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Standardization and Program Effect Analysis (Study 2.4) Final Report

Volume III: Design-to-Cost Analysis

31 July 1975

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

Systems Engineering Operations
THE AEROSPACE CORPORATION

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Volume III: Design-to-Cost Analysis

Prepared by

Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

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Volume III: Design-to-Cost Analysis

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FOREWORD

This report documents The Aerospace Corporation effort on Study 2.4, Standardization and Program Effect Analysis, which was performed under NASA Contract NASW 2727 during FY 75. The study direction at NASA Headquarters was under Mr. N. Rafel, Director of Program Practices of the Low Cost Systems Office.

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

Volume I	Executive Summary
Volume II	Equipment Commonality Analysis
Volume III	Design-to-Cost Analysis
Volume IV	Equipment Compendium

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

Volume II documents the analyses performed in selecting the flight-proven hardware for the NASA new starts.

Volume III provides information on the design-to-cost procedures used on an Air Force satellite program.

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

ACKNOWLEDGMENTS

Grateful acknowledgment is given to the following individuals who contributed their time to discuss the "design-to-cost" aspects of the ELMS spacecraft program.

Lt Col W. Niles	SAMSO Program Director
Maj H. Withee	SAMSO Spacecraft Project Officer
O. C. MacFarlane	SAMSO Contracting Officer
R. Tomlinson	SAMSO Cost Estimating
E. Offenhartz	Program Manager, GAC
G. Graff	Program Director, Aerospace
E. Edwards	MTS, Aerospace

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TABLES

FIGURES

NOMENCLATURE

AEDC	Arnold Engineering Development Center
AFSCF	Air Force Satellite Control Facility
BC	The Boeing Company
CDR	Critical Design Review
CER	Cost Estimating Relationships
CIDR	Configuration Item Design Review
CPFF	Cost Plus Fixed Fee
DAC	Date of Award of Contract
ELMS	Earth Limb Measurements Satellite
FP	Fixed Price
GAC	Grumman Aerospace Corporation
GD/C	General Dynamics/Convair
HRC	Honeywell Radiation Center
ORD	Orbital Requirements Document
RFP	Request for Proposal
RRI	Riverside Research Institute
SAMTEC	Space and Missile Test Center, Vandenberg AFB
SOW	Statement of Work
STG	Space Test Group

1. INTRODUCTION

This task examines the program procedures that were incorporated into an on-going "design-to-cost" spacecraft program. Program procedures are the activities that support the development and operations of the flight unit: contract management, documents, integration meetings, engineering, and testing. This report is limited to the program procedures that were implemented, with emphasis on areas that may depart from normal satellite development practices.

The only satellite program as of this date that has used the design-to-cost philosophy was the spacecraft portion of the Earth Limb Measurements Satellite (ELMS) program. The other portions of the ELMS program not using the design-to-cost concept were the payload (sensors), orbital data reduction, and launch vehicle.

Contractor participation in the ELMS program began when the Request for Proposal (RFP) was issued on 5 April 1973. After an evaluation and negotiation period, the Grumman Aerospace Corporation (GAC) proposal was accepted and contract go-ahead was on 19 September 1973. The spacecraft program was terminated in November 1974 after 13 months of a 27-month program. The termination was attributed to low program priority and the shortage of funds, combined with a projected overrun at completion. Although the program was not continued to completion, it has provided data on the design-to-cost philosophy. The experience gained from the 13-month program should be useful for any other program that may plan to use design-to-cost as a cost control method.

The abrupt contract termination has limited the number of reports to be completed and accessibility to the submitted reports. Reports that were reviewed are listed in the references, including the document concerning design-to-cost which is described in the RFP letter of transmittal (Ref. 1). Discussions were held with individuals associated with the ELMS spacecraft at various levels and capacities, including the program office, contracting officer, and cost estimator at SAMSO; program office and technical personnel at The Aerospace Corporation; and the program office at GAC. Since discussions would tend to be subjective, many discussions were held about similar concerns in an attempt to obtain objective information. After each discussion, minutes were written and coordinated to ensure that the discussions had been correctly recorded.

2. DESCRIPTION OF ELMS

The objective of the two-flight ELMS program was to determine the earth limb infrared radiance as a function of altitude and wavelength over a variety of sun illumination conditions and geographical locations. Each ELMS spacecraft was to be an orbiting platform for the sensor and was to provide electrical power, cooling, telemetry, and command functions to operate the payload for a minimum of 20 days on orbit. In addition to sensor cooling, the spacecraft would have provided a deployable optical shield that was cryogenically cooled to enhance payload performance (Ref. 2).

The launch vehicle was to be a modified Atlas F. The ELMS was to be placed in ballistic trajectory and circularized at the ballistic apogee by an on-board solid rocket motor which was to be jettisoned after completion of its burn. The final orbit was to be 556 ≤ 37 km (300 ≤ 20 n mi) circular in a 65-deg inclination. The satellite was to be earth-oriented with the payload sensor looking normal to the orbit plane. The sensor would scan either vertically or horizontally by controlling the spacecraft roll attitude. To provide vertical scan, the spacecraft would oscillate ± 0.22 rad (± 12.5 deg) per 134 sec, or it could hold at any of the angular positions. All payload and spacecraft data were to be stored on tape for playback to an Air Force remote tracking station. The real-time data were for 32 kbps and playback rate was for 1.024 Mbps.

The spacecraft in the launch and orbital configuration is shown in Figure 1. To fit within the 1.65 m (65 in.) nose cone fairing, the solar array and payload sensor shield were designed to be deployable. The basic spacecraft is 1.4 m (4.6 ft) in diameter by 4.12 m (13.5 ft) long. The internal arrangement of the payload and spacecraft components can be seen in the expanded view in Figure 2. Basically, the equipment module contains the housekeeping subsystem and provides space for the payload sensor. The tank module, located aft of the equipment module, houses the 1270 liter (45 cu ft) tank for the cryogenic helium. This cryogen was to be used for open loop cooling of the payload sensor. Aft of the tank module is located the solid rocket motor for the final orbit circularization.

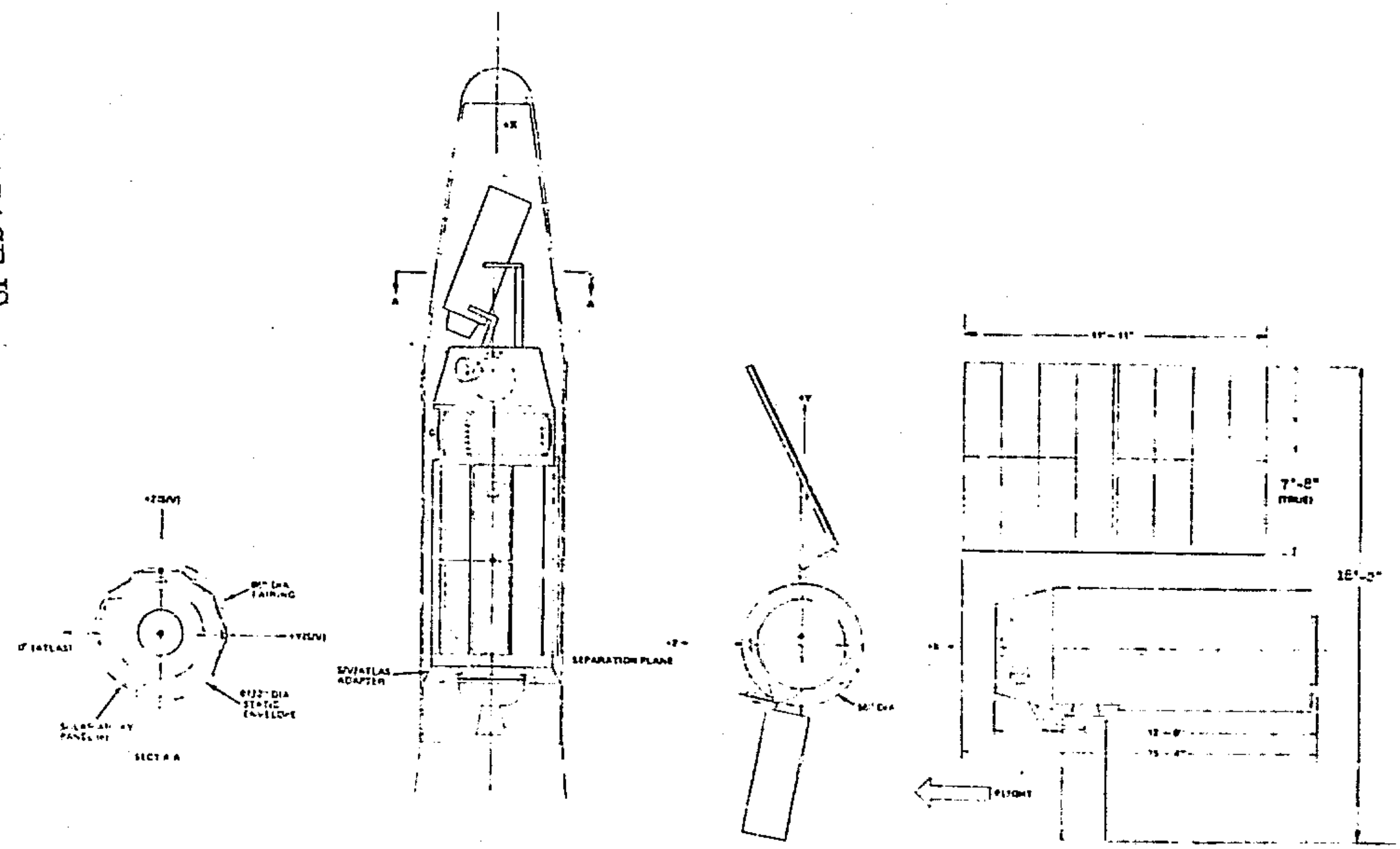

Figure 1. Launch and On-Orbit Configuration

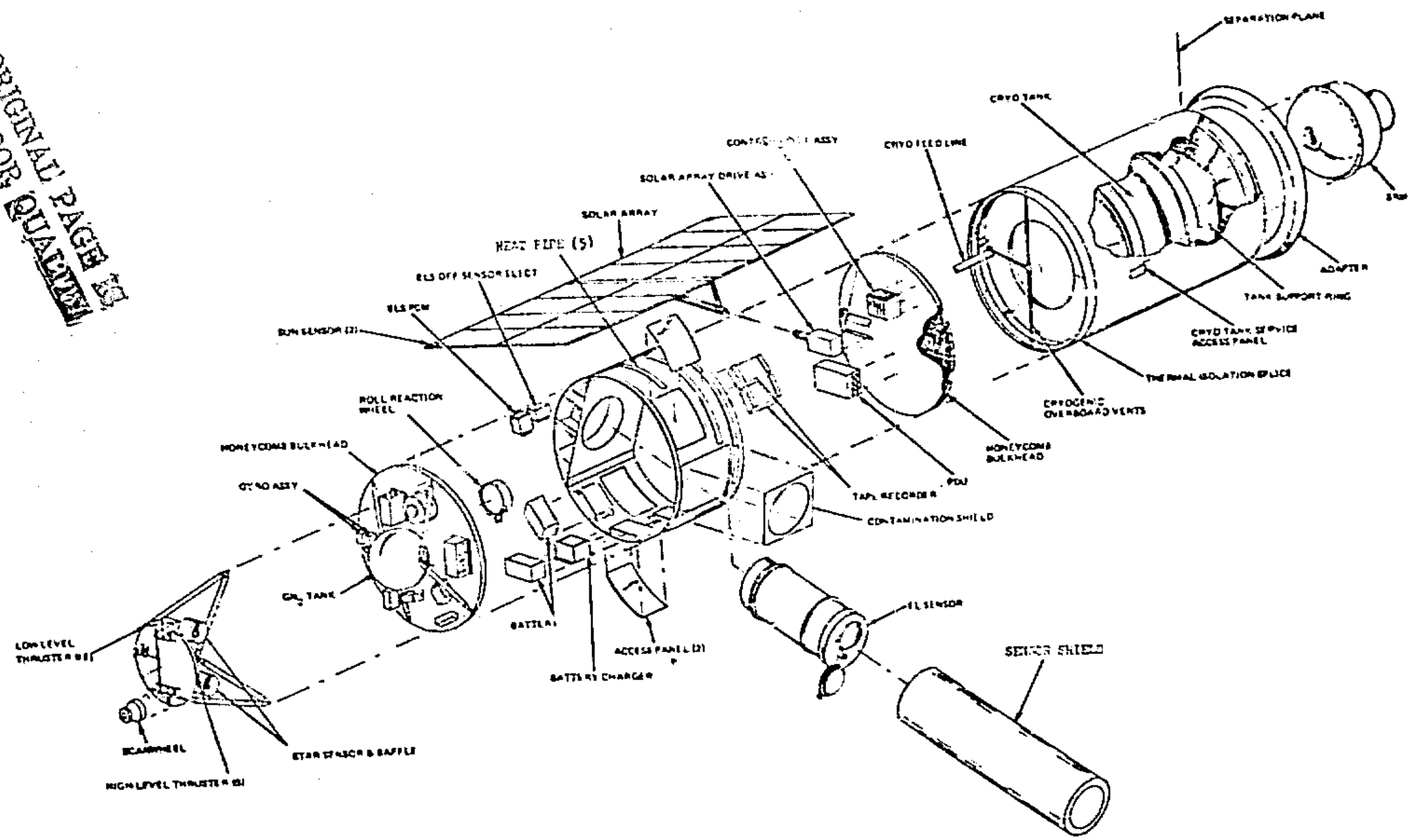

Figure 2. Internal Arrangement

The spacecraft weight breakdown is shown in Table 1 for the subsystems, payload, and expendables. The proposal baseline weight represents the spacecraft weight at the start of the program and includes a contingency of 82 kg (180 lb). The last weight status was the October 1974 weight statement (Ref. 3) that had a contingency of 14 kg (30 lb). The actual weight growth was 264 kg (582 lb) or a 21 percent increase over a 12-month period. The average weight increase for 12 satellites that were selected for comparison from completed programs was about 20 percent. The ELMS still had 10 months remaining before the first launch, which would indicate that the growth rate for changes was greater than the average satellite program.

The major contributors to the weight increase were in the electrical power, thermal control, and structural subsystems. In the electrical power subsystems, the solar array assembly increased in weight due to the replacement solar panels. The solar panels offered in the RFP were not available and a substitute was made available. The thermal control weight increased due to the lack of definition for the payload cryogenic shield, and the inadequacies of the proposed payload cryogenic controls. The solar panel and thermal changes influenced the design of the structural and attitude control subsystems. In addition to the weight growth, the mass inertia increased, which then required larger reaction wheels. Other subsystems also increased in weight as shown in the weight breakdown.

Table 1. ELMS Satellite Weight Breakdown

Item	Proposal Baseline		Oct. '74 Status Wt.	
	kg	lb	kg	lb
Structures	184	406	226	499
Thermal Control	237	523	277	610
Propulsion	71	156	98	215
SRM (Dry)	(28)	(61)	(29)	(64)
Controls & Separation	(43)	(95)	(68)	(151)
Electrical Power	154	340	235	518
Attitude Control	31	68	51	113
TT&C	33	72	50	110
Payload	113	250	102	225
Dry Weight	823	1815	1038	2289
Expendables	500	1103	481	1061
Cryogen (Thermal)	(196)	(431)	(167)	(369)
Nitrogen (Control)	(16)	(36)	(23)	(51)
Solid Propellant	(288)	(636)	(291)	(641)
Launch Weight	1324	2918	1520	3350

NOTE: Weight includes contingencies of 82 kg (180 lb) for proposal Baseline and 14 kg (30 lb) for Oct. '74

3. PROGRAM MANAGEMENT

The ELMS program involved several associate contractors and government organizations for hardware and services. The overall organization is shown in Figure 3 (Ref. 4). The hardware procurements were with GAC for the spacecraft, Honeywell Radiation Center (HRC) for the payload, General Dynamics/Convair (GD/C) for the booster and adapter, and the Boeing Company (BC) for the nose cone fairing. The service organizations involved were the Air Force Satellite Control Facility (AFSCF) for the orbital operational control, SAMTEC/STG for the launch site operations, Riverside Research Institute (RRI) for orbital data reduction, The Aerospace Corporation for the system engineering, and SAMSO/ELMS for program integration.

The spacecraft contractor had a highly centralized project management arrangement. The GAC/ELMS program director reported directly to the Vice President for Space. Reporting to the GAC program director were the engineering, assembly and test, and subcontract procurement managers. Contracts, quality assurance, configuration management, and program control were staff to the program director. At the peak activity period, the team size grew to approximately 220 members.

The SAMSO program office had a "mini SPO" arrangement under the Deputy for Technology to manage the large number of contractors and service organizations. The GAC contract was the responsibility of the ELMS spacecraft project officer. A group of system and subsystem technical specialists were provided by Aerospace to assist the project officer. The average number of SAMSO officers and Aerospace MTS providing direct support were four and eight, respectively. In addition to the direct SAMSO support, there was an average of six part-time SAMSO personnel supporting procurement, program control, launch vehicle, SAMTEC, and STP.

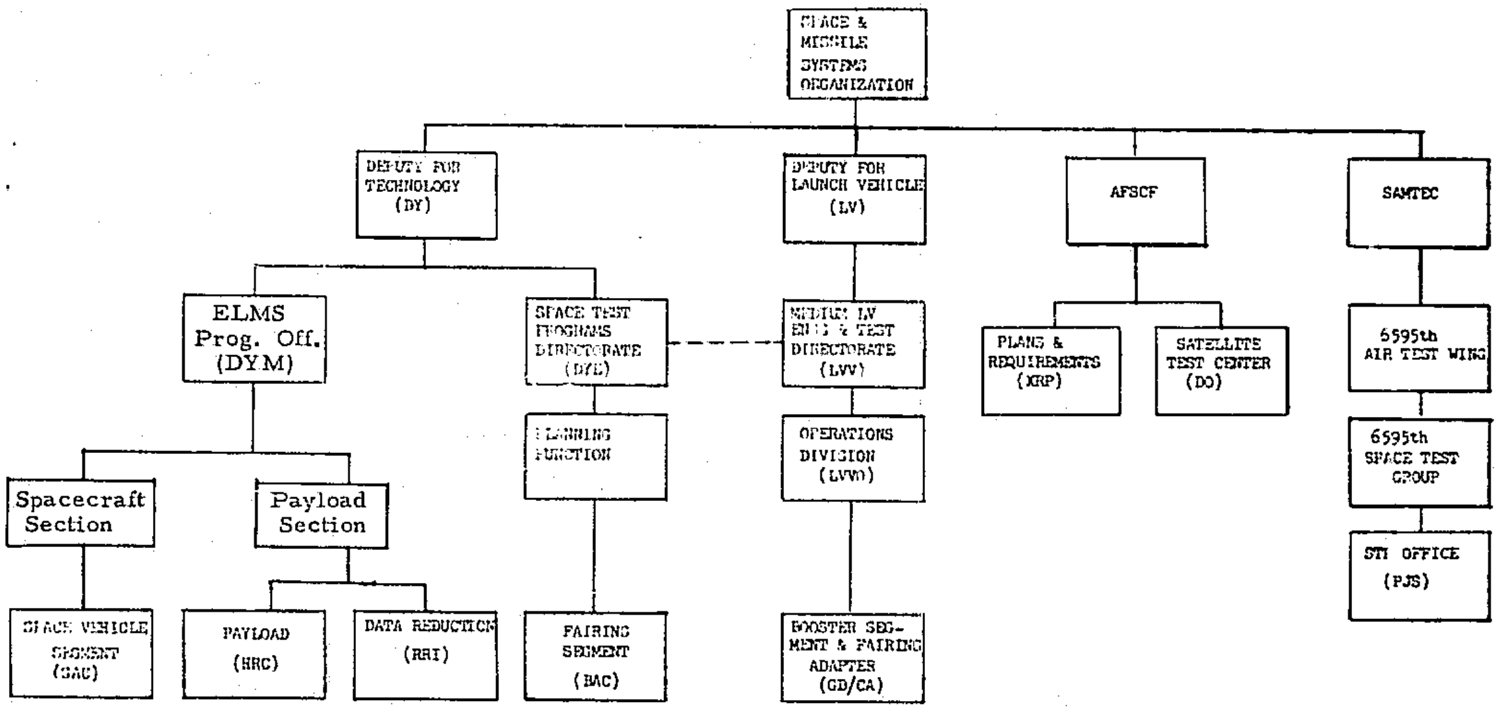

Figure 3. ELMS/SAMSO Program Organization

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4. CONTRACT DESCRIPTION

The GAC contract for the ELMS spacecraft was a cost plus fixed fee (CPFF) contract with a provision covering the maximum obligation of the government. A copy of this provision is contained in Exhibit 1. This cost ceiling provision was obtained from WPAFB/ASD and is the type used in the lightweight fighter aircraft contracts with Northrop and General Dynamics/Convair Corporations. SAMSO did not attempt to make a legal assessment of the provision; however, unofficial comments by corporations have implied that the maximum obligation is not a binding ceiling. The term "best effort" may not make the cost ceiling a legally binding cost limit.

The contents of the GAC contract (Ref. 5) had no direct reference to design-to-cost; however, GAC was required to conduct detailed analytical requirements studies and design studies to define the design to meet the requirements of the contract. With the cost ceiling and schedule, the cost, performance, and risk tradeoff analyses are implied. The indication that design-to-cost will be employed is in the RFP letter of transmittal. The phrase used is that the Air Force intends "...to employ a design to cost philosophy on this procurement with a cost objective of $14M" (Ref. 1).

The spacecraft procurement emphasized simplified and streamlined procurement and management approaches, minimum documentation and reporting, and maximum use of low cost, flight proven hardware. To meet these goals, the design-to-cost philosophy was employed.

The major parts of the spacecraft contract were:

a. CPFF with maximum obligation of the government
b. Deliver two spacecraft, with the second article being a refurbished qualification spacecraft
c. Provide open-cycle cooling for the payload sensor
d. Extensive all-up qualification and acceptance testing of the integrated payload/spacecraft

(11) GOVERNMENT FURNISHED PROPERTY

Pursuant to the clause hereof entitled "Government Property (Cost Reimbursement)", the Government shall furnish the Contractor for use in the performance of this contract the property described in paragraph 1.2 of said Attachment 1, not later than 75 JAN Ø8 for Item 0001AA and not later than 75 APR 25 for Item 0001AB and that Government Furnished Property identified in "Best and Final Cost - Attachment - Consolidated List of Government Furnished Property, Special Tooling and Test Equipment, Use of Government Facilities on a No Charge Basis" dated 75 JUL 26 which is hereby incorporated by reference. Military aircraft will be provided to transport spacecrafts from Contractor's plant to Arnold Engineering Development Center for testing and return to Contractor's plant, and from Contractor's plant to Vandenberg AFB, CA.

(12) MAXIMUM OBLIGATION OF THE GOVERNMENT

(a) Notwithstanding any provisions of the clauses entitled "Limitation of Funds" or "Allowable Cost, Fixed Fee, and Payment" or any other provision of the General Provisions hereof to the contrary, the maximum obligation of the Government for all effort (direct and indirect), materials, supplies, services, and data required to be performed under this contract shall not, at any time, including termination, exceed $ 12,976,400.00 The Contractor will exert his "best efforts" to accomplish the tasks enumerated in this contract within the Government's maximum obligation set forth herein. It is not anticipated that any amount in excess of such limitation will be added to this contract.

(b) Indirect and direct costs incurred by the Contractor and otherwise allowable and allocable to this contract and which exceed the maximum obligation of the Government under this contract will not be recognized by the Government, and the Contractor shall not request any reimbursement from the Government under this or any other Government contract or subcontract for any such costs either as direct or indirect charges. Any references in the General Provisions to estimated costs shall be construed in a manner consistent with this purpose.

(c) Notwithstanding the above limitations, the Contractor agrees that (i) title to any equipment, supplies or materials purchased or fabricated by the Contractor in the performance of this contract shall pass to the Government under the provisions of the "Government Property (Cost Reimbursement)" clause to the same extent as though the Contractor were entitled to be reimbursed all the allowable cost thereof; and (ii) he shall maintain a complete record pursuant to the * clause of all costs which are normally allowable under the terms of a cost reimbursement contract. Except as specifically modified by this provision, all the clauses of this contract shall apply to the work the cost of which is borne by the Contractor.

(13) REDIRECTION OF EFFORT

Notwithstanding any other provisions of this contract, the Procuring Contracting Officer shall be the only individual authorized to redirect the effort or in any way amend any of the terms of this contract.

* "Examination of Records by Comptroller General"

Exhibit 1

e. Spacecraft to accomplish circularization into final mission orbit

f. Contract period of performance to be 27 months, with the first launch at the end of the 22nd month and the second at the end of the 25th month.

From the early beginnings of ELMS through contract negotiations, there was no official DOD guide on implementing design-to-cost. There were many studies and papers addressing design-to-cost by DDR&E and "captains" of industry to promote the concept (Refs. 6, 7, and 8). The SAMSO procurement office conducted an extensive investigation in March 1973 to determine the procurement actions that are necessary to implement design-to-cost. The conclusion was to implement the "maximum obligation" provision discussed above. The official DOD guide was published in October 1973 (ref. 9) and was directed toward controlling unit production costs for major weapon systems where large productions are involved.

GAC implemented the design-to-cost philosophy by creating a balance between performance, schedule, risk, and cost (Ref. 10). The rationale was that the aerospace industry possesses extensive experience on spacecraft design. The design-to-cost philosophy was implemented throughout the duration of the GAC contract.

The other hardware and service contractors were not using the design-to-cost concept. The cost ceiling necessitated GAC to be aware of the cost performance tradeoff analyses. The type of contract for each contractor is summarized in Table 2.

Table 2. Types of Contracts

Elements	Company	Types of Contract
Spacecraft • Spacecraft • Field Support • AGE & Software	Grumman Aerospace Corp.	CPFF+ Max. Obl. (1)
Payload • Payload • Associated AGE	Honeywell Radiation Center	CPFF
Launch Vehicle • Atlas F • Agena Adapter • Launch Services • Associated AGE	General Dynamics/Convair Aerospace Div.	CPFF
Fairing • Nose Cone Fairing • Fairing Adapter • Associated AGE	The Boeing Company	FP
Data Reduction • Post Flt. Data Reduction	Riverside Research Institute	
GSE/TD (3) • System Engineering • Technical Support	The Aerospace Corporation	Enabling Clause (2)

NOTE: (1) Maximum obligation to government.
(2) Contract for services of technical group.
(3) All contracts contained a GSE/TD enabling clause.

5. SPACECRAFT COST

The ELMS spacecraft RFP disclosed in the letter of transmittal a procurement cost objective of $14M. This value was later corroborated by contractors who submitted proposals ranging from below to above the $14M cost objective; however, three major contractors declined to respond to the RFP. The contract was awarded to GAC for a total price of approximately $13M. This price included a fixed fee of approximately $1.4M. The selection criteria were based on technical and cost reasonableness evaluations.

Generally, the satellite program funding level is based on estimates from pre-RFP contractor studies and the SAMSO cost model. Both techniques provide inputs for determining and justifying the program cost level. The contractor studies that were performed were for a predecessor satellite study, the Background Mapping Satellite (BMS). The BMS was a one-flight advanced technology program that was planned for a long orbital life. It was to employ a closed-loop cryogenic cooling system and the spacecraft would accommodate a number of payload sensors. The spacecraft cost estimates ranged from $25M to $30M.

The SAMSO cost model is based on subsystem cost estimating relationships (CERs) which are determined from a data bank of historical satellite program costs. These CERs are related to specific satellite parameters, such as weight, stabilization method, electrical power level, payload characteristics, etc. For ELMS, the satellite parameters were not within the data bank. For example, there were no costing precedents for design-to-cost, short design life (three weeks), extensive use of flight proven components, or open-loop cryogenic cooling. Since these design parameters were difficult to quantify, they were allowed for by estimating a cost range. A breadboard concept was assumed for the low end and an operational concept was assumed for the high end. The breadboard concept cost is roughly one-third a normal spacecraft cost. The resulting cost range was a series of estimates. The estimator's lower value was used in the pre-proposal planning.

It should be recognized that the SAMSO model will estimate a higher cost than a contractor, because the SAMSO cost includes an average number of contract changes and other factors that will increase the cost. The contractor estimate does not anticipate changes beyond the Statement of Work. Under design-to-cost there can be no changes that will increase the cost. The changes must be justified by cost/performance tradeoff analyses.

The changes to the GAC proposed baseline configuration during the 13-month program duration are briefly described in Section 2, Description of ELMS. At termination, approximately 50 percent of the GAC work was completed with an approximate expenditure of $11M. The estimated cost to complete would have exceeded the $13M cost obligation.

6. PROGRAM SCHEDULE

The master schedule of the spacecraft and payload is shown in Table 3 (Ref. 5). The GAC internal schedule for the conceptual phase, validation phase, and qualification testing is included to show the time allocated for each phase to meet the master schedule. During the first three months, the cost/performance trades, preliminary design, and documentation were being performed simultaneously. All of these functions require coordination between subcontractors, subsystems, and costs. This phase was completed with the accomplishment of the Configuration Item Design Review (CIDR).

According to the design-to-cost guidelines (Ref. 9), the conceptual phase is recommended to start after the completion of the Orbital Requirements Document (ORD). In the ELMS plan, both the ORD and conceptual phase were being performed concurrently. Similarly, concurrent activities were in progress during the validation phase to meet the master schedule.

The detail design was being performed during the validation phase. There is a good likelihood that adjustments to the cost goals can occur during this phase because the production cost begins to firm up. The ELMS schedule, however, did not have adequate time for alternatives or design modifications after the approval of the preliminary design at the CIDR. The CIDR was held three months from the date of award of contract (DAC). Mini Critical Design Reviews (CDRs) of the subsystem detail design were held between four and seven months from DAC. A spacecraft CDR was initiated nine months from DAC. The systems level CDR was not completed. During the CDR phase, the fabrication of the qualification model was initiated in order to meet the start of the system qualification testing which was scheduled for about one year from DAC. After the qualification test, the model would be refurbished for the second flight article. Any design change at the CDR would have had a major impact on the program schedule.

Table 3. Program Milestones

Milestones: Spacecraft	Milestones: Payload	Months from DAC
DAC - 19 September 1973		0
(Conceptual - CIDR)*		3
	Mass & Fit Check Model	4-1/2
(Validation - CDR)*		10
	Qual. Model - available	12
(Qual. Test - start)*		12-1/2
	Flt. Model Fab. - complete	14
	1st Flt. Model - delivery	16
	Qual. Model Refurb. - complete	17-1/2
	2nd Flt. Model - delivery	19-1/2
1st Spacecraft - delivery		20
1st Launch		22
2nd Spacecraft - delivery		23
2nd Launch		25
End - 20 December 1975		27

*Internal GAC schedule

7. DOCUMENTATION AND MEETINGS

Along with the delivery of two flightworthy spacecraft and flight support at Vandenberg (VAFB), data in the form of documents were also required as summarized in Table 4. This list is representative of the types and quantity of reports required of the program. Most of these reports were submitted in draft form for approval by SAMSO. The total sum of reports can exceed 100 documents if each monthly performance and test report is counted separately. Over 40 percent of these reports were scheduled for delivery within three months from DAC.

The cost performance report combined with an updated master schedule was intended to provide monthly data on the actual expenditure, estimate to complete, manpower and loading, and problem analysis. It was the management tool for controlling the cost and maintaining the schedule. Because it had a short development period, this program needed a closely spaced management review cycle. The approach provided cost and schedule control, but the actual program progress was not clearly definable in the absolute sense. It is difficult to measure technical progress between milestones.

All of the management and technical meetings, and review held at GAC were chaired by SAMSO. The contractor planned the agenda and schedule, and wrote and published the minutes. The types and frequency of the meetings and reviews are listed in Table 5. The monthly management and status meetings provided the cost, performance, schedules, and individual problem area status. The technical meetings coordinated the interfaces, examined the technical progress, and reviewed the spacecraft for buy-off. The as-required meetings included special working group meetings on interfaces and mini CDRs. The GAC program office was involved in meetings on 20 percent of the working days.

Table 4. Deliverable Documentation (Reference 4)

No.	Title	Date Submitted (mo)	Freq. (**)	Copies
1.	Cost Performance	1	Mthly.	4
2.	Minutes of Formal Reviews, Inspection	3 Days	As Req.	5
3.	Program Schedule	1	As Req.	5
4.	Subsystem Design Ana. Rpt. - Elect. Pwr.	4	1 Req.	4
5.	High Risk/Long Lead Time Items	1.5	1 Req.	4
6.	Subsystem Design Ana. Rpt. - Att. Control	4	1 Req.	4
7.	System Segment Specifications	2	1 Req.	10
8.	Engineering Change Proposals	As Req.	As Req.	12
9.	Configuration Item Development Spec.	2.5	1 Req.	13
10.	Configuration Item Product Fab. Spec.	9	1 Req.	12
11.	Subsystem Design Ana. Rpt. - Thermal Cont.	5	1 Req.	4
12.	Subsystem Design Ana. Rpt. - TT&C	4	1 Req.	4
13.	Configuration Management Plan	1.5	1 Req.	6
14.	System Integration Plan	1.5	1 Req	13
15.	Engineering Data Interface	2	1 Req.	17
16.	System/Subsystem Summary	2	1 Req.	13
17.	System Test Plan	1	1 Req.	14
18.	Category I Test Plan/Procedures	1.5	As Req.	13
19.	Category II Test Plan/Procedures	1.5	As Req.	14
20.	Subsystem Design Ana. Rpt. - Structures	1.5	1 Req.	4
21.	Acceptance Test Reports	S/C Del.	1 per S/C	1
22.	EMI Plan - Spacecraft	1	1 Req.	9
23.	EMI Plan - Systems, Subsystem & Comp.	4	1 Req.	9
24.	Test Reports - *for each Cat. I & Cat. II Tests	*	*	6
25.	Reliability/Maintainability Prog. Plan	2	1 Req.	6
26.	Subsystem Design Ana. Rpt. - Dynamic Model	3	1 Req.	6
27.	Subsystem Design Ana. Rpt. - Loads & Stress	7	1 Req.	5
28.	Suspect Material Deficiency Notice	As Req.	As Req.	6
29.	Rel. Reporting & Feedback Failure Summary	As Req.	As Req.	-
30.	System Safety Plan	1	1 Req.	13
31.	Aerospace Ground Eqt. Plan	1	1 Req.	14
32.	Exercising Capability Plan - Field	6	1 Req.	12
33.	Subsystem Design Ana. Rpt. - Qual. Data	2	1 Req.	10
34.	Subsystem Design Ana. Rpt. - System Safety	2	1 Req.	13
35.	Contamination Prevention & Control Plan	-	As Req.	14
36.	Mass Properties Rpt. - Missiles & Space	1	Mthly.	-
37.	Missile System Ground Safety Plan	18	1 Req.	13
38.	Missile Flt. Safety - Range Safety	18	1 Req.	15
39.	Flight Plan Approval Package	6	1 Req.	17
40.	Orbital Requirements Doc. .	4	As Req.	16
41.	Abstract of New Technology	As Req.	As Req.	4
42.	Technical Information and Research Plan	As Req.	As Req.	3
43.	Test Facility Requirements Doc.	*	*	14
44.	Subsystem Design Ana. Rpt. - Orbit Circ.	5	1 Req.	5
45.	EL MS Spacecraft Flight Reports	Post Flt.	-	22
46.	Agenda/Design Reviews Mtg.	As Req.	As Req.	5
47.	Engineering Drwg. for Design Review	-	-	-
48.	Forecast of Propellant Requirements	-	Semi Annual	2

(*) determined by GAC (**) All specs. plans & design analyses required revisions as necessary.

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Table 5. Meetings and Reviews

No.	Meetings	Frequency	Date
	Contractor Sponsored		
1.	Monthly Technical and Interface Mgt. and Status*	Monthly	1st Wk.
2.	Technical Interface Working Group	As Req.	--
3.	Configuration Item Design Review	1	3 Mo. DAC
4.	Critical Design Review	1	9 Mo. DAC
5.	Acceptance Reviews - Incremented and Formal	2	20 Mo. DAC
6.	Post-Flight Mission Reviews	2	Post Flt.
	USAF Sponsored		
7.	Launch Test Working Group @ VAFB	8	TBS
8.	Satellite Control Facility Mtg. @ AFSCF	8	TBS
9.	Flight Readiness Meetings @ VAFB	2	Pre-Flt.
10.	Post-Flight Quick-Look Mtg. @ VAFB	2	Post Flt.

* First Interface review meeting not later than 2 mo. from DAC and subsequent meetings as required, but no more than one month between reviews.

8. ENGINEERING

The basic engineering practice was the same as that used on any other SAMSO satellite program. The analysis and engineering drawings received the normal detail procedure of the checking and approval cycle. The reliability programs such as quality control, qualification testing, system testing, and inspection were implemented according to the procedures for developing a fully qualified spacecraft. There appeared to be no reduction in reliability requirements or increase in risk. If there was any risk, it was in the vehicle testing program which is discussed in Section 9.

During the conceptual phase, which was the initial three months of the contract, GAC performed its cost/performance tradeoff analysis with the potential subcontractors to preliminary-design the spacecraft and to select the subcontractors. The schedule was tight to complete the preliminary design, select the subcontractor, and supply documentation. The contractor requested that the Aerospace interface be minimized through CIDR. This arrangement was approved by SAMSO since it permitted GAC to conduct cost performance trades to arrive at a design that would meet the requirements.

At the completion of the conceptual phase, the contractor was not required to present the spacecraft system test plan to meet the system requirements and criteria at the CIDR. Following this milestone, the CDR was performed incrementally and culminated in a formal review six months after the CIDR. At this meeting the spacecraft configuration item product fabrication specifications were presented. Concurrent with the documentation, the qualification model was being fabricated.

From the above series of events and concurrent activities, it is apparent that the cost/performance tradeoffs must be performed prior to CIDR, i.e., prior to subcontractor selection and manufacturing.

Following CIDR, both the prime and subcontractors had definitized the design. The design then was basically frozen, and the remaining effort was to develop and demonstrate design adequacy.

It was observed that neither the cost nor the schedule would be benefited by implementing cost/performance changes after the subcontractors were selected and under way. Changes become costly and the schedule will suffer if the suppliers are redirected. The cost/performance trades during the initial three months consumed a considerable amount of GAC manpower, but these trades were cost-effective since subcontract costs were either maintained or reduced over the proposal estimates. To reduce the estimated cost to complete, changes to the contract such as schedule and delivery quantity would have been required. The spacecraft performance requirement was not changed or revised, nor were any such changes proposed. The unforeseen technical problems were predominantly the unavilability or scarcity of critical parts, which caused late delivery or affected design, and misunderstanding of spacecraft requirements.

Unavoidable problems were:

a. Solar panels thought available during the RFP period were no longer in stock. Replacement solar panels required the solar array to be redesigned, which affected other subsystems.

b. Connectors, diodes, and resistors were in short supply and caused delays up to five months.

Technical problems were:

a. Parts shielding for electromagnetic interference

b. A deployable payload cryogenic shield

c. Telemetry transmitter development

d. Payload cryogenics controls

Most of these changes or shortages impacted the spacecraft through weight increase, inertia increases, and thermal balance. The weight increased to such a level that weight savings were required of the structure by special machining. The mass inertia increase, particularly the solar array change, caused the control subsystem to increase its control muscle. Various changes discussed above required thermal analyses to be performed to check the heat balance which, in some instances, required additional thermal heat pipes. The delay in parts delivery resulted in premium labor to maintain the schedule or in having to use commercial parts with replacement at a later date with high reliability parts. This latter approach would cause labor costs to double.

9. TESTING

The spacecraft testing concept was to perform extensive all-up qualification and acceptance testing of the integrated payload/spacecraft. The test plan was to fully qualify all of the hardware designs, perform all necessary engineering and development tests, test the tracking, telemetry, and command subsystems against an actual AFSCF/RTS, and perform a space vehicle qualification test and an acceptance test of each flight system. The system qualification and system acceptance tests were to be performed under simulated mission conditions with test hardware fully operable and were to demonstrate actual spacecraft operations as closely as possible (Ref. 4).

The above testing specifications and procedures have been developed over the years to satisfy performance and to provide good reliability. Based on this background, it would appear that any reduction in tests would put more importance on the remaining tests. To reduce costs, this area received much attention and changes were recommended by the contractor. These were:

a. Waive 100 percent humidity testing requirements for component level qualification (accepted by change order)

b. Allow the use of spacecraft as the test bench by isolating subsystems to perform subsystem checks (accepted by change order)

c. Allow changes in test schedule and sequence during the bench tests

d. Use the GAC testing facilities instead of the Arnold Engineering Development Center (AEDC) to perform the system qualification tests (accepted by change order)

The above items were changes in the testing sequence and did not affect the basic testing philosophy except for the substitution of GAC for the AEDC facility. The GAC test chamber was smaller and could not accommodate the deployment tests of the solar array. The eliminated

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tests of the array deployment in the chamber were replaced with tests performed under ambient pressure conditions. This test modification eliminated the testing of array deployment under vacuum conditions.

To delete an earlier test series and to accomplish it concurrently with system test would appear to be a high schedule and cost risk approach. Early detection of component design deficiency will result in a higher likelihood of successful system test and maintenance of the schedule. Rerun of system test is costly because the cost rate is relatively high.

Flight-proven hardware was used to reduce the number of component qualification tests; however, considerable man-hours were expended to qualify the item by similarity. Evidence of sufficient qualification testing was difficult to provide for some items. There were indications that it might have been more economical to perform the qualification testing.

System integration documentation for activities at the launch site is normally prepared by the spacecraft contractor because of his detailed working knowledge of the spacecraft. To reduce program cost, the integration documentation preparation function was assumed by SAMSO. This phase of the program covers the launch tower modifications, contamination control, ground handling equipments, launch base integration, launch pad testing and operation, coordination of hardware flow, and maintenance of the detail test schedule.

10. AREAS PRODUCING COST INCREASES

The areas that produced the greatest cost increases were:

a. Inflation: This program had its highest activity during the nation's highest inflation rate period. Normal inflation of 5 to 7 percent was included; however, the actual inflation was in the 10 to 15 percent range.

b. Technology: There was no need for technology breakthrough, but there were significant engineering developments that were uncommon to satellites. These were the large 1270 liter (45 cu ft) cryogenic helium tank to cool the payload, the deployable cryo-cooled payload shield, and the spacecraft that oscillates to scan the earth limb.

c. Supplier Deliveries: In addition to high inflation, there was a period of fuel shortage which caused parts shortages and long delays. These delays required the use of overtime to make up scheduled deliveries.

d. Interface: The payload interface data were not completely defined at the start of the contract. The interface requirements were not defined as scheduled.

e. Documentation: The number and contents of the documents required were clearly identified in the RFP/SOW. The costly item in this area was the man-hours required to work the comments from the review cycle and to update the documents. This problem can be attributed to the unacceptable submittals.

f. Meetings: The meetings required more resources than were planned. Adequate allowance was not made to prepare for meetings and to resolve close-out action items.

g. Engineering: The proposed GAC baseline spacecraft configuration was changed over the program duration. These changes were in all subsystems and caused the weight to approach the booster capabilities before reaching design completion. The growth rate was much greater than normal.

h. Schedule: The schedule was tight for a low priority program. The contract did not provide for flexibility in the schedule for shortages of critical parts.

i. Management: The management was centralized; however, the project offices had difficulty in managing the program because all elements were not under the same type of contract. The contractual approach was being tried for the first time and the requisite experience, guidelines, and training in design-to-cost were lacking. There appeared to be the spirit but not the appropriate contractual and operating tools to manage the contract.

11. AREAS REDUCING COST

The areas where cost reductions were realized were:

a. Team Concept: The contractor team members were selected on their multi-discipline, mobile, and "doer" characteristics. The team members were all located within one area so that decisions could be made and coordinated quickly.

b. Procurement Cycle: The subcontractors and suppliers participated in the cost/performance activity during the proposal phase and after the award of the contract. The selected suppliers for the proposal were required to resubmit after the prime contract was awarded.

c. Cost/Performance: The design-to-cost concept required economic considerations by the engineers. The cost ceiling forced the engineers to think in terms of cost, but it was hard for them to accept the concept in those areas where a failure could result in mission loss.

12. CONCLUSIONS

Extensive cost/performance trades are generally performed during the system analyses. This type of cost/performance analysis normally ceases to be a significant consideration after the preliminary design. However, with design-to-cost, cost control will play the major role throughout the life of the program. The use of design-to-cost to control cost of programs requiring large resources to develop is difficult to implement, however, because of the technical problems that may be encountered during this phase. The magnitude of the resources required during the ELMS spacecraft development phase was a major portion of the overall program funding. With the difficulties experienced in ELMS, the development cost increased substantially and caused program costs to overrun.

To accommodate the rising costs, the design was examined during the detail design phase to reduce costs. Such contractor review was conducted after a major portion of the funds was expended. Cost problems should have been detected earlier, and studies should have been performed early in the program to determine what modifications could be incorporated to accommodate the projected cost overrun.

The test procedures were also examined as a potential area of cost reduction. Since the initial test plan was scoped for delivering a fully qualified spacecraft, any reduction in development and subsystem testing would then place more importance on qualification, acceptance, and functional tests. This area was discussed, and changes in the test plan were recommended by the contractor to reduce cost by deferring tests. There was no evidence that a technical assessment was conducted in this area for making changes to testing procedures that have been established over the years.

The members of the ELMS program recognized that the project was high risk and were willing to accept reduction in spacecraft reliability. This philosophy was not applicable, however, in all aspects of the spacecraft. There were vital functions in the ELMS spacecraft that had to operate in orbit such as separation, maintain stable and controllable pointing, and provide telemetry. There are no cost trades for these functions, since they must be accomplished in flight. Technical guidelines for cost/ performance tradeable items must be established and personnel must be trained to conduct these analyses early in the program.

In the area of contract management, SAMSO, through years of satellite development, has found the need for visibility into the contractor's performance. The management procedure requires specific cost and technical documents and frequent technical meetings to monitor to progress and evaluate the design adequacy. The Air Force goal is to achieve mission success. This operating procedure must be modified for design-to-cost, where mission performance is traded against cost. The program procedures must be adapted to the design-to-cost philosophy.

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