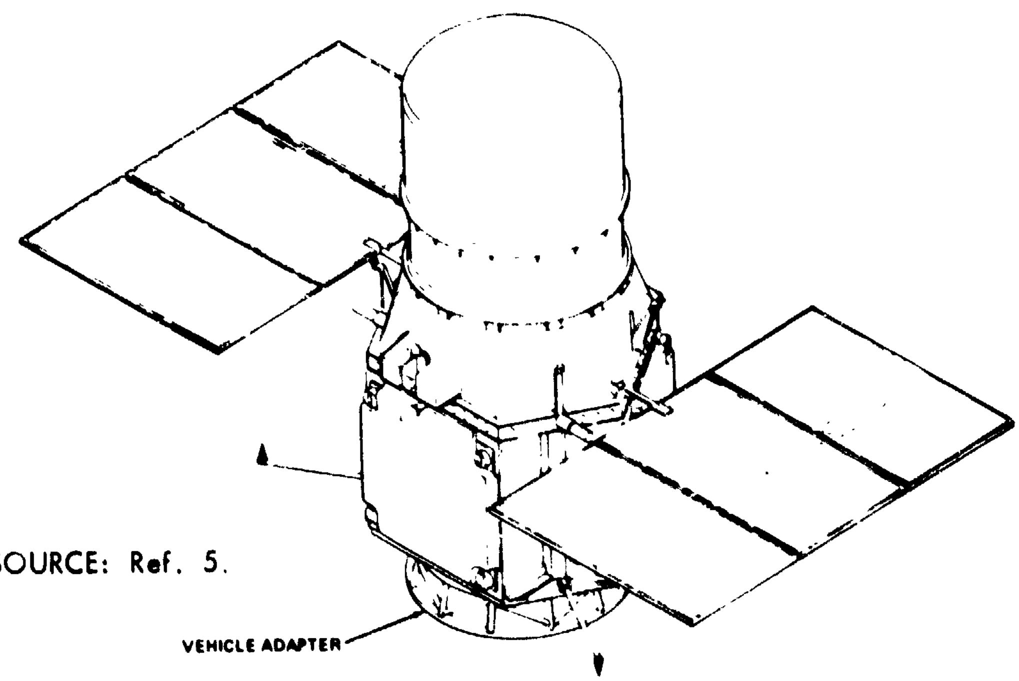
The three-axis-stabilized version of the STPSS has a dry weight of about 1000 lb without payload or propulsion system. It is about 7.5 ft in diameter, and about 32 in. thick. One of the reasons behind this "pancake" design was to minimize the length of the spacecraft so that it would fit into the space shuttle without occupying primary bay space, allowing the Space Test Program missions the option of flying on board the space shuttle as a secondary payload.

The MMS design, depicted in Fig. 2, consists of a centrally located triangular-shaped module support structure having attach points for: (1) the power module, (2) the attitude control and stabilization (ACS) module, (3) the communications and data handling (C&DH) module, (4) the mission adapter-payload module, and (5) either a small or large impulse propulsion module. In this design, all missions are flown with the first four modules; the propulsion module is optional, depending on the mission. For missions requiring large orbital transfers, either the IUS or other appropriate solid motors replace the propulsion modules shown in Fig. 2. As will be discussed later in this section, several equipment options are available within each of the three main modules (power, ACS, and C&DH) to accommodate mission-specific requirements. For example, the solar array design shown in Fig. 2 is generally considered to be similar to that of the stabilized version of the STPSS. Again, it is modular and may be tailored to the mission power requirement. The MMS is designed for remote on-orbit replacement and servicing and, as a result, is a much more sophisticated design than the STPSS. The payload interface (power, thermal, mechanical, and data handling) is constant for all missions.

The MMS weighs about 1400 lb without the solar array or space propulsion system. The overall width is about 4.5 ft and its length, without



Exploded view



SOURCE: Ref. 5.

Fig. 2—Modular multimission spacecraft

payload or propulsion, is about 5 ft. The MMS design is suitable only for operation in the main payload bay of the space shuttle.

The third standard spacecraft design included in the initial phase of the study was the AEM (Fig. 3). Boeing is currently building two versions of the AEM: the HCMM and the SAGE. The outward physical appearance of the two versions is very similar in that most of the differences involve components housed within the spacecraft. The AEM is three-axis stabilized and can be matched with appropriately sized solid rocket motors for orbital translation. In its current design, it is limited to operational altitudes less than 1000 n mi because it relies on magnetic torques rather than reaction jets to unload the momentum wheels (Appendix D). It is a low-cost expendable design that uses off-the-shelf components throughout. The physical configuration of the AEM is a "hexagonal nut" 36 in. across the flat and 25 in. long (excluding payload and propulsion). It weighs about 210 lb.

The fourth standard spacecraft, the L-AEM, is a derivative of the AEM that has been increased in diameter to a nominal 5 ft (Fig. 4). The L-AEM design can be procured in three different configurations: the baseline option (L-AEM-BL), the spin-stabilized option (L-AEM-S), and the precision option (L-AEM-P). The configuration changes are achieved by modifying the equipment list. The L-AEM-BL weighs about 670 lb without propulsion or payload.

SPACECRAFT COMPARISONS

Spacecraft Requirements

The nominal spacecraft requirements for the AEM, L-AEM, STPSS, and MMS, categorized by mission, communication, electrical power, stabilization and control, and reaction control system and propulsion, are shown in Table 1. Of the four spacecraft, the AEM is the smallest and has the least capability. It is about 3 ft in diameter, can carry a 150 lb payload, and is limited to operating altitudes less than 1000 n mi.

All three configurations of the L-AEM have a minimum life of one year and a payload capability of 1000 lb. Both the L-AEM-S and L-AEM-P can operate from low earth orbit to geosynchronous altitude; the L-AEM-BL is restricted to altitudes less than 1000 n mi.

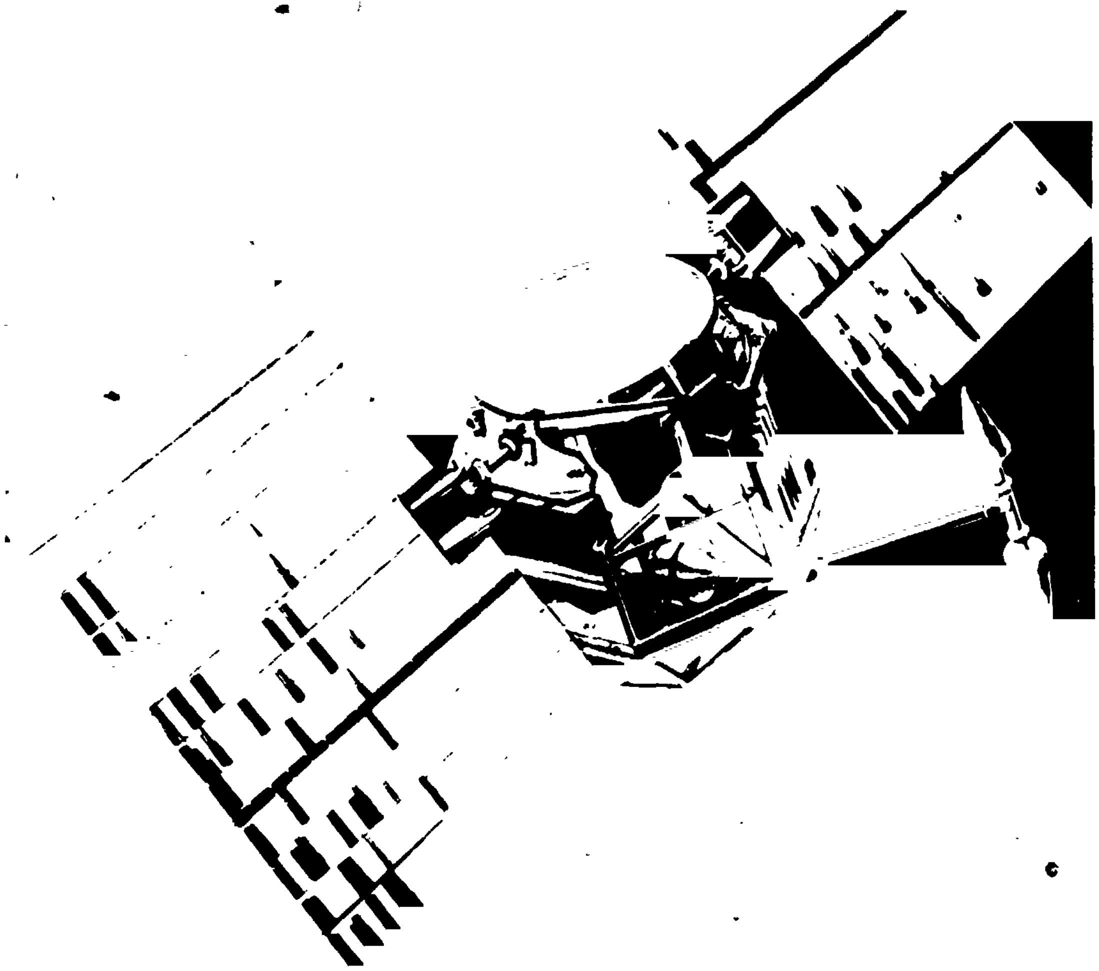
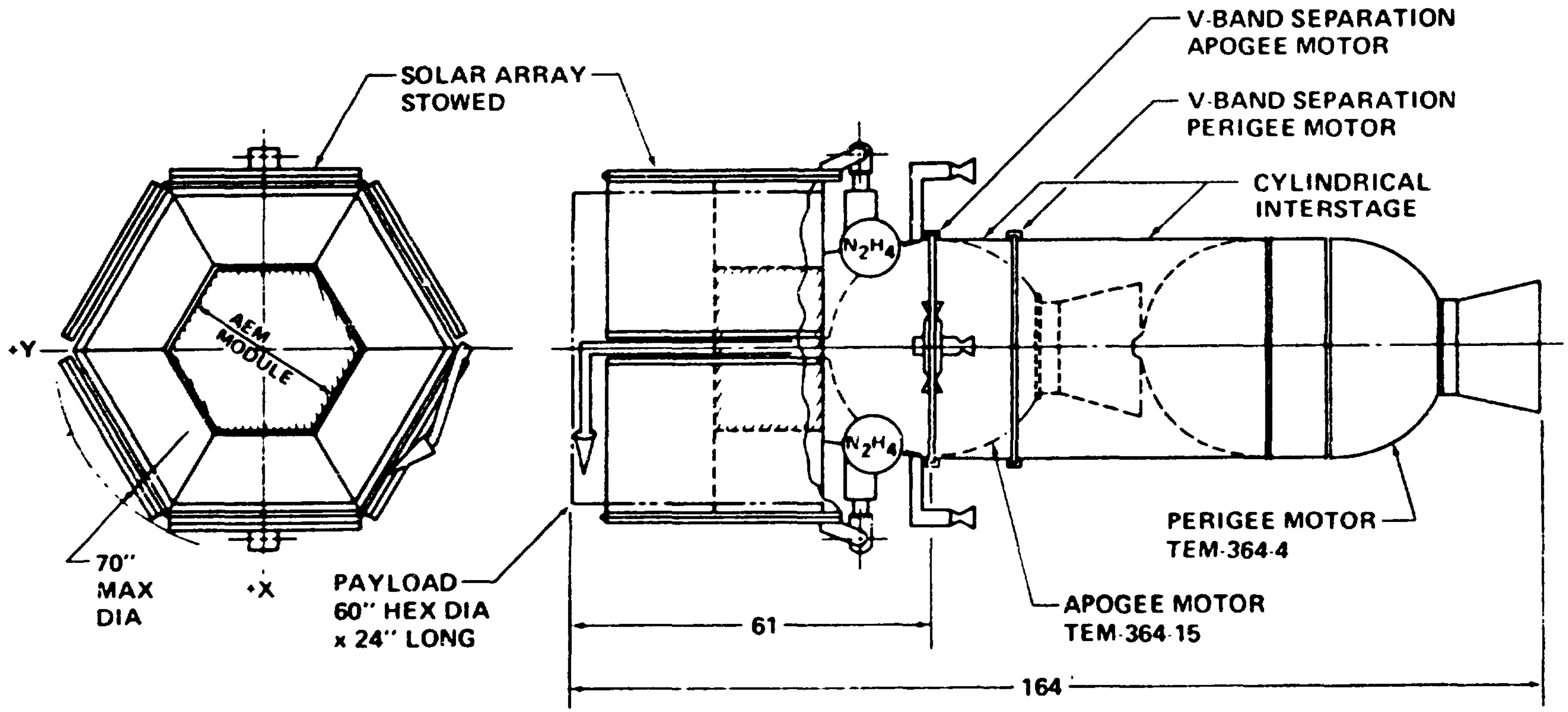


Fig. 3—Applications Explorer spacecraft

AEM Modified Launch Configuration



SOURCE: Ref. 28

Fig. 4—L-AEM configuration

Table 1

NOMINAL SPACECRAFT REQUIREMENTS

Requirement Category	AEM	STPSS	MMS	L-AEM
Mission				
Operating mode	Expendable	Expendable	On-orbit service	Expendable
Mission duration, yr	1	1	1-2	1
Design payload weight, lb	80	1000	4000	1000
Max. payload weight, lb	150	1500	4000	>1000
Orbit range	LEO[a] (<1000 n mi)	LEO-Geosynch.	LEO-Geosynch.	LEO-Geosynch.
Communications				
Link	VHF and STDN[b]	SGLS[c]	STDN and TDRSS[d]	SGLS
Data bit rate, kbps[e]	8	128 and 256	64	128 and 256
Data storage, bits	4.5×10^8	1×10^8	9×10^8	9×10^8
Electrical Power				
Bus voltage, V	28 ±4	28 + 5	28 ±7	28 ±4
Battery capacity, Ah[f]	10	60	20 to 150	40
Peak array, W	238	380-1200	As required (≤3600)	318-1000
Housekeeping, W	28	100-200	350	104-132
Battery charging	direct	Individual charge	Parallel charge	Individual charge
Stabilization and Control				
Pointing accuracy, deg	±1, pitch, roll; ±2, yaw	±1-±0.1, all axes	<±0.01, all axes	±1-±0.05, all axes
Pointing stability, deg/sec	±.01	±.01-.003	$\pm 10^{-6}$	~ ±.01
Orientation	3-axis	Spinning and 3-axis	3-axis	Spinning and 3-axis
Reaction Control System and Propulsion				
Impulse, klb-sec[g]	[illegible] 3	1.7-2000	12-230	2.8-1065
Type	Hydrazine	Cold gas, solids	Hydrazine	Hydrazine, solids

[a] Low earth orbit.

[b] Space Tracking and Data Acquisition Network.

[c] Space Ground Link System.

[d] Tracking and Data Relay Satellite System.

[e] Kibobits per second.

[f] Ampere-hours.

[g] Kilopound-seconds.

The STPSS can carry a nominal payload of about 1000 lb, can be operated at altitudes up to geosynchronous, and weighs about 1000 lb. It can be procured in three different configurations--a spinning version (STPSS-S), a low-cost, three-axis-stabilized version (STPSS-LC), and a three-axis-stabilized precision version (STPSS-P).

The MMS is the most sophisticated of the standard spacecraft considered in this study: it is designed for on-orbit servicing and reuse. It can carry a payload of about 4000 lb and can also be operated up to geosynchronous altitude.

AEM and MMS spacecraft have communications systems that are compatible with the Space Tracking and Data Acquisition Network, while the L-AEM and STPSS are compatible with the Space Ground Link System. This difference in the communication system needs to be corrected before the AEM and MMS can be used for Air Force missions. (The modifications necessary to make this correction are discussed later.) Another difference is in the data rate capability of the communication systems. Both the AEM and MMS have data rates considerably less than that of the L-AEM and STPSS, i.e., 8 and 64 kbps,* respectively, as compared with 128 to 256 kbps.

All of the spacecraft use 28 V electric power systems. The basic differences are in the solar array designs and battery charging systems. The AEM has a fixed solar array capable of providing about 40 to 50 W for experimental use. The other designs treat the solar array as a mission-specific item. The peak array power for the L-AEM is 1000 W, almost as much as the 1200 W of the STPSS output; the MMS power system can handle arrays having a peak output of up to 3600 W. The battery-charging system of the MMS is different from those of the L-AEM and STPSS. All three provide for more than one battery, but an individual charging system is used by the L-AEM and STPSS, whereas a parallel charging system is used for the MMS.

In stabilization and control capability, the MMS is again superior to the other spacecraft with a pointing accuracy of $\pm$ 0.01 deg and a pointing stability of $\pm 10^{-6}$ deg/sec. The L-AEM design provides essentially the

*The communications data rate is given in kbps, the power system capacity in volts (V), and the solar array output in watts (W).

same variety of options for stability and control of the spacecraft as the STPSS. The spin-stabilized options are identical in capability, while the capability of the precision option exceeds that of the STPSS-P but is less than that of the MMS. The L-AEM-BL option is more accurate than the STPSS-LC option in the pitch and roll axes and identical in the yaw axis.

Both the AEM and MMS have hydrazine attitude control systems; the STPSS uses a cold gas system in combination with solid rockets for orbit translation. The MMS hydrazine propulsion modules (SPS-I and SPS-II)* provide a choice of module configurations that can be selected depending upon the delta velocity required. The reaction control system used in the L-AEM is a derivative of the hydrazine system of the SAGE version of the AEM. The major difference is that the L-AEM-P configuration has a reaction control system sized to provide three-axis stability during the solid-rocket-powered orbital translation phase. Consequently, it includes nozzles with relatively large thrust levels (65 and 155 lb) in addition to the normal thrusters. There seems to be no reason why the L-AEM-P configuration cannot be spin-stabilized during orbit translation, therefore it has been assumed to have this capability, especially for the geosynchronous missions where larger-size solid motors are required than those discussed in Ref. 28. In Ref. 28 the overall length of the L-AEM, payload, and solid rocket kick stages was restricted to less than the diameter of the shuttle. This allowed placement of the spacecraft perpendicular to the shuttle longitudinal axis and hence minimized the length of the shuttle bay used for the flight. The application of the L-AEM in this case study has not been restricted in this manner.

The individual spacecraft configurations and the modifications considered necessary to allow their use by the Air Force in carrying out the Space Test Program missions are described below.

AEM

As mentioned earlier, there are two basic AEM configurations--HCMM and SAGE--which consist of the same base module with different mission-specific equipment. The HCMM configuration uses a hydrazine

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*Space Propulsion System (SPS).

orbit-adjust module, while the SAGE configuration includes a second momentum wheel and a tape recorder.

For Air Force use, the SAGE configuration was selected as being most appropriate. The only modifications that were considered relate to the conversion of the communication system to make it SGLS-compatible. These changes are itemized below and discussed in detail in Appendix C. Basically, the changes involve replacing some of the AEM communication equipment with the appropriate STPSS communication equipment.

- Replace S-band transmitter with STPSS S-band (SGLS) transmitter.
- Replace S-band transponder with STPSS S-band (SGLS) transponder.
- Replace command demodulator with STPSS dual signal conditioner.
- Modify pulse code modulation (PCM) encoder for dual baseband.
- Modify command decoder/processor.

Although the power system of the AEM is very limited ($\sim$ 50 W), no changes were made in this system for Air Force use. Also, the non-redundant design of the AEM was unaltered. In addition, the current AEM design does not allow for the use of encryption equipment--this was not changed because it is not a requirement for all Air Force missions considered in this study.

STPSS

Each of the three available STPSS configurations (summarized in Table 2) consists of a core and an orientation module (or a spin-control module in the STPSS-S case). In addition, a variety of mission-specific equipment is available for each configuration. The core module is the same in all cases. The orientation or spin module determines the attitude stability and pointing accuracy of the spacecraft. The configurations used in this study are those identified by TRW in their study.[1]

No changes were made except, by direction of the Air Force, the hydrazine reaction control system (RCS) designed by TRW for the STPSS was not considered in this analysis because of its relatively high cost compared with the cold gas reaction control system/solid rocket option.

Table 2

STPSS CONFIGURATIONS

STPSS-P	STPSS-LC	STPSS-S
Core Module + Orientation Module • 3-axis • Precision (±0.1 deg) • 1 deg freedom solar drive • Cold gas RCS + Mission-Specific Equipment • Solar panels (max. 1200 W) • Extra 10^8 tape recorder • Encryption unit (GFE) • Orbit transfer module (solids or IUS) • Antenna	Core Module + Orientation Module • 3-axis • Low cost (±1 deg) • 1 deg freedom solar dr. • Cold gas RCS + Mission-Specific Equipment Same choices as for STPSS-P.	Core Module + Spin Control Module • Spin • Low cost (±1 deg) • Cold gas RCS + Mission-Specific Equipment Same choices as for STPSS-P, *except* • Solar panels (max. 380 W)

MMS

The basic MMS, summarized in Table 3, consists of three primary modules, plus a variety of mission-specific equipment, all of which are attached to a structural subsystem. For Air Force use (1) the attitude control module is retained without modification, (2) one 20 Ah battery is added to the power module so that it would have the same

Table 3

MMS CONFIGURATIONS

MMS	MMS-AF
Attitude Control Module	Attitude Control Module
+	+
Power Module • Two 20 Ah batteries	Power Module • Three 20 Ah batteries
+	+
C&DH Module • TDRSS- and STDN-compatible	C&DH Module • SGLS-compatible • [Data rate 128-256 kbps][a]
+	+
Mission-Specific Equipment • Antenna • Solar panels (as required) • Space propulsion (SPS-I, SPS-II, IUS) • Solar drive • Extra tape recorders (8×10^9 bits) • Extra batteries (one 20 Ah or three 50 Ah)	Mission-Specific Equipment Same as above, *except* • Solid rockets for orbit translation

[a]Additional option.

energy storage capacity as the STPSS, and (3) the communications system is changed to be compatible with SGLS.

Listed below are the detail modifications to the MMS communication module needed to achieve this compatibility. Again, these modifications consist mainly of replacing MMS communication equipment with STPSS equipment that performs a similar function.* The necessary changes to increase the data rate to 128-256 kbps have not been considered as requirements.

SGLS Compatibility

- Replace S-band transponder with STPSS S-band SGLS transmitter and receiver.
- Replace or modify command decoder with STPSS decoder.
- Replace premod processor with STPSS dual baseband unit.

Increase Data Rate

- Replace data bus controller
- Replace clock and format generator
- Replace standard computer interface

with STPSS bus controller (data formatter).

- Replace remote interface unit with STPSS data interface unit.

Although the parallel battery-charging design used in the MMS power module has been of some concern to the Air Force, it was not considered necessary to change it (see Appendix B), since the power regulation unit will have adequate redundancy to meet Air Force requirements, and the MMS power system will be a flight-proven design before the missions considered in this study are undertaken.

SPACE TEST PROGRAM MISSION MODEL

In accordance with the directions provided by the Work Statement for this study, Space Test Program missions(26) to be flown during the

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*It should be noted that if the Air Force Solar Infrared Experiment (SIRE) is flown on the MMS, these changes in the communication module will have already been made before any of the missions considered in this study. As noted later in this section, the MMS cost estimates are based on this assumption, hence the nonrecurring cost associated with these changes is not included in the study.

1980-1990 time period are divided into three payload groups (Table 4). The principal distinguishing feature of each group is the spacecraft requirements. For example, payloads in groups I and III all require a spacecraft with *nominal* capability and either *three-axis* or *spin* stabilization. We have taken this to mean that these missions could be flown on the AEM, STPSS-S, STPSS-LC, L-AEM-S, or L-AEM-BL spacecraft. Those payloads in group II require a spacecraft with a *high* capability and *three-axis* stability. This requirement can only be met by the STPSS-P, L-AEM-P, or MMS.*

Of the estimated twenty flights to be flown between 1980 and 1990, the Work Statement indicated that about 75 percent (15 flights) would be in payload group I, 10 percent (2 flights) in payload group III, and 15 percent (3 flights) in payload group II. Using the estimated division between large (over 150 lb) and small payloads given in the Work Statement for each of the payload groups, we can presume a total of 114 payloads for the nominal case or about 6 payloads per spacecraft.

As mentioned previously, Ref. 26 provided a listing of over 52 Space Test Program payloads that were to be considered as representative of those that would be flown between 1980 and 1990. These payloads were analyzed in terms of their spacecraft requirements for accuracy, stabilization, and weight. The results of that analysis are shown on the right-hand side of Table 4 to allow direct comparison with the guidance given in the Work Statement for this study.

We found that the overall division of payloads between group II and groups I and III was a little different from that suggested by the Work Statement, i.e., only 11 percent, rather than 15 percent, of the payloads fell into payload group II. We also found that the percentage of small payloads in groups I and III was larger, i.e., 90 percent, rather than 85 percent. Appropriate adjustments for these relatively minor mismatches caused an increase in the total number of Space Test Program payloads from 114 to 151, which is equivalent to

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*For this reason, group II is distinguished from groups I and III in the discussion that follows.

Table 4

SPACE TEST PROGRAM PAYLOAD CATEGORIES

Payload Groups	Percent of STP Flights	Number of STP Flights	Number of Experiments			Spacecraft Requirements		Percentage of Total Payloads		Percentage of Large Payloads[a]		Percentage of Small Payloads	
			Small	Large	Total	Stability	Capability	Gr. I & III or Gr. II	Bluebook	Gr. I & III or Gr. II	Bluebook	Gr. I & III or Gr. II	Bluebook
I	75	15	60	15	75	Spin or 3-axis	Nominal	85	89	15	10	85	90
III	10	2	24		24	Spin or 3-axis	Nominal						
II	15	3	12	3	15	3-axis	High	15	11	20	20	80	80
Total		20	96	18	114					16	11	84	89

[a] ≥150 lb.

about 7.5 payloads per spacecraft. In addition to this, the preliminary status of the mission model suggested that the number of payloads in the program and the number of payloads per spacecraft should be included in the sensitivity analysis.

As indicated on Table 5, the Space Test Program missions[26] are divided into eight different orbits that distinguish between 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 divided into those that are sun-oriented and those that are earth-oriented. As you may see, 45 percent of the Space Test Program payloads would fly in this orbit. The second orbit is a highly elliptical one (7000 × 200 n mi) having an additional 28 percent of the Space Test Program payloads.

Table 5

SPACE TEST PROGRAM MISSION CATEGORIES

Number	Type	Orbit (n mi)	Inclination (deg)	Launch Range	Percentage of Payloads	No. of Payloads
1	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

The missions in both of these orbits are launched from the Western Test Range (WTR). The missions flown on the WTR (orbits 1, 2, and 8) represent about 75 percent of the Space Test Program payloads. The payloads flown out of the Eastern Test Range (ETR) all require large orbit translations; e.g., up to geosynchronous. The last column in Table 5 indicates the number of Space Test Program payloads in the nominal case that are flown in each of the orbits during the 1980-1990 time period. The total number of Space Test Program payloads in the nominal case is 114.

In Fig. 5 these orbits are related to the perigee and apogee altitude ranges of individual payloads. The payloads are identified by page number in the bluebook[26] at the top of the figure Each payload generally has a wide range of acceptable operating altitudes, which has made it reasonably easy to collapse the Space Test Program payloads into eight orbits.*

In addition to ordering the Space Test Program payloads according to orbit parameters, they were also matched with each of the spacecraft being considered in this study. In making these assignments, the following were considered: payload weight, maximum altitude, orientation, power availability, data rate, pointing accuracy, and stability. The resulting match between individual Space Test Program payloads and the various spacecraft is illustrated in Table 6. Space Test Program payloads are identified by bluebook page number. Of the 52 payloads in the bluebook, 6 were not included in the mission model for various reasons (see footnotes to Table 6). Of the remaining 46 payloads, the AEM with its 150 lb payload capability and 1000 n mi altitude limitation can accommodate only 10 (22 percent). The spinning versions of the L-AEM (L-AEM-S) and STPSS (STPSS-S) can both handle 26 percent of the total payloads. The baseline version of the L-AEM is limited to orbital altitudes of less than 1000 n mi and to earth-oriented missions and therefore can accommodate only 28 percent of the payloads. The low-cost

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*It is recognized that when these payloads are actually flown, a larger number of orbits may be used depending upon the capabilities of the spacecraft and payload requirements; this should not affect the results of this study.

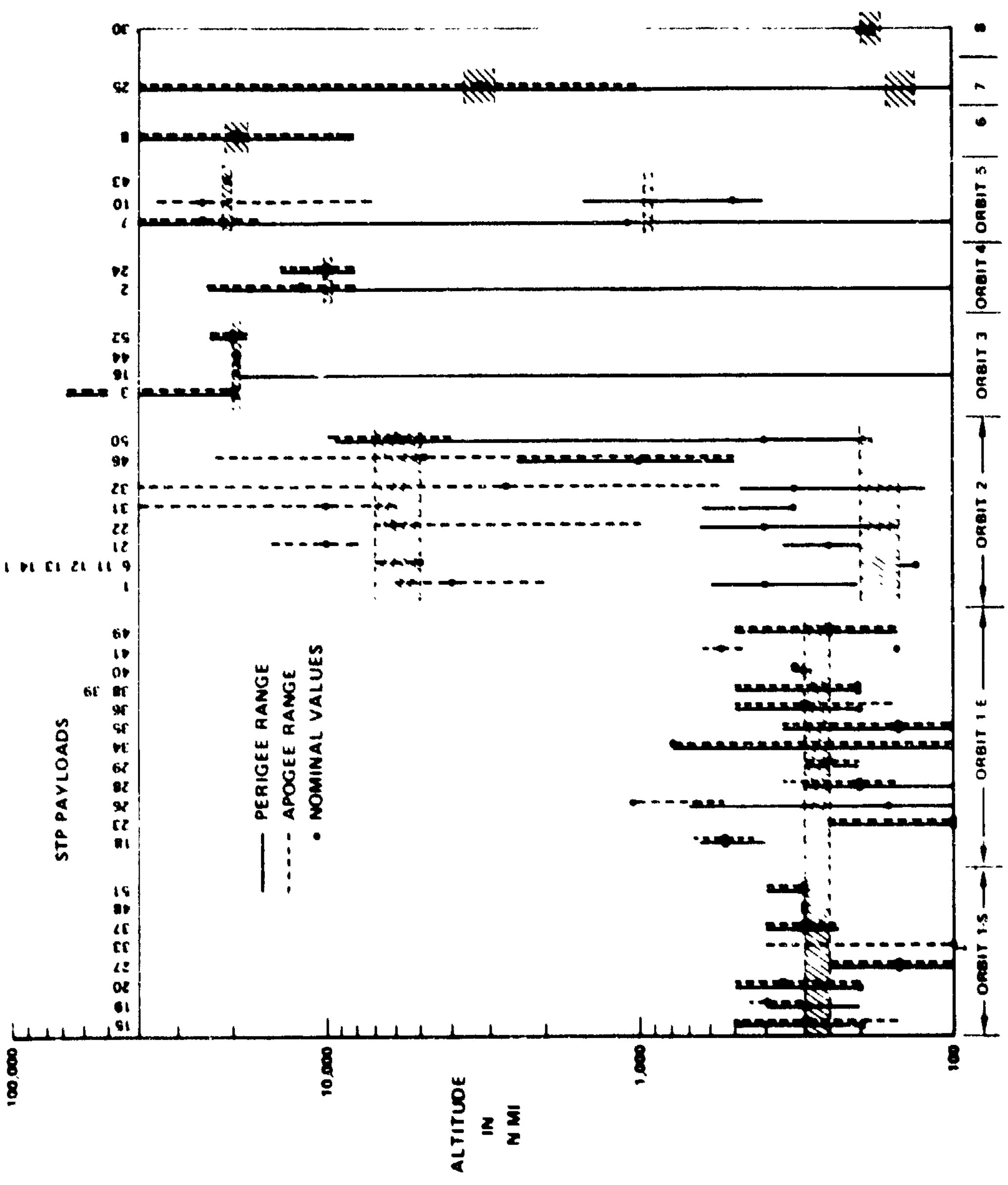

Fig. 5 —Baseline Space Test Program orbit options

Table 6

SPACECRAFT MISSION CAPABILITY

Space Test Program Payloads (Bluebook Page Number)	Spacecraft							
	AEM (150 lb, <1000 n mi)	L-AEM-S	L-AEM-BL	L-AEM-P	STPSS-S	STPSS-LC	STPSS-P	MMS-AF
1				X		X	X	X
2				X		X	X	X
3[a]				X		X	X	X
6				X		X	X	X
7		X		X	X	X	X	X
8[b]				X		X	X	X
10		X		X	X	X	X	X
11				X		X	X	X
12				X		X	X	X
13				X		X	X	X
14				X		X	X	X
15				X		X	X	X
16		X		X	X	X	X	X
17				X		X	X	X
18	X		X	X		X	X	X
19				X			X	X
20				X			X	X
21				X		X	X	X
22				X		X	X	X
23	X	X	X	X	X	X	X	X
24		X		X	X	X	X	X
25				X		X	X	X
26	X	X	X	X	X	X	X	X
27		X		X	X	X	X	X
28		X	X	X	X	X	X	X
29	X		X	X		X	X	X
30				X			X	X
31[c]		X		X	X	X	X	X
32				X		X	X	X
33				X		X	X	X
34	X	X	X	X	X	X	X	X
35	X		X	X		X	X	X
36	X		X	X		X	X	X
37				X		X	X	X
38	X		X	X		X	X	X
39	X		X	X		X	X	X
40[c]		X	X	X	X	X	X	X
41[d]			X	X		X	X	X
43				X			X	X
44[e]				X		X	X	X
46[f]		X		X	X	X	X	X
48				X			X	X
49	X		X	X		X	X	X
50				X		X	X	X
51				X		X	X	X
52				X		X	X	X
Total payloads	10	12	13	46	12	41	46	46

[a]Payloads 4 and 5 eliminated--excessive altitude (69,000 n mi) and already flown.

[b]Payload 9 eliminated--excessive altitude (69,000 n mi).

[c]Assumes that only a portion of the payload is spun.

[d]Payload 42 eliminated--inconsistent data.

[e]Payload 45 eliminated--SIRE mission exceeded TRW STPSS design power level.

[f]Payload 47 eliminated--insufficient data.

STPSS (STPSS-LC) spacecraft can handle 89 percent of the payloads, whereas all three precision configurations (L-AEM-P, STPSS-P, and MMS) can handle all of the payloads.

Consistent with the Work Statement guidelines, we have assumed that those payloads that require spinning can be accomplished on a three-axis-stabilized spacecraft by allowing portions of the payload to spin. It is also assumed that the total payload integration costs for the mission model will not vary substantially as a function of the procurement option. A further assumption that was made is that those payloads having accuracy requirements in excess of the capability of the L-AEM-P, STPSS-P, and MMS really have attitude determination requirements rather than pointing accuracy requirements.

In the analysis of program costs that follows (Sec. IV), only those spacecraft and combinations of spacecraft that can accommodate the entire Space Test Program mission model were considered. The various procurement options will be evaluated on a constant performance basis.* To expand the mission model up to 114 payloads of the nominal case, a linear extrapolation of the characteristics of the 46 payload model given in the bluebook has been used.

SPACECRAFT AND LAUNCH COSTS

Spacecraft

Estimating the costs of the AEM, L-AEM, STPSS, and MMS presented an interesting problem because each was at a different stage of development. The AEM was well along in the development process, and the contractor, Boeing, was confident that the ceiling price would not be exceeded. Should the L-AEM be developed, Boeing would have AEM experience to build on. The three STPSS configurations were the result of a short study by TRW, and they lacked the specificity of the AEM and MMS. Since preliminary designs generally change, and changes generally

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*It is clear that some procurement options, such as the pure MMS option, will have excess capability. However, no attempt has been made to determine the value of this excess capacity for the Space Test Program.

increase cost, one needs to question whether an estimate of current STPSS designs would be representative of final cost. The MMS was somewhere between the AEM and STPSS; some hardware had been developed, design was complete, and NASA had gone out to industry for bids. Thus the situation was one in which some costs were known, some were partly known, and others were unknown. It was necessary to develop estimates that would reflect relative differences in the size, complexity, and capability of the spacecraft as currently specified.

Recurring Costs. An examination of existing parametric cost-estimating models showed that they had been developed from data on conventional spacecraft, i.e., spacecraft for which low cost was not a dominant consideration. Thus a procedure was required that would provide comparable estimates of the various spacecraft but estimates in keeping with current experience. The method adopted was to develop a model calibrated to reflect AEM experience, in essence saying that AEM costs are known and those of the other spacecraft can be extrapolated from that base using conventional scaling techniques. Estimates of Unit 1 cost for each spacecraft are shown in Table 7. These estimates include allowances for modifications of the AEM and MMS to meet Air Force requirements.

By using the same model for all estimates it can be argued that they should be comparable. The point has been made, however, that such a procedure ignores an important element of spacecraft cost. The AEM and L-AEM are not comparable to the STPSS and MMS, because they consist of a single module produced by a single contractor. With two, three, or even four contractors involved in production, integration, and test of the different modules, additional costs could be incurred. Whether that would produce a significant cost difference is a matter of some disagreement, but the assumption made here is that it would not. While that assumption may favor the STPSS somewhat and the MMS even more, if it had any effect at all it would be to strengthen the conclusions of the study.

As a check on the spacecraft estimates, they were plotted against weight (Fig. 6) and compared with a regression line from the *SAMSO Unmanned Spacecraft Cost Model* (third edition).[29] All are within the

Table 7

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

standard error of estimate (the dashed lines) of the regression line. The AEM has a higher relative cost than the other spacecraft because of a lower percentage by weight of structure. All other spacecraft have costs lower than would be predicted by the SAMSO model, and that seems appropriate because the model was derived from data on conventional spacecraft.

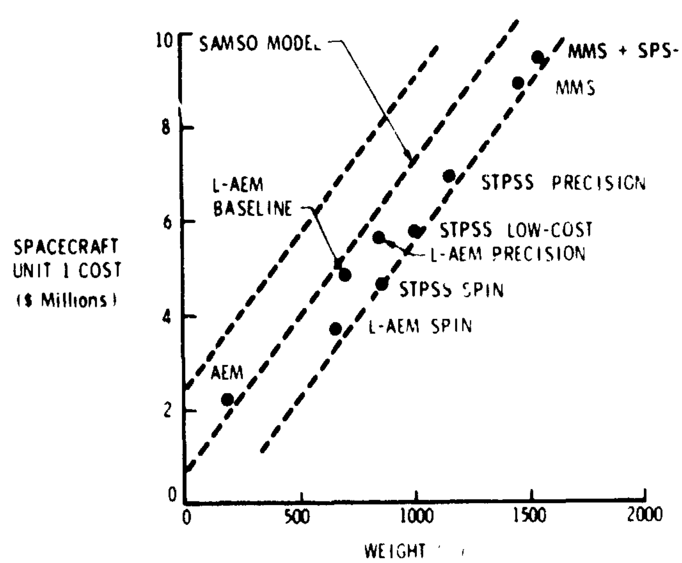

Fig. 6—Spacecraft unit cost versus weight

Cost-quantity effects in spacecraft depend more on the size of each individual procurement than on the cumulative quantity procured. A block buy of six may reduce total cost by 20 percent, but a buy of six spacecraft one at a time may produce no cost reduction.* Since the manner of procurement could not be specified in this study, cost reduction was related to annual production rate according to the following empirically derived schedule:

Annual Production	Cost (%)
1	100
2	90
3	87
4	85

In estimating spacecraft costs it was further assumed that:

1. Procurement of the AEM by the Space Test Program Office begins at Unit 9. The first eight units will be procured by NASA before 1980.
2. Procurement of the MMS by the Space Test Program Office begins at Unit 5. The first four units will be procured by other agencies before 1980.
3. NASA procures two MMS per year during the decade considered. The Air Force buy is incremental to NASA procurement.
4. The Air Force procures MMS for SIRE, which means that an Air Force-compatible communication and data handling subsystem would be developed for MMS and would be available to the Space Test Program Office for the missions discussed in this study at no additional cost.

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*A block buy usually means accepting delivery from the contractor of all the spacecraft at one time or over a short period of time. The alternative is to spread the delivery uniformly over a much longer time period.

<u>Nonrecurring Costs</u>. Nonrecurring costs were estimated for the STPSS and L-AEM only; for the other spacecraft those costs would not be borne by USAF and would be irrelevant in comparisons of USAF outlays. The *SAMSO Unmanned Spacecraft Cost Model* provided the basic estimating equations, which were derived from a sample of up to 28* space programs over the period 1959-1972. Some spacecraft had been 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.

An initial assumption was that the first spacecraft manufactured and tested would be a flight model, i.e., there would be no qualification test model. It was later decided that a qualification test model would be desirable, and the estimates were modified to reflect that decision. The higher estimate is the one included in the final program costs.

For the L-AEM nonrecurring costs the basic estimate provided by Boeing was scaled up to include a test model, but as shown in Table 8, the difference between L-AEM and STPSS nonrecurring costs is striking. When L-AEM costs are estimated in the same manner as those for the STPSS, the differences are far less. It is possible to construct a rationale for some degree of difference, e.g., L-AEM would be a follow-on to AEM, and there would be some transfer of learning. Also, STPSS consists of modules that are developed separately, then integrated, and each module is essentially a separate spacecraft. Configuration changes in L-AEM are handled on the basis of different kits rather than different modules. Nevertheless, the discrepancy between the estimates based on the SAMSO model and those based on Boeing figures is too great to be ignored. In the discussion of program costs in Sec. IV the impact of that discrepancy on the issue of spacecraft selection will be examined.

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*Sample size varied for each spacecraft subsystem.

Table 8

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

Launch Costs

The other major category of cost in the 10-year program considered is the cost to launch spacecraft and place them in orbit at the specified altitude and inclination. The basic launch vehicle is the space shuttle, but at present neither the cost nor the guidelines for allocating cost among users has been determined. Estimates of cost range from \$15 million to \$30 million, of which the users may pay all or nothing. The intent of the study was not to estimate launch costs but to examine whether those costs could influence the choice of spacecraft. Consequently, launch costs were assigned to each payload based on a range of assumptions: Space shuttle launch cost was \$15.4 million or \$30 million. Costs are allocated on a basis of weight or according to either of two NASA-proposed tariff schedules, or are not allocated at all, i.e., only a service charge is incurred.

In the initial phase of this study a NASA formula was suggested as a basis for prorating launch cost; it considered weight, length, inclination, and altitude as independent variables, i.e.:

$$\begin{aligned} SRU = {} & .00215 \text{ length} + .0238 \text{ length}^2 + .000203 \text{ weight} \\ & - .00000000169 \text{ weight}^2 - .000122 \text{ inclination} \\ & + .00442 \text{ inclination}^2 + .00109 \text{ altitude} + .000232 \text{ altitude}^2 \end{aligned}$$

where SRU = Service Rendered Units, which may not exceed 100. It represents a percentage of total launch cost. Length is in feet, weight in pounds, inclination in degrees, and altitude in nautical miles. If the SRU exceeds 100 ft it is assumed to be truncated at 100.

A formula proposed since the earlier phase* consists of prorating the dedicated shuttle cost on the basis of whichever of the load-factor ratios below is larger:

1. $\dfrac{\text{payload length (in feet)}}{60}$**

2.*** $\dfrac{\text{payload weight (in pounds)}}{\text{shuttle orbital capacity (in pounds) to the desired inclination and altitude}}$

In this study, we have assumed a direct relationship between load factor, as determined above, and the cost factor for prorating the dedicated shuttle cost. In some formulations of this tariff rate, the load factor is multiplied by as much as a 1.4 cost factor; this has not been used in this study. Because the launch cost is very sensitive to payload length when using this NASA tariff, an attempt was made to minimize launch cost by placing payloads laterally rather than longitudinally in the shuttle bay whenever the payload length was less than 13 ft. Launch costs estimated using the above method are identified as the *modified NASA tariff*.

The other cost-allocation schemes considered were: a full allocation by weight, i.e.,

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*Private conversation with Mr. Edwin G. Dupnick at the Johnson Space Center of NASA, October 1976.

**Payload length is the sum of the lengths of the Space Test Program payload, spacecraft, and solid kick stages.

***For this study, nominal shuttle capacities of 65,000 lb for ETR launches and 39,000 lb for WTR launches have been used. A nominal altitude of 150 n mi has been used. Solid rocket kick stages are used to translate the spacecraft to higher orbits. Payload weight is the sum of the weights of the Space Test Program payload, spacecraft, and kick stages.

$$\frac{\text{payload weight}}{\text{shuttle orbital capacity}} \times \$15.4 \text{ million} ,$$

plus a service charge of $1 million; an allocation of only half the shuttle cost plus a service charge; and, a service charge only.

Kick Stages

A variety of solid propellant kick stages were required, and to simplify the task of assigning a cost to each kick stage a simple cost-estimating relationship was derived from the cost of several existing stages:

$$C = 2900\ W^{.585}$$

where C = stage cost in 1976 dollars, and
W = stage weight (lb).

Where the IUS was used, a cost of $4.3 million was charged.

IV. STANDARD SPACECRAFT ACQUISITIONS FOR THE AIR FORCE: PROGRAM COSTS AND CONCLUSIONS

PROGRAM COSTS

In this section, the total program costs are discussed for a variety of procurement options, each of which is capable of performing all of the Air Force Space Test Program missions. For this constant-performance comparison, program cost is used as the principal measure for distinguishing among procurement options. The analysis described in this section was accomplished 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 were defined partly as a result of the outcome of the first phase of this analysis; for that reason the sequential nature of the analysis is preserved in the discussion that follows. Finally, the conclusions are presented for the case study of the Air Force standard spacecraft procurement decision. All costs are in millions of 1976 dollars.

Nominal Case

A nominal case was defined 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 Air Force

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*As mentioned in Sec. III, the Work Statement for this study indicated that the number of payloads (defined as the set of experiments combined on one page of the bluebook)(26) to be flown per spacecraft could vary from a combination of 1 large payload plus 4 small payloads to as many as 12 small payloads. In Sec. III it was found that for the nominal size program (114 payloads), the average number of payloads per spacecraft would be about 6 but that it might increase to 7 or 8. For this study, this assumption has been treated as a maximum value rather than as an average value while allocating the Space Test Program payloads to specific spacecraft; this will be discussed later in this section when the sensitivity excursions are described.

Space Test Program position that its payloads always have a secondary status, they are always taken to an altitude of 150 n mi by the shuttle; solid rocket kick stages (not the IUS) are then used for translation into the proper orbits. Both ETR and WTR launches of the shuttle are considered. It has been assumed that the shuttle cost of $15.4 million will be prorated by weight and that a service charge of $1 million per launch will be made.

The number of spacecraft that would need to be procured for each of four different procurement options is shown in Table 9. The four options are: all-STPSS, all-MMS, AEM plus STPSS, and AEM plus MMS. An option consisting of all three types of spacecraft would not be cost-effective in view of the magnitude of the nonrecurring cost associated with providing the STPSS-P, given that the program already includes the MMS.

Table 9

NUMBER OF SPACECRAFT

(Nominal case)

Spacecraft Type	Procurement Options			
	STPSS	MMS	AEM/STPSS	AEM/MMS
AEM	0	[illegible]	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

It can be seen that the STPSS-S configuration is never 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 an STPSS-S spacecraft than to load up the STPSS-LC or STPSS-P spacecraft. When considering programs with a larger number of payloads, the spin configuration is included in the procurement mix.

The costs associated with these procurement options are shown in Table 10, broken out by the spacecraft, kick stages, and launch operations. The cost of the all-solid kick stages is nearly insignificant (about 2 percent of the total). Launch costs represent about 25 percent of the total cost.

Table 10

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

Payload Variations

Those results 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: (1) The maximum number of payloads per spacecraft was increased from 6 to 10; (2) the number of payloads in the program was allowed to range from 92 to 228; (3) the IUS was used as a kick stage for missions with large payload weights and high altitude requirements; (4) the percentage of shuttle costs prorated to Space Test Program payloads was varied from 0 to 100 percent; (5) criteria other than weight were used for allocating shuttle cost; (6) shuttle cost was increased from $15.4 to $30 million; and (7) lower development cost was assumed for the STPSS to reflect the elimination of the qualification test model. Of the above cases, maximum payloads per spacecraft, payloads in the Space Test Program, allocation criteria for launch costs, and shuttle cost were found to be the most important in terms of program costs.

The variation of total program cost with maximum payloads per spacecraft is illustrated in Fig. 7. As the maximum increases, the reduction in program cost for the all-MMS case is much larger than for any of the other options. This is partly because of the large payload

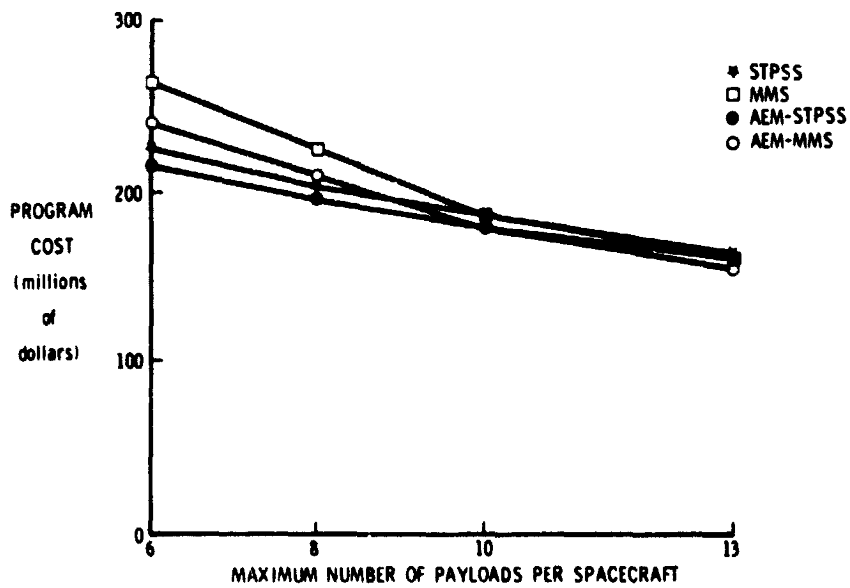

Fig. 7—Effect of the maximum number of payloads per spacecraft (nominal case)

capability of the MMS. The result is that the ability to distinguish between the procurement options on the basis of cost disappears when the maximum number of payloads increases above 10. *However, the total program cost is about 30 percent lower than in the nominal case (maximum number of payloads = 6) when the number of payloads is allowed* *to increase to 13.* That was found to be true across a wide number of excursions.

It should be noted here that assuming a maximum number of payloads per spacecraft of 13 results in an average number of payloads per spacecraft of only 5 to 8, depending on the procurement option. The largest benefit is from orbits 1 and 2 where the majority of Space Test Program payloads are scheduled to be flown. To illustrate that, Fig. 8 presents a detailed breakdown of the distribution of the actual maximum number of payloads per spacecraft by orbit for the all-STPSS procurement option. For orbit 1-S, for example, if the assumed maximum number of payloads per spacecraft is allowed to increase from 6 to 13, the actual maximum number of payloads assigned to a spacecraft increases from 5 to 10.* The difference between the actual number of payloads assigned to a spacecraft and the upper limit occurs in all orbits because of the limited number of payloads in each orbit. In orbit 1-S, for example, the mission model includes only 20 payloads, which were distributed evenly between two spacecraft when the assumed maximum number of payloads per spacecraft was increased to 10. Consequently, the average number of payloads per spacecraft for a given procurement option does not increase substantially as a result of allowing the assumed maximum number of payloads per spacecraft to increase from 6 to 13.

The main difficulty associated with increasing the number of payloads per spacecraft lies in the payload-integration area. Although the specific performance limits of each spacecraft were imposed while allocating payloads, payload-integration problems and costs were not explicitly examined. Based on the saving in program costs identified as a result of increasing the maximum number of payloads per spacecraft, it appears that a systematic study of the payload integration problems and costs would be useful.

Figure 9 illustrates the variation in program cost as a function of Space Test Program size. Here program size was doubled to 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.

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*While 13 payloads are never allocated to a spacecraft in the example shown in Fig. 8, this is not the case for other procurement options, especially those including the MMS.

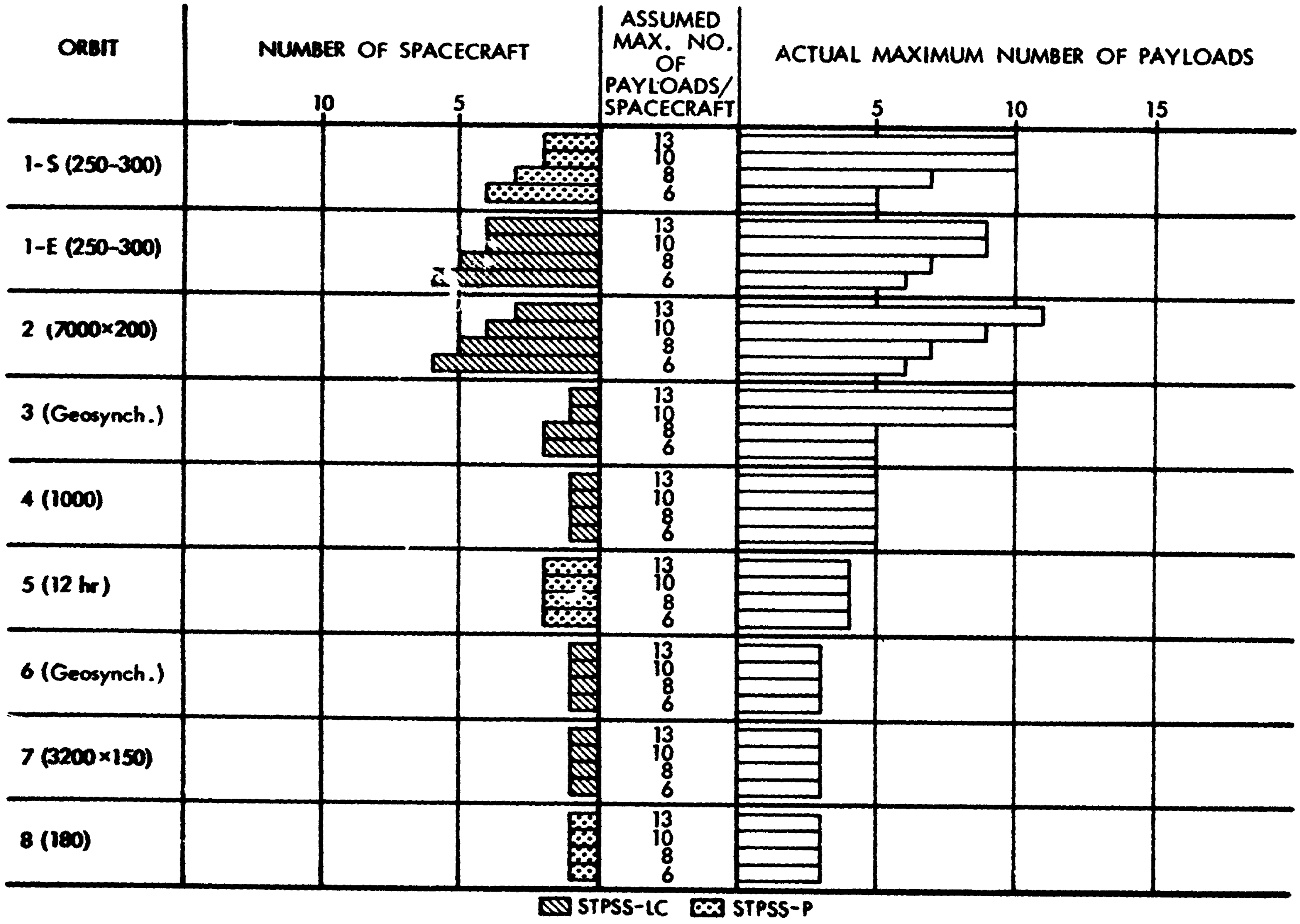

Fig. 8—All-STPSS nominal case

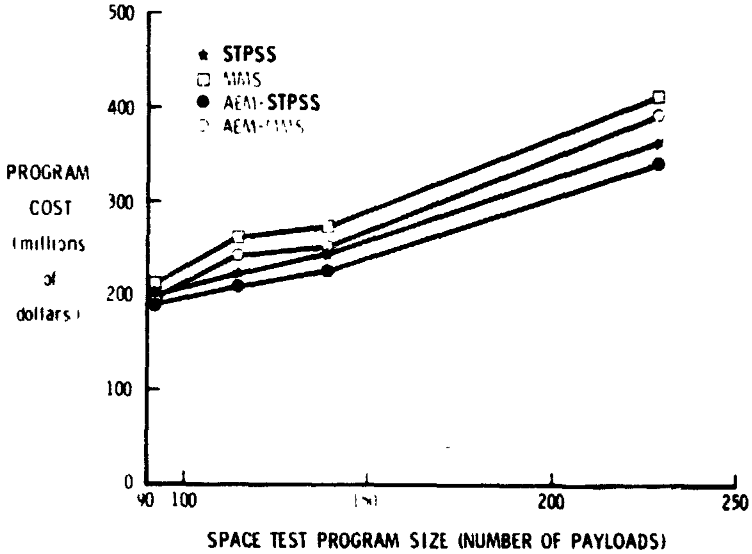

Fig. 9—Effect of Space Test Program size (nominal case)

As shown, no such effect was found. The ordering of the various procurement options remained unchanged, whereas the program cost increased nearly linearly.

Launch Cost Variations

Table 11 displays 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. The results of the variations considered are also shown in Table 11. For ease in reading the table, all costs more than 10 percent above the lowest cost in each row are enclosed in parentheses--all other costs are considered to be essentially the same.

In looking at the other cases it is clear that increasing the shuttle cost to $30 million per launch has no effect on relative results, although the magnitude of program costs increases about 15 percent. 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 conclusions either. The STPSS looks slightly worse

Table 11

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	(553)	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.

and the AEM/MMS slightly better, but the only definite conclusion is still that the MMS is not attractive when the maximum number of payloads per spacecraft is 6.

The effect of two different 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. Adaptation of a more recent tariff schedule, *modified NASA tariff*, altered these results somewhat; both the pure MMS and the 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.

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 10 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 tariff 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 or geosynchronous altitude operation. Of these, only the last promised a sizable impact on program cost because of the increased number of Space Test Program payloads that could be captured (from 22 to 72 percent). To obtain a first-order approximation of the cost of an AEM having such a capability, the cost of the STPSS cold-gas reaction control system was added to the cost of the basic AEM. Such a reaction control system would be needed for the AEM to operate at geosynchronous altitude. This configuration is referred to henceforth as the upgraded AEM.*

Table 12 compares the cost of upgraded AEM/STPSS and upgraded AEM/MMS combinations with those considered in the previous nominal case. In that excursion the upgraded AEM/MMS combination appeared to have program costs more than 20 percent below those of the other procurement options. 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, and (2) when the upgraded AEM is used in combination with the MMS, the nonrecurring cost of the STPSS is not incurred.

Table 12

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.

To test the sensitivity of the above result to the estimated cost of the upgraded AEM, nonrecurring cost was increased by $10 million and unit 1 recurring cost was increased from $2.44 million to $4.88 million. The results, also shown in Table 12, indicate that the upgraded AEM/MMS combination continues to be the preferred procurement

*We have assumed that the upgraded AEM is limited to a payload of 150 lb, a data rate of 8 kbps, experimental power of 40-50 W and no encryption capability--the same as the basic AEM.

option.* Other candidates become competitive only when the program size is expanded to 228 payloads.

In this last case, an upgraded AEM spacecraft with costs of that magnitude would probably also have greater payload, power, and data rate capabilities. Furthermore, it would probably also be a redundant design to minimize the single-point failure modes. *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 the Boeing Company 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. Revised Boeing cost estimates (as described in Appendix A) were used to compute program costs for a variety of procurement options including the L-AEM. Table 13 shows those options compared with others for the nominal case. Where the L-AEM is used, all three configurations (baseline, spin, and precision) were considered; but for the same reasons discussed earlier for the STPSS, the spin configuration is included only when the mission model includes 228 payloads.

Two procurement options are included that use the MMS but none that uses the STPSS in combination with the L-AEM. There are two reasons for this. First, the MMS has been used primarily when its use would decrease the total number of spacecraft necessary to fly the designated payloads as a result of its large payload capability (4000 lb); the payload capabilities of the STPSS and L-AEM are identical, so we always chose the lower-cost L-AEM. Second, consideration of both the L-AEM and STPSS in a single procurement option would mean that the nonrecurring cost associated with developing both spacecraft would have to be included in the total program cost.

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*The use of the modified NASA tariff increases the program cost of the MMS and AEM/MMS options relative to the other options shown in Table 12, and thereby would not alter this observation.

Table 13

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.

Table 13 illustrates that all of the procurement options that use the L-AEM are preferred over those made up of the three original spacecraft. In fact, 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.

In Sec. III, the uncertainty surrounding the estimates of the nonrecurring costs of the L-AEM spacecraft configurations was discussed. The nominal case in Table 13 includes the lower set of estimates, because it is felt that they more closely reflect the nonrecurring costs of the L-AEM. However, the effect of higher nonrecurring costs for the L-AEM on the choice of a procurement option has been examined. The second set of estimates in Table 13 shows that when L-AEM development cost is increased, the AEM-STPSS combination is also attractive for some conditions. As mentioned earlier, however, it is not known whether the L-AEM would be developed (if it is developed) by NASA, the Air Force, or jointly. The L-AEM would probably be suitable for NASA missions as well as for the Air Force Space Test Program missions used in this analysis. In the case described here, it is assumed that the Air Force would underwrite all the nonrecurring costs of the L-AEM. If either of the other two development alternatives was followed, the attractiveness of the L-AEM would be enhanced. Consequently, *it is concluded from these excursions that development of the L-AEM would be more appropriate for* *the Air Force's Space Test Program than the development of the STPSS and that the use of the L-AEM in combination with the AEM or the MMS would constitute alternative cost-effective procurement options.*

In the analysis of the L-AEM spacecraft for Air Force Space Test Program missions, the L-AEM-BL configuration was found to be able to accommodate only 28 percent of the missions, primarily because of limitations on its maximum operating altitude and orientation. Consequently, in the L-AEM procurement options the more expensive and more versatile L-AEM-P configuration has been used when the L-AEM-BL configuration would have been adequate except for those limitations. To evaluate the effect of increasing the capability of the L-AEM-BL configuration to allow geosynchronous altitude and sun-oriented operations, the cost of the L-AEM-BL was increased to allow for an increase in size of the hydrazine reaction control system.* Options containing this configuration are labeled L-AEM-1.

Table 14 compares the four procurement options based on the L-AEM, with four options based on the L-AEM-1 design. As expected, the program costs for the procurement options based on the L-AEM-1 design are lower than those based on the L-AEM design; but, given the accuracy of the spacecraft designs and cost-estimating procedures, most of the options are comparable. *This means that giving the L-AEM-BL more capability is worthwhile but not essential in deciding on the procurement option for conducting the Air Force Space Test Program missions.*

Earlier in this section, it was shown that an *upgraded AEM* in combination with the MMS provided the lowest total program cost. The upgraded AEM differs from the L-AEM in that it has the payload, data rate, and power limitations of the original AEM; L-AEM capability is greater in all of these areas. Table 15 displays a comparison of the program costs for the four procurement options derived from the L-AEM and the two options using the upgraded AEM. Again, the upgraded AEM/MMS procurement option is the preferred solution (as indicated by the parentheses), but by less of a cost margin than before. This result

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*It is assumed that the additional sun sensor required for sun orientation would be part of the payload package and therefore would not affect the cost of the L-AEM-BL.

Table 14

EFFECT OF UPGRADING THE L-AEM[a]

(L-AEM-1)

Case	No. of Payloads in Program	Max. No. of Payload per Spacecraft	Program Cost ($ millions)							
			L-AEM	AEM/ L-AEM	L-AEM/ MMS	AEM/ L-AEM/ MMS	L-AEM-1	AEM/1 L-AEM-1	L-AEM-1/ MMS	AEM/ L-AEM-1/ MMS
Nominal	114	13	135	133	139	132	130	127	135	129
	114	6	185	181	187	186	174	171	177	178
	228	13	198	208	(212)	199	190	200	(211)	194
	228	6	(306)	297	(373)	(323)	292	276	(365)	(315)

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

Table 15

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.

occurs for the same reasons as stated earlier (p. 75), except in this case the L-AEM spacecraft is displaced by the cheaper upgraded AEM rather than the STPSS. However, the limited capability of the upgraded AEM, i.e., 50 W of power and a maximum payload of 150 lb, makes this conclusion somewhat tenuous in view of the uncertainty associated with Air Force Space Test Program missions for the 1980 to 1990 period. Any major growth in payload power or weight requirements would mean procurement of more MMS and fewer upgraded AEM; that would quickl decrease any total program cost advantage that the option might have. To illustrate this, three to four additional MMS in the upgraded AEM/MMS option would eliminate the difference in program cost between the pure L-AEM option and the upgraded AEM/MMS option for the nominal case.

In addition, one of the current Air Force requirements of new spacecraft is to minimize single-point failure modes in the spacecraft design. As indicated in Appendix I, that was one of the specifications for the L-AEM design and has been accounted for in its recurring cost. To illustrate the effect on program cost of increasing AEM redundancy so that the L-AEM and the upgraded AEM options will be more comparable, an excursion was made in which it was assumed that whenever an AEM or upgraded AEM is included in an option, two spacecraft would be flown in the same shuttle.* The results are shown in Table 15. It can be seen that for the case of 114 payloads and 6 payloads per spacecraft, several L-AEM options are within the lower 10 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 option could be lost in either of the two ways mentioned above, i.e., by growth in the power and/or weight requirements of the Air Force Space Test Program mission model, or by spacecraft design requirement for minimizing single-point failure modes, *it is concluded that the L-AEM spacecraft, or some very similar design, would provide a basis for minimizing the Air Force Space Test Program costs.* The L-AEM could be used individually or in combination with the AEM and/or the MMS. This conclusion is reinforced by the analysis of a variety of procurement options that considered the uncertainties in the spacecraft costs and designs, the Air Force Space Test Program mission model, and the shuttle cost and tariff schedule.

The procurement results for the nominal case that include the L-AEM are shown in Table 16. A comparison of these options indicates

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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 16

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-AF	--	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.

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 program.

The distribution of the program cost of the pure L-AEM procurement option is illustrated in Fig. 10. About $134 million is spent procuring spacecraft and solid rocket kick stages. The launch costs are shown for both WTR and ETR. For the ETR launches, the launch costs are very similar for the three allocation schemes. However, the original NASA tariff rate that is a function of spacecraft payload weight and length, altitude, and orbital inclination imposes a disproportionally high cost on WTR launches. For the $15.4 million shuttle case, the WTR launch costs

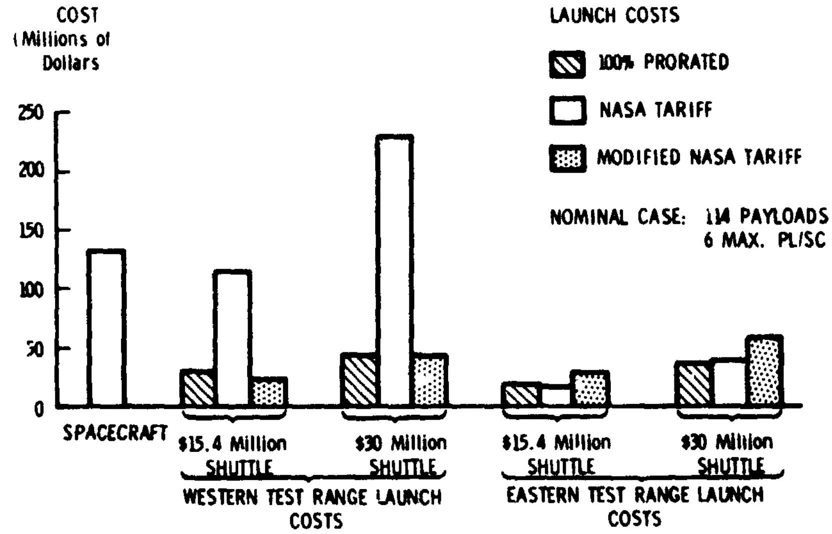

Fig. 10—Distribution of program costs (L-AEM option)

exceed $100 million. The most significant factor is the orbit inclination. The use of the modified NASA tariff rate redresses this drastic cost imbalance. The variation in shuttle cost considered in this study does not appear to greatly alter the launch costs, providing the earlier NASA tariff rate is not used.

CONCLUSIONS

Four major conclusions have been drawn from this case 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 the STPSS development.

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 Space Test Program mission model.

C-2

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 a 30 percent lower program cost; the major portion of this savings occurs 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 case 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 dissertation, but it probably would not affect the spacecraft procurement decision.

V. NASA-DOD COOPERATION: ORGANIZATIONAL OBSERVATIONS FROM THE CASE STUDY

In this section, the NASA and DoD organizational interactions that occurred throughout the case study are discussed within the context of the results of the cost-benefit analysis for each phase of the study. Observations are made concerning the direction the Air Force and NASA might take with regard to the Air Force decision on acquisition of a standard spacecraft and how this direction might be influenced by the economic analysis and organizational factors. Observations are also made on the impact of the future dependence of the Air Force on NASA's space shuttle for launching its payloads. Finally, some of the organizational factors that contributed to the successful completion of this case study are discussed.

MOTIVATIONS FOR PARTICIPATING IN THE STANDARD SPACECRAFT STUDY

Although the procurement decision analyzed in the case study discussed in Secs. III and IV was strictly that of the Air Force Space Test Program Office, two program offices at the NASA Goddard Space Flight Center became voluntarily involved to the extent that they shared in the funding of the study and provided access to the details of their spacecraft designs and costs. It was clear from the start of this study that the NASA program offices were interested primarily in having their respective spacecraft designs considered for the Air Force Space Test Program missions and hoped that by cooperating in the study they could best ensure that their designs were represented fairly. This allowed them to argue their case at all of the progress reviews, thereby avoiding waiting until the study results were published before reacting to the outcome.

The discussion of the behavior of the Air Force and NASA that follows must be cast within the context outlined in Sec. II for NASA-DoD cooperation in space. This context includes 15 years of operating experience with the Space Council and AACD. This coordination machinery has demonstrated the authority on a number of occasions to inquire into a wide range of NASA-DoD activities to ensure that unnecessary duplication does not occur. For this study, the AACB is the appropriate coordinating body that could be expected to inquire into the Air Force procurement of a new standard spacecraft. As will be discussed later in this section, the AACB inquiry took place between the first and second phases of the study. In addition to the pressure of the AACB, the Air Force faced the traditional budgetary cycle that involves the DoD and the Office of Management and Budget (OMB). The budgetary process consists of a detailed review of both expenditures and objectives on a line-item basis. The Air Force usually justifies expenditure of funds on a "new start" by demonstrating its economic feasibility, especially when there appears to be alternative means to accomplish the same task. While the OMB obstacle loomed large for the Air Force Space Test Program Office, it also represented a significant factor in shaping the behavior of the NASA MMS Program Office as well. At the time of this study, NASA authorization for procurement of the complete MMS program had not yet been given and it was possible that the OMB review of this line item in NASA's budget could be mooted by having additional support for the required expenditures or additional applications for the MMS, i.e., Air Force Space Test Program missions.

In addition to the OMB and AACB, the staff of the Senate Committee on Aeronautical and Space Sciences inquired at the outset of the study about the objectives of the study, the motivation of the Air Force Space Test Program Office regarding the developmental responsibility for the new spacecraft, and the objectivity and independence of The Rand Corporation in accomplishing this study. As far as is known, no further Congressional inquiry has been made concerning this study of the Air Force standard spacecraft procurement decision. However, should the Air Force go forward with its own standard spacecraft design, the Congressional inquiry may be reopened as part of the budgetary review.

MMS Program Office

Participation by the MMS Program Office was not without risk, because this study, while concentrating on the relative accuracy of the costs of the candidate spacecraft designs, did produce estimates of the absolute procurement cost of the MMS. As mentioned above, the risk for the MMS program stemmed from the fact that NASA was not firmly committed to the procurement of the MMS at the outset of this study and the procurement cost of the MMS was to be a major consideration in NASA's decision. Too high a cost estimate for MMS from this study might have created problems for the MMS Program Office with respect to the timing of its request for proposals for the major spacecraft subsystems. On the other hand, the advantage of participating in the study was twofold: First, an independent validation of the MMS cost estimates relatively close to those that NASA was quoting would provide substantiation for the MMS program; and second, if the study results showed that the Air Force procurement option for the Space Test Program should include some MMS, then the MMS program could use this information to help justify going forward with MMS.

The program manager of the MMS had funded a substantial amount of fabrication, design, and subcontractor work before this study, providing him with the confidence in the range of the cost estimate outcomes. This preliminary work was a valuable input to the Rand study.

AEM Program Office

The situation with the other NASA Program Office (AEM) was substantially different from that of the MMS Program Office. The AEM program was under contract and two missions had been justified and approved by NASA. Consequently, the AEM Program Office not only knew what the procurement costs were going to be, but also had an approved program. Any application of the AEM to the Air Force Space Test Program would be an augmentation for the AEM program. We were interested in including the AEM in this study not only because of its potential application, but also because it represented a base case for our relative cost and technology analyses.

The initial position of the AEM Program Office, described above, changed. After initiation of this study, the AEM Program Office indicated that they were also interested in the application of a larger diameter AEM-type spacecraft that would be shuttle-compatible. This larger spacecraft was viewed by NASA as a small MMS (SMMS) that would be the follow-on spacecraft for the AEM. The introduction of this spacecraft (L-AEM) into the study created a problem with respect to reporting the results of the initial study. The difficulty centered around the Air Force requirement to make procurement decisions during the summer of 1976 for the spacecraft that would be used on the initial Air Force shuttle flight. The L-AEM spacecraft design had not been defined technically; this would take two months of study by Boeing and would thereby postpone the Air Force decision point.*

One interest of the AEM Program Office in having the L-AEM design considered in the Rand case study was based on the hope of providing some justification for initiating the SMMS program, albeit for Air Force missions. At the time of this study, the AEM Program Office had not established a NASA requirement for the SMMS.

As indicated in Sec. IV, the results of the first phase of the case study illustrated that a spacecraft having some of the characteristics of the L-AEM (the upgraded AEM) would be part of the preferred procurement option for the Space Test Program missions (see Table 12). Consequently, it was our feeling that consideration of the L-AEM spacecraft should be encouraged because it offered substantial cost savings for the Air Force, even if it meant postponing the midsummer Air Force procurement decision.

Air Force Space Test Program Office

The Air Force Space Test Program Office had for several years contracted for individual spacecraft designed to handle a specific set of experiments. This involved contracting for the launch vehicle, spacecraft development, and payload integration. As discussed in Sec. III, its interest in the standard spacecraft approach for carrying out its missions centered around the availability of the space shuttle and the possibility of realizing substantial budget savings by applying its low-cost design philosophy to a standard spacecraft design. The Space Test Program Office had been selected for one of the first Air Force missions to fly on the shuttle, hence its critical schedule problem if it were to use a standard spacecraft design.

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*NASA funded Boeing during the spring of 1976 to make a preliminary design for the L-AEM spacecraft and to estimate its cost using the same approach as used for the AEM spacecraft.

The Air Force had studied the standard spacecraft approach for several years and was convinced that substantial savings could be realized, but to be able to support this position during the FY 77 budget review it needed an independent economic assessment, hence its interest in having the Rand study supported.* The AACB panel on unmanned spacecraft also supported the need for an economic evaluation of the various standard spacecraft of both NASA and DoD that might be applicable for the Air Force Standard Test Program missions.

While the Space Test Program Office emphasized throughout the study that it was *not* necessarily interested in an outcome that included its standard spacecraft design (STPSS), this position was, to some degree, contrary to the role that the Space Test Program Office had played in carrying out its missions in the past. As indicated earlier, it had been involved largely in funding the development of its own spacecraft. The interaction that occurred throughout the study verified that the Air Force initial emphasis was indeed valid.

Rand Corporation

There were several motivations for Rand's participation in this study. First, although the standard spacecraft procurement decision

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*Concurrent with the Rand study of the standard spacecraft, but independent of it, the Air Force Space Test Program Office and NASA Low-Cost Systems Office jointly funded a cost study with Aerospace Corporation that compared the MMS and STPSS for one of the upcoming missions, i.e., the Solar Maximum Mission (SMM).[30] The spacecraft cost estimating approach used by Aerospace relied upon the SAMSO cost model[29] directly without adjusting the results for the use of flight-proven subsystems or other low-cost experience; this resulted in a unit cost for the MMS about twice as high as that used in the Rand case study (Fig. 6, Sec. IV). Although we were not privileged to the reconciliation of these divergent cost estimates by the Air Force and NASA, we understand that the Aerospace cost estimates were accepted as being very conservative and could be considered as an upper bound, assuming that these spacecraft are purchased in the normal manner that other DoD spacecraft are purchased. The successful experience of the Air Force Space Test Program in acquiring individual spacecraft at a cost considerably less than that estimated using the SAMSO model tends to validate the magnitude of the Rand cost estimates. A recent check with the NASA MMS Program Office confirmed that the industrial cost proposals for the development and production of the three major systems of the MMS are in fact close to those estimated by Rand.

was not a major factor in the Air Force's role in carrying out its national securitv mission, it represented a decision involving several millions of dollars; a savings of a few percent, especially during an era of tight budgets, would make more funds available for other Air Force projects. Second, the study was in an area where Rand had recognized competence, i.e., technological-economic analyses of space systems, and the objectivity needed to evaluate the alternatives. Furthermore, the availability at Rand of the analytical skills needed for the study made it possible for the study to be undertaken within a very short time frame.* Third, as is the case in many studies, Rand's participation in this study provided the opportunity for updating and expanding our cost and technical data bases for unmanned spacecraft; an area that clearly has become the main Air Force and NASA approach in space research and operational systems since the near-term prospects for U.S. manned spaceflight (except for the space shuttle) have dimmed from what they were during the 1960s.

ORGANIZATIONAL INTERACTIONS AFTER THE FIRST PHASE OF THE STANDARD SPACECRAFT STUDY

As indicated in Sec. IV, the first phase of the case study did not include the Boeing-designed L-AEM spacecraft. The results from this phase of the study indicated that the Air Force's preferred procurement option consisted of a combination of MMS and an upgraded AEM design. If the upgraded AEM design did not become available, as described in Sec. IV, then our results indicated that the Air Force could pursue the development of its STPSS design without encountering an economic penalty.

Armed with this conclusion, plus a healthy skepticism of the willingness of NASA (1) to provide the MMS on the schedule necessary for meeting the Air Force's shuttle flight and at a cost approaching that used in the Rand study, and (2) to upgrade the AEM spacecraft as indicated, the Air Force Space Test Program Office sent forward through

*Although the study took eight months to complete because of the study extension (consideration of the L-AEM), the Air Force needed results within four months; this corresponded to the end of the first phase.

Air Force Headquarters to NASA a *Memorandum of Agreement on the Procurement of USAF Designated Small Multi-Mission Modular Spacecraft Systems Between the National Aeronautics and Space Administration and the Department of Defense* (See Appendix J).

This memorandum essentially called for NASA to underwrite the development of the SMMS having capabilities compatible with the Air Force requirements but determined jointly by NASA and DoD. The DoD agreed to purchase a block of the SMMS for the STP missions, paying only the recurring costs of the SMMS. The Air Force agreed to make payments to NASA three years in advance for subsequent spacecraft delivery. The purpose of an advance payment of $1 million was to relieve NASA's immediate budget problems that prevented NASA from initiating the development of the SMMS with FY 77 NASA funds. Such a delayed development would jeopardize the Air Force Space Test Program's initial shuttle schedule.

NASA's rejoinder to the Air Force-proposed Memorandum of Agreement stated that (1) a joint NASA/USAF working group reviewing the SMMS concluded that an agreement can be reached on a set of joint technical requirements; (2) NASA is in no position to initiate the SMMS program because NASA mission requirements will not support new-start funding for either FY 77 or FY 78; and (3) based on the results of the first phase of the Rand study, NASA would make available the MMS to meet the Air Force's March 1979 shuttle launch date, and would consider upgrading the AEM to meet the Air Force requirement, but that NASA was unable to fund such a modification. It should be noted that no specific mention was made about the Air Force-proposed advanced funding of $1 million.

As of September 1976, the Air Force was not intending to follow up NASA's offer because NASA apparently was not willing to quote a price for the MMS and because NASA's offer left the Air Force without assurance that the upgraded AEM would ever be developed by NASA. In the latter case, the Air Force could be facing a total program cost of about $100 million more than if the upgraded AEM was developed.* Given a procurement

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*The estimated program cost for the MMS/upgraded AEM option is $146 million, as compared to $222 million for the pure STPSS option, $263 million for the MMS option, or $240 million for the AEM/MMS option (see Sec. IV, Table 12).

cost of this magnitude, the pure STPSS option would appear more attractive to the Air Force simply because, as an Air Force-run program, it minimizes the need for interagency coordination.

While the Air Force Memorandum of Agreement was clearly an effort to gain NASA's commitment to provide a standard spacecraft capable of meeting the Air Force requirements and schedule, it was also an important organizational step demonstrating to OMB and the AACB that the Air Force was not necessarily committed to developing its own standard spacecraft, providing a joint NASA-DoD agreement could be reached. The significance of this bargaining position is reflected in the alteration in NASA's position regarding the availability of new-start funding to support the development of the SMMS. As mentioned above, NASA's initial response was that new start funding would not be available until FY 79. At the August meeting of the Unmanned Spacecraft Panel of the AACB where the Air Force presented its requirements and support for the SMMS, NASA's response was that new start funding might be available in FY 78--one year earlier than its first position--and that interim solutions to meet the Air Force needs for the first space shuttle launch were being examined.

ORGANIZATIONAL INTERACTIONS AFTER THE FINAL PHASE OF THE STANDARD SPACECRAFT STUDY

As indicated in Sec. IV, the incorporation of the L-AEM spacecraft as designed by Boeing created a dominant solution for the Air Force Space Test Program missions that used the L-AEM spacecraft and drastically altered the results of the first phase of the study by eliminating the MMS from the preferred procurement option. While this result had little impact on the progress of the MMS program,* it provides the AEM Program Office with some justification for the early start of a new spacecraft development. Unfortunately, NASA had already taken a negative position on the SMMS (or L-AEM), as discussed earlier, and the AEM Program Office was somewhat concerned about the suitability of the L-AEM design. As it

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*During the summer of 1976, the approval for the MMS Program Office to secure proposals for the three major subsystems was forthcoming. While use of the MMS by the Air Force would have been beneficial for the MMS Program Office, it was not essential.

turns out, NASA had agreed to the Air Force specifications for the L-AEM design without apparently realizing that the resultant Boeing design might resemble the STPSS design rather than reflecting the AEM heritage as an upgraded AEM. Consequently, even the AEM Program Office was not interested in pursuing the development of the L-AEM as specified by Boeing.

As for the Air Force, the similarity of the L-AEM spacecraft to the STPSS has reintroduced the possibility that the Space Test Program Office should develop its own standard spacecraft, especially since NASA was reluctant to pursue the development of the SMMS or L-AEM without first justifying it for NASA missions. Following the conclusion of the Rand study, the Air Force Space Test Program Office issued a request for proposals for the spacecraft to support its first shuttle-launched missions. Whether or not the spacecraft designs for these missions will represent the beginning of an Air Force standard spacecraft design must await the outcome of a number of future Air Force decisions. For example, the Air Force has informed the contractors bidding on the spacecraft for their next two Space Test Program missions that the criteria for evaluating their proposals will include special credit for designs that reflect evidence of standardization. While the value of this additional credit was not available to Rand, it is not exactly clear how much of a spacecraft weight and cost penalty the contractors are willing to risk to provide the excess performance capability needed for a standard spacecraft design. Furthermore, Boeing, the designer of both the AEM and L-AEM, is reexamining its corporate position on continuing to design and develop unmanned spacecraft. In any event, it appears that the possibility of procuring NASA spacecraft for the Air Force Space Test Program will be determined on an individual basis and will certainly depend on whether the Air Force follows a procurement strategy that evolves into a standard spacecraft of its own design.

SPACE SHUTTLE-RELATED ORGANIZATIONAL PROBLEMS

Aside from the spacecraft procurement issue, the Rand case study touched on a couple of space shuttle-related issues. Beginning in 1980, the Air Force is committed to the use of the space shuttle as its primary launch vehicle. While the Air Force has considered the procurement of two shuttles for its own use, it appears at this time that the Air Force will mainly contract for NASA to launch Air Force payloads onboard NASA-operated shuttles. For many Air Force missions this will simply mean flying aboard a shuttle dedicated exclusively to Air Force payloads. For others, such as the Space Test Program missions, the shuttle will be shared with non-Air Force payloads. In these cases, the issue of prorating the cost of the shuttle will be important. As discussed in Sec. IV, a variety of shuttle tariff formulas were evaluated to determine their impact on the procurement option selection. While the shuttle tariff formulas examined in this study did not substantially affect the procurement option selection, they did represent a large impact on the absolute cost of carrying out the Air Force Space Test Program missions. And of particular interest to the Air Force was that none of the NASA shuttle tariff schedules dealt with the secondary payload concept. As mentioned in Sec. IV, this concept involved not specifying the mission inclination, altitude, or launch time and selecting a spacecraft design that would fit into a nonprimary payload portion of the shuttle bay. Given these characteristics, the Air Force Space Test Program Office felt that some compensation should be incorporated in the NASA shuttle tariff schedule; however, no such compensation was ever made, and it appears from the latest NASA shuttle tariff schedule available at the time of this study that it will not be part of the agreed-upon shuttle operation.

The second shuttle-related issue involved the loss of program control that the Air Force expects as a result of the conversion to the use of the shuttle for launching its space payloads. As indicated in Sec. II, the DoD, from the beginning of the U.S. space program, has been deeply involved in launch vehicle development and the operation of the vehicles for the purpose of placing payloads into orbit. The Air Force provided launch services for NASA for many years. With the advent of the space shuttle, the DoD will relinquish one additional component of its role in the space program; it will no longer be responsible for launching its own payloads into orbit. For the Air Force Space Test Program Office, this transition carries with it the feeling of loss of program control. Not only will NASA operate the shuttle, but it will also evaluate whether or not adequate testing has been accomplished to make the payload safe for shuttle operation, hence the feeling of direct invasion into the Air Force development program. Furthermore, one objective of the Space Test Program has been to shorten the time delay between deciding to conduct an experiment and getting the results from the experiment. With the NASA shuttle in the loop, this delay time not only promises to be longer than if expendable boosters were used, but the length of the delay is largely a function of NASA rather than the Air Force.

ORGANIZATIONAL FACTORS AFFECTING THE SUCCESSFUL COMPLETION OF THE CASE STUDY

In retrospect, a number of organizational factors affected the successful completion of the procurement analysis* of the Air Force standard spacecraft decision. Of these, the principal factors include (1) the acceptance of Rand's credibility, (2) the ripeness of the Air Force procurement decision, (3) the tractability of the study, and (4) the short schedule and low budget constraints. Each of these is briefly discussed below.

Acceptance of Rand's Credibility

From the outset of this study both NASA and the Air Force felt that Rand met the criteria for the type of organization that could produce the independent, objective, and sound study needed for guiding their procurement decisions. They selected Rand on a sole-source basis. It is recognized that this may have been a self-serving acceptance given the underlying motivations of both NASA and the Air Force to use the results as a basis for justifying, at least partly, their future course of action within their own organizations and with the OMB and the AACB. Even so, the reliance of NASA and the Air Force on Rand for this study implied a willingness to defend this choice to Congress, the OMB, and the AACB. Regardless of whether the motivation was self-serving or not, the NASA and Air Force acceptance of Rand provided

*See footnotes on pp. 2 and 5.

the basis for a cooperative working relationship at all levels. It also yielded an understanding of the impact of the time and budget constraints, a number of productive informal progress review sessions, and expedient resolution of problems having to do with data, ground rules, and other inputs.

Ripeness of the Air Force Procurement Decision

At the outset of this study it was quite apparent that the Air Force Space Test Program Office was on the verge of making a procurement decision to buy or develop a standard spacecraft. There were several reasons for this impression. First, the Space Test Program Office is an operating office having the responsibility of providing spacecraft for experimental missions. Second, the Air Force had selected the Space Test Program Office for one of the first Air Force payloads to fly on the space shuttle (Orbital Flight Test -5). The schedule for this shuttle flight would require a FY77 spacecraft procurement decision. Third, its past experience with designing low-cost spacecraft had been noticeably successful and had influenced NASA's AEM and MMS programs. The application of this experience to the STPSS tended to support its position that a low-cost standard spacecraft was the approach to follow during the space shuttle era.

Under these circumstances, it was not surprising that the Space Test Program Office was anxious to move forward with the study regardless of whether or not the preferred procurement option included the STPSS. This contributed to the Air Force cooperation and interest in the study.

Tractability of the Problem

Although this case study included a wide variety of uncertainties that ranged from the spacecraft descriptions to the space shuttle launch costs, it had the characteristics of a problem that could be handled using conventional analytic methods. Because of these uncertainties, one of the largest risks that threatened the study was associated with having the results be overwhelmed by the magnitude of the uncertainties so that no guidance could be given. The other major risk had to do with becoming so involved in the details of the spacecraft design, mission model, cost estimating relationships, etc., in order to minimize the uncertainties, that guidance for the procurement option would not be provided. Recognition of these extreme outcomes at the beginning of the case study provided the guidance and assurance that the study direction, while oscillating between micro and macro analyses, would not deviate to either extreme at the expense of the other.

Short Schedule and Low Budget Constraints

The schedule and budget constraints were both a problem and an asset. The problem centered on managing the study so that it remained sufficiently focused to allow the study to be completed within the time and budget limitations and yet broad enough to assure that the conclusions were valid.

An example of this focusing problem is the initial concern for the technological comparability of the various standard spacecraft. The Air Force had not had an opportunity to examine in detail the MMS technology but felt that because of its greater performance and its being designed for in-space servicing, it might incorporate substantially more advanced technology than that being used in the STPSS. The inclusion of the AEM in the study was encouraged because it represented a spacecraft with known cost and technology and thereby serves as a benchmark for assessing the technologies employed in the STPSS and MMS. To explore this uncertainty concerning the relative technology of the various spacecraft, a relatively large portion of the budget was expended on technology assessments and comparisons of the spacecraft subsystems (Appendixes B to G). It turned out that this assessment demonstrated that all of the spacecraft designs drew on essentially the same technological base, thus simplifying the problem of estimating the relative cost for the spacecraft. Conceivably, the large expenditure of resources on the technology assessment could have left the project with a misallocated budget, *but in fact it turned out the added understanding of the technological limitations and operations of each of the spacecraft designs provided the basis for many of the spacecraft configuration excursions. It was through these excursions that the principal conclusion of the study surfaced.*

As a result of the need to focus the study because of the time and budget constraints, a number of interesting related studies were not undertaken. For example, the following studies were never addressed:

(1) Whether the continued use of expendable boosters was a reasonable alternative to the use of the space shuttle;
(2) Whether specialized spacecraft would be competitive, cost-wise, with standard spacecraft;
(3) Whether the inclusion of a NASA mission model would have altered the preferred procurement option;
(4) Whether the payload integration costs associated with doubling the maximum number of payloads per spacecraft would exceed the operational savings; and
(5) Whether standard spacecraft could be used for Air Force operational missions.

On the asset side, the short time frame and low budget reduced the problem of keeping the clients' interest. This was the case, at least, for the first phase of the study that lasted four months. Because of this, many of the normal procedural functions were streamlined, and the interactions with the clients were informal and oriented toward eliminating bottlenecks and providing the necessary guidance and inputs for the study to go forward. There was a commitment by both the clients and Rand to carry out the study as planned.

This cooperation and commitment began to wane for a number of reasons after the first phase of the study was completed. First, the introduction of the L-AEM into the study was initiated as a unilateral NASA decision prior to the completion of the first phase. Rand's response attempted to retain the study unity between NASA and the Air Force by sponsoring the inclusion of the L-AEM in the study on the basis that it reflected an attempt to accomplish the upgrading of the AEM that we had recommended. At the same time, we encouraged the formulation of a NASA-Air Force joint set of specifications for the L-AEM and that any such extension of the study be agreed upon by both NASA and the Air Force. Although a set of joint specifications emerged for the L-AEM and the NASA-Air

Force interface was retained, there was a subtle shift in sponsorship from the Air Force Space Test Program Office/MMS Program Office to the AEM Program Office during the two months between the first and second phases of the study. This seemed to negatively affect the participation of the Air Force Space Test Program Office. In addition, a NASA GSFC reorganization during this period affected the leadership of the AEM Program Office and resulted in a reassignment to NASA headquarters of the project monitor in the AEM Program Office. As mentioned earlier, the MMS Program Office interest in the study also decreased after the completion of the first phase of the study because the results had been favorable to the MMS, i.e., tended to validate the MMS cost estimates and included the MMS in the preferred procurement option, and because there were no inputs required from the MMS Program Office for the second phase. As a consequence, the Rand-client interaction was substantially different for the two phases of the study. Clearly, it would have been more desirable for the study to have collapsed the two phases into one continuous study. To do this would have meant delaying the Air Force inputs to the FY 77 budget process; the penalty for doing this was uncertain at the time. In retrospect, it appears that such a delay could proably have been accepted with a minimum penalty.

VI. APPLYING THE NASA-DOD COOPERATION EXPERIENCE TO OTHER SITUATIONS: PROSPECTS AND PROBLEMS

Section II traced the evolution of NASA and DoD cooperation in space activities from the development of President Eisenhower's space policies during the pre- and post-Sputnik era through the mid-1960s. The cost and organizational implications of DoD utilization of NASA standard spacecraft designs for the Space Test Program missions were investigated using a case study approach in Secs. III and IV. The case study examined the process of NASA-DoD cooperation in one area. This cooperation benefited from experiences gained during nearly 20 years of NASA-DoD interaction.

In a variety of situations, it is often hypothesized that improved cooperation between agencies having overlapping areas of responsibility or between nations having similar interests will lead to increased economic efficiency. Such cooperation is considered especially important during periods of tight financial (budgetary) constraints, where it is often seen as a means of sharing the costs and risks associated with a specific project. Over the years, numerous attempts have been made to establish cooperative relationships among agencies or nations, with varying degrees of success. In general, the more successful cooperative arrangements involved a specific project and were for a few participants (agencies or countries) or for a short time. Examples include the Concorde aircraft co-development and co-production by France and England, the Apollo-Soyuz rendezvous project between the USSR and the United States, and the European cooperation on the space shuttle program (which has finally centered on the Space Lab Module after many aborted attempts at much more extensive participation). In contrast, the NASA-DoD cooperation cited in this study is unusual because it has dealt with a broad spectrum of projects and problems and has been in effect for over 15 years.

In this section, NASA-DoD cooperation is reexamined for lessons that might facilitate future interagency cooperation in other situations. This is done first by reviewing the NASA-DoD cooperation experience and by identifying two major categories of factors that appear to be essential for the NASA-DoD successful experience. Next, the difficulty of achieving an effective organizational structure to support interagency cooperation, even when these two essential categories of factors are present, is illustrated by the review of the NASA-DoD relationship and by recounting the problems encountered in applying the apparently successful NACA cooperation model to NASA.

Finally, two possible situations where interagency or international cooperation appears to be important are briefly examined as candidates for testing the applicability of the NASA-DoD experience. It should be noted that this examination is not meant to do justice to a topic which requires extensive analysis, but rather is intended to illustrate the need for a future study to specifically examine, in detail, the experience of a number of different cooperative arrangements. One purpose for such research would be to identify the factors contributing to successful cooperative agreements within a variety of contexts. Such a study would require significant additional research and is outside the scope of this dissertation.

NASA-DOD COOPERATION EXPERIENCE

The two primary categories of factors contributing to the continuing success of NASA-DoD cooperation in space activities have been (1) a common subset of missions and resources--manpower, data, spacecraft, launch vehicles, facilities, etc.--where cooperation was possible and desirable; and (2) a common organizational responsibility to the Executive Branch (the President and the Bureau of the Budget), which in turn was responsible to the Congress.*

In the NASA-DoD case, a large subset of common interests and objectives provided natural areas for cooperation, be it in areas of manpower, launch vehicles, spacecraft, or data. The similarity of interests provided various cooperative arrangements in the form of joint projects,

*The Congressional responsibility for overseeing NASA and DoD space activities rested mainly with the permanent committees in the House of Representatives and the Senate (Sec. II, p. 19).

shared hardware and facilities, and common management and procurement procedures. However, even where the interests were common, it was not easy to achieve a high degree of cooperation. The inclination to create separate management procedures was as strong as the desire to build separate facilities and support organizations.

Congress recognized the potential for NASA and DoD to create duplicate capabilities, and thus specified in the Space Act of 1958 that... *in order to keep the costs of the U.S. Space program as low as possible, unnecessary duplication of effort, facilities, and equipment should be avoided by close cooperation among Federal agencies....* This statement of Congressional intent, along with the provision for organizational arrangements* to oversee the NASA-DoD relationship, provided the legislative basis for such cooperation.

Even with these factors, it took four to five years before the organizational structure for cooperation was developed and institutionalized as part of the NASA and DoD standard operating procedure. Situations that do not include these two categories of factors could expect to encounter possibly even more difficulty in establishing a cooperative relationship.

THE DIFFICULTIES OF TRANSFERRING NACA EXPERIENCE TO NASA

The transferral of organizational experience from one situation to another is generally much more difficult than anticipated. For instance, during the debate between Congress and the Executive Branch on the formulation of NASA, it was often suggested that the experience of the National Advisory Committee for Aeronautics (NACA) was directly applicable to the new space agency and should be used as an organizational model for NASA. In 1959, NACA, employing 8000 scientists, engineers, and other personnel and operating several major research and testing facilities, had already demonstrated many years of service to the aircraft industry and the military services. In 1952 it began to study the mechanics and problems of space flight and was the agency responsible for such technical contributions as the blunt nose design

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*The Civilian Military Liaison Committee (CMLC) and the National Aeronautics and Space Council.

for ICBM reentry vehicles and the X-15 experimental rocket-propelled aircraft. It had a long history of cordial relationships and cooperation with the Department of Defense, as well as with other governmental agencies. Its main interaction with other agencies had been through its advisory capacity and the coordination of all the scientific work in aviation in the government. Dr. Hugh L. Dryden, Director of NACA in 1958, viewed its main function as "a coordinating body."(13) It was organized to do this mainly through the 17-member Advisory Committee and the five major and 22 subordinate committees. The membership of these committees and subordinate committees was drawn from experts in industry, government, and military departments. NACA functioned as a permanent, independent agency in the Executive Branch, reporting directly to the President and requiring his supervision.

President Eisenhower, in his proposed legislation for NASA, saw NASA functioning in much the same capacity and way in the space arena that NACA had functioned in aviation. This accounted partly for his decision not to provide machinery for resolving disputes short of Presidential involvement. The opposing view was based primarily on the observation that continued cooperation could not be assumed, as NASA was to be a new operating agency with broadened functions and scope, whereas NACA had been primarily a research agency.(15) And, as such, NACA lacked the tradition of directing and coordinating major programs. To inculcate a spirit of decisionmaking in an organization that has lived and thrived on a tradition of peaceful advice-giving would be very difficult. The expectation was that the inevitable commingling of civilian and military in the space field would create areas of conflict requiring organizational machinery for resolution.(13)

As it materialized, the organizational viewpoint of neither the Administration nor the Congress was entirely correct for NASA. Congress was correct in its assessment that organizational machinery was needed to resolve conflicts and to ensure coordination between DoD and NASA. The Administration was correct in its assessment that working-level coordinating boards could adequately provide the interaction needed to solve interagency problems. As described earlier in this section, both were also wrong in important ways which contributed to the four to five years before the NASA-DoD coordination machinery really began functioning as it has for the past 10 to 12 years.

POSSIBLE RESEARCH AREAS

Although it is difficult to successfully transfer past organizational experience to new situations, as demonstrated above, it is also important to thoroughly examine applicable experience and apply it where appropriate. But caution and considerable additional research should guide any attempt to apply NASA-DoD experience with coordination machinery to other situations. Thus, this section merely attempts to identify several situations where improved interagency or international cooperation may be particularly important and suggests a study approach for these situations.

One prospective situation where improved cooperation may be advantageous is between the new Department of Energy and other U.S. governmental agencies whose activities affect the U.S. energy policy. For instance, the Department of Transportation, Environmental Protection Agency, Department of the Interior, NASA, and DoD will all interact with the Department of Energy. In this situation, the motivation for coordination machinery would be to resolve conflicting policies and jurisdictional questions as well as to minimize duplication of effort or to make new programs possible through joint efforts. Because of the different perspectives and possibly conflicting legislative directives of these agencies, it is conceivable that--without proper interagency cooperation--conflicts counterproductive to some broader objectives of the United States could arise.

Without carrying out an extensive analysis of the transferability of the NASA-DoD experience with interagency coordination, it appears that this situation contains only *one* of the two principal factors identified as being important for the NASA-DoD success--that all of these agencies have a common authority, i.e., Congress and the Executive Branch. The missing factor is that these agencies *do not* produce a common specific output (data, missions, projects, etc.) whose value can be measured directly, but rather the output of the Department of Energy is expected to be plans, services, and policy directives for the nation and other governmental agencies. Consequently, it does not appear that the NASA-DoD experience can be applied directly without additional research.

If such a research project were to be undertaken, one of the first tasks would involve a careful analysis of enabling legislation of the Department of Energy and other relevant governmental agencies to identify the provision for cooperation, to assess the potential success and motives for cooperative efforts, and to identify areas where changes could be made to enhance cooperation. Another task of this research project would be a broad study of cases where long-term interagency cooperation has been attempted. The cases included should be relevant to the areas and types of cooperation that the Department of Energy might be involved in as its program progresses. Given the results of the analysis of past experience with interagency cooperation and the assessment of cooperation requirements as seen by the Department of Energy, a first-order matching of lessons, experience, and "need" could take place. A more detailed analysis of the areas where a match occurs or does not occur could lead to the selection of the organizational structure and operating procedures to support cooperation between the Department of Energy and other governmental agencies.

Another situation where cooperation appears to be important is in the international arena of bilateral and multinational weapons acquisition programs. There seems to be both political and economic pressures influencing DoD to get more deeply involved in such programs. The effective participation of DoD in such agreements will depend on establishing a basis for coordinating and cooperating with the countries and industries involved in the agreements.

This situation contains only *one* of the two principal factors identified as being important to the NASA-DoD long-term successful cooperation. In this instance, the factor is the production of a common product where a joint effort might yield economic benefits to the countries involved in the co-production or co-development agreement. But the other essential factor is absent in this situation: There is no authority common to all participants. Thus, the direct transferral of the NASA-DoD experience to this situation appears to be inappropriate without further analysis.

However, a considerable body of experience--both good and bad--has been gained with a similar attempts to undertake co-production and co-development programs. The organizational content of such experiences should be evaluated as an input to the formulation of a decision criterion for DoD's participation in future multinational procurement programs. A large number of case studies are available: the Multi-Role Combat Aircraft, the A-300 airbus, the Concorde, the MBT-70 tank, the space shuttle laboratory module, the F-16, and the INTELSAT communications satellite. In analyzing this experience, one should attempt to identify the various approaches used to ensure the cooperation and the principal factors of each, and to assess the contribution of these factors to the success or failure of the cooperative effort.

In summary, neither of the situations (cited above as potentially interesting areas where either interagency or international cooperation is important) satisfies both of the essential categories of factors underlying the successful experience with cooperation between NASA and DoD. Consequently, the NASA-DoD experience does not seem to apply directly; however, the first step in the research approach outlined for both situations suggests the applicability of the organizational analysis presented in this report for the NASA-DoD situation to a variety of other situations where interagency or international cooperation has been a major component. To the extent that the NASA-DoD experience contributes to this body of knowledge in interagency cooperation, it can be directly useful for these new situations.

Appendix A
ESTIMATES OF COST
by
J. P. Large

Spacecraft traditionally have been very expensive to produce because of stringent weight and performance requirements, heavy emphasis on reliability, and small production quantities. Various parametric cost-estimating models have been developed from experience over the past 15 or so years, and those models reproduce the cost of the traditional spacecraft with acceptable accuracy. Initially, it was thought that such a model could be used to estimate the costs of the AEM, L-AEM, STPSS, and MMS. Such a model would have insured cost-comparability among them, perhaps at the sacrifice of absolute accuracy in some instances.

It developed, however, that models based on 15 years of spacecraft data estimate costs that are higher than those experienced in the Air Force Space Test Program and those in the AEM contract. The SAMSO cost model, for example, estimates the nonrecurring and recurring cost of HCMM at about $14 million, mainly for development; Boeing's ceiling estimate was approximately $5 million, and at the time of the Rand study it did not appear that the ceiling would be exceeded. At the same time, GSFC was estimating a unit cost of under $10 million for MMS compared to the SAMSO model's estimate of about $19 million. The GSFC estimate was based on some hardware development; component costs were based on vendor quotes and analogy with known costs.

At both ends of the spectrum, then, costs were known to a reasonable degree of accuracy. The problem was to ensure relative accuracy between the AEM and MMS and to estimate L-AEM and STPSS costs that would reflect their relative complexity. The decision was made to develop a cost model based on a combination of AEM costs and traditional scaling curves. That would assume implicitly that if Boeing could produce an AEM for about $2 million, all spacecraft manufacturers could be equally efficient in producing larger spacecraft using a philosophy of low cost, use of flight-proven components, etc.

Cost-estimating equations for spacecraft subsystems are typically of the type

$$Y = aX^b \quad \text{or} \quad Y = a + bX^c$$

where Y = cost, and

X = weight or other subsystem characteristic.

In the SAMSO model, for example, the cost of the attitude control system is given by

$$\text{ACS cost in thousands of 1974 \$} = 14.72\ (\text{ACS dry weight})^{.90}$$

In developing a model for this study the b-value, 0.90, was used with an a-value based on AEM. That procedure gave the following equations* (all these costs are in thousands of 1976 dollars):

Structure, thermal control, interstage	$= 4.8\ (\text{weight})^{.74}$
Electrical power system	$= 5.65\ (\text{weight})^{.84}$
Attitude control system	$= 14.7\ (\text{weight})^{.9}$
Communications and data handling	$= 25.4\ (\text{weight})^{.9}$

In addition, the costs of system test and integration, program management, quality assurance, reliability, etc., must be included, and they add about another 50 percent to the total. On top of that are the costs of special components, such as tape recorders, hydrazine tanks, and solar panels not included in the basic configuration.

Component costs, even those of existing, flight-proven components, vary considerably and add another measure of uncertainty to the total. Vendor quotes, for example, can vary by more than an order of magnitude. As shown below, the range of bids for a PCM encoder was from \$21,400 to \$611,000; in that same case the second-lowest bid was \$41,200. Also,

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*It may be noted that the ACS estimating equation is essentially the same as the one cited above for the SAMSO model. Apparently, inflation effects have been offset by factors such as a low-cost design approach and the cost-quantity effect.

RANGE OF BIDS

Item	Range ($ thousands)	Ratio
S-band transmitter	29.1-39.8	1:1.37
Magnetometers	17.7-25.7	1:1.45
Rocket motor assembly	21.2-31.8	1:1.50
Louvers	9.6-28.1	1:2.93
Command decoder and remote command processor	62.3-1188.0	1:19.1
PCM encoder	21.4-611.0	1:28.6

component price is highly dependent on quantity procured, i.e., the quantity ordered at one time, not the total quantity over time. The table below shows what may be an extreme case, but it illustrates a point on which vendors agree--six S-band transponders bought one at a time will cost substantially more than six procured in one buy.

INFLUENCE OF SIZE OF BUY ON COST

Buy	Unit Price ($)	Cost-Reduction (%)
1	306,000	0
2	294,000	3.9
3	267,000	12.7
4	227,000	25.8

The same principle obtains at the system level, but the cost there is more a function of production rate than quantity. A manufacturer may have a fixed, sustaining cost of, say, $1 million per year whether he builds one spacecraft or four. The hypothetical example below illustrates the effect of rate in such a situation.

Annual Rate	Sustaining Cost per Spacecraft
1	1,000,000
2	500,000
3	333,333
4	250,000

The equation used to adjust recurring costs for quantity effects was:

$$f = .8 + 1.97\ n^{-1}$$

where f = adjustment factor applied to cost
n = total number of spacecraft procured
$f = 1$ if $n \leq 10$.

Cost-Estimating Equations

AEM Cumulative cost = 2.28 n (f).

STPSS

Spin $= 2.866\ f\ n + 1.743\ f_1\ n_1$

Low-cost $= 2.866\ f\ n + 2.812\ f_2\ n_2$

Precision $= 2.866\ f\ n + 3.995\ f_3\ n_3$

where n = number of core modules
n_1 = number of spin models
n_2 = number of low-cost modules
n_3 = number of precision modules.

MMS

Regular: Cumulative cost $= 8.965\ n_1\ f$

SPS-I $= 9.350\ n_2\ f$

Calculation of f includes 20 MMS procured by NASA over 10-year period.

L-AEM

Baseline: Cumulative cost $= 4.815\ n_1\ f$

Precision $= 5.678\ n_2\ f$

Spin $= 3.706\ n_3\ f$.

The remainder of Appendix A consists of tables showing estimated 10-year program costs of spacecraft and shuttle launches for various procurement options.

Table A-1

SPACECRAFT COSTS--NOMINAL CASE

($ millions)

Maximum AEM and L-AEM-BL altitude = 1000 n mi
AEM and L-AEM-BL orientation = Earth only

Payloads	114		228	
Payloads/spacecraft	13	6	13	6
Spacecraft Type	Cost			
AEM	2.3	6.8	11.4	16.0
STPSS				
Nonrecurring	22.9	22.9	26.9	26.9
Spin	--	--	26.2	40.5
Low-cost	57.1	90.7	67.8	110.9
Precision	35.0	34.3	41.8	47.5
Total	117	155	174	242
AEM	2.3	9.1	11.4	20.5
MMS	108.8	162.5	155.6	251.1
Total	111	172	167	272
STPSS				
Nonrecurring	22.9	22.9	26.9	26.9
Spin	--	--	20.0	41.6
Low-cost	62.5	109.6	88.4	150.1
Precision	34.5	34.2	43.6	52.1
Total	120	167	179	271
MMS	117	190	176	297
L-AEM				
Nonrecurring	9.8	9.8	11.3	11.3
Spin	--	--	14.3	31.1
Precision	86.9	123.9	108.9	168.3
Total	97	134	135	211
L-AEM				
Nonrecurring	11.9	11.9	14.5	14.5
Baseline	20.4	29.6	19.0	31.4
Spin	--	--	15.2	32.4
Precision	29.5	28.7	33.1	36.5
STPSS				
Nonrecurring	18.4	18.4	18.4	18.4
Low-cost	41.5	73	63.5	106.2
Total	122	162	164	239

Table A-1 (Cont.)

Payloads	114		228	
Payloads/spacecraft	13	6	13	6
Spacecraft Type	Cost			
L-AEM				
Nonrecurring	11.9	11.9	14.5	14.5
Baseline	18.7	26.8	17.9	29.8
Spin	--	--	14.3	31.0
Precision	65.1	93.4	88.2	133.7
Total	96	132	135	209
AEM	2.3	6.9	11.4	16.0
L-AEM				
Nonrecurring	11.9	11.9	14.5	14.5
Baseline	14.2	13.6	4.5	4.3
Spin	--	--	21.5	31.3
Precision	65.8	94.4	88.8	135.3
Total	94	127	141	201
L-AEM				
Nonrecurring	9.8	11.9	11.3	11.3
Baseline	--	26.8	--	--
Spin	--	--	3.8	10.8
Precision	58.5	93.4	76.6	104.1
MMS	33.7	--	58.5	142.5
Total	102	132	150	269
AEM	2.3	9.1	11.4	20.5
L-AEM				
Nonrecurring	9.8	9.8	11.3	11.3
Spin	--	--	3.8	10.8
Precision	58.5	96.2	76.6	104.1
MMS	25.5	16.5	34.3	80.4
Total	96	132	137	227

Table A-2

SPACECRAFT COSTS WITH ADDED CAPABILITIES:
UPGRADED AEM AND L-AEM-1

($ millions)

Maximum AEM and L-AEM-BL altitude = Geosynchronous
AEM and L-AEM-BL orientation = Earth and sun

Payloads	114		228	
Payloads/spacecraft	13	6	13	6
Spacecraft Type	Cost			
AEM	17.1	33.0	37.8	59.5
STPSS				
Nonrecurring	22.9	22.9	26.9	26.9
Spin	--	--	31.6	27.2
Low-cost	32.3	32.5	25.3	44.7
Precision	38.2	38.4	45.1	53.0
Total	111	127	167	211
AEM	12.2	26.7	46.1	66.6
MMS	56.1	73.4	65.4	127.6
Total	68	100	112	194
L-AEM				
Nonrecurring	11.9	11.9	14.5	14.5
Baseline	52.2	85.3	67.6	115.8
Spin	--	--	14.3	31.0
Precision	27.3	25.9	31.1	34.7
Total	91	123	128	196
AEM	2.3	6.9	11.4	16.0
L-AEM				
Nonrecurring	11.9	11.9	14.5	14.5
Baseline	47.5	72.7	54.6	91.2
Spin	--	--	21.6	31.3
Precision	27.4	26.2	31.3	35.1
Total	89	118	133	188
L-AEM				
Nonrecurring	11.9	11.9	14.5	14.5
Baseline	35.5	85.1	52.2	72.5
Spin	--	--	3.8	10.8
Precision	17.5	25.9	21.0	26.9
MMS	33.7	--	58.5	142.5
Total	99	123	150	267

Table A-2 (Cont.)

Payloads	114		228	
Payloads/spacecraft	13	6	13	6
Spacecraft Type	Cost			
AEM	2.3	9.1	11.4	20.5
L-AEM				
Nonrecurring	11.9	11.9	14.5	14.5
Baseline	35.5	60.3	52.3	72.5
Spin	--	--	3.8	10.8
Precision	17.5	27.1	16.4	20.8
MMS	25.5	16.5	34.3	80.4
Total	93	125	133	220
L-AEM				
Nonrecurring	9.8	9.8	11.3	11.3
Spin	--	--	14.3	31.1
Precision	86.9	123.9	108.9	168.3
Total	97	134	135	211

Table A-3

LAUNCH COSTS--NOMINAL CASE

($ millions)

Maximum AEM and L-AEM-BL altitude = 1000 n mi
AEM and L-AEM-BL orientation = Earth only
Space shuttle cost/launch = $15.4 million
Kick stages = Solid rockets

Payloads	114		228	
Payloads/spacecraft	13	6	13	6
100% weight attribution				
AEM/STPSS	37	51	65	93
AEM/MMS	41	63	68	111
STPSS	37	51	60	94
MMS	41	67	65	112
L-AEM	36	50	58	90
AEM/L-AEM	36	50	62	90
L-AEM/MMS	34	51	57	96
AEM/L-AEM/MMS	33	50	57	89
50% weight attribution				
AEM/STPSS	26	37	48	69
AEM/MMS	27	44	46	77
STPSS	26	38	42	68
MMS	28	46	43	77
L-AEM	26	37	42	66
AEM/L-AEM	26	37	46	67
L-AEM/MMS	24	37	39	68
AEM/L-AEM/MMS	24	37	41	66
Service charge				
AEM/STPSS	16	24	30	44
AEM/MMS	14	24	24	42
STPSS	16	24	25	43
MMS	14	24	22	41
L-AEM	16	24	25	43
AEM/L-AEM	16	24	29	44
L-AEM/MMS	14	24	22	41
AEM/L-AEM/MMS	14	24	24	42
NASA tariff				
AEM/STPSS	79	127	157	241
AEM/MMS	83	144	149	258
STPSS	79	126	131	235
MMS	83	146	134	252
L-AEM	85	134	142	247
AEM/L-AEM	85	133	167	254
L-AEM/MMS	78	134	129	242
AEM/L-AEM/MMS	77	133	141	242
Modified NASA tariff[a]				
AEM/STPSS	35	47	61	87
AEM/MMS	60	90	97	158
STPSS	34	46	55	84
MMS	61	97	92	163
L-AEM	38	51	76	92
AEM/L-AEM	44	49	76	99
L-AEM/MMS	42	51	71	92
AEM/L-AEM/MMS	38	53	66	95

[a]Assumes that whenever possible, the spacecraft and its kick stages will be oriented perpendicular to the shuttle axis.

Table A-4

LAUNCH COSTS FOR UPGRADED AEM

($ millions)

Maximum AEM altitude = Geosynchronous
AEM orientation = Earth and sun
Space shuttle cost/launch = $15.4 million
Kick stages = Solid rockets

Payloads	114		228	
Payloads/spacecraft	13	6	13	6
100% weight attribution				
AEM/STPSS	34	42	61	81
AEM/MMS	29	43	59	93
50% weight attribution				
AEM/STPSS	25	33	47	63
AEM/MMS	21	31	43	70
Service charge				
AEM/STPSS	17	24	32	46
AEM/MMS	12	20	28	44
NASA tariff				
AEM/STPSS	86	126	168	249
AEM/MMS	65	109	152	259
Modified NASA tariff[a]				
AEM/STPSS	39	50	74	95
AEM/MMS	45	64	89	139

[a]Assumes that whenever possible, the spacecraft and its kick stages will be oriented perpendicular to the shuttle axis.

Table A-5

LAUNCH COSTS FOR THE L-AEM-1[a]

($ millions)

Maximum L-AEM-BL altitude = Geosynchronous
L-AEM-BL orientation = Earth and sun
Space shuttle cost/launch = $15.4 million
Kick stages = Solid rockets

Payloads	114		228	
Payloads/spacecraft	13	6	13	6
100% weight attribution				
L-AEM	36	49	57	89
AEM/L-AEM	35	49	62	81
L-AEM/MMS	33	50	56	91
AEM/L-AEM/MMS	33	49	56	88
50% weight attribution				
L-AEM	26	37	41	66
AEM/L-AEM	26	36	45	62
L-AEM/MMS	23	37	39	66
AEM/L-AEM/MMS	24	37	40	65
Service charge				
L-AEM	16	24	25	43
AEM/L-AEM	16	24	29	42
L-AEM/MMS	14	24	22	41
AEM/L-AEM/MMS	14	24	24	42
NASA tariff				
L-AEM	85	133	141	247
AEM/L-AEM	85	133	167	246
L-AEM/MMS	76	133	128	237
AEM/L-AEM/MMS	77	133	141	241
Modified NASA tariff[b]				
L-AEM	38	51	76	92
AEM/L-AEM	44	49	76	90
L-AEM/MMS	41	51	71	92
AEM/L-AEM/MMS	39	54	65	95

[a]Only the L-AEM-BL configuration is modified to give it geosynchronous and sun-orientation capability.

[b]Assumes that whenever possible, the spacecraft and its kick stages will be oriented perpendicular to the shuttle axis.

Appendix B

POWER SUBSYSTEM: A COMPARISON OF AEM, STPSS, AND MMS

by

N. E. Feldman and P. A. CoNine

BASIC DESCRIPTION OF THE AEM[31]

The AEM spacecraft comes in two versions: Both have a standard 28 V power bus, a single 10 Ah rechargeable nickel cadmium (NiCd) battery, and are powered by two fixed arrays (not sun-tracking) with approximately 23 sq ft of solar cells. (For further details, see Table B-1.) The solar-cell arrays can provide a peak power of 238 W end-of-life (EOL) when the sun angle is most favorable. Because the arrays do not sun track, the average power produced during illumination is about 130 W. However, to optimize power output in the orbit planned for SAGE, the two solar arrays are driven to an angle of ±50 deg with respect to the local horizontal. These motors are shown in the power subsystem diagram of Fig. B-1.

Up to 50 W can be provided to the experiment module with a voltage regulation of 28 V ±2 percent. Voltage regulation to the experiments is relaxed for peak pulse loads above 50 W, e.g., the regulation is relaxed to ±5 percent when the experiments require a peak pulse load of 120 W.[32] This peak pulse load option is used on the SAGE vehicle, where the specification states that this 120 W load must be handled for a maximum of 4 sec. Although the 4 sec time period is the specified value, the spacecraft may be able to handle this amount of experiment power for up to a few minutes.

The HCMM vehicle power budget during normal orbital operation, i.e., standby, is:

Experiment	22 W
Telemetry	4 W
Attitude control and determination	12 W
Power circuitry	12 W
Total	50 W

Table B-1

POWER SYSTEM COMPARISONS

Characteristic	AEM (32)	STPSS (2)	MMS (6)
Voltage level	28 ±4 V dc at bus ±2% to experiments	28 ±5 V dc at bus optional 28 V ±0.5 V to experiments (±1.8%)	28 ±7 V dc[m]
Array			No array on base module
Average power during illumination	133 W[a]	1200 W max[i]	
Average power over low-altitude orbit	68 W[a]	500-600 W nominal[i]	1200 W max, bus rating[n]
Material	N/P silicon	N/P silicon	
Resistance	1 to 3 ohm-cm	2 ohm-cm	
Size of solar cells	2 × 2 × 0.03 cm	2 × 4 × 0.036 cm	
Efficiency	11%	~ 10%	
Cover glass thickness	6 mils	6 mils	
Total dimensions of array	Each panel consists of 2 strings × 82 cells in series × 5 in parallel × 6 panels on each of two non-sun-tracking paddles	Each panel consists of 2 strings of 96 cells in series by 3 in parallel (50 W/panel-EOL max) up to 24 panels	
Total area of array	23.2 sq ft	6 sq ft/panel	
Array power/ft^2 EOL	10.3 W/ft^2[b]	8.3 W/ft^2	
Total weight of array and support structure	19.6 lb	132 lb	
Spacecraft power consumption, excluding experiments	~ 50 to 80 W[c]	92-197 W[j]	350 W
Power available for experiments	40 to 50 W[d]	~ 400 W nominal[i]	850 W max
Kind of battery	NiCd	NiCd	NiCd
Battery rating	10 Ah	3 × 20 Ah[k]	2 × 20 Ah baseline or up to 3 × 20 Ah or 1 to 3 × 50 Ah[c]
Battery coefficient, Ah/lb	0.49	0.38	0.40
Number of batteries	1	3	1 to 3
Depth of discharge[e]	14% (BOL); 16.5% (EOL)[f]	25%	25% low earth orbit; 50%[p] synchronous orbit
Power available during eclipse[g]	44 Whr	420 Whr	280 Whr for 2 × 20 Ah battery or 1050 Whr for 3 × 50 Ah battery[q]
Weight of battery, power conditioning and distribution	51.1 lb	253.3 lb	334 lb[q]
Battery charging method	Across both solar arrays in parallel	Separate control for each battery	One power regulating unit for all batteries[r]
Dissipation of excess power	"Shunt resistors"[h]	"Shunt modules"[i]	Peak power tracker,[s] excess power is left on the array, there is a 2 to 5°C rise in array temperature

NOTES TO TABLE B-1

From Refs. 31 and 32:

[a]This is the average power produced by the stationary array during illumination. At an optimal sun angle, a maximum of 238 W can be produced. Assuming a low earth orbit illumination interval of approximately 60 min, the solar array power output is 7952 Wmin corresponding to 7952/60, or 133 W. Average power available for the orbit is 68 W, which can be derived in the following way:

$$\frac{7952 \text{ W} \cdot \text{min}}{59.1 \text{ min} + \dfrac{42.9 \text{ min}}{0.75}} = 68 \text{ W}$$

where 59.1 min is the period of illumination and 42.9 min is the period of occultation during low earth orbit. The factor of 0.75 is the derived overall battery efficiency.

[b]Based on maximum array output of 238 W.

[c]The HCMM vehicle, excluding experiments, uses 59 W during a data pass. The SAGE vehicle uses 47 W to 79 W for the portions of the mission discussed in the text. The remainder of the power produced during illumination is used for battery charging.

[d]Fifty watts could be available for an appreciable fraction of the orbit, but the orbital average power that could be made available for experiments and telemetry of the experimental data is no more than 40 W. This assumes 68 W orbital average available: 12 W for attitude, 12 W for power subsystems, and 4 W for housekeeping telemetry.

[e]Depth of discharge is given for the low orbit case, which is the higher stress one because of the high frequency of occultation. Depth of discharge for synchronous orbit can be as high as 62 percent.

[f]During prelaunch, launch, and completion of the acquisition phase, the depth of battery discharge reaches 61.5 percent (Ref. 31, pp. 1-26). This is a one-time condition. The AEM requires only an 8 Ah battery, but a space-qualified 10 Ah battery was readily available. It proved to be more practical to incorporate the standard battery rather than to redesign the battery and charging circuits. Thus, the lower depth of discharge values (0.14 or 0.166 rather than 0.25 as on STPSS and MMS) reflect overdesign, not high risk, on STPSS or MMS designs.

[g]Calculated using depth of discharge for low earth orbit.

[h]In shunt loads, based on battery Ah and temperature monitors.

From Ref. 1:

[i]Reference 1 (p. 6-1) lists a total nominal orbital average system power of 500 W to 600 W, with 400 W for experiments. Page 3-5 of the same report discusses using up to 24 panels, which would provide 1200 W in the three-axis-stabilized configuration with sun-tracking arrays. In the spin-stabilized configuration, however, the solar arrays are

NOTES TO TABLE B-1 (Cont.)

mounted to the six faces of the space vehicle; it should be noted that not all solar cells are exposed to the sun simultaneously on this spacecraft, therefore, about $1200/\pi$ of 382 W are available on this design.

[j]Electrical power consumption of the standard STPSS modules, excluding experiments, is determined by the stabilization system used: spinning spacecraft, 92 W; three-axis earth reference, 136 W; three-axis stellar (and wheels), 185 W; three-axis stellar with hydrazine, 197 W.

[k]TRW does not recommend using batteries smaller than 20 Ah for missions requiring less than 500 W because the nonrecurring costs associated with designing a smaller capacity battery and with interface redefinition would increase program cost by about $200K to $300K. Recurring battery cost savings due to using the smaller battery are not substantial, since, typically, cell hardware contributes only 20 percent to battery total cost, with the other 80 percent due to test and quality control requirements.

[ℓ]Excess power generated by the STPSS solar array is shunted into resistive modules on the surface of the spacecraft and radiated into space.

From Ref. 5:

[m]Page 22 says, "28 ±7 V dc negative ground."

[n]The power subsystem can support an orbital average load of 1200 W in any orbit from 500 to 1665 km and at geosynchronous altitude. This includes being able to accommodate a peak load of 3 kW for 10 min, day or night. These determine the peak and average power requirements of the power regulating unit and batteries.

[o]The choice of various numbers of batteries and two sizes allows a large variation in battery capacities to be chosen to suit the particular experiment: 20, 40, 50, 60, 100, or 150 W.

[p]The most recent specification calls for a 60 percent depth of discharge in synchronous orbit instead of 50 percent.

[q]The baseline power module weighs about 254 lb, including the case, louvers, and all module attachment hardware. The heat sink louvers, which prevent thermal runaway of the switching semiconductors, weigh 12 to 13 lb. The weight of the power subsystem frame or box, i.e., without electronics, just structure, is about 54 lb; and the attachment hardware is about 25 lb. Thus, the 254 lb power system module, excluding thermal and structural elements, weighs about 262 lb. Each 20 Ah battery weighs about 50 to 53 lb; each 50 Ah battery weighs about 100 to 110 lb. Thus, for the baseline case, the weight of the battery and power conditioning is about 354 lb; and, for 3 × 50 Ah batteries, the total weight can be as much as 585 lb. Note that these figures include some structure but do not include the vehicle harness, i.e., power distribution.

NOTES TO TABLE B-1 (Cont.)

[r]While all the batteries are connected to a single power regulator unit, the unit has been designed to compensate for loss of a single cell, or even an entire battery, without jeopardizing the total power system.

[s]NASA Goddard's MMS program office has decided to use a peak power tracker rather than the separate battery charging modules, plus shunt modules typically used in direct energy transfer systems. The tracker works by tracking the peak power point of the solar array. When peak power is not required, the power regulating unit forces the solar array operating point to a lower level. Therefore, no excess power is produced which would have to be dissipated. The peak power tracker lends itself to simpler interfaces than the direct energy transfer system with shunt module dissipators.

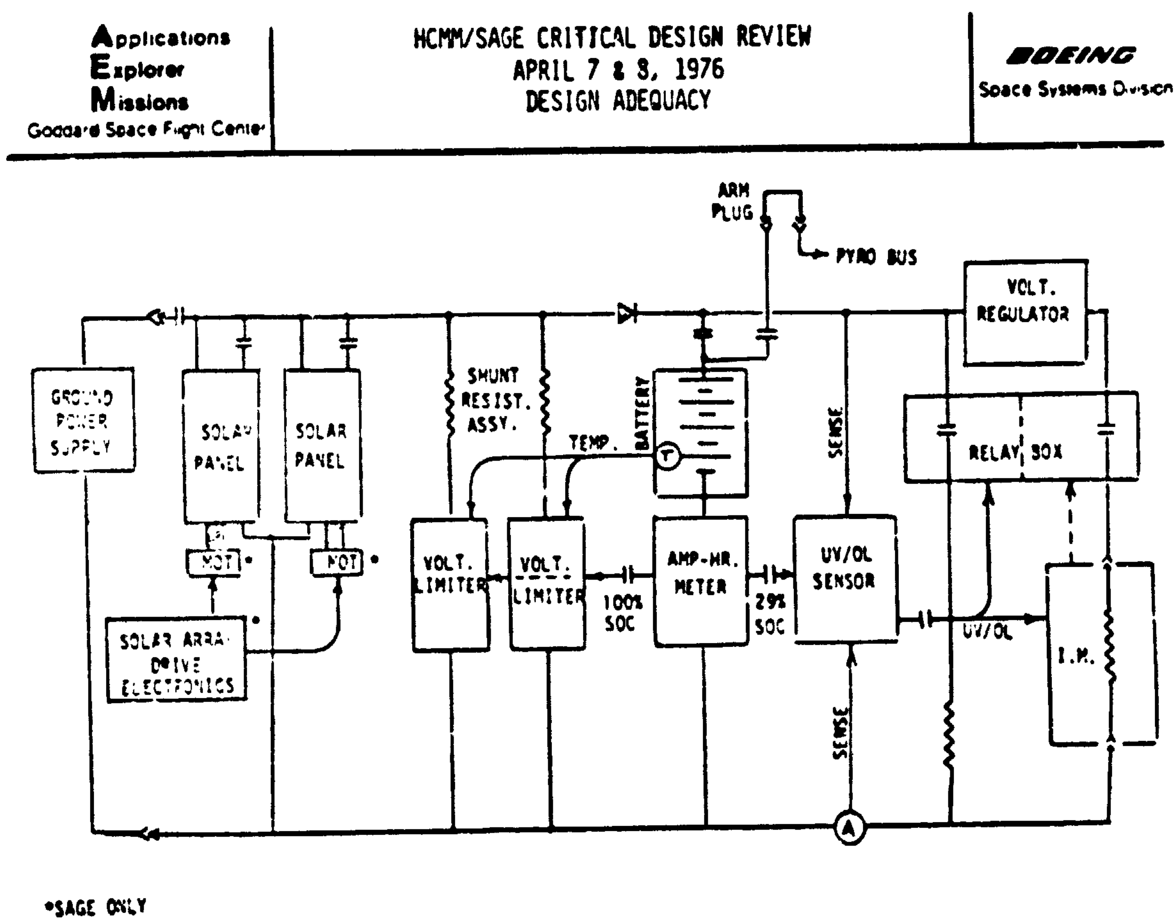

Fig. B-1—Power and distribution subsystem block diagram

The duration of the data pass is 10 min during illumination and 15 min during occultation. The HCMM vehicle power budget during data pass is roughly as follows:

Experiment		24 W*
Telemetry		35 W
Attitude control and determination		12 W
Power circuitry		12 W
	Total	83 W (10 to 15 min)

The remainder of the energy produced during illumination is used for battery charging and this energy is later used by the spacecraft during eclipse. During the eclipse, 46 Whr of energy are available from the battery; this is about 75 percent of the energy used in charging the battery. Examination of the power system performance for the HCMM and SAGE missions indicates that about half the energy out of the arrays is used for battery charging.

On the SAGE vehicle, there are some high short-duration loads (less than 4 sec) from the experiment and from the tape recorder.** The timing for the experiment module is such that the tape recorder peak demands and experiment peak demands do not occur at the same time; the power system is not adequate for this. The telemetry subsystem requires 18 W to 21 W, except during tape dump (once per day), when this subsystem uses 51 W of power (500 sec duration). The total SAGE power demand during tape dump is:

Standby power to experiment		9 W
Telemetry		51 W
Attitude control and determination		16 W
Power circuitry		12 W
	Total	88 W (500 sec)

---

*Tables of subsystem electric load demands provided by Boeing show an HCMM payload total power consumption of 34 W during a data pass. However, a total of the entries adds only to 24 W. Either there is an error in a table entry, or else there is a mistake in addition.

**One such load is the 120 W pulse option (2 to 4 sec duration) to the experiments. The experiment module, which includes the experiment and a tape recorder, requires only 9 W during standby but can draw a maximum pulse power of 117 W during acquisition (4 sec duration).

The maximum experiment power for durations of more than a few seconds is required by the SAGE experiment (during the track interval), not the HCMM experiment. The power breakdown for the SAGE vehicle for the 180 sec track interval during data taking is as follows:

Experiment	43 W
Telemetry	19 W
Attitude control and determination	16 W
Power system circuitry	12 W
Total	90 W (180 sec)

The power consumed by experiments plus telemetry can be high for short periods of time, e.g., it is 59 W for 10 to 15 min and 62 W for 3 min.

DESCRIPTION OF STPSS[1] AND COMPARISON WITH AEM

The STPSS spacecraft also has a 28 V bus, but its voltage regulation is not quite as stringent as the AEM (±5 V rather than ±4 V, as shown in Table B-1). Additional power regulation equipment (±1.8 percent regulation) can be added if the experiments require it (optional), but the associated weight and power loss are not mentioned. The STPSS spacecraft is equipped with three 20 Ah batteries and up to 24 solar panels may be used in two arrays. These arrays can provide up to 1200 W maximum (during illumination) in the three-axis-stabilization configuration with sun tracking. Use of the same 24 panels around a spinning spacecraft will generate only about $1200/\pi$, or 380 W.* Spacecraft subsystems, excluding experiments, require approximately 100 to 200 W, depending on which one of four stabilization techniques is used. A block diagram of the STPSS power subsystem is shown in Fig. B-2.

The STPSS spacecraft can supply substantially more power for experiments than the AEM, i.e., 400 W compared to 40 W. Short-term peak load data comparable to those available for the AEM are not available for the STPSS. Other characteristics, shown in Table B-1, are relatively standard.

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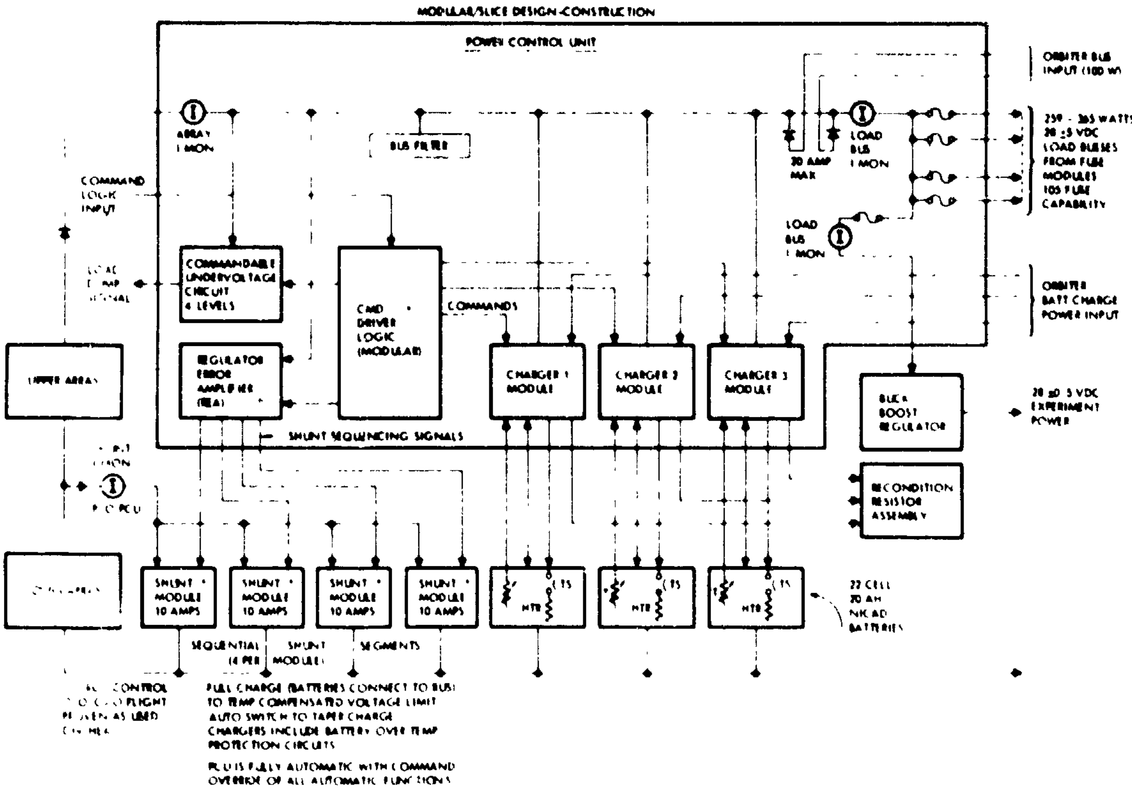
*The average power available for experiments over an orbital period also depends on the orbit.



SOURCE: Ref. 1.

Fig. B-2 — STPSS power subsystem

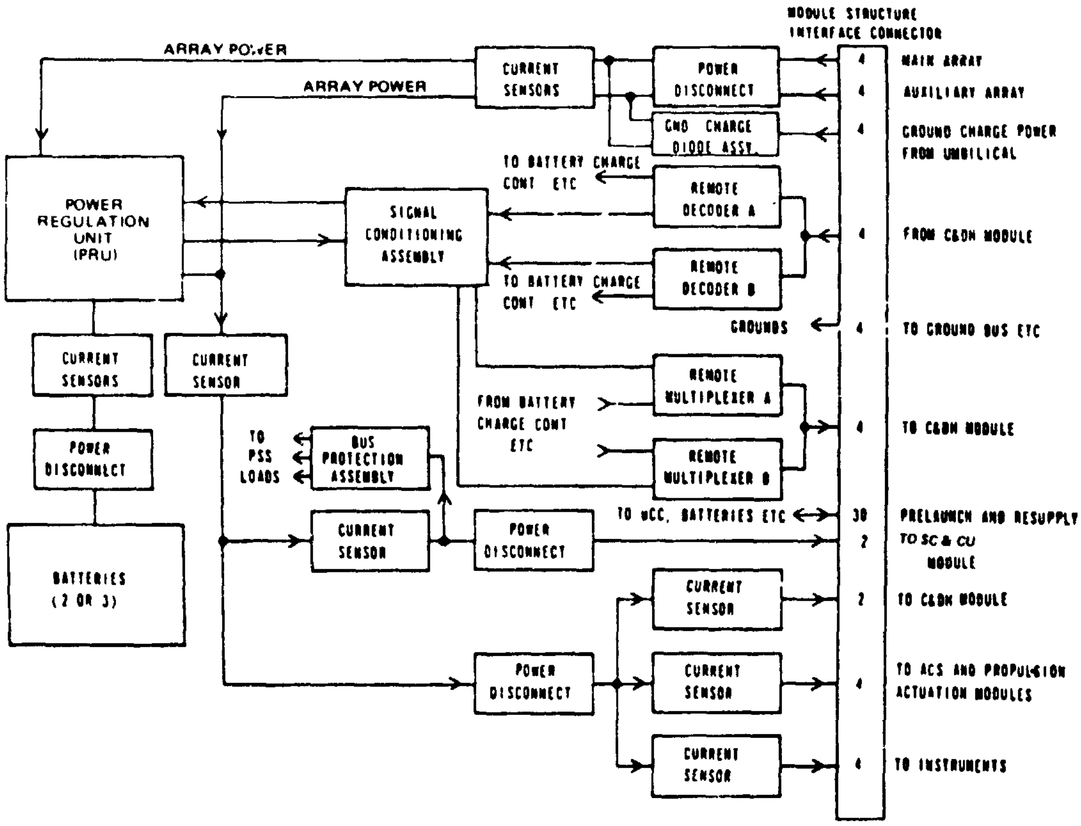
DESCRIPTION OF MMS[5] AND COMPARISON WITH STPSS

The MMS is the largest spacecraft of the three. The MMS base module does not include an array and the assumption is made that any array that is adequate for each payload can be easily incorporated.

The MMS power regulation system has been designed with an emphasis on simplified interfaces and substantial redundancy. The spacecraft is designed to be able to handle orbital average powers up to 1200 W (this would require a peak power from the array of 2400 W or more in a low altitude earth orbit). Power to the spacecraft loads and the batteries is controlled through a switching type of series regulator--the PRU, or power regulating unit. The PRU is designed to adapt to power array levels between 600 and 3600 W; its efficiency ranges from about 0.88 to 0.96. The nominal battery configuration is two of 20 Ah each. However, one to three batteries with either 20 or 50 Ah ratings can be accommodated.

When the MMS is shuttle launched, there should not be a large cost impact associated with integration and testing for every new array, since the shuttle imposes fewer size constraints and lower stresses (vibration, acoustic) than previous launchers.

All of the MMS batteries and spacecraft loads are controlled by a single PRU (see Fig. B-3). In the event of a single battery cell



SOURCE: Ref. 5

Fig. B-3—MMS block diagram--power subsystem module

failure caused by a short circuit, the PRU can change its (voltage/ temperature) operating point to accommodate the lower battery terminal voltage; while this will underutilize the undamaged batteries by one cell out of 22, the total energy available will still be more than if the battery with the failed cell were placed off line.* In the STPSS,

*In the three-battery case, two cells out of 66 are sacrificed because of the one cell failure, while open circuiting a single battery sacrifices 21 cells.

each battery has its own charge control unit. The latter is frequently considered a more reliable system in the event of a single point failure and has been the system considered preferable by the Air Force. Replacement of the MMS power system with one similar to that used on the STPSS would require a substantial amount of redesign.

The PRU, however, has considerable redundancy: two peak power tracking circuits, two bias supply circuits (bias converters with separate fuses), three control logic circuits, and six switching regulators (each rated for 600 W or 18 A maximum). With little additional cost or time, it is possible to arrange two regulators in parallel to supply each of three batteries, with separate logic control for each pair of regulators. The battery outputs would be diode-isolated from the load bus. These modifications would result in a battery charging system more analogous to that of the STPSS.

The unregulated bus voltage (28 ±7 V) was selected to permit extraction of the full Ah rating from the battery, even after several years of aging when the discharge voltage may have decreased to as low as 21 V. On the high side of the voltage range, the batteries require a maximum of 33.4 V at the terminals under worst case charging conditions (highest current level and a battery temperature of 0°C). Because the PRU has a voltage clamp at 35 V, the tolerance was set at ±7 V for symmetry. The ±7 V tolerance requires that the experiments incorporate a preregulator with a larger dynamic range than would be required for the AEM or STPSS (±4 V and ±5 V, respectively). The PRU locates the peak power point by hunting around the equilibrium value at a 70 Hz rate. The resultant 0.5 V peak-to-peak 70 Hz ripple (at a 7 A load) that the PRU imposes on the bus also must be removed by the preregulator at the input of each experiment (it is not practical to filter out so low a frequency).

The PRU is a series regulating element and thus tends to provide lower efficiency than the conventional shunt regulators, e.g., the direct energy transfer systems used on the AEM and STPSS. At synchronous altitudes, this shows up as about a 5 to 10 percent lower efficiency for the PRU approach. In addition, the PRU approach may be as much as 10 percent heavier than the direct energy transfer systems. It has been claimed that in low earth orbits, e.g., altitudes around 300 n mi, an optimized PRU may provide up to 30 percent more power than the direct energy transfer systems for arrays with long thermal time constants (τ). This is because the array is more efficient at lower temperature when it first comes out of eclipse and the PRU takes full advantage of this. For an array like Skylab, the thermal constant is about 20 min. Thus, it takes 60 min (3τ) to get to 90 percent of the final ΔT, and this is the whole illumination period. For lightweight arrays such as the Flexible Roll Up Solar Array (FRUSA), the thermal time constant is only a few minutes and the improvement over a direct energy transfer system in low earth orbit may be no more than 5 to 10 percent.

OVERVIEW

Because many maximum or average power levels can be defined for each space vehicle, Table B-2 summarizes some of the more useful values. Shorter-term peak power levels available for experiment packages may be limited by a variety of considerations unrelated to the factors that dominate in Table B-2. The regulated 28 V ±2 percent power supply for experiments on the AEM, for example, is limited to 50 W maximum; however, the regulator can supply 120 W at 28 V ±5 percent for up to 4 sec. Short-term peak power levels may be limited by the excess output of the solar array, by the battery energy storage capacity, by the surge current limit of the battery, or by the peak power handling capability of some component in the power conditioning subsystem. Short-term power levels--that is, those lasting seconds to minutes--are generally only a factor of 2 to 10 times the average power level, but only penalties such as cost, weight, or reliability inhibit the use of larger factors. Because the complete power subsystems of the STPSS and MMS are not as well defined as for the AEM, and no power-time profiles are available for each experiment, no short-term peak power summary is shown.

There is no doubt that the peak power tracker design of the MMS can squeeze more power out of a given array in a low altitude orbit than a direct energy transfer system, but the primary justification for its use on the MMS is that the array characteristics and array integration into the space vehicle need not be optimized--any handy oversized array is acceptable and can easily be integrated. In this case,

Table B-2

POWER SUMMARY

Characteristic	AEM	STPSS	MMS
Peak array power possible, W	238[a]	1200	≥3600[b]
Average array power available to space vehicle during illumination, W	133	1200	3600
Average power available over a low altitude orbit,[c] W	68	500-600	1200[d]
Average spacecraft housekeeping power, excluding experiments and associated telemetry, W	28	100-200	350
Continuous or average power available for experiments over a low altitude orbit, W	40	400	850

[a]The 238 W is the peak of the power curve which roughly resembles a positive half sine wave, since the array is not sun-tracking.

[b]The 3600 W is set by the peak power handling capability of the PRU; actually, there is no maximum since still higher power arrays would merely be used less efficiently. The excess electrical power would not be drawn from the array, which merely results in a slightly higher array temperature.

[c]This assumes that power is supplied at a constant rate to the spacecraft loads over the entire low altitude orbit and that the battery capacity is adequate to store the energy required over the period the array is occulted.

[d]The power bus is rated for 1200 W maximum, limiting the total load that can be supplied.

however, optimizing the array power output is not likely to prove necessary. Thus, there is a clear dichotomy in emphasizing peak power tracking for efficiency in a multipurpose vehicle.

Some of the ±7 V variation of the MMS bus must be due to series voltage drop in the PRU. In addition to this slow dc variation, there is a superimposed 70 Hz ripple caused by hunting of the peak power tracker about the optimum. While this has been measured to be about

0.5 V peak to peak at a 7 A load (it is limited by the low impedance of the batteries), it may be as much as 3 V peak to peak around the maximum 40 A load. Virtually all experiment packages will require their own preregulators to remove both variations, i.e., the ±7 V dc and 3 V peak-to-peak 70 Hz ripple. Series type preregulators are simple, lightweight, and reliable, but excess power must be available, since their efficiencies over so large a range is poor, i.e., 50 to 60 percent. Furthermore, the additional preregulator dissipation at each experiment package increases thermal problems. Switching regulators (dc-to-dc converters) are more complex, heavier, and require more filtering to control electromagnetic interference but offer efficiencies of 85 to 90 percent or more.

The entire problem can be eliminated by installing one large preregulator (e.g., 28 V ±2 percent) for the entire spacecraft. Where this decision has been made late in a program, it has resulted in spacecraft with unnecessary duplication--the experiments already contained preregulators and too much expense and delay was involved in removing them once they had been designed into the experiment packages. A new MMS specification, which provided for only a one year life and less extreme battery and ripple conditions, would place much less burden on the experiment packages.

Appendix C

COMMUNICATIONS AND DATA HANDLING SUBSYSTEM: A COMPARISON OF AEM, STPSS, AND MMS

by

P. A. CoNine

Table C-1 summarizes the communications and data handling subsystems for the AEM, the MMS, and the STPSS. It can readily be seen that the three C&DH systems are substantially different and not compatible. Major differences include frequencies, modulation, formats, data rates, polarization, and security equipment. None of the C&DH equipment on the three spacecraft is beyond or even pushing the state of the art. Most of the equipment on the AEM and STPSS has been used on previous spacecraft. While some of the MMS equipment will be new, the overall spacecraft is in the latter stages of development. Because the STPSS missions are not concerned with cross-linking data to another spacecraft, it is not necessary to pay any further attention to the TDRSS transponder.

DESCRIPTION OF THE AEM

The AEM spacecraft is currently being built by Boeing in two versions: the HCMM and the SAGE. The HCMM has a VHF command and housekeeping telemetry system and an S-band telemetry unit for experimental data; the SAGE vehicle has all communications at S-band frequencies. The command and telemetry formats are compatible with the NASA-STDN satellite tracking and telemetry system. The HCMM spacecraft is the only one in this study with a VHF command receiver and housekeeping transmitter; however, the communication system has been designed so that it can become S-band-compatible (as on the SAGE) merely by changing the transponder/transmitter-diplexer units. No further consideration will be given to the VHF system.

The AEM telemetry system has a low data rate of 1 or 8 kbps, although on the SAGE tape recorder playback can be as high as 1 Mbps. The command rate is a low 600 bps. The memory is small and is used

Table C-1

C&DH CHARACTERISTICS OF AEM, MMS, AND STPSS

Characteristic	AEM-HCMM[a](31)		AEM-SAGE(31)	MMS(5)	STPSS(1)
Telemetry and Command Band	VHF	S-band	S-band	S-band	S-band
Tracking System Compatibility	STDN	STDN	STDN	STDN	SGLS
Uplink Frequency, MHz	148	2025-2120	2025-2120	2025-2120	1750-1850
Uplink Subcarrier Modulation	FCM/FSK/AM/AM	n.a.	PCM/FSK/AM/FM	PSK	Ternary FSK with AM
Command Format	60 bits	n.a.	60 bits	96 bits[f]	43 bits[j]
Command Bit Rate	600 bps	n.a.	60 bps	2K, 1K, 125 bps[g]	2 kbps
Downlink Frequency, MHz	136	2280	2200-2300	2200-2300	2200-2300
Telemetry Format:					
Word length	8 bits	8 bits	8 bits	8 bits(3)	8 bits
Minor frame length	256 words	128 words	128 words[d]	128 words	Variable(2)
Major frame length	64 minor frames	64 minor frames	64 minor frames	128 minor frames	Variable(2)
Maximum Bit Rate	1.024 kbps[b]	8.192 kbps	1 Mbps[e]	64 kbps	8-128 kbps[k]
Power Output	1/4 W	2 W	1 W, housekeeping 2 W, experiment	1.7, 3.5, or 7.1 W[h](34)	2 W[ℓ]
Communications Security	Not available	Not available	Not available	Not available	Available
Antenna Polarization	RHCP	RHCP	RHCP	1 with RHCP and 1 with LHCP(34)	RHCP(2)
Memory Size	256 words × 32 bits/word and 256 words × 16 bits/word[c]		256 words × 32 bits/word and 256 words × 16 bits/word	16K bits × 18 bits/word[i]	8K words × 32 bits/word[m]
Tape Recorder Capacity	None	None	4.5×10^8 bits	Up to 9×10^8 or up to 8×10^9 bits (optional)	10^8 bits

[a]Two versions of the AEM spacecraft are currently being designed by Boeing: HCMM and SAGE. The HCMM vehicle uses the VHF band for commands and for housekeeping telemetry and S-band for downlink experimental data. The SAGE mission uses S-band for commands, telemetry, and data.

[b]Data rate during the boost phase is 8192 bps.

[c]Commands are compared with words in a 256 word, 16 bits/word PROM (Programmable Read Only Memory). Delayed commands are stored in the remote command processor, which consists of a 256 word, 32 bits/word CMOS/RAM (Complementary Metal Oxide Substrate/Random Access Memory) semiconductor memory (pp. 1-134 to 1-136 of Ref. 31).

[d]Assumed the same as the HCMM vehicle because no change is indicated.

[e]Tape recorder playback rate. Real time data rate is limited to 1 kbps or 8 kbps. A new encoder would be required if higher bit rates are needed.

[f]Reference 33 lists the command format as fixed at 96 bits (48 bit introduction and 48 bit command word). Page 34 of Ref. 5 lists the command format as 48 bits (which can be assumed to be only the command word portion of the total format).

[g]With use of the 2000 bps command rate, a single 5 min command contact per day is required for loading of commands in the on-board computer. This command load will allow the computer to operate the spacecraft for periods of 24 to 72 hr.

[h]Mission selectable.

[i]The MMS C&DH computer includes storage for attitude control information, as well as commands. The STPSS C&DH computer is used only for storing commands, and a separate computer handles attitude control. Therefore, the apparent large difference in the capacities of the two C&DH computers is one of definition not actual capability.

[j]SGLS itself has variable command formats. Page 8-3 of Ref. 1 shows a 43 bit format as TRW's conception of what is required.

[k]By changing subcarriers, this can be increased to 256 kbps. This is SGLS's maximum capacity.

[ℓ]If appreciably higher data rates or more services are desired, there is provision for the standard 2 W transmitter to be used to derive a higher power transmitter (e.g., 20 W) in the payload segment.

[m]Word length deduced from data bus supervisory line formats, p. 8-5 of Ref. 1.

chiefly for storing commands for later processing and for verifying received commands with those stored in memory.

DESCRIPTION OF STPSS AND COMPARISON WITH AEM

The STPSS spacecraft is designed for Air Force missions. It has an S-band communication system which can handle a maximum command rate of 2 kbps and telemetry rates of 256 kbps. It is SGLS-compatible and uses ternary frequency-shift keying (FSK) coding. An on-board computer can handle stored commands, telemetry storage, format control, and memory dumps. Data and commands can be encrypted if necessary.

The C&DH for the STPSS spacecraft is far more sophisticated and has a much greater capacity than that on the AEM (see Table C-1). It is doubtful if experiments of the size that would be carried on the AEM would require as sophisticated a system as presently envisioned for the STPSS. However, currently planned AEM telemetry and control equipment probably could not be used because of the basic incompatibility of the NASA-STDN and AF-SGLS systems.

To make the AEM compatible with the SGLS system requires replacing the S-band transmitter and the S-band transponder, the command demodulator, and modifying or replacing the PCM encoder and the command decoder/processor. Personnel at Boeing indicate that the "black boxes" can be replaced one-for-one with SGLS-compatible equipment without causing major spacecraft redesign. It appears that SGLS-compatible equipment exists that could be used on the AEM. Encryption and decryption units can be added to SGLS equipment if required, but not to STDN. There is some question whether the AEM can meet the signal isolation requirements of encrypted missions. However, Boeing personnel state that an SGLS-compatible AEM can have encryption capability. Items such as the sequencer timer and remote command processor are one-time programmable, with the programming dependent on the spacecraft and mission, and could be used with the proper programming. The STPSS's bus controller, computer, and data interface units are more sophisticated than anything currently on the AEM. The functions that these would handle on the AEM are done as part of the PCM encoder and the command decoder/processor, although those done on the AEM are simpler.

Changes required to make the AEM compatible with SGLS are summarized in Table C-2.

DESCRIPTION OF MMS AND COMPARISON WITH STPSS

The MMS is a large NASA multimission modular spacecraft. Like the STPSS, the C&DH system is capable of transmitting high data rates and has a computer on board for data processing and formatting. However, as is shown in Table C-1, the MMS and STPSS C&DH systems differ substantially because of the STDN-SGLS incompatibilities. The uplink frequency, uplink subcarrier modulation, antenna polarization, communication security protection, and command format differences necessitate the following changes:

1. Replace the STDN transponder with an SGLS transponder.
2. Replace the phase-shift keying (PSK) demodulator with an SGLS single conditioner (includes PSK demodulator).
3. Modify the signal conditioner output, modify the command decoder input, or add a suitable piece of equipment between the two to make the signal conditioner and the command decoder compatible.
4. Redesign the MMS omni antenna.

Further details on interchanging STDN/SGLS communication components are summarized in Table C-3. While the differences between the two C&DH systems are substantial, it is possible that proper preliminary design of the spacecraft would enable communication black boxes to be interchanged with minimal impact. However, if a decision is made late in the design cycle, substantial problems will most likely occur. Available STPSS equipment could be used directly on the MMS. Capabilities are similar, so sizes, weights, and power requirements should be also.

Table C-2

C&DH CHANGES REQUIRED TO RUN STP MISSIONS ON THE AEM

AEM[a] Equipment	Changes to AEM for STP Compatibility	STPSS Equipment
Antennas	Usable	Antenna
Hybrid	Usable	Hybrid
	Replace[b]	Receiver
S-band transmitter		Transmitter
S-band transponder		
Command demodulator	Replace[c] Add (if necessary)[d]	Dual signal conditioner Decryption unit
Command decoder/processor	Modify or replace[e]	Command decoder
PCM encoder	Modify (if necessary)[f] Add (if necessary)[g]	Dual baseband unit Encryption unit
Tape recorder	Usable[h]	Tape recorder Bus controller (data formatter)[i]
Sequencer timer[i]	Modify (if necessary) Not on AEM[j]	 Computer
Remote command processor	Modify[j] Not on AEM[k] Usable[ℓ]	 Data interface unit Harness

[a]Only AEM S-band equipment as on the SAGE will be considered.

[b]The AEM spacecraft uses one antenna and transmitter for experimental data transmission and another antenna and a transponder for receiving commands and broadcasting housekeeping information. Because of differences in the uplink frequencies, at least the receiver portion of the transponder must be replaced. If the current AEM communication configuration is to be maintained, a transponder and a transmitter or two transmitters and one receiver, are required. It may be possible to use STPSS receivers and transmitters on the AEM. Otherwise, several other SGLS-compatible transmitter/receivers have flown or will fly on Fleet Satellite Communication System, P72-1, P72-2, and the S-3.

[c]The STDN-compatible AEM command demodulator operates with binary FSK coding. SGLS uplinks are ternary FSK so this unit must be replaced. The receiver-demodulator unit on the S3 vehicle may be an appropriate replacement for the receiver and demodulator on the AEM (capacity is 1000 bps).

[d]AEM requirements do not include a secure uplink. If a secure uplink is required, then a decrypter must be added between the signal conditioner and the command decoder and these items modified accordingly.

NOTES TO TABLE C-2 (Cont.)

[e]The command decoder processor can be retained for clear uplinks. However, the Air Force Satellite Control Facility (AFSCF) command format would have to be compatible with the decoder and new software would be required. This affects the STPSS.

[f]The SGLS ground system can process PCM signals, however, some modification may be necessary because the AEM uses biphase L Manchester coding and the STP biphase M. However, the current AEM encoder has no provision for dual baseband, which may or may not be necessary for small STP missions run on the AEM. The STPSS dual baseband unit is not directly substitutable on the AEM because it does not include encoding provisions. The P72-1, P72-2, and S-3 spacecraft have had PCM encoders with bit rates of 8, 32, and 16 kbps, respectively. These could probably be used on the AEM if higher data rates are desired.

[g]Boeing personnel state that encryption is possible for the AEM transmissions; there appears to be some question about signal isolation, however.

[h]The optional AEM tape recorder has a larger capacity than STPSS.

[i]Data formatting on the AEM occurs in the PCM encoder. Timing is provided by the sequencer timer. There is no item as sophisticated as the bus controller on the AEM; and for small experiments, it is probably not required. There should be little impact in setting the sequencer timer for STP missions. The AEM is not capable of transmitting data rates as high as the STPSS. Therefore, experiments with real time data rates over 8 kbps cannot be run on the AEM.

[j]The AEM remote command processor is not the same as the STPSS computer. The AEM processor is used simply for verifying commands and storing them for future execution. Modifying the remote control processor for SGLS-type commands should not be a major undertaking because commands are unique to a given spacecraft and its mission anyway.

[k]Experimental data on the AEM go directly to the PCM encoder. Data interface units are not really necessary on the small spacecraft.

[ℓ]Boeing says that the AEM spacecraft can be modified for SGLS compatability merely by replacing black boxes.

Table C-3

C&DH CHANGES REQUIRED TO RUN STP MISSIONS ON THE MMS

MMS Equipment	Changes to MMS for STP Compatibility	STPSS Equipment
	Payload module[a]	Antenna
	Payload module[a]	Hybrid
Diplexer	Replace[b]	Diplexer
		Receiver
Transponder		Transmitter
	Payload module[a]	Switch
PSK demodulator	Replace[c] Add (if necessary)[d]	Dual signal conditioner Decryption unit
Central command decoder[e]	Modify or replace[f] (software change)	Command decoder
Premodulation processor	Replace[g] Add (if necessary)[h]	Dual baseband unit Encryption unit
Tape recorder	Usable[i]	Tape recorder
Data bus controller[e] Clock and format generator[e] Standard computer interface	Usable[j]	Bus controller (data formatter)
Computer	Usable[k]	Computer
Remote unit	Usable[ℓ]	Data interface unit
Harness and connectors	Usable with proper design[m]	Harness
Signal conditioning and control unit	Unique and necessary[n] to MMS vehicle	

[a]The antenna or antennas and their components are considered payload-unique on the MMS. The requirement for hybrids and switches would depend on the exact placement and design of the MMS antenna system. It can be assumed that for Space Test Program missions that the STPSS antenna can be used on the MMS.

[b]Because of differences in uplink frequencies, the STDN transponder cannot be used for SGLS. Reference 1 shows a receiver and transmitter rather than an integrated transponder; however, these could be combined into an SGLS transponder.

[c]The modulation differences necessitate replacing the PSK demodulator with an SGLS signal conditioner, which includes an FSK demodulator.

[d]STPSS system requirements do not include a secure uplink. However, if a secure uplink is to be considered, it is then necessary to add a decrypter

NOTES TO TABLE C-3 (Cont.)

between the signal conditioner (that replaces the MMS PSK demodulator) and the command decoder. A KIR 23 would be considered appropriate for STPSS missions. The KIR 23 output and the decoder input would have to be made compatible by modifying the decoder input or adding a suitable piece of hardware. Further, uplink communications security equipment imposes constraints on the command word format, which in turn influences the decoder. Hence, if a secure uplink is employed, it would be necessary to modify the MMS decoder so that it is compatible with the communications security unit.

[e]These items form the STACC (Standard Telemetry and Command Components) central unit as shown in Ref. 35.

[f]The MMS command decoder can be retained for clear uplinks. However, the AFSCF command format would have to be compatible with the decoder and new software is required. The decoder could also be replaced with the STPSS one.

[g]The premodulation processor (PMP) generates a 1.024 MHz subcarrier, which is modulated by the telemetry data stream. The MMS ranging signal is not combined with the subcarrier in the PMP but is combined in the transponder; SGLS transponders usually do not accomplish the combining in the transponder (unless the transponder performs the baseband assembly function). The PMP can be retained if the SGLS transponder incorporated in the MMS departs from normal practice and combines the ranging signal with the subcarrier. If the SGLS transponder selected performs the baseline assembly function, the PMP will not be required. The PMP also includes electronics for TDRSS compatibility which would serve no useful purpose on satellites communicating with the satellite control facility. It is desirable that a baseband assembly unit be substituted for the PMP.

SGLS has a capability of using two subcarriers. The need for two subcarriers at most is infrequent; the penalty for the capability of having two is also small. While it cannot be demonstrated at this time that two subcarriers are necessary, the capability of having two subcarriers available as an option is desirable.

[h]Most STP missions do not require secured downlink; thus the basic MMS configuration for STP application need not have communications security equipment. However, the communications system design must be such that it can readily accept communications security equipment without costly modifications. For those missions requiring secured downlink, communications security equipment must be added to the MMS between the telemetry format generator and the premodulation processor for downlink protection. A KG-46 is considered to be appropriate for STP programs and is expected to be available in time for use on the MMS. The spacecraft must comply with Tempest requirements to protect the classified data. Proper design practice will provide a high degree of confidence that Tempest requirements can be satisfied with little or no modification. There should be 90 dB isolation between the data and the clock, the input and output signal leads should be

NOTES TO TABLE C-3 (Cont.)

well shielded, and the input and output signal leads should be run in separate cables and connectors. The encryption unit would be GFE.

[i]The MMS tape recorder has a larger capacity than the STPSS one and so should satisfy all Space Test Program missions.

[j]The MMS telemetry format and data rates offer a great deal of flexibility and can be used by STP; they will probably accommodate a large percentage of the payloads. However, there may be some penalties involved in accepting the fixed minor frame length (128 words), the fixed number of subcommutated words (4), and the fixed major frame length (128 minor frames). Supercommutation of the minor frame words and/or of the subcommutated data is provided in the MMS design and will add the flexibility. A recent change to the MMS clock will permit data rates of 128 and 256 kbps.

[k]The MMS computer is larger than that of the STPSS because it handles attitude control as well as C&DH However, there is adequate room in the MMS computer for STP data handling.

[ℓ]The MMS remote unit is usable for STP missions assuming that the data bus controller, clock and format generator, and standard computer interface used is that of the MMS. Using the STPSS bus controller rather than these units would require using an STPSS data interface unit.

[m]Assumes an initially compatible design.

[n]Involved with solar panel deployment on MMS and is required. The STPSS vehicle has nothing comparable. It can be assumed that the changes that must be made in the decoder will not jeopardize this function.

Appendix D

ATTITUDE CONTROL AND STABILIZATION SUBSYSTEM: A COMPARISON OF AEM, STPSS, AND MMS

by

T. B. Garber

The function of the attitude control and stabilization system is to provide the means of orienting the satellite in some specific attitude and then to maintain that orientation with acceptable angle and angular rate errors. In addition, the stabilization and control system should also be able to provide the information necessary for after-the-fact attitude determination.

Table D-1 presents the performance specification and the physical characteristics of the attitude control systems that have been proposed for three spacecraft, NASA's AEM and MMS, and the Air Force's STPSS. In the case of the STPSS design, three different attitude control systems can be incorporated into the spacecraft depending upon the level of performance required.

Of the three spacecraft designs, that of the AEM is the most firm. As can be seen from Table D-1, the performance requirements of the AEM attitude control system are quite modest. The performance of the AEM control system should, under normal conditions, exceed the specifications, with pointing errors roughly one-half those shown.

Basically, the AEM spacecraft is inertially stabilized in roll and yaw by virtue of the angular momentum of a wheel spinning about the pitch axis, normal to the orbital plane. Control of the spacecraft about the pitch axis is achieved by modulating the pitch wheel's angular rate. Errors in the spacecraft's pitch and roll attitudes are detected by a horizon scanner.

To remove the small roll and yaw errors that result from both external and internal disturbances, electromagnets are used to generate the necessary torques. A three-axis magnetometer provides the required knowledge of the earth's magnetic field vector. In addition to damping precessional and nutational spacecraft motion, the electromagnets also provide the necessary torque to unload the pitch wheel (desaturation).

Table D-1

ATTITUDE CONTROL AND STABILIZATION SYSTEMS

Characteristics and Specifications	AEM	STPSS I	STPSS II	STPSS III	MMS
Type of Stabilization	Three-Axis	Spin	Three-Axis	Precision Three-Axis	Precision Three-Axis
Performance:					
Attitude control	±1° pitch, roll ±2° yaw	1°-2° spin axis	1°-2° all axes	0.1° all axes	Less than 0.01° all axes
Rate control	±0.01°/sec all axes	--	0.01°/sec	0.003°/sec	Less than 10^{-6}°/sec all axes (long term)
Attitude determination	±0.5° pitch, roll ±2° yaw	--	0.2°-0.4°	0.02°	--
Control Torques:					
RCS	None	Cold gas, N_2	Cold gas, N_2	N_2; N_2H_4 option	Hydrazine (optional)
Momentum wheels	Pitch bias wheel, roll wheel option	None	None	3, reaction	4, reaction wheels
Electromagnets	3	None	Option	Option	3, pitch, roll, yaw
Nutation damper	None	1	None	None	None
Sensors:					
Earth	Mounted on pitch wheel	1	2, conical scan	None	None
Sun	3 head sun sensor	1	2	2	Both fine and coarse (solar array)
Star	None	None	None	2 strapdown trackers	2 strapdown trackers
Magnetic	3 axis magnetometer	None	Option	Option	3 axis magnetometer
Gyros	None	None	2 rate	4 rate (1 standby)	3 axis + redundancy
Accelerometers	1	None	None	None	None
Miscellaneous:					
Computer	Minimal	None	Yes, dedicated	Yes, dedicated	Yes, shared
Control system weight	29 lb	95 lb	165 lb	289 lb	253 lb (not including N_2H_4 RCS weight)

The AEM attitude control system does not include reaction jets as a means of torque generation. Thus there are no limits on operational lifetimes due to fuel considerations. However, magnetic torques are relatively weak and as a consequence control time constants tend to be large--on the order of an orbital period. Also, magnetic torques decrease with increasing altitude and for the AEM design, they become ineffective for altitude in excess of 1000 n mi.

The simplest of the STPSS designs utilizes spin stabilization. Thus, ideally, the spin axis of the vehicle is inertially fixed. No provisions are made for a despun platform.* A mechanical nutation damper is provided to remove unwanted spin axis wobble and cold gas jets are used to reorient or stabilize the direction of the spin axis. Sun and earth sensors are used for attitude determination.

The second STPSS design is a low-cost, three-axis system with performance specifications similar to those of the AEM spacecraft (see Table D-1). The attitude control system of this version of the STPSS differs from that of the AEM in that a pitch momentum wheel is not used to provide roll-yaw stabilization and cold gas reaction jets are the primary means of generating control torques. Two conical scan earth sensors provide pitch-roll attitude information, while a rate gyro is used to detect yaw attitude errors.

Since, without a pitch momentum wheel, this version of STPSS does not have any inherent stability, disturbances from either internal or external torques must be countered by the reaction control system. For low altitude orbits where aerodynamic and gravity gradient disturbance torques can be large, control system fuel requirements for a one-year mission might be excessive. This situation could be alleviated by adding electromagnetic torques and a magnetometer to the control system so that almost continuous use of the reaction jets would not be necessary.

The third version of the STPSS is designed to attain precise pointing accuracies and rate control. To improve performance relative to the low-cost three-axis design, two star trackers, two rate gyros,

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*In essence, the body of the AEM spacecraft is a despun platform with the pitch wheel inertially stabilized.

and three reaction wheels are added to the stabilization and control system and the two earth sensors are removed. Also, with the addition of the star trackers, a star catalog and the spacecraft's ephemeris must be ground-supplied periodically and thus an on-board computer becomes mandatory. Pointing accuracies of 0.05 deg per axis can be expected from the precision STPSS design.

Unlike the AEM design, the three reaction wheels of the precision STPSS have no momentum bias and are used only to provide reaction control torques. The primary function of the cold gas reaction jet system is to unload the wheels when they approach saturation. As in the case of the low-cost STPSS design, electromagnetic torques and a magnetometer could be added as a supplement to the cold gas system if secular disturbance torques become a problem.

The final spacecraft design to be considered is MMS. The attitude control system of this spacecraft is very similar to that of the precision STPSS. The major difference is that the MMS uses electromagnetic torques to unload the reaction wheels rather than a jet reaction system. However, a hydrazine jet reaction system can be added as an option.

The pointing accuracy specification of the MMS is ±0.01 deg per axis, which is better by a factor of five than that claimed for the precision STPSS. Since the same model strap-down star tracker assembly is proposed for both the MMS and the precision STPSS, the superior performance projected for the MMS must result from either a better gyro reference unit or more frequent stellar updates.

Considering the relatively modest STPSS attitude control performance specifications, it is apparent that all five spacecraft designs of Table D-1 are well within the state of the art. In all cases the major components that have been selected, such as earth sensors, reaction wheels, or star trackers, are developed items of equipment with a history of previous spacecraft use. The AEM and the STPSS spin-stabilized configuration have the least complex attitude control systems, while the precision STPSS and MMS vehicles have the most complex systems.

Appendix E

REACTION CONTROL/PROPULSION SUBSYSTEM: A COMPARISON OF AEM, STPSS, AND MMS

by

J. R. Hiland

Comparative technical evaluations were made for the reaction control/propulsion subsystems contained in the three basic spacecraft designs discussed in this study. There are two versions of the AEM spacecraft: HCMM and SAGE. The STPSS designs encompass three basic configurations: (1) spin stabilized, (2) three-axis stabilized (low-cost), and (3) three-axis stabilized (precision). The MMS spacecraft is a single three-axis stabilized design that can employ several subsystem options within this basic categorization.

The reaction control/propulsion subsystems discussed herein use either cold gas (GN_2) or hydrazine (N_2H_4) as the propellant and perform functions such as spacecraft stabilization, reaction wheel unloading, orbit adjustment, and orbit transfer. Solid propellant rocket motors, which in some cases are also used for stabilization and orbit transfer, are considered separately and not included in this discussion.* Cold gas and hydrazine RCSs consist, essentially, of the same basic components, i.e., tank(s), fill and drain valves, isolation valves, pressure regulator and/or transducer, filters, thrusters, plumbing, and, in cases where the RCS is a separate module, some mounting structure and electrical harness. In this analysis, when the RCS is a secondary subsystem to a particular spacecraft module (usually orientation or attitude control system), the structure and harness is assumed accountable to the primary subsystem. The primary difference in cold gas versus hydrazine system components is in their relative complexity and hence cost. Other potential differences in degree of technological development within a given propellant type have essentially been nullified

*In this study, the stable of solid rocket motors described in Ref. 1 were used for the kick stages to provide orbit translation and circularization.

by the commonly adopted design goal of using flight-proven components where possible for the RCSs evaluated.

Table E-1 shows component breakdowns of the RCS for the various versions of the three spacecraft and is used as a basis for the discussion that follows. The development status of a component is indicated by either a P for flight-proven, PM for flight-proven but requiring some modification for the subject applications, or N if the item represents new hardware, such as plumbing or structure. For costing purposes in this exercise, however, new plumbing or structure can probably be treated as flight-proven, since the technology involved is not new; only the tailoring of these items for each specific configuration is required.

DESCRIPTION OF THE AEM REACTION CONTROL SYSTEM

Only the HCMM version of the AEM uses a reaction control system and it is a small hydrazine system packaged as a separate module. This orbit adjust subsystem provides a nominal 262.4 ft/sec velocity correction capability with the maximum spacecraft weight of 265.5 lb to circularize the orbit and minimize nodal drift. All components are flight-qualified and currently in production. The single 0.287 lb thrust chamber is from the NASA/GSFC IUE program and the propellant flow control valve (included as part of the total thruster assembly) will consist of two single-seat Wright Components, Inc., valves welded together in a series redundant configuration, each valve seat being controlled by a separate coil. The dual version valve, while a minor modification, has been tested by Hamilton Standard and is expected to meet all requirements. The hydrazine tank with elastomeric diaphragm is from the IUE program and needs only very minor modifications to the plumbing and mounting connections. The rest of the RCS is quite straightforward.

DESCRIPTION OF THE STPSS COLD GAS REACTION CONTROL SYSTEM AND COMPARISON TO AEM

There are two cold gas RCSs contemplated for the STPSS. The three-axis version shown in Table E-1 uses twelve 0.1 lb_F thrusters in both the low-cost and precision orientation modules for on-orbit control and reaction wheel unloading. The spin control module of the spin-stabilized

Table E-1

RCS SYSTEM COMPONENT BREAKDOWN

Item	Quantity	Size	Status[a]	Unit Weight (lb)	Total Weight (lb)	Total Cost ($)
AEM-HCMM, Orbit Adjust Module, Hydrazine						
Tanks	1	9.6" dia. (400 psi)	P	2.7	2.7	
Thrusters	1	0.287 lb_F	PM	0.8	0.8	
Valves						
Drain and fill	2		P	0.15	0.3	
Isolation						
Miscellaneous						
Press. regul.						
Press. transd.	1		P	0.6	0.6	
Filters						
Plumbing			N		0.7	
Structure			N		3.8	
Total dry weight, lb					8.9	
Propellant weight, lb					10.6	
Total wet weight, lb					19.5	
STPSS 3-Axis,[b] Orientation Module, Cold Gas						
Tanks	2	13" dia. (4000 psi)	P	17.0	34.0	30K
Thrusters	12	0.1 lb_F	P	0.5	6.0	60K
Valves						
Drain and fill	1		P	0.1	0.1	
Isolation	4		P	0.4	1.6	
Miscellaneous						60K
Press. regul.	2		P	1.2	2.4	
Press. transd.	1		P	0.2	0.2	
Filters	1		P	0.3	0.3	
Plumbing			N	2.0	2.0	
Structure						
Total dry weight, lb					46.6	150K[c]
Propellant weight, lb					18.4	
Total wet weight, lb					65.0	
STPSS 3-Axis and Orbit Transfer, Transfer/Orientation Module, Hydrazine						
Tanks	1	36" dia.	PM[d]	56.0	56.0	80K
Thrusters	12	0.1 lb_F	P[e]	0.5	6.0	240K
	4	4 lb_F	P	0.6	2.4	100K
	1	300 lb_F	P	50.0	50.0	125K
Valves						
Drain and fill	2		P	0.25	0.25	
Isolation	3		P	0.8	2.4	
Miscellaneous						100K
Press. regul.						
Press. transd.	1		P	0.4	0.4	
Filters	1		P	0.3	0.3	
Plumbing			N	6.0	6.0	
Structure						
Total dry weight, lb					124.0	645[f]
Propellant weight, lb					666.0	
Total wet weight, lb					790.0	

Table E-1--Continued

Item	Quantity	Size	Status[a]	Unit Weight (lb)	Total Weight (lb)	Total Cost ($)
MMS-SPS-I, Propulsion Module, Hydrazine						
Tanks	1[g]		P	10.2	10.2	20K
Thrusters	12	0.2 lb_F	P	0.6	7.2	144K
	4	5 lb_F	P	1.25	5.0	48K
Valves						
Drain and fill	2		P	0.25	0.5	4K
Isolation	4		P	0.7	2.8	20K
Miscellaneous						
Press. regul.						
Press. transd.	2		P	0.5	1.0	10K
Filters	2		P	0.25	0.5	4K
Plumbing	25 ft		N		5.0	5K
Harness			N		14.0	
Structure			N		29.0[h]	
Total dry weight, lb					75.2	
Propellant weight, lb					55.0	
Total wet weight, lb					130.2	
MMS-SPS-II, Propulsion Module, Hydrazine						
Tanks	1	36" dia. × 55.5 cylindrical	PM[i]	125.0	125.0	100K
Thrusters	12	0.2 lb_F	P	0.6	7.2	144K
	4	5 lb_F	P	1.25	5.0	48K
Valves						
Drain and fill	2		P	0.25	0.5	4K
Isolation	4		P	0.7	2.8	20K
Miscellaneous						
Press. regul.						
Press. transd.	2		P	0.5	1.0	10K
Filters	2		P	0.25	0.5	4K
Plumbing	25 ft		N		5.0	5K
Harness			N		14.0	
Structure			N		81.0[h]	
Total dry weight, lb					242.0	
Propellant weight, lb					1050.0	
Total wet weight, lb					1292.0	

[a]P = flight-proven; PM = flight-proven but requires some modification; N = new hardware.

[b]Spin module cold gas system is same as three-axis except uses 8 thrusters of 4 lb_F each, which weigh and cost the same (0.5 lb/$5K each). System dry weight is reduced by 2 lb.

[c]TRW estimates that $100-150K should be added to this value for integration and test costs.

[d]Uses 2 end forgings from Viking Orbiter tank and existing elastomeric diaphragm.

[e]Flight-qualified but have not flown.

[f]TRW estimates that $200-300K should be added to this value for integration and test costs.

[g]SPS-I can employ 1, 2, 3, or 4 tanks providing propellant weights of 55, 110, 165, or 220 lb and corresponding system dry weights of 75, 87.2, 99.4, or 111.6 lb.

[h]Includes propulsion module structure, drive electronics, remote interface unit, GN_2 and miscellaneous.

[i]Existing flight-qualified tank developed for Viking Orbiter (VO-75) but will replace surface tension expulsion device with an elastomeric (AF-E-332) bladder.

version of the STPSS uses the same cold gas system, except that the twelve 0.1 lb_B thrusters are replaced with eight 4 lb_F thrusters of the same basic configuration. The unit weights and costs of these thrusters are estimated to be the same as the three-axis units. All components in both cold gas systems are flight-proven.

While the component development status of both the AEM hydrazine system and the STPSS cold gas systems appears to be about the same, different costing bases will be required to reflect the relative degrees of component complexities between them, particularly for tanks and thrusters. Hydrazine tanks typically use diaphragms or bladders for propellant expulsion and gaseous nitrogen (GN_2) for pressurization and require two drain and fill valves per tank. Cold gas tanks simply contain GN_2 under high pressure (in this case, 4000 psia) thus eliminating the diaphragm/bladder and one drain and fill valve. Hydrazine thruster assemblies typically consist of propellant flow control valves, injector thermal standoff and capillary feed tubes, catalytic decomposition chamber, injector, thrust nozzle, heaters (for thrust, chamber, valves, and catalyst bed), temperature sensors, and in some cases, filters and cavitating venturis; whereas cold gas thruster assemblies consist essentially of solenoid valves and a thrust nozzle. Hence, a sizable component cost differential is justifiable between these two types of RCSs, as well as some anticipated difference in system integration and test costs.

DESCRIPTION OF THE STPSS ALTERNATIVE HYDRAZINE REACTION CONTROL SYSTEM AND COMPARISON TO AEM

An alternative to the STPSS three-axis version spacecraft is to use a transfer/orientation module in place of the cold gas equipped orientation module and solid rocket propulsion for orbit transfer. This transfer/orientation module contains (in addition to attitude control system equipment) a hydrazine RCS to perform all of the spacecraft functions, such as three-axis stabilization, reaction wheel unloading, and orbit transfer and adjustment. Table E-1 shows the component breakdown for this system.

The 36-in. diameter spherical tank will be fabricated using the end forgings from the Viking Orbiter tank and incorporating an existing flight-proven elastomeric diaphragm. The 0.1 lb_F thrusters are flight-proven. The 300 lb_F thruster, as purchased, has a very heavy valve and gimbal mount assembly, which will be removed for this application. The $125K cost shown in Table E-1 is the estimate after these changes.

In comparison to the AEM hydrazine system, this RCS is larger (employs more components and of larger unit size) but is basically the same technologically; the required fabrication modifications and the indicated deviations from flight-proven status appear not of significant magnitude to warrant much, if any, variation in the costing basis employed.

DESCRIPTION OF THE MMS REACTION CONTROL SYSTEM AND COMPARISON TO STPSS

Two hydrazine RCS/propulsion systems have been configured to accommodate the various missions being considered for the MMS. The first, SPS-I, meets the orbit adjust and reaction control requirements for spacecraft in the 2500 lb class that would be launched by a Delta 2910. The second, SPS-II, meets the requirements of orbit transfer, orbit adjust, and reaction control for spacecraft in the 4000 to 10,000 lb class and would be used only by missions that are shuttle-launched. Component breakdowns of each system are shown in Table E-1.

The SPS-I system can use 1, 2, 3, or 4 of the tanks shown to provide propellant capacities of 55, 110, 165, or 220 lb, depending upon specific mission requirements. Two additional fill and drain valves and a filter and pressure transducer (totaling 2.0 lb) are required with each additional tank.* As indicated, all components in the SPS-I system are flight-proven or flight-qualified except for plumbing, harness, and structure, and for costing purposes these items can probably be treated as flight-ready per earlier discussions. The total SPS-I system is estimated to have a nonrecurring cost of $900K and a recurring cost of $600K.

The SPS-II system is the same as SPS-I except that it uses a large single cylindrical tank and, hence, requires more structure. The tank

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*Efforts are under way to do without these items as tanks are added.

(36 in. in diameter by 55.5 in. in length) is an existing flight-qualified design that was developed for the Viking Orbiter (VO-75) program. It presently has a surface tension device for propellant expulsion, which will most likely be replaced with an elastomeric (AF-E-332) bladder. Such replacement would entail about a 25 percent modification to the overall tank assembly. As indicated in Table E-1, the structure weight is increased from 29 lb to 81 lb compared to SPS-I. However, it should be noted that these weights include propulsion module structure, drive electronics, remote interface unit, GN_2, and other miscellaneous items; hence, some care in cost bookkeeping appears warranted for both the SPS-I and SPS-II systems. The total SPS-I system costs are estimated to be \$500K nonrecurring and \$750K recurring on the basis that the SPS-I system will be built first.

In comparing these two MMS hydrazine systems with the STPSS cold gas systems, the same comments apply as presented earlier in the comparison of STPSS cold gas systems and the AEM hydrazine system i.e., a different cost base is required for cold gas hydrazine components. With respect to the STPSS hydrazine system, the same cost base should apply with perhaps some minor adjustments for the required component modifications noted herein. Moreover, the 0.2 lb_F and 5 lb_F thrusters of the MMS systems are estimated at \$12K each compared to \$20K and \$25K each for the 0.1 lb_F and 4 lb_F thrusters in the STPSS hydrazine system. This difference is probably reconcilable on the basis that the MMS thrusters have single-seat/single-coil propellant flow control valves versus dual-seal/dual-coil valves in the STPSS thrusters and perhaps less contractor testing and paperwork required, since the MMS thrusters are standard NASA items.

Appendix F

STRUCTURAL SUBSYSTEM: A COMPARISON OF AEM, STPSS, AND MMS

by

M. M. Balaban

AEM STRUCTURAL SUBSYSTEM

The principal elements of the AEM(31,36,37) structural subsystem that are of interest for a shuttle application consist of a base module and an instrument module. The base module structure contains support subsystems for the HCMM and SAGE missions, including all appendages and mechanisms to support these subsystems. The differences between these missions have no effect on the primary structural subsystem.

The base module consists of an 18 in. long hexagonal body with six longerons tied to a 7 in. conical structure that mates with a standard Scout series 25E adapter. Open truss bulkheads rigidize each end of the hexagonal enclosure. This design provides approximately 7.3 sq ft of usable flat surface for experiment mounting.

The structural elements of the base module are primarily sheet and stringer aluminum. Side panels of the hexagon are 0.012 in. thick clad 2024-T3 aluminum sheet riveted to the six corner longerons. Panel edge members, equipment support stiffeners, and truss-type bulkheads are also formed from 2024-T3 aluminum sheet. The longerons are standard Burner IIA extrusions, specifically shaped for hexagonal structure corners.

The truss-type bulkheads at either end of the hexagonal body provide structural rigidity, with good accessibility to the interior. These bulkheads are 2024-T3 formed parts attached to the body longerons. The forward bulkhead ties to the four longerons that serve as attach fittings to the instrument module. The center diagonal is easily removed by disconnecting fasteners at each end so as to provide better access for installing or removing interior components.

The aft bulkhead supports the modular orbit-adjust system for HCMM missions. The orbit-adjust system, which is fabricated, tested, and serviced as a separate module, is bolted to the aft bulkhead at three points. Shims are bonded to the aft bulkhead to provide proper lateral and angular alignment once the spacecraft mass properties have been determined.

The instrument module contains the mission instruments and the supporting electronics. This module is connected by low-heat-conduction, bolted-in fittings at four of the six longeron forward ends so as to provide direct load transfer. Fiberglass blocks and thermal blankets reduce heat conduction to less than 0.2 W/°C. This type of attachment fitting was used in the Burner IIA and P42-1 units. The four structural attach points feed acceleration loads directly into the base module longerons.

The total weight of the AEM structural subsystem is 47.7 lb, consisting of 27.2 lb of primary structure, 17.5 lb of secondary structure, and 3 lb of mechanisms.

MMS STRUCTURAL SUBSYSTEM

The primary structural elements of the MMS[38,39] for shuttle operation are the module support structure and the transition adapter. The power, attitude control and stabilization, and C&DH module skins are secondary structural elements in that they support elements of the spacecraft subsystems.

Module Support Structure

The module support structure provides structural continuity between the transition adapter, subsystem modules, and propulsion module. Its construction is basically a three-dimensional truss, with the six corners as the primary load points. (Electrical connectors and other insignificant loads may be hung on the struts themselves.) The Rockwell technical proposal for fabrication shows the structural elements to be primarily sheet, angles, and channels. The corner fittings appear to be 60 deg V-shaped channels especially designed for triangular corners.

Transition Adapter

The transition adapter is the interface between the module support structure and the mission adapter. During shuttle boost, it is also the element that connects to the flight support system. The attachment points are provided by three load pins. The drogue point is the attachment element to the remote manipulator system of the orbiter, used for initial contact in the retrieval operation. The transition adapter also supports operational or mission-unique elements such as solar arrays (and associated mechanisms), booms, and antennas.

Structurally, the transition adapter is a ring with an I-beam cross section. It contains automated machined fittings, formed extrusion, and sheet metal components. Flanges and webs are formed from annealed material then heat treated to the T-6 (temper) condition. Standard mechanical fasteners are used for component joining. Final machining of mating surface and drilling of subsystem attach holes take place after structural assembly.

Spacecraft and Structural Weights

Table F-1 shows the weights budgeted for MMS subsystems in their baseline configurations. The MMS total weight including payload will be defined by GSFC for each mission on the basis of spacecraft and launch vehicle configuration.

Table F-1

BASELINE MMS STRUCTURE WEIGHT SUMMARY

	Baseline Configuration Weight (lb)	
Subsystem	Total	Structural and Thermal Components
Module support structure	168	150
Transition adapter	115	115
C&DH module	199	103
Power module	358	107
Attitude control and stabilization module	371	117
Thermal control	3	3
Electrical integration	98	0
Total	1312	595[a]

[a]The thermal weight breakdown is as follows: louvers = 39 lb, blankets = 6 lb, other = 3 lb. Total thermal weight = 48 lb. The net structural weight is then 595-48 = 547 lb.

STPSS STRUCTURAL SUBSYSTEM

The description of the STPSS structure presented here provides only the overall dimensions and configuration.[1] Additional details, such as individual member materials and thicknesses, are not available because no actual design has yet been undertaken. The STPSS consists mainly of a core module and an orientation module.

Core Module

The core module has the shape of a thin hexagonal nut. It connects to the shuttle orbiter at two trunnions and a stabilizing fitting. Box beams spread the load from the trunnion to the central ring, which is the primary load-carrying member. Honeycomb panels define the hexagonal perimeter of the core module. They also provide mounting surfaces for equipment on the interior and thermal radiators on the exterior. The panels transfer the load to the trunnions and directly to the central ring via the webs.

Orientation Module

Each orientation module is also hex-nut shaped and mates with the core module at the central ring. The two versions of the three-axis-stabilized module (i.e., the "orientation" version and the transfer/orientation version) have identified structure except for brackets that connect the appropriate propulsion unit. The spin-orientation module is thinner because its equipment does not require as much volume.

Spacecraft Weights

Table F-2 summarizes the spacecraft structural component weights. The TRW estimate of structural weight was deduced from HEAO* data. The HEAO spacecraft, which carries a 7000 lb payload with a safety factor of 3, weighs about 20 lb/axial length (in.). Taking a 1500 lb payload weight for the STPSS spacecraft, and a safety factor of 2, TRW deduced a structural weight of 25 lb/sq. in.

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*High Energy Astronomical Observatory--a spacecraft that was actually designed and analyzed by TRW.

Table F-2

STPSS STRUCTURAL COMPONENT WEIGHT SUMMARY

Component	Structural Component Weight (lb)
Core module	240
Spin-control-orientation module	70
Three-axis-orientation module	150
Precision three-axis module	150
Solar array	
Standard 50 W subpanel (19" × 45")	3.0 ea.
"Picture frame" (boom, hinges, etc.)	2.0-2.6 ea.

SOURCE: Ref. 1.

COMPARISON OF STRUCTURAL SUBSYSTEMS

The AEM is primarily aluminum sheet and stringer construction, using standard Burner IIA extrusions for longerons. The conical shell that interfaces between the spacecraft and the Scout F booster is probably the most "exotic" structural element from a structures standpoint. However, it too is formed from aluminum sheet, and fabrication appears to be well within the state of the art and, in addition, will not be used on STPSS missions.

The module support structure of the MMS is a simple 3-D truss. The subsystem modules utilize honeycomb panels that frame into aluminum stock edges. The transition adapter is of more ..lex construction; however, the fabrication procedures appear to be ed on proven techniques.

The basic structure of the STPSS appears to use more nonstandard components, i.e., rings and diverging box beams. The structural weight is also a higher percentage of the instrument payload weight than it is in the AEM and MMS. Additionally, alignment may be a more critical aspect of STPSS construction because loads have to be transferred between the inner cylinders of the core module and orientation module with minimal edge moments. The additional complexity of the STPSS structure will be reflected primarily as a fabrication cost, rather than as one of development risk.

In summary, the AEM and MMS structural subsystems appear to use proven techniques and, for the most part, standard members. The STPSS certainly is no simpler in construction and is probably more costly on a relative basis.

Appendix G

THERMAL CONTROL SUBSYSTEM: A COMPARISON OF AEM, STPSS, AND MMS

by

W. D. Gosch

COMPARATIVE EVALUATION OF THE THERMAL CONTROL SUBSYSTEM ON THE STPSS AND AEM SPACECRAFT

There are two major differences between the thermal control subsystem of the STPSS and that of the AEM (Table G-1). First, the AEM design uses louvers, while the STPSS relies on radiators and heaters for controlling spacecraft component and structure temperatures. Second, the STPSS requires high temperature insulation around the

Table G-1

THERMAL CONTROL ELEMENTS OF THE AEM, STPSS, AND MMS SPACECRAFT

	Spacecraft					
	AEM		STPSS			MMS
	3-Axis			3-Axis		
Element	Type I	Type II	Spin	Low-Cost	Precision	3-Axis
Spacecraft weight (lb)	214	274	888	1043	1167	1312
Thermal control weight (lb)	~ 3	3+[a]	(b)	(b)	(b)	39
Thermal control elements:						
• Louvers	1	2	--	--	--	6
• Radiators	X	X	X	X	X	X
• Heaters	X	X	X	X	X	X
• Multilayer insulation	X	X	X	X	X	X
• Thermal coatings	X	X	X	X	X	X
• High-temp. insulation			X	X	X	
• Interface insulators	X	X	X	X	X	X

[a]A second louver and radiator are added for this mission.

[b]Structure and thermal control weights combined: core middle = 250 lb, spin module = 75 lb, orientation (low-cost and precision) = 160 lb. TRW did not determine actual weights of the thermal control elements but they indicate it would be on the order of 10-15 lb.

solid rocket kick stage motor. This motor is imbedded inside the hexagonal modules and must be thermally isolated during and after firing to prevent excessive heat transfer to the spacecraft modules.

The louvers specified for the AEM were flight-qualified on the Mariner '64 and '71. The Boeing STP 72-1 and the S3 programs used a total of 17 louver assemblies identical to the ones proposed for the AEM spacecraft.

Multilayer insulation blankets for shielding the spacecraft from the heat generated by the solid rocket motors during and after firing are made of materials that can withstand the higher temperatures, such as titanium.

The "low temperature" multilayer insulation blankets are used to decouple the spacecraft from the external environment. For the AEM the blankets consist of an outer layer of aluminized 1 mil Kapton, 10 layers of doubly aluminized 1/8 mil perforated mylar separated by silk net spacers, a single layer of Dacron plain-woven cloth to act as a filter, and an inner layer of aluminized 1 mil Teflon (Teflon side facing the base module). The STPSS uses insulation blankets on the entire outer surface of each module with the exception of cutouts for the radiator panels.

On the AEM, heaters are used in the thermal control system solely for maintaining the orbit adjust system component (thruster valves and catalyst bed) temperatures within the design limits during the initial velocity trim. The heaters are subsequently commanded off and remain inactive for the remainder of the mission. They could be reactivated at any time by ground command if required. The total heater power required during velocity trim is 3 W.

The STPSS uses a heater for the solid rocket motor. It is thermostatically actuated to ensure adequate temperature levels at the time of firing. The STPSS also uses thermostatically controlled component heaters with sufficient power to maintain component temperatures above the minimum allowable under the coldest conditions.

Thermal control coatings used on the AEM and STPSS provide interior and exterior radiation control. Interior coatings enhance the internal radiation heat transfer from bay to bay. Coatings are used on the external surfaces to reduce the temperature effects of direct or reflected sunlight. These surfaces include the backside of the solar array, the louver radiator surface (AEM), the thermal control trim radiator, the shunt dissipater panel, solar array and antenna appendages, and the S-band antenna.

Radiators for dissipating heat generated inside the spacecraft are used on both the AEM and the STPSS. In the case of the STPSS (which has no louvers) the control of component temperatures within the spacecraft is achieved with a combination of radiators, second surface mirrors, and thermostatically controlled heaters. On the AEM, component temperature control is achieved with louvers and thermal-control trim radiators. The baseline design radiator for the AEM spacecraft radiator is sized to satisfy the HCMM mission requirements and is painted white. The radiator's properties can be adjusted by paint stripes to attain the desired trim.

Since most of the elements of the AEM thermal control subsystem have been flight-proven on previously designed Boeing spacecraft, they should be considered at least state of the art if not off-the-shelf. The same holds true for the TRW-proposed STPSS design.

COMPARATIVE EVALUATION OF THE STPSS AND MMS SPACECRAFT

To date, contracts have not been awarded for the design, development, or production of either the MMS or the STPSS. Consequently, the information available for making a comparative evaluation of the MMS and STPSS is less detailed than for the AEM-STPSS evaluation. However, based on the information from GSFC, Aerospace Corporation, and TRW, thermal control subsystem concepts are sufficiently well defined that a reasonable comparative technical evaluation can be made.

The same two differences between the AEM and STPSS are indicated for the STPSS and MMS (Table G-1). The MMS spacecraft uses two louvers on each of three modules: power module, ACS module, and the C&DH module. As previously stated, the STPSS relies on radiators, second surface mirrors, and thermostatically controlled heaters for maintaining the spacecraft structure and components within specified temperature limits. Louvers are generally considered to be more expensive than heaters. However, personal contact with a thermal control system engineer at

GFSC revealed that their analysis of the spacecraft heat balance, using louvers rather than heaters and radiators, indicated it is more economical to use louvers. The propulsion module for the MMS spacecraft (either SPS-I or SPS-II) is mounted at the base of the spacecraft structure and is thermally isolated from the structure and modules. A small quantity of heat is transferred at the interface between the structure and propulsion module and is accounted for in the thermal control analysis of the entire spacecraft. As noted previously the STPSS spacecraft uses a solid propellant rocket motor for propulsion and must be thermally isolated from the modules with high temperature multilayer insulation to prevent excessive heat transfer into the modules during and after firing.

The design objectives for both spacecraft, from a thermal control point of view, are generally the same, namely, thermally isolate each individual module from the environment and other parts of the spacecraft. The same basic design philosophy of using low-cost, proven elements for the thermal control subsystem appears to apply to the MMS and the STPSS. Thermal control elements for the MMS can be considered as at least state of the art if not off-the-shelf.

Appendix H

PROGRAM OPTIONS FOR THE SAMSO SPACE TEST PROGRAM

by

S. H. Dole and L. N. Rowell

Alternative approaches (i.e., different mixes of spacecraft, orbits, and payloads) to carrying out a complete Space Test Program during the 1980-1990 period were generated so that different sets of total program costs could be computed and compared. This appendix includes only a representative sample of the alternative program options that were examined in this study. First, the STPSS mission model is discussed and disaggregated into eight categories of orbits, and then the various standard spacecraft configurations considered in this study are identified with the payloads in these orbit categories according to their ability to accommodate the payload requirements. After this, the procurement options are determined for a variety of conditions.

ANALYSIS OF PAYLOADS IN THE STPSS "BLUEBOOK"[26]

We adopted the premise that we could consider the payloads given in Ref. 26 to be "representative" of those that would be orbited, thus the payloads in the bluebook were analyzed, as follows. Of the 51 payloads listed therein, four were eliminated because they required special spacecraft, or because they had already been launched into space (Nos. 4, 5, 9, 45),* and one (No. 42) was eliminated because the orbit was not clearly defined. The remaining 46 payloads were categorized according to their orbital orientation and apogee altitude and perigee altitude requirements. The standard orbits that were selected to provide a means of grouping payloads (and the number of bluebook payloads captured by each) are:

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*The numbers are those of the bluebook pages where the payloads are described.

Orbit Number	Description
1-S	Sun-synchronous (98.4 deg inclination), 250 to 300 n mi circular, sun-oriented [8]*
1-E	Sun-synchronous, 250 to 300 n mi circular, earth-oriented [13]
2	Elliptical, 7000 × 200 n mi, polar [13]
3	Geosynchronous (19,372 n mi) circular, low inclination, sun-oriented [4]
4	10,000 n mi circular, low inclination [2]
5	12 hr orbit, 21,000 × 900 n mi, 63.4 deg inclination [illegible]
6	Geosynchronous circular, low inclination, earth-oriented [1]
7	3200 × 150 n mi, 30 deg inclination [1]
8	180 n mi circular, polar [1]

The velocity increments required to place the spacecraft into the above standard orbits are given in Table H-1. These ΔVs were used for the selection and sizing of appropriate kick stages.

The payloads were also ordered according to the spacecraft capabilities that are needed to accommodate the payload. In addition to mission altitude and orientation, we also used payload weight, power, data rate, stabilization requirements, and pointing accuracy as filters for assigning spacecraft. These assignments are given in Tables H-2 to H-5 where the letters "x" or "y" indicate a compatibility between spacecraft capability and payload requirements. The letter "y" in the AEM spacecraft row applies when that spacecraft's maximum altitude capability is assumed to be geosynchronous rather than its current limit of 1000 n mi; this was one of the spacecraft design excursions that was examined in the study.

PROGRAM OPTION DEVELOPMENT

On the basis of information provided by SAMSO, it appeared that the Space Test Program would be orbiting approximately 114 payload packages during the 1980-1990 time period. Since there were only 64 representative payloads in the sample we had available to work with, it was

*Numbers in brackets are the number of the bluebook payloads accommodated by the orbit.

Table H-1

STANDARD ORBITS, VELOCITY INCREMENTS

Orbit Number	ΔV_1 (ft/sec)[a]		ΔV_2 (ft/sec)[b] [Apogee altitude (n mi)]		Total ΔV (ft/sec)	Remarks
1-S	174	[150]	172	[250]	346	250 n mi circular orbit
1-E	258	[150]	255	[300]	513	300 n mi circular orbit
	258	[150]	171	[300]	429	250 x 300 n mi orbit
2	5,581	[150]	55	[7,000]	6,136	200 x 7,000
3	7,984	[150]	4,820	[19,372]	12,804	Geosynchronous
4	6,505	[150]	4,601	[10,000]	11,106	10,000 circular
5	8,136	[150]	419	[21,000]	8,555	12 hr 900 x 2,000 (ΔV in plane)
	8,136	[150]	3,116	[21,000]	11,252	12 hr 900 x 21,000 63.4 deg (ΔV changes orbit plane inclination 35 deg at 21,000 n mi altitude)
6	7,984	[150]	4,820	[19,372]	12,804	Same as Program Option 3
7	3,536	[150]	-0-	-0-	3,536	150 x 3,200 n mi
8	53	[150]	53	[180]	106	180 n mi circular

[a] ΔV_1 is velocity increment added at shuttle altitude of 150 n mi to carry spacecraft to apogee altitude.

[b] ΔV_2 is the velocity increment added at apogee altitude to achieve desired orbit.

Table H-2

ORBIT 1-S: PAYLOAD ASSIGNMENTS

Orbit 1-S: Sun synchronous, 250-300 n mi circular, sun-oriented								
Payload number	15	19	20	27	33	37	48	51
Weight (lb)	50	10	76	250	1	12	135	3
Candidate Spacecraft AEM					y[a]	y		y
STPSS-S				x				
STPSS-LC	x			x	x	x		x
STPSS-P or MMS	x	x	x	x	x	x	x	x

[a]y applies when AEM maximum altitude is geosynchronous (19,382 n mi).

Table H-3

ORBIT 1-E: PAYLOAD ASSIGNMENTS

Orbit 1-E: Sun-synchronous, 250-300 n mi circular, earth-oriented													
Payload number	18	23	26	28	29	34	35	36	38	39	40	41	49
Weight (lb)	13	9	13	525	53	13	40	60	6	5	331	135	25
Candidate Spacecraft AEM	xy	xy	xy		xy	xy	xy	xy	xy	xy			xy
STPSS-S		x	x	x		x					x		
STPSS-LC	x	x	x	x	x	x	x	x	x	x	x	x	x
STPSS-P or MMS	x	x	x	x	x	x	x	x	x	x	x	x	x

Table H-4

ORBIT 2: PAYLOAD ASSIGNMENTS

Orbit 2: Elliptical (7,000 x 200 n mi), polar													
Payload number	1	6	11	12	13	14	17	21	22	31	32	46	50
Weight (lb)	17	16	4	8	15	8	4	44	70	18	1	5	110
Candidate Spacecraft AEM	y	y	y	y	y	y	y	y		y	y	y	
STPSS-S										x		x	
STPSS-LC	x	x	x	x	x	x	x	x	x	x	x	x	x
STPSS-P or MMS	x	x	x	x	x	x	x	x	x	x	x	x	x

Table H-5

ORBITS 3, 4, 5, 6, 7, and 8: PAYLOAD ASSIGNMENTS

Orbit	3[a]				4[b]		5[c]			6[d]	7[e]	8[f]
Payload number	3	16	44	52	2	24	7	10	43	8	25	30
Weight (lb)	12	3	147	13	29	2	25	19	475	(30)	43	30
Candidate Spacecraft AEM	y	y		y	y	y	y	y		y	y	
STPSS-S		x				x	x	x				
STPSS-LC	x	x	x	x	x	x	x	x		x	x	
STPSS-P or MMS	x	x	x	x	x	x	x	x	x	x	x	x

[a] Geosynchronous (19,372 n mi) circular, low inclination, sun-oriented.

[b] 10,000 n mi circular, low inclination.

[c] 12-hour orbit, 21,000 x 900 n mi, 63.4 deg inclination.

[d] Geosynchronous circular, low inclination, earth-oriented.

[e] 3,200 x 150 n mi, 30 deg inclination.

[f] 180 n mi circular, polar.

necessary to scale this number up by a factor of 2.48 to yield a closer approximation of the complete program. Consequently, both the numbers of payloads and their aggregated weights taken from Tables H-2 to H-5 were multiplied by 2.48 in developing the program options. Other numbers of total payloads in the ten-year period, 92, 138, and 228, were assumed in some of the cases to test the effect on results. As above, appropriate multiplying factors were used.

Groups of payloads (for a given orbit) were assigned to specific spacecraft with the following limits being observed:

1. Maximum payload weights that can be loaded on a single spacecraft: AEM = 150 lb; STPSS = 1000 lb or 1500 lb; MMS = 4000 lb.
2. Maximum circular orbital altitudes reachable by the spacecraft: AEM(x) = 1000 n mi; AEM(y) = 19,372 n mi; STPSS and MMS = 19,372 n mi.
3. The maximum number of payloads that can be loaded on a single spacecraft in separate program options was assumed to be 6, 8, 10, or 13.
4. Maximum experimental power: AEM = 50 W; STPSS-S = 290 W; STPSS-LC and STPSS-P = 400 W; MMS = 850 W.*
5. Maximum data rate: AEM = 8 kbps; STPSS = 128 kbps; MMS = 64 kbps.

The number of spacecraft flights for six different cases, four different program options, and four different assumed upper limits on the number of payloads that could be placed on a single spacecraft are summarized in Table H-6. As may be seen from Table H-6, the total number of shuttle flights required to place all of the STPSS payloads into orbit ranged from a minimum of 12 to a maximum of 26. The ranges in numbers of launches, as a function of the assumed payload limitations, are shown below:

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*The power limitation affected only the payload packages for the AEM and STPSS-S spacecraft; for all others, different limitations were more critical.

Table H-6

SUMMARY OF TABLES H-7 THROUGH H-23

CASES →		I	II	III	IV	V	VI
STPSS MAXIMUM PAYLOAD WEIGHT (LB) →		1000	1500	1000	1000	1000	1500
MAX. AEM ALT. (N MI) →		1000	1000	1000	1000	19372	19372
TOTAL NO. OF PAYLOADS →		114	114	92	138	114	114
PROGRAM OPTION	SPACECRAFT	NUMBER OF SPACECRAFT FLIGHTS					
		(13) (10) (8) (6)	(13) (10) (8) (6)	(13) (10) (8) (6)	(13) (10) (8) (6)	(13) (10) (8) (6)	(13) (10) (8) (6)
		A	B	C	D	E	F
1 (AEM + STPSS)	AEM	1 1 2 3	1 2 3 4	0 0 1 2	0 0 2 3	7 7 9 11	6 8 10 13
	STP/LC	10 11 14 16	10 11 13 15	10 11 12 15	12 15 16 18	5 5 7 8	5 5 6 7
	STP/P	5 5 5 5	3 3 4 5	4 4 4 4	4 4 5 5	5 5 5 5	3 3 4 4
	MMS	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
	TOTAL NO. FLIGHTS →	16 17 21 24	14 16 20 24	14 15 17 21	16 19 23 26	17 17 21 24	14 16 20 24
		G		H	I	J	
2 (AEM + MMS)	AEM	1 2 3 4	SAME AS G	2 2 3 4	2 3 3 5	7 8 10 13	SAME AS J
	STP/LC	0 0 0 0		0 0 0 0	0 0 0 0	0 0 0 0	
	STP/P	0 0 0 0		0 0 0 0	0 0 0 0	0 0 0 0	
	MMS	13 14 17 20		11 12 13 16	13 16 18 21	8 8 10 11	
	TOTAL NO. FLIGHTS →	14 16 20 24		13 14 16 20	15 19 21 26	15 16 20 24	
		K	L	M	N		
3 (ALL STPSS)	AEM	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	SAME AS K	SAME AS L
	STP/LC	11 12 16 19	11 13 16 19	11 12 14 18	12 15 17 21		
	STP/P	5 5 5 5	3 3 4 5	3 3 3 3	4 4 5 5		
	MMS	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0		
	TOTAL NO. FLIGHTS →	16 17 21 24	14 16 20 24	14 15 17 21	16 19 22 26		
		O		P	Q		
4 (ALL MMS)	AEM	0 0 0 0	SAME AS O	0 0 0 0	0 0 0 0	SAME AS O	SAME AS O
	STP/LC	0 0 0 0		0 0 0 0	0 0 0 0		
	STP/P	0 0 0 0		0 0 0 0	0 0 0 0		
	MMS	14 16 20 24		12 14 16 20	14 18 21 26		
	TOTAL NO. FLIGHTS →	14 16 20 24		12 14 16 20	14 18 21 26		

Maximum number of payloads per single spacecraft	13	10	8	6
Number of launches	12-17	14-19	16-23	20-26

Each of the cells of the matrix represented by Table H-6 is expanded in Tables H-7 through H-23. In these tables, the total number of spacecraft required are disaggregated by orbit so that one can determine the appropriate kick stages that would provide the velocity increment necessary to translate the spacecraft from the nominal shuttle parking orbit (150 n mi) to the mission orbit. Tables H-7 through H-23 also tabulate the maximum number of payloads actually assigned to a spacecraft in a given orbit.

INTEGRATION COSTS

The costs of integrating and testing a complete spacecraft appear to be predominantly a function of the complexity of the individual payloads themselves rather than of the characteristics of the spacecraft on which they are mounted or of the number of payloads that have to be integrated into a single spacecraft. Some information provided by Mr. W. A. Myers, of Rockwell International, indicates that mission integration costs might include the costs of about three engineering man-months per payload at the low-cost end, up to total costs of possibly $1,000,000 per payload for highly complex payloads. A typical mission integration job would require one engineer per payload over a period of six to nine months. He indicated that there should be very little difference between the STPSS and the MMS relative to mission integration. The test procedures might be slightly more complicated with the MMS so the nonrecurring costs (of developing procedures) could be a little higher.

Table H-7

CASE I (A)[a]

PROGRAM OPTION 1: USE LEAST EXPENSIVE SPACECRAFT AND MINIMIZE NUMBER OF FLIGHTS

ORBIT	SPACECRAFT	MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
		NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	0 - 0	0 - 0	1 - 5	2 - 5
1-S	STPSS-P	2 - 10	2 - 10	2 - 8	2 - 5
1-E	AEM	1 - 3	1 - 3	2 - 5	3 - 5
1-E	STPSS-LC	3 - 10	3 - 10	3 - 8	3 - 6
2	STPSS-LC	3 - 11	4 - 9	5 - 7	6 - 6
3	STPSS-LC	1 - 10	1 - 10	2 - 5	2 - 5
4	STPSS-LC	1 - 5	1 - 5	1 - 5	1 - 5
5	STPSS-P	2 - 4	2 - 4	2 - 4	2 - 4
6	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
7	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
8	STPSS-P	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	1	1	2	3
	STPSS-LC =	10	11	14	16
	STPSS-P =	5	5	5	5
TOTAL NUMBER OF FLIGHTS:		16	17	21	24

[a]Roman capitals correspond to those in Table H-6.

Table H-8

CASES I(G) AND II(G)

PROGRAM OPTION 2: USE AEM AND MMS AND MINIMIZE NUMBER OF FLIGHTS					
		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS -- NUMBER OF PAYLOADS/FLIGHT			
1-S	MMS	2 - 10	2 - 10	3 - 8	4 - 5
1-E	MMS	2 - 10	2 - 7	2 - 5	2 - 5
1-E	AEM	1 - 13	2 - 10	3 - 8	4 - 6
2	MMS	3 - 11	4 - 9	5 - 7	6 - 6
3	MMS	1 - 10	1 - 10	2 - 5	2 - 5
4	MMS	1 - 5	1 - 5	1 - 5	1 - 5
5	MMS	1 - 8	1 - 8	1 - 8	2 - 4
6	MMS	1 - 3	1 - 3	1 - 3	1 - 3
7	MMS	1 - 3	1 - 3	1 - 3	1 - 3
8	MMS	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	1	2	3	4
	MMS =	13	14	17	20
TOTAL NUMBER OF FLIGHTS:		14	16	20	24

Table H-9

CASES I(K) AND V(K)

PROGRAM OPTION 3: ALL PAYLOADS ON STPSS AND MINIMIZE NUMBER OF FLIGHTS BY COMBINING PAYLOADS ON SAME ORBIT					
		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS -- NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	0 - 0	0 - 0	1 - 7	2 - 5
1-S	STPSS-P	2 - 10	2 - 10	2 - 7	2 - 5
1-E	STPSS-LC	4 - 9	4 - 9	5 - 7	6 - 6
2	STPSS-LC	3 - 11	4 - 9	5 - 7	6 - 6
3	STPSS-LC	1 - 10	1 - 10	2 - 5	2 - 5
4	STPSS-LC	1 - 5	1 - 5	1 - 5	1 - 5
5	STPSS-P	2 - 4	2 - 4	2 - 4	2 - 4
6	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
7	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
8	STPSS-P	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS	STPSS-LC =	11	12	16	19
	STPSS-P =	5	5	5	5
TOTAL NUMBER OF FLIGHTS:		16	17	21	24

Table H-10

CASES I(O), II(O), V(O), AND VI(O)

PROGRAM OPTION 4: ALL PAYLOADS ON MMS AND MINIMIZE NUMBER OF FLIGHTS					
		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS -- NUMBER OF PAYLOADS/FLIGHT			
1-S	MMS	2 - 10	2 - 10	3 - 7	4 - 5
1-E	MMS	3 - 11	4 - 9	5 - 7	6 - 6
2	MMS	3 - 11	4 - 9	5 - 7	6 - 6
3	MMS	1 - 10	1 - 10	2 - 5	2 - 5
4	MMS	1 - 5	1 - 5	1 - 5	1 - 5
5	MMS	1 - 8	1 - 8	1 - 8	2 - 4
6	MMS	1 - 3	1 - 3	1 - 3	1 - 3
7	MMS	1 - 3	1 - 3	1 - 3	1 - 3
8	MMS	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	MMS =	14	16	20	24
TOTAL NUMBER OF FLIGHTS:		14	16	20	24

Table H-11

CASE II(B)

PROGRAM OPTION 1: USE LEAST EXPENSIVE SPACECRAFT AND MINIMIZE NUMBER OF FLIGHTS

		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS -- NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	1 - 10	1 - 10	1 - 5	2 - 5
1-S	STPSS-P	1 - 10	1 - 10	2 - 8	2 - 5
1-E	AEM	1 - 8	2 - 7	3 - 6	4 - 6
1-E	STPSS-LC	2 - 13	2 - 10	2 - 8	2 - 5
2	STPSS-LC	3 - 11	4 - 9	5 - 7	- 6
3	STPSS-LC	1 - 10	1 - 10	2 - 5	2 - 5
4	STPSS-LC	1 - 5	1 - 5	1 - 5	1 - 5
5	STPSS-P	1 - 8	1 - 8	1 - 8	2 - 4
6	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
7	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
8	STPSS-P	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	1	2	3	4
	STPSS-LC =	10	11	13	15
	STPSS-P =	3	3	4	5
TOTAL NUMBER OF FLIGHTS:		14	16	20	24

Table H-12

CASES II(L) AND VI(L)

PROGRAM OPTION 3: ALL PAYLOADS ON STPSS AND MINIMIZE NUMBER OF FLIGHTS BY COMBINING PAYLOADS ON SAME ORBIT

		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS -- NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	1 - 10	1 - 10	1 - 7	2 - 5
1-S	STPSS-P	1 - 10	1 - 10	2 - 7	2 - 5
1-E	STPSS-LC	3 - 11	4 - 9	5 - 7	6 - 6
2	STPSS-LC	3 - 11	4 - 9	5 - 7	6 - 6
3	STPSS-LC	1 - 10	1 - 10	2 - 5	2 - 5
4	STPSS-LC	1 - 5	1 - 5	1 - 5	1 - 5
5	STPSS-P	1 - 8	1 - 8	1 - 8	2 - 4
6	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
7	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
8	STPSS-P	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	STPSS-LC =	11	13	16	19
	STPSS-P	3	3	4	5
TOTAL NUMBER OF FLIGHTS:		14	16	20	24

Table H-13

CASE III(C)

PROGRAM OPTION 1: USE LEAST EXPENSIVE SPACECRAFT AND MINIMIZE NUMBER OF FLIGHTS

ORBIT	SPACECRAFT	MAXIMUM NUMBER OF PAYLOADS PER FLIGHT: 13	10	8	6
		NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	1 - 8	1 - 8	1 - 8	2 - 5
1-S	STPSS-P	1 - 8	1 - 8	1 - 8	1 - 6
1-E	AEM	0 - 0	0 - 0	1 - 2	2 - 4
1-E	STPSS-LC	3 - 9	3 - 9	3 - 8	3 - 6
2	STPSS-LC	2 - 13	3 - 9	4 - 7	5 - 6
3	STPSS-LC	1 - 8	1 - 8	1 - 8	2 - 4
4	STPSS-LC	1 - 4	1 - 4	1 - 4	1 - 4
5	STPSS-P	2 - 3	2 - 3	2 - 3	2 - 3
6	STPSS-LC	1 - 2	1 - 2	1 - 2	1 - 2
7	STPSS-LC	1 - 2	1 - 2	1 - 2	1 - 2
8	STPSS-P	1 - 2	1 - 2	1 - 2	1 - 2
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	0	0	1	2
	STPSS/LC =	10	11	12	15
	STPSS/P =	4	4	4	4
TOTAL NUMBER OF FLIGHTS:		14	15	17	21

Table H-14

CASE III(M)

PROGRAM OPTION 2: USE AEM AND MMS AND MINIMIZE NUMBER OF FLIGHTS

ORBIT	SPACECRAFT	MAXIMUM NUMBER OF PAYLOADS PER FLIGHT: 13	10	8	6
		NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	MMS	2 - 8	2 - 8	2 - 8	3 - 6
1-E	MMS	1 - 12	1 - 10	1 - 8	1 - 6
1-E	AEM	2 - 7	2 - 8	3 - 6	4 - 5
2	MMS	2 - 13	3 - 9	4 - 7	5 - 6
3	MMS	1 - 8	1 - 8	1 - 8	2 - 4
4	MMS	1 - 4	1 - 4	1 - 4	1 - 4
5	MMS	1 - 6	1 - 6	1 - 6	1 - 6
6	MMS	1 - 2	1 - 2	1 - 2	1 - 2
7	MMS	1 - 2	1 - 2	1 - 2	1 - 2
8	MMS	1 - 2	1 - 2	1 - 2	1 - 2
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	2	2	3	4
	MMS =	11	12	13	16
TOTAL NUMBER OF FLIGHTS:		13	14	16	20

Table H-15

CASE III(M)

PROGRAM OPTION 3: ALL PAYLOADS ON STPSS AND MINIMIZE NUMBER OF FLIGHTS BY COMBINING PAYLOADS ON SAME ORBIT

		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	1 - 8	1 - 8	1 - 8	2 - 5
1-S	STPSS-P	1 - 8	1 - 8	1 - 8	1 - 6
1-E	STPSS-LC	3 - 9	3 - 9	4 - 7	5 - 6
2	STPSS-LC	2 - 13	3 - 9	4 - 7	5 - 6
3	STPSS-LC	1 - 8	1 - 8	1 - 8	2 - 4
4	STPSS-LC	1 - 4	1 - 4	1 - 4	1 - 4
5	STPSS-LC	1 - 4	1 - 4	1 - 4	1 - 4
5	STPSS-P	1 - 2	1 - 2	1 - 2	1 - 2
6	STPSS-LC	1 - 2	1 - 2	1 - 2	1 - 2
7	STPSS-LC	1 - 2	1 - 2	1 - 2	1 - 2
8	STPSS-P	1 - 2	1 - 2	1 - 2	1 - 2
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	STPSS/LC =	11	12	14	18
	STPSS/P =	3	3	3	3
TOTAL NUMBER OF FLIGHTS:		14	15	17	21

Table H-16

CASE II (P)

PROGRAM OPTION 4: ALL PAYLOADS ON MMS AND MINIMIZE NUMBER OF FLIGHTS

ORBIT	SPACECRAFT	MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
		NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	MMS	2 - 8	2 - 8	2 - 8	3 - 6
1-E	MMS	2 - 13	3 - 9	4 - 7	5 - 6
2	MMS	2 - 13	3 - 9	4 - 7	5 - 6
3	MMS	1 - 8	1 - 8	1 - 8	2 - 4
4	MMS	1 - 4	1 - 4	1 - 4	1 - 4
5	MMS	1 - 6	1 - 6	1 - 6	1 - 6
6	MMS	1 - 2	1 - 2	1 - 2	1 - 2
7	MMS	1 - 2	1 - 2	1 - 2	1 - 2
8	MMS	1 - 2	1 - 2	1 - 2	1 - 2
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	MMS =	12	14	16	20
TOTAL NUMBER OF FLIGHTS:		12	14	16	20

Table H-17

CASE IV(D)

PROGRAM OPTION 1: USE LEAST EXPENSIVE SPACECRAFT AND MINIMIZE NUMBER OF FLIGHTS

		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	1 - 12	2 - 8	2 - 6	2 - 6
1-S	STPSS-P	1 - 12	1 - 9	2 - 6	2 - 6
1-E	AEM	0 - 0	0 - 0	2 - 5	3 - 5
1-E	STPSS-LC	4 - 10	4 - 10	4 - 8	4 - 6
2	STPSS-LC	3 - 13	4 - 10	5 - 8	7 - 6
3	STPSS-LC	1 - 12	2 - 6	2 - 6	2 - 6
4	STPSS-LC	1 - 6	1 - 6	1 - 6	1 - 6
5	STPSS-P	2 - 5	2 - 5	2 - 5	2 - 5
6	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
7	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
8	STPSS-P	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	0	0	2	3
	STPSS-LC =	12	15	16	18
	STPSS-P =	4	4	5	5
TOTAL NUMBER OF FLIGHTS:		16	19	23	26

Table H-18

CASE IV(I)

PROGRAM OPTION 2: USE AEM AND MMS AND MINIMIZE NUMBER OF FLIGHTS

		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	MMS	2 - 12	3 - 8	3 - 8	4 - 6
1-E	MMS	2 - 12	2 - 9	2 - 8	2 - 6
1-E	AEM	2 - 8	3 - 7	3 - 8	5 - 6
2	MMS	3 - 13	4 - 10	5 - 8	7 - 6
3	MMS	1 - 12	2 - 6	2 - 6	2 - 6
4	MMS	1 - 6	1 - 6	1 - 6	1 - 6
5	MMS	1 - 9	1 - 9	2 - 5	2 - 5
6	MMS	1 - 3	1 - 3	1 - 3	1 - 3
7	MMS	1 - 3	1 - 3	1 - 3	1 - 3
8	MMS	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	2	3	3	5
	MMS =	13	16	18	21
TOTAL NUMBER OF FLIGHTS:		15	19	21	26

C-3

Table H-19

CASE IV(N)

PROGRAM OPTION 3: ALL PAYLOADS ON STPSS AND MINIMIZE NUMBER OF FLIGHTS BY COMBINING PAYLOADS ON SAME ORBIT

		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-P	1 - 12	1 - 9	2 - 6	2 - 6
1-S	STPSS-LC	1 - 12	2 - 8	2 - 6	2 - 6
1-E	STPSS-LC	4 - 10	4 - 10	5 - 8	7 - 6
2	STPSS-LC	3 - 13	4 - 10	5 - 8	7 - 6
3	STPSS-LC	1 - 12	2 - 6	2 - 6	2 - 6
4	STPSS-LC	1 - 6	1 - 6	1 - 6	1 - 6
5	STPSS-P	2 - 5	2 - 5	2 - 5	2 - 5
6	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
7	STPSS-LC	1 - 3	1 - 3	1 - 3	1 - 3
8	STPSS-P	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	STPSS-LC =	12	15	17	21
	STPSS-P =	4	4	5	5
TOTAL NUMBER OF FLIGHTS:		16	19	22	26

Table H-20

CASE IV(Q)

PROGRAM OPTION 4: ALL PAYLOADS ON MMS AND MINIMIZE NUMBER OF FLIGHTS

ORBIT	SPACECR T	MAXIMUM NUMBER OF PAYLOADS PER FLIGHT: 13	10	8	6
		NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	MMS	2 - 12	3 - 8	3 - 8	4 - 6
1-E	MMS	3 - 13	4 - 10	5 - 8	7 - 6
2	MMS	3 - 13	4 - 10	5 - 8	7 - 6
3	MMS	1 - 12	2 - 6	2 - 6	2 - 6
4	MMS	1 - 16	1 - 6	1 - 6	1 - 6
5	MMS	1 - 9	1 - 9	2 - 5	2 - 5
6	MMS	1 - 3	1 - 3	1 - 3	1 - 3
7	MMS	1 - 3	1 - 3	1 - 3	1 - 3
8	MMS	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	MMS =	14	18	21	26
TOTAL NUMBER OF FLIGHTS:		14	18	21	26

Table H-21

CASE V(E)

PROGRAM OPTION 1: USE LEAST EXPENSIVE SPACECRAFT AND MINIMIZE NUMBER OF FLIGHTS

ORBIT	SPACECRAFT	MAXIMUM NUMBER OF PAYLOADS PER FLIGHT: 13	10	8	6
		NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	0 - 0	0 - 0	1 - 5	2 - 5
1-S	STPSS-P	2 - 10	2 - 10	2 - 8	2 - 5
1-E	AEM	1 - 3	1 - 3	2 - 5	3 - 5
1-E	STPSS-LC	3 - 10	3 - 10	3 - 8	3 - 6
2	AEM	3 - 7	3 - 8	4 - 7	5 - 6
2	STPSS-LC	1 - 13	1 - 10	1 - 8	1 - 5
3	STPSS-LC	1 - 10	1 - 10	2 - 5	2 - 5
4	AEM	1 - 5	1 - 5	1 - 5	1 - 5
5	STPSS-P	2 - 4	2 - 4	2 - 4	2 - 4
6	AEM	1 - 3	1 - 3	1 - 3	1 - 3
7	AEM	1 - 3	1 - 3	1 - 3	1 - 3
8	STPSS-P	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	7	7	9	11
	STPSS-LC =	5	5	7	8
	STPSS-P =	5	5	5	5
TOTAL NUMBER OF FLIGHTS:		17	17	21	24

Table H-22

CASES V(J) AND VI(J)

PROGRAM OPTION 2: USE AEM AND MMS AND MINIMIZE NUMBER OF FLIGHTS

ORBIT	SPACECRAFT	MAXIMUM NUMBER OF PAYLOADS PER FLIGHT: 13	10	8	6
		NUMBER OF FLIGHTS- NUMBER OF PAYLOADS/FLIGHT			
1-S	MMS	2 - 10	2 - 10	3 - 8	4 - 5
1-E	AEM	1 - 13	2 - 10	3 - 8	4 - 6
1-E	MMS	2 - 10	2 - 7	2 - 5	2 - 5
2	AEM	3 - 7	3 - 8	4 - 7	5 - 6
2	MMS	1 - 13	1 - 10	1 - 8	1 - 5
3	MMS	1 - 10	1 - 10	2 - 5	2 - 5
4	AEM	1 - 5	1 - 5	1 - 5	1 - 5
5	MMS	1 - 8	1 - 8	1 - 8	1 - 3
5	AEM	0 - 0	0 - 0	0 - 0	1 - 5
6	AEM	1 - 3	1 - 3	1 - 3	1 - 3
7	AEM	1 - 3	1 - 3	1 - 3	1 - 3
8	MMS	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	7	8	10	13
	MMS =	8	8	10	11
TOTAL NUMBER OF FLIGHTS:		15	16	20	24

Table H-23

CASE VI(F)

PROGRAM OPTION 1: USE LEAST EXPENSIVE SPACECRAFT AND MINIMIZE NUMBER OF FLIGHTS

		MAXIMUM NUMBER OF PAYLOADS PER FLIGHT			
		13	10	8	6
ORBIT	SPACECRAFT	NUMBER OF FLIGHTS - NUMBER OF PAYLOADS/FLIGHT			
1-S	STPSS-LC	1 - 8	1 - 10	1 - 5	2 - 5
1-S	STPSS-P	1 - 13	1 - 10	2 - 8	2 - 5
1-E	AEM	1 - 8	2 - 7	3 - 6	4 - 6
1-E	STPSS-LC	2 - 13	2 - 10	2 - 8	2 - 5
2	AEM	2 - 10	3 - 8	4 - 7	5 - 6
2	STPSS-LC	1 - 13	1 - 10	1 - 8	1 - 5
3	STPSS-LC	1 - 10	1 - 10	2 - 5	2 - 5
4	AEM	1 - 5	1 - 5	1 - 5	1 - 5
5	STPSS-P	1 - 8	1 - 8	1 - 8	1 - 5
5	AEM	0 - 0	0 - 0	0 - 0	1 - 3
6	AEM	1 - 3	1 - 3	1 - 3	1 - 3
7	AEM	1 - 3	1 - 3	1 - 3	1 - 3
8	STPSS-P	1 - 3	1 - 3	1 - 3	1 - 3
TOTAL NUMBER OF SPACECRAFT FLIGHTS:	AEM =	6	8	10	13
	STPSS-LC =	5	5	6	7
	STPSS-P =	3	3	4	4
TOTAL NUMBER OF FLIGHTS:		14	16	20	24

Appendix I
L-AEM SPECIFICATIONS

STATEMENT OF WORK FOR A SHUTTLE LAUNCHED ADAPTATION OF THE AEM FOR LARGE DIAMETER PAYLOADS THAT RESULTED IN THE L-AEM DESIGN

5.0 CONTRACTOR TASKS

5.1 BASELINE DEFINITION

The Contractor shall design a baseline adaptation of the AEM base module for comparison with other vehicles by the Contractor. The baseline design shall be consistent with the following requirements:

- The payload interface shall be hexagonal 60 in. in maximum diameter.
- The spacecraft shall be three-axis stabilized with control capability to 0.5 deg in pitch and roll and 1 deg in yaw, with capability to be modified to control to 6 arc minutes or spin stabilized with control capability to ±1 deg.
- Solid propulsion shall be provided to inject the spacecraft into a circular orbit at altitudes up to geosynchronous altitude (orbiter altitude 150 n mi).
- A SGLS-compatible telemetry, timing, and control shall be provided using Carrier I with capability to also incorporate Carrier II for transmitting payload data at high data rates.
- Provision shall be made for payload weights up to 1000 lb.
- The power system array shall be one-axis with setable angle with 100 sq ft of array area. Two 20 Ahr batteries will be provided.
- The thermal system shall use louvers and heaters with a maximum power input from a payload of 10 W (insulated).
- No single-string failure modes.

5.2 SHUTTLE INTERFACE

5.2.1 The shuttle interface shall be defined including an adapter to support one or more spacecraft with payloads in the shuttle over the short or long spacelab tunnel or over Orbital Maneuvering System kit.

5.2.2 IUS interface shall be defined.

5.2.3 Mixed DoD payloads shall be considered.

Appendix J

AIR FORCE AND NASA CORRESPONDENCE ON PROPOSED MEMORANDUM OF AGREEMENT

Following the completion of the first phase of the case study (see Section IV for the results), the Air Force sent forward through Air Force Headquarters to NASA a proposed Memorandum of Agreement concerning the procurement of the NASA Small Multimission Modular Spacecraft. This appendix contains this proposed memorandum of agreement and the correspondence between NASA and the Air Force concerning it.

COPIED

12 July 1976

Dear John:

For over two years, the Space and Missile Systems Organization (SAMSO) has been studying the needs, concepts, and utilities of free-flyer spacecraft to be flown on Orbiter missions. We have concluded that there is a need for a standard spacecraft with capabilities greater than your Applications Explorer Mission (AEM) spacecraft, but considerably less than your Multi-Mission Modular Spacecraft (MMS) to fly DoD Space Test Program experiments in the Space Transportation System (STS) era. We have also concluded that significant cost advantages can be achieved by adopting a standard spacecraft configuration which could be used by NASA, DoD or other government agencies.

In April of this year, we briefed General Snavely and Mr. E. Z. Gray on our concepts and plans. In May 1976, Goddard Space Flight Center (GSFC) informed us that NASA plans to develop a spacecraft with capabilities similar to our standard spacecraft. We informed GSFC that we would use the NASA standard spacecraft if it would be developed on a schedule which meets our needs.

I believe it is time to formalize our intentions. We have prepared a proposed Memorandum of Agreement (MOA) which outlines our standard satellite requirements (attachment 1). It also presents our views on the managerial and financial responsibilities of each agency in the development and procurement of the spacecraft.

The Space Test Program is planning to fly the first of these spacecraft on the Orbital Flight Test-5 mission. To meet this schedule, development of the spacecraft would need to commence in FY 77. We are prepared to provide NASA $1.0M in FY 77 funds to assist in this effort to assure the timely availability of the spacecraft.

I would appreciate any assistance you can provide in obtaining a rapid response to our proposed MOA. I would also welcome your thoughts on the appropriate NASA signature level to the agreement to assure commitments are fulfilled.

Sincerely,

(Signed) John Martin
Assistant Secretary
Research and Development

1 Attachment
Memorandum of Agreement,
w/1 attachment

Mr. John F. Yardley
Associate Administrator for
Space Flight
Code M
National Aeronautics and
Space Administration
Washington, D.C. 20546

MEMORANDUM OF AGREEMENT

ON

THE PROCUREMENT OF

USAF DESIGNATED SMALL MULTI-

MISSION MODULAR SPACECRAFT

SYSTEMS

BETWEEN

THE NATIONAL AERONAUTICS AND

SPACE ADMINISTRATION

AND

THE DEPARTMENT OF DEFENSE

1.0 PURPOSE AND SCOPE

1.1 PURPOSE: This agreement defines the responsibilities and policies that will govern the development, production and acceptance of the Small Multi-Mission Modular Spacecraft (SMMS) and supporting systems for use on Space Test Program (STP) missions with the Space Transportation System (STS). This agreement is directive in nature and will serve as the governing agreement for more detailed policies as developed by the implementing agencies: Goddard Space Flight Center (GSFC) for the National Aeronautics and Space Administration (NASA) and the Space Test Program for the Department of Defense (DOD). Amendments or revisions to this Memorandum may be made only by the mutual consent of the DOD and NASA.

1.2 SCOPE: Effective and efficient use of the STS demands an environment of interagency cooperation and avoidance of duplicative efforts. STS joint development and use is covered by presidential directive issued in January, 1972. This agreement addresses joint NASA and DOD responsibilities and financial liabilities for the development, production and use of a STS compatible spacecraft , SMMS , and supporting systems.

2.0 EXPLANATION OF TERMS: The following explanations are provided to clarify specific terms used in this agreement.

2.1 SPACE TRANSPORTATION SYSTEM (STS): The STS is the reusable launch vehicle system consisting of two solid rocket motors, an expendable fuel tank, and orbiter vehicle with its payload bay. Attendant support systems, launch tower and operations services are included as part of the overall system. Existing NASA terminology for the STS will be used.

2.2 DOD SPACE TEST PROGRAM: The Space Test Program (STP) is a Department of Defense (DOD) activity under the executive management of the United States Air Force (USAF) to provide spaceflight opportunities for DOD experimenters who are not authorized their own means for spaceflight.

2.3 SMALL MULTI-MISSION MODULAR SPACECRAFT (SMMS): Presently, the SMMS can be categorized as a proposed GSFC development for a low cost, multi-purpose spacecraft bus which is compatible with the STS. Supporting systems include the flight support system and the ground handling and checkout systems.

3.0 POLICIES AND PRINCIPLES: The following policies and principles will govern the relationship between the DOD and NASA relevant to STP procurement and use of the Small Multi-Mission Modular Spacecraft and support systems.

3.1 DELEGATION OF AUTHORITY: The authority to decide matters which are binding on GSFC and STP in executing this agreement and any other supplemental agreements, except where specifically reserved by the undersigned, is hereby delegated to these directors:

For the DOD Space Test Program:

The Director of the Space Test Program
Headquarters, Space and Missile Systems Organization
SAMSO/YAT
P.O. Box 92960
Worldway Postal Center
Los Angeles, CA 90009

For the NASA Goddard Space Flight Center:

The SMMS Program Director
Goddard Space Flight Center
Greenbelt, MD 20771

All matters which cannot be resolved by these organizations shall revert to the undersigned or their designates for resolution.

3.2 GENERAL FINANCIAL POLICY: The DOD will provide funds for SMMS systems and equipment for STP missions on a firm-fixed price basis. NASA is liable for the developmental costs of the standard SMMS systems and equipment configurations. Pending definition of STP mission requirements and acceptable lease policies, STP may enter into lease agreements with GSFC for reusable equipment. Specific financial schedules will be developed on a mission by mission basis according to the specific guidelines in paragraph 5.

4.0 ORGANIZATION RESPONSIBILITIES FOR THE SMMS SYSTEMS

4.1 SMMS SYSTEMS REQUIREMENTS PREPARATION AND PROPOSAL EVALUATION

4.1.1 General SMMS requirements are provided in the SMMS Requirements Attachment to this Memorandum of Agreement.

4.1.2 GSFC and STP are responsible jointly for the establishment of the detailed SMMS systems requirements, related exhibits and data requirements.

4.1.3 GSFC will develop specifications, test and qualification criteria for the SMMS systems, subsystems and components.

4.1.4 STP will review these specifications, test and qualification criteria for compliance with STP requirements.

4.1.5 GSFC and STP are responsible jointly for the preparation of all SMMS systems acceptance test criteria.

4.1.6 GSFC will prepare the request for proposal (RFP) according to NASA source selection procedures.

4.1.7 STP will review the RFP documents for compliance with STP systems performance, qualification and acceptance requirements. Deviations will be assessed and resolved with GSFC before release of the RFP to industry.

4.1.8 GSFC will conduct the proposal evaluation according to established NASA procedures.

4.1.9 STP will advise GSFC on pertinent STP requirements during the proposal evaluation period.

4.1.10 NASA will award the SMMS systems contract(s) from among those bidders which satisfy STP requirements.

4.1.11 STP will concur in the selection(s).

4.2 SMMS SYSTEMS DEVELOPMENT

4.2.1 GSFC is responsible for the development of the SMMS systems to the baseline set of requirements and specifications as established at the award of the SMMS development contract(s). These systems include:

4.2.1.1 Spacecraft (SMMS)

4.2.1.2 SMMS Flight Support System (FSS)

4.2.1.3 SMMS Ground Support Equipment (GSE)

4.2.1.4 SMMS Systems Software

4.2.1.5 SMMS Systems Documentation

4.2.2 Design changes to the SMMS systems baseline which have resulted from NASA or STP mission unique requirements will be the responsibility of the originating agency.

4.2.3 STS imposed design changes to the SMMS systems will be a NASA responsibility and fiscal liability.

4.2.4 GSFC is responsible for generating, refining and maintaining all design documentation pertaining to the SMMS systems. STP will have direct access to contractor documentation.

4.2.5 NASA will notify STP for all SMMS system level reviews and important subsystem design meetings.

4.2.6 STP will be responsible for maintaining the currency of STP requirements as related to the SMMS systems.

4.3 STP ACCEPTANCE POLICIES FOR SMMS SYSTEMS

4.3.1 STP is the DCD authority for the acceptance of any SMMS system.

4.3.2 Specific conditions for acceptance will be established by GSFC for each SMMS system. The general criteria guidelines for acceptance of SMMS systems include:

4.3.2.1 conformance with system requirements,

4.3.2.2 conformance with approved acceptance test procedures,

4.3.2.3 subsystems operating histories, and

4.3.2.4 component qualification status.

Software acceptance is conditional on planned verification test cases and joint GSFC and STP validation requirements.

4.3.3 After STP acceptance of an SMMS system, STP and its mission contractor will assume primary responsibility for the hardware and the mission integration and checkout activities.

4.3.4 After STP acceptance of SMMS systems, NASA will retain responsibility and financial liability for insuring these systems are compatible with the STS.

5.0 NASA AND DOD FINANCIAL POLICIES: The following financial policies and principles shall apply to the Small Multi-Mission Modular Spacecraft and supporting flight, ground handling and checkout systems. It is the intent of this section to enumerate financial liability of each agency with respect to SMMS expendable and reuseable equipment, software and documentation.

5.1 EXPENDABLE EQUIPMENT

5.1.1 Small Multi-Mission Modular Spacecraft (SMMS)

5.1.1.1 NASA has developmental responsibility and non-recurring fiscal liability for the SMMS.

5.1.1.2 NASA has production responsibility per the interagency procurement model and assumes recurring fiscal liability for all NASA missions using the SMMS.

5.1.1.3 DOD has fiscal liability for the recurring costs of the SMMS needed to support STP missions. Such liability shall be a function of the joint agency cost model. DOD payment will commence to NASA three years before scheduled launch on a TBD, TBD and TBD reimbursement basis.

5.1.2 Other expendable equipment used to satisfy a specific STP mission shall be procured on a cost reimbursement schedule as mutually agreed by STP and GSFC.

5.2 REUSABLE EQUIPMENT

5.2.1 SMMS Flight Support System (FSS)

5.2.1.1 NASA has developmental responsibility and financial liability for the flight support system of the SMMS. DOD will fund NASA for the recurring production costs of FSS for STP use.

5.2.1.2 Based on the STP mission frequency, cost and availability of NASA equipment, DOD is liable for user charges for the lease of flight support equipment at a mutually acceptable rate.

5.2.2 Ground Support Equipment

5.2.2.1 NASA has developmental responsibility and financial liability for the ground support equipment (GSE) of the SMMS. DOD will fund NASA for the recurring production costs of GSE for STP use.

5.2.2.2 Based on the STP mission frequency, cost and availability of NASA equipment, DOD is liable for user charges for the lease of ground support equipment at a mutually acceptable rate.

5.3 SMMS SYSTEMS SOFTWARE AND DOCUMENTATION

5.3.1 NASA is responsible for the costs attendant to the development and test of all SMMS systems software and SMMS documentation.

5.3.2 DOD is responsible for the cost required to tailor the SMMS software and documentation needed to satisfy unique STP mission requirements.

5.4 SMMS SYSTEMS DESIGN CHANGES

5.4.1 Pre-award Phase: NASA bears the responsibility and financial liability for the costs of design changes during the pre-award phase.

5.4.2 Development Phase: NASA and DOD are responsible and cost liable as applicable for SMMS systems design changes which originate from each respective agency.

5.4.3 Post Delivery Phase: NASA and DOD are responsible and cost liable as applicable for SMMS systems design changes which originate from each respective agency.

6.0 SCHEDULES: STP will identify SMMS and supporting systems delivery requirements to NASA on a mission by mission basis. Delivery and destination schedule requirements for these systems shall be based on STP mission requirements, integration lead times and launch dates. NASA will consider these schedule requirements and recommend SMMS and supporting systems purchase, lease arrangements and associated systems costs within sixty (60) days. Based on the mission needs and budgetary constraints, STP will determine the preferred procurement or lease arrangements for the SMMS and supporting systems. The final mission specific agreement will form a mission annex to this memorandum. NASA will retain full responsibility for meeting the performance, cost and delivery schedules of each coordinated mission annex.

7.0 This agreement is effective upon the date of the signatures below. Changes to or cancellation of this agreement may be made only by mutual consent of the signatories.

SIGNATURES

MEMORANDUM OF AGREEMENT

INTERAGENCY DEVELOPMENT AND

PRODUCTION OF THE SMALL

MULTI-MISSION MODULAR SPACECRAFT

FOR: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

______________________________ DATE ______________

FOR: DEPARTMENT OF DEFENSE

______________________________ DATE ______________

SMMS REQUIREMENTS ATTACHMENT TO MEMORANDUM OF AGREEMENT (Cont'd)

CHARACTERISTIC	REQUIREMENT
Orbit Transfer Propulsion	Capable of Transfer to 10K nm, circular orbit
Experiment Module Interface	Standard Mechanical, Electrical, Data Thermally Isolated
Flight Support	Minimum Induced Loads Minimum Interface For Orbiter Services Deployable by remote manned system, Pre-Release Checkout, and Contingency Retrieval Capability
Ground Support	Promote Pre-Launch Checkout and Verification Transportable Self-Contained Equipment

NOTE: SMMS must consider selected SAMSO policies and military specifications.

MISSION ANNEX TO MEMORANDUM OF AGREEMENT

STS MISSION DESIGNATOR: OFT #5 LAUNCH DATE: MAR, 80

STP MISSION DESIGNATOR: P80B TITLE: TBD

SMMS SYSTEMS PROGRAM REQUIREMENTS

SYSTEM/ REQUIREMENTS	PERFORMANCE	MISSION PECULIAR COST (IN MILLIONS)	DELIVERY DATE	DESTINATION	REMARKS
SPACECRAFT	BASELINE	$	MAR 79	TBD	
FLIGHT SUPPORT SYSTEM	BASELINE/ UPDATED	$	SEP 79	TBD	
GROUND SUPPORT SYSTEM	BASELINE/ UPDATED	$	JUL 79	TBD	
SOFTWARE	CURRENT	-----	AS APPLICABLE	TBD	
DOCUMENTATION	DEVELOPMENTAL	-----	AS APPLICABLE	STP	

STP DIRECTOR, DATE

SMMS PROGRAM MANAGER, DATE

MISSION ANNEX TO MEMORANDUM OF AGREEMENT

STS MISSION DESIGNATOR: STS #7; LAUNCH DATE: JUL 80

STP MISSION DESIGNATOR: P80C; TITLE: LASERCOM

SMMS SYSTEMS PROGRAM REQUIREMENTS

SYSTEM/ REQUIREMENT	PERFORMANCE	MISSION PECULIAR COST (IN MILLIONS)	DELIVERY	DESTINATION	REMARKS
SPACECRAFT	BASELINE		MAR 79	TBD	
FLIGHT SUPPORT SYSTEM	NONE	-----	-----	-----	MISSION WITH IUS
GROUND SUPPORT SYSTEM	PARTIAL		JUL 79	TBD	
SOFTWARE	SUBCARRIER INCLUDE 1.7 MHZ	-----	AS APPLICABLE	TBD	
DOCUMENTATION	DEVELOPMENTAL	-----	AS APPLICABLE	STP	

STP DIRECTOR, DATE

SMMS PROGRAM MANAGER, DATE

MISSION ANNEX TO MEMORANDUM OF AGREEMENT

STS MISSION DESIGNATOR: STS; LAUNCH DATE: 1981

STP MISSION DESIGNATOR: P81A; TITLE: TEAL RUBY

SMMS SYSTEMS PROGRAM REQUIREMENTS

SYSTEM REQUIREMENT	PERFORMANCE	MISSION PECULIAR COST (IN MILLIONS)	DELIVERY	DESTINATION	REMARKS
SPACECRAFT	BASELINE		MAR 80	TBD	
FLIGHT SUPPORT SYSTEM	NONE	-----	-----	TBD	
GROUND SUPPORT SYSTEM	NONE	-----	-----	TBD	
SOFTWARE	CURRENT	-----	AS APPLICABLE	TBD	
DOCUMENTATION	PRODUCTION	-----	AS APPLICABLE	STP	

STP DIRECTOR: DATE

SMMS PROGRAM MANAGER, DATE

COPIED

August 24, 1976

Honorable John J. Martin
Assistant Secretary of the Air Force
(Research and Development)
Washington, D.C. 20330

Dear Mr. Martin:

The joint USAF/NASA working group reviewing the Small Multi-Mission Spacecraft (SMMS) has completed their study and concluded that agreement can be reached on a joint set of technical requirements. I believe there is an opportunity here for both agencies to initiate such a joint program that will be cost effective to each.

We, however, are in no position to initiate such a program at this time since NASA does not have any missions that require new start funding for SMMS in either FY 77 or FY 73. We, therefore, cannot meet your schedule requirement of March 1979 with such a spacecraft.

There is an alternative which may be attractive to you. The recent Rand Study conducted for the USAF showed that the Space Test Program (STP) can use a combination of the larger NASA Multi-Mission Spacecraft (MMS) and upgraded Applications Explorer Missions (AEM) of $60-80M. We can jointly study the feasibility of providing you one or two of the larger MMS and use of the NASA planned Flight Support Systems to meet the March 1979 date for your Teal Ruby mission. Since both the USAF Teal Ruby spacecraft and the second NASA MMS flight are planned for the fifth Shuttle Orbiter Test Flight, this approach would be an efficient use of common hardware by both agencies.

Another possible alternative to meet your near term objectives is the upgrading and adaptation to the shuttle of the AEM spacecraft now under NASA contract to Boeing for two Scout-launched missions. We will be pleased to consider modifying this contract to meet your requirements, but we have no funds to support any such modifications at this time.

Please let me know of your interest in either of these alternatives, and we will be prepared to discuss costs and schedules. From our standpoint, the most attractive approach to a joint SMMS program would be that the USAF meet its short-term objectives by one of the alternatives above, and join NASA in a longer range development program to meet both of our long-term requirements. NASA is ready to work toward this objective. Please let me know of your desires on this matter.

Sincerely,

John E. Naugle
Associate Administrator
National Aeronautics and Space Administration
Washington, D.C. 20546

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