LPC DOCUMENT NO. 629-6
VOLUME II, BOOK 3
ADDENDUM 1

CR-123618

DATA REQUIREMENT MA-02
FINAL REPORT

TECHNICAL REPORT
COST ESTIMATING DATA
BASELINE, REVISION 1

STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

CONTRACT NO. NAS8-28429
JANUARY 13, 1972 TO MARCH 15, 1972

MARCH 15, 1972

PREPARED FOR
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

· LOCKHEED PROPULSION COMPANY
P.O. BOX 111 REDLANDS, CALIFORNIA 92373

LPC Document No. 629-6
Vol II, Book 3
Addendum 1

Data Requirement MA-02

FINAL REPORT

TECHNICAL REPORT
COST ESTIMATING DATA
Baseline Revision 1

STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

Contract No. NAS8-28429

January 13, 1972 to March 15, 1972

A. H. Von Der Esch
Lockheed Propulsion Company
Vice President, Technical and Marketing

MARCH 15, 1972

PREPARED FOR
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

ABSTRACT

Lockheed Propulsion Company has elected to submit Addendum 1 in support of the March 8, 1972 presentation at NASA/MSFC.

This addendum reflects the results of the redistribution of baseline costs, which have provided LPC with better visibility into the program content.

The addendum section reflects the firm LPC cost position as vectored from the baseline vehicle with the appropriate rationale.

LOCKHEED PROPULSION COMPANY
P.O. BOX 111 REDLANDS, CALIFORNIA 92373

FOREWORD

This document is Book 3, Cost Estimating Data, Baseline - Revision 1, Technical Report. It is a part of Lockheed Propulsion Company's final report for the Study of Solid Rocket Motors for a Space Shuttle Booster. The final report consists of the following documents:

Volume I	Executive Summary
Volume II	Technical Report
Book 1	Analysis and Design
Book 2	Supporting Research and Technology
Book 3	Cost Estimating Data
Volume III	Program Acquisition Planning
Volume IV	Mass Properties Report

CONTENTS

CONTENTS (Continued)

Section 1

SUMMARY

Lockheed Propulsion Company's objective from the outset of the Space Shuttle Program has been to provide complete and conservative design and cost parameters for an expendable Solid Rocket Motor (SRM) Booster Vehicle for the Space Shuttle Program. With this approach, LPC has attempted to identify the maximum technical and cost risks that could be encountered by NASA in employing a solid rocket motor as the Space Shuttle Booster Vehicle. Therefore, LPC believes that the baseline vehicle costs presented in this report are distinctly conservative and will be reduced upon further definition and detailed estimating. Two items, which LPC has not included and which will affect a fixed-payload program cost, are escalation and profit, both of which were directed in the Study Contract to be deleted from consideration.

As directed by NASA, LPC also attempted to determine "hard" versus "soft" costs, and an upper band was established above the baseline for a "worst condition." As a result of Lockheed's solid rocket motor experience, the propulsion system costs are "hard" and, therefore, an upper limit of 2 percent on the SRM cost has been defined. LPC believes that the Stage costs are "soft" and a 30-percent upper limit on the Stage cost was established. With the SRM and Stage combined, a total of 10-percent upward variation has been identified in the Booster Vehicle (WBS 3.3) Program costs. A lower range has also been established, which identifies potential reductions for thrust vector control, thrust termination, and recovery.

The Booster Vehicle selected as the baseline configuration is a parallel-burn (two-motor) 156-inch-diameter SRM vehicle sized for the large (65,000-pound) Orbiter payload. The baseline program assumed for study purposes includes a 5-year (1973 - 1978) development/qualification program, a 13-year (1976 - 1988) production program, and an 11-year (1978 - 1988), 440 vehicle launch program.

The development program includes 25 SRMs; 5 development motor tests, 4 PFRT motor tests, 2 inert booster vehicles (2 SRMs per vehicle) and 6 launches (1 unmanned and 5 manned flights with 2 SRMs per vehicle). All 25 motors in the development program will be fabricated in LPC's existing, large-motor Potrero manufacturing facility. The development program schedule was established at 5 years to minimize annual funding and could be shortened by as much as 1 year without impacting the launch schedule.

The production program of 440 launches includes manufacture of 883 SRMs (880 for launches and 3 for production facility start-up demonstration) and 440 sets of Stage hardware. Due to the nature of the solid rocket motor, quality is ensured by the facility process controls in manufacturing. Thus a three-motor test program is planned to demonstrate that the production facilities will reproducibly deliver the SRMs qualified during development. As directed in the Study Contract, all launches were considered to be from Kennedy Space Center (KSC).

Lockheed Propulsion Company, as prime contractor for the Booster Vehicle, would utilize all of the industry production capability before additional facility expansion. LPC would subcontract to at least two other SRM manufacturers for a portion of the production motors. Additionally, all components would be considered for dual procurement to ensure a redundant capability for Booster Vehicle delivery. This LPC plan provides Booster Vehicle procurement at a very low risk to NASA in the event of a labor, facility, or material problem at any time during the program. This approach also results in a relatively low facility expansion cost ($25.7 million) for the production program and avoids the building of a brand new facility, which would cost approximately $70 million.

The three production facility start-up demonstration tests are considered adequate by LPC to qualify the three production facilities (LPC and two others) for the baseline costing effort. It was considered that NASA might desire additional testing to qualify the new subcontractors ("second sources") and, therefore, nine motor tests were included in establishing the upper limit 2-percent variation in SRM costing. However, LPC recommends only three tests and has used this in the baseline costing.

Previously, it has been stated that the baseline design is conservative. As evidence of this, all metal structures have a minimum safety factor of 1.4. This has naturally imposed an additional cost on materials, but LPC believes that this should be maintained, thus guaranteeing the high reliability required for a man-rated system. As a bonus feature, analysis indicates that the motor chamber with this safety factor (wall thickness 0.460 inch) will withstand water impact loads at 100 feet per second and at entrance angles up to 45 degrees. Although recovery/reuse is not considered in the baseline costing, Lockheed's SRM design should therefore not require additional strengthening (higher material costs) should recovery/reuse prove cost-effective for the Booster Vehicle.

As further evidence of a conservative design, the safety factor for all ablative insulation materials was established at 2.0. Once again, it is felt that this should be maintained for man-rated reliability. In the areas of thrust termination (TT) and thrust vector control (TVC), no firm requirement was established by either the Phase B contractors or by the customer. LPC assumed that the Booster Vehicle would require both TT and TVC, plus a strenuous TVC duty cycle, which sized the system conservatively.

The baseline costs are backed by firm vendor quotes on procured components and conservative labor estimates. Lockheed's labor estimates were prepared from a task definition or "ground-up" standpoint, based on previous LPC large-motor experience, other LPC rocket motor programs, and also on related industry experience on solid propellant rocket motors. Nine full-scale, 156-inch-diameter demonstration motors have been test-fired to date, five by Lockheed Propulsion Company. These tests are summarized in the following table.

SUMMARY OF 156-INCH LARGE SOLID ROCKET MOTOR TESTS

No.	Date	Motor Description		Test Data	
		Designation	Fabrication	Maximum Thrust (lb)	Average Thrust (lb)
1.	1964 May	156-3	LPC	0.95M	0.88M
2.	Sep	156-4	LPC	1.09M	1.00M
3.	1965 Feb	156-2C-1	TCC	3.25M	2.97M
4.	Dec	156-1	TCC	1.47M	1.29M
5.	Dec	156-5	LPC	3.11M	2.84M
6.	1966 Jan	156-6	LPC	1.03M	0.94M
7.	Apr	L-73	LPC	0.66M	0.60M
8.	May	156-7	TCC	0.39M	0.32M
9.	May	156-9	TCC	0.98M	0.88M

All of these motors, with thrust levels up to three million pounds, performed within 2 percent of their calculated parameters, and only one incident (involving the loss of an exit cone in a moveable nozzle test by another contractor) was experienced. This is a significant feat in that each of the nine motors was a "one-of-a-kind" configuration and involved reuse of LPC-designed case hardware as many as four times. Lockheed is proud of this 100-percent successful completion of its five 156-inch motor tests, which were accomplished under-budget on firm fixed price contracts (see USAF Testimonials in Appendix A of the Cost Book).

As previously stated, the experience gained in these programs was applied by all LPC branches in estimating the labor for the Booster Vehicle. In the area of motor processing, the hands-on-hardware "first-unit" labor hours for the baseline were estimated, and then a 90-percent labor improvement or learning curve was applied. Comparison with both LPC experience and other SRM industry experience indicates that this is conservative; in the majority of previous programs, improvement curves in the middle to low eighties have been experienced. For example, on the basis of two large weapon systems, Minuteman and Poseidon, an improvement curve in the 80- to 85-percent range should be achievable in the Booster Vehicle. For this additional reason, LPC, employing a 90-percent curve, has estimated the baseline configuration production costs in a conservative manner.

As another consideration in development of the costs, LPC began this study on 13 January 1972 assuming that the Booster System (WBS 3.0) was to be costed. On 2 February, LPC was notified that the SRM contractors were to price at the Booster Vehicle level (WBS 3.3). While this was intended by NASA to alleviate the SRM contractors' efforts in the short study time available, it did turn out to add another variable, which is reflected as additional conservatism in the LPC costs. Included in LPC's costs are some items that could be interpreted as belonging under Booster Management (WBS 3.1), System Engineering (WBS 3.2), or Booster System Support (WBS 3.5), which may not be included in the cost estimates of the other study contractors.

The Booster Vehicle program costs (WBS 3.3) presented by LPC on 14 and 23 February 1972 were based on the previously defined configuration and costing assumptions. The LPC baseline Booster Vehicle cost estimate presented on these dates is summarized below.

	SRM	Stage	Total Booster Vehicle
Development	$ 141.6M	$ 48.2M	$ 189.8M
Production	2,545.7M	929.0M	3,474.7M
	$2,687.3M	$977.2M	$3,664.5M
Total Program Cost/Launch	$ 6.0M	$ 2.2M	$ 8.2M
Recurring Cost/Launch	$ 5.8M	$ 2.0M	$ 7.8M

The total program cost per launch is developed by dividing the total program cost (3,664.5 million) by the total number of manned launches (445). Although cost per launch does not normally include amortization of DDT&E or non-recurring production items, LPC chose to attempt to display the total program liability that NASA could encounter in employing a solid rocket motor Booster Vehicle. The standard way of displaying cost per launch is by using the recurring unit cost, which, for LPC's baseline, is $7.8M. Once again, these program costs were developed early in the Study Program with the objective of identifying the maximum technical and cost risk that could be encountered by NASA.

On 12 February, after the cut-off date for the 14 and 23 February presentations, Lockheed began a second iteration of the program baseline configuration and cost. Labor and material were analyzed in more depth, more definition was prepared to separate recurring from nonrecurring costs, and the Operations portions of the SRM and Stage were separated into more identifiable activities. This resulted in a redistribution of the baseline costs as shown in the following two tables:

	SRM	Stage	Operations	Total
Development	$ 131.0M	$ 31.0M	$ 27.8M	$ 189.8M
Production	2,303.9M	626.5M	544.3M	3,474.7M
	$2,434.9M	$657.5M	$572.1M	$3,664.5M

Note that in both tables the previously shown total program costs have remained unchanged but are redistributed by LPC for better understanding.

	Total Costs	Recurring Cost/Launch	Total Cost/Launch
Recurring SRM production	$2,242.8M	$5.1M	$5.1M
Recurring Stage production	626.5M	1.4M	1.4M
Recurring operations	544.3M	1.2M	1.2M
Nonrecurring production	61.1M	0	0.1M
Development	189.8M	0	0.4M
Total	$3,664.5M	$7.7M[a]	$8.2M

The next step in the second iteration of the baseline configuration and cost was to review areas where cost might be overly conservative and could thus be reduced. Since the hardware is a major portion of the SRM cost, additional definition and breakdown of vendor component and material costs were requested from the subcontract suppliers. In vehicle configuration, better design definition was developed and rebids were prepared in some areas. As an example, in January, prior to completion of the TVC system sizing, quotes had to be obtained on the actuator. LPC requested bids on the actuator used on the S1-C Vehicle, knowing that it would be more than adequate for the job. The actuator requirement was found to be far less and was rebid at a significantly lower cost. Safety factors of all hardware were maintained and the material costs still reflect safety factors of 1.4 on structures and 2.0 on ablative insulations.

The motor processing tasks and the improvement/learning curve were reviewed in considerable depth. A steeper curve (86 percent) was selected as realistic but still sufficiently conservative in comparison to other major solid rocket motor programs and LPC's 156-inch motor experience. Assembly and support labor were also analyzed and some areas of redundancy between WBS paragraphs were identified and deleted. The analysis of labor and material on the SRM has resulted in a lower unit cost position for the SRM baseline. These analyses have been time-consuming and, although some areas of the Stage attachment hardware and Operations have been reviewed and reduced, additional effort is being expended by Lockheed toward further definition, analysis, and reduction.

To support a final report date of 15 March, a cut-off was made on 8 March in the second costing iteration. The reduced program costs are shown in the following table as "Baseline, Revision 1" and are compared by item to the original baseline costs shown previously.

(a) As a minor note, the redistribution identified additional nonrecurring production costs, resulting in a lower recurring cost per launch.

	Baseline Cost	Reduction	Baseline Revision 1
Recurring SRM Production	$2,242.8M	$266.8M	$1,976.0M
Recurring Stage Production	626.5M	155.7M	470.8M
Recurring Operations	544.3M	98.0M	446.3M
Nonrecurring Production	61.1M	0	61.1M
Development	189.8M	3.7M	186.1M
	$3,664.5M	$524.2M	$3,140.3M
Total Cost/Launch	$ 8.2M	$ 1.1M	$ 7.1M
Recurring Cost/Launch	$ 7.7M	$ 1.1M	$ 6.6M

Each of the reductions shown in this table is discussed in the Addendum to the cost book of the final report. The cost per launch, both recurring and total, has been reduced by over a million dollars. Further analysis will yield even more reductions in the areas of Stage and Operations. It is believed by Lockheed that the SRM, however, will not yield further major reductions without a change in either performance or hardware safety factors, which is not recommended by LPC.

Therefore, the Baseline Revision 1 costs ($3,140.3B) are submitted as Lockheed's formal position on the SRM Booster Vehicle (WBS 3.3).

The conclusions of the LPC study are:

(1) The LPC 156-inch-diameter baseline design meets all the technical requirements for the Booster Vehicle.

(2) The baseline design appears to have the structural capability to withstand recovery-load impacts should recovery/reuse prove cost-effective for the Booster Vehicle.

(3) The SRM Booster Vehicle, because of its demonstrated technology, can be developed to meet all NASA schedule requirements.

(4) The Baseline Revision 1 costs are realistic and achievable and are subject to further reduction.

(5) The cost for development ($186.1M) of an expendable SRM Booster Vehicle are less than 4.0 percent of the total Space Shuttle Development budget ($5.5B).

(6) The Baseline Revision 1 SRM Booster Vehicle cost per launch (recurring $6.6M, total $7.1M) is less expensive than that of a liquid booster.

In summary, Lockheed believes that an SRM propulsion system can perform the mission, can be easily developed in the time available, and will prove to be a cost-effective booster vehicle for the Space Shuttle Program.

Section 2

INTRODUCTION

On 12 February 1972, Lockheed Propulsion Company undertook a second iteration of the program baseline configuration and cost. The purpose of this activity was (1) to ensure that total program costs were complete, and (2) to review areas where costs might be overly conservative and could be reduced.

Labor and material were analyzed in more depth, more definition was prepared to separate recurring from non-recurring costs, and the Operations portions of the SRM and Stage were separated into more identifiable activities. This resulted in a redistribution of the baseline costs which has provided LPC better visibility into the program content.

The following three sections of this book contain the redistributed baseline costs (Section 3), the reduced Baseline - Revision 1 costs (Section 4) and the revised Baseline - Revision 1 WBS charts and tables (Section 5) requested by NASA. The cost formats for both Sections 3 and 4 are identical to provide the reader a basis of comparison of the new LPC program costs (Baseline - Revision 1) with the costs presented as the original baseline.

A summary of the Baseline - Revision 1 program costs, which is LPC's formal position, is shown in the following table.

BOOSTER VEHICLE TOTAL PROGRAM COSTS
BASELINE - REVISION 1

($ in Millions)

	Total Cost	Recurring Cost/Launch	Total Cost/Launch
Recurring SRM Production	$1,976.0	$4.5	$4.5
Recurring Stage Production	470.8	1.1	1.1
Recurring Operations	446.3	1.0	1.0
Non-recurring Production	61.1	0	0.1
Development	186.1	0	0.4
	$3,140.3	$6.6	$7.1

Section 3

LPC BASELINE COST DEFINITION

This section contains the original baseline costs presented to NASA on 14 and 23 February 1972. Costs have been outlined in more detail than previously presented.

Two notes have been added to the charts for clarification. If a cost number differs from that displayed in either the 14, or 23 February presentations, it will be identified as a change by one of these two notes.

3.1 BOOSTER VEHICLE TOTAL PROGRAM COSTS

The following chart is identical to that presented on 14 and 23 February. It is shown here to clarify the point of departure for the redefinition and redistribution activity.

BOOSTER VEHICLE TOTAL PROGRAM COSTS
LPC BASELINE COST DEFINITION

($ IN MILLIONS)

	SRM	STAGE	TOTAL
DEVELOPMENT	$ 141.6	$ 48.2	$ 189.8
PRODUCTION	2,545.7	929.0	3,474.7
	$2,687.3	$997.2	$3,664.5

The first step in this activity was to identify the Operations costs which were included under SRM and Stage by the Work Breakdown Structure. The total program costs have not been changed, only redistributed to remove the transportation, assembly, installation, and launch support costs from SRM and Stage fabrication. SRM and Stage have been redefined as fabrication, inspection, and package for shipment, F. O. B. - manufacturing site. Operations costs begin with transportation to KSC from the manufacturing site and include all assembly, installation, checkout, and launch support.

The Operations costs included in development are distributed as follows:

SRM	$10.6M
Stage	17.2M
Total	$27.8M

Similarly, the Operations costs in the production breakdown is:

SRM	$241.8M
Stage	302.5M
Total	$544.3M

Adding these elements to the SRM and Stage costs shown would return all the costs into the original format on the previous page.

BOOSTER VEHICLE TOTAL PROGRAM COSTS
LPC BASELINE COST DEFINITION

($ IN MILLIONS)

	SRM	STAGE	OPERATIONS	TOTAL
DEVELOPMENT	$ 131.0*	$ 31.0*	$ 27.8*	$ 189.8
PRODUCTION	2,303.9*	626.5*	544.3*	3,474.7
	$2,434.9*	$657.5*	$572.1*	$3,664.5

* NEW DISPLAY FROM BASELINE

The only change on the chart below is the separation of the non-recurring production ($61.1M) from the SRM production ($2,303.9) on the previous chart. This resulted in a lower recurring cost per launch ($7.7M) than previously reported ($7.8M). All other costs remain unchanged from the previous chart.

The chart below presents breakdowns of each line item on this page.

BOOSTER VEHICLE TOTAL PROGRAM COSTS
LPC BASELINE COST DEFINITION

($ IN MILLIONS)

	TOTAL COSTS	RECURRING COST/LAUNCH	TOTAL COST/LAUNCH
RECURRING SRM PRODUCTION	$2,242.8*	$5.1*	$5.1*
RECURRING STAGE PRODUCTION	626.5*	1.4*	1.4*
RECURRING OPERATIONS	544.3*	1.2*	1.2*
NONRECURRING PRODUCTION	61.1*	0 ↓	0.1*
DDT&E	189.8	0	0.4
TOTAL	$3,664.5	$7 7 ↓	$8.2

* NEW DISPLAY FROM BASELINE
↓ COSTS LOWER THAN PREVIOUSLY REPORTED

3.2 TOTAL RECURRING SRM PRODUCTION BASELINE COSTS

Displayed here are the Recurring SRM Production costs with all non-recurring and Operations costs removed. Labor and material have been separated to aid in obtaining visibility into the major cost elements. One item, i.e. TVC, power and electrical, stands out as an area requiring further study and will be discussed later in the Baseline - Revision 1 costs.

TOTAL RECURRING SRM PRODUCTION COSTS - 440 LAUNCHES
LPC BASELINE COST DEFINITION

($ IN MILLIONS)

	COST *	% OF TOTAL *
LABOR		
ENGINEERING	$ 6.0 *	0.2
MANUFACTURING	189.2 *	8.4
PRODUCT ASSURANCE	46.4 *	2.1
PROGRAM MANAGEMENT	12.4 *	0.6
TVC, POWER & ELECTRICAL	156.9 *	7.0
LABOR SUBTOTAL	$410.9 *	18.3 *
MATERIAL		
CASE & INTERNAL INSULATION	$ 812.7 *	36.2
PROPELLANT	342.0 *	15.2
NOZZLE (W/LOCKSEAL)	396.8 *	17.7
TVC	185.4 *	8.3
IGNITER	28.2 *	1.3
THRUST TERMINATION	36.6 *	1.6
POWER & ELECTRICAL	26.1 *	1.2
TOOLING MAINTENANCE	4.1 *	0.2
MATERIAL SUBTOTAL	$1,831.9 *	81.7 *
TOTAL SRM	$2,242.8 *	100.0
RECURRING SRM COST/LAUNCH	$5.1 *	

* NEW DISPLAY FROM BASELINE

3.3 TOTAL RECURRING STAGE PRODUCTION BASELINE COSTS

This chart shows the recurring Stage costs and, in classical cost element format, reflects the labor and material breakdown as a percent of the whole. Formatting it in this manner has highlighted Structures and Avionics as significant cost elements for further review.

TOTAL RECURRING STAGE PRODUCTION COST - 440 LAUNCHES

LPC BASELINE COST DEFINITION

($ IN MILLIONS)

	COST *	% OF TOTAL *
LABOR		
PROG MGMT & SYSTEMS ENG	$ 2.4 *	0.4
STRUCTURES	271.6 *	43.4
AVIONICS	146.0 *	23.3
POWER	41.7 *	6.6
LABOR SUBTOTAL	$461.7 *	73.7 *
MATERIAL		
STRUCTURES	$113.0 *	18.0
AVIONICS	38.6 *	6.2
POWER	9.2 *	1.5
MAJOR GROUND TESTS	4.0 *	0.6
MATERIAL SUBTOTAL	$164.8 *	26.3 *
TOTAL	$626.5 *	100.0
RECURRING STAGE COST/LAUNCH	$1.4 *	

* NEW DISPLAY FROM BASELINE

3.4 TOTAL RECURRING OPERATIONS BASELINE COST

Operations cost begins with hardware transportation from the manufacturing site to KSC, and includes assembly, installation, checkout and launch support. All items are directly traceable to the Work Breakdown Structure in Section 5.

TOTAL RECURRING OPERATIONS COST - 440 LAUNCHES
LPC BASELINE COST DEFINITION

($ IN MILLIONS)

	COST *	% OF TOTAL *
LABOR		
SRM ASSEMBLY	$123.8 *	22.8
PROG MGMT & SYSTEMS ENG	4.1 *	0.8
AGE MAINTENANCE AND SPARES	10.3 *	1.9
FLIGHT TEST SUPPORT	1.4 *	0.2
OPERATIONS SUPPORT	3.5 *	0.6
INSTALL, ASSEMBLY & CHECKOUT	188.6 *	34.6
MAJOR GROUND TEST	116.4 *	21.4
LABOR SUBTOTAL	$448.1 *	82.3 *
MATERIAL		
AGE MAINTENANCE & SPARES	$ 15.5 *	2.8
TRANSPORTATION	80.7 *	14.9
MATERIAL SUBTOTAL	$ 96.2 *	17.7 *
TOTAL	$544.3 *	100.0
RECURRING OPERATIONS COST/LAUNCH	$1.2 *	

* NEW DISPLAY FROM BASELINE

3.5 TOTAL NON-RECURRING PRODUCTION BASELINE COST

The presentations of 14 and 23 February identified only the production facilities ($25.7M). Other non-recurring costs have since been identified which were previously included in the SRM. A number of the non-recurring costs are related to Stage and Operations, but due to the Work Breakdown Structure, were included in the SRM as the only location under WBS 3.3, where it could be properly cited. Examples of this are the Operations System Engineering and the Stage System Engineering, which could be included under WBS 3.2 if LPC were pricing to WBS 3.0.

TOTAL NONRECURRING PRODUCTION COSTS
LPC BASELINE COST DEFINITION

($ IN MILLIONS)

	COST	% OF TOTAL
LABOR		
SRM FACILITY STARTUP COSTS (3 PPQ'S)	$ 2.4 *	
OPERATIONS SYSTEM ENGINEERING	1.0 *	
AGE DESIGN & FABRICATION	10.2 *	
STAGE SYSTEM ENGINEERING	0.3 *	
LABOR SUBTOTAL	$13.9	22.8
MATERIAL		
SRM FACILITY STARTUP COSTS (3 PPQ'S)	$ 6.2 *	
FACILITY COSTS	25.7	
AGE DESIGN & FABRICATION	15.3 *	
MATERIAL SUBTOTAL	$47.2 *	77.2
TOTAL	$61.1 *	100.0

* NEW DISPLAY FROM BASELINE

3.6 TOTAL DEVELOPMENT BASELINE COSTS

The Development Program costs have been defined as labor and material at this time. Due to the time available, it was decided to investigate only recurring production costs to attempt to identify major areas where over-conservative costs could be reduced. Lockheed is continuing to review the program costs and will include Development in the next iteration. An example is production tooling, which is included in Development at NASA's direction and must be included in the next review.

TOTAL DDT&E COSTS
LPC COST DEFINITION

($ IN MILLIONS)

	COST	% OF TOTAL COST
LABOR	$ 67.9*	35.8*
MATERIAL	121.9*	64.2*
TOTAL	$189.8	100.0

* NEW DISPLAY FROM BASELINE

Section 4

BASELINE - REVISION 1 COSTS

This section contains the reduced costs submitted as Baseline - Revision 1. To maintain continuity and aid in clarification, the original baseline costs are included, and the format of Section 3 has been retained.

As discussed in the summary, the reductions shown are those identified on 8 March 1972. The costs identified for the SRM have been reviewed in considerable depth, and further major reductions do not appear available without a change in either performance or hardware safety factors, which is not recommended by LPC. The Stage and Operations areas, however, could yield further reductions and are being reviewed as of the date of this report. As stated previously, Lockheed is continuing its analysis in all areas and further reductions to Baseline - Revision 1 are anticipated and will be reported when available.

4.1 TOTAL BOOSTER VEHICLE PROGRAM COSTS - BASELINE - REVISION 1

This chart identifies the new LPC total cost (Baseline - Revision 1) and the specific areas where costs have been reduced. A total reduction of $524.2 million has been identified to date without modification of the baseline configuration or safety factors. The Baseline - Revision 1 cost per launch has been reduced by over one million dollars in both recurring and total.

Subsequent charts are included to provide clarification of each item reduced.

TOTAL BOOSTER VEHICLE PROGRAM COSTS

BASELINE COST - REVISION 1

($ IN MILLIONS)

	BASELINE COST	COST REDUCTIONS	REVISED COSTS
RECURRING SRM PRODUCTION	$2,242.8	$266.8*	$1,976.0↓
RECURRING STAGE PRODUCTION	626.5	155.7*	470.8↓
RECURRING OPERATIONS	544.3	98.0*	446.3↓
NONRECURRING PRODUCTION	61.1		61.1
DDT&E	189.8	3.7*	186.1↓
TOTAL	$3,664.5	$524.2*	$3,140.3↓
TOTAL COST/LAUNCH	$8.2	$1.1M*	$7.1 ↓
RECURRING COST/LAUNCH	$7.7	$1.1M*	$6.6 ↓

* NEW DISPLAY FROM BASELINE
↓ COSTS LOWER THAN PREVIOUSLY REPORTED

4.2 TOTAL RECURRING SRM PRODUCTION COSTS - BASELINE - REVISION 1

The costs on this page show a greater reduction in labor than in material; details of each are shown in the following two charts. The labor reductions resulted from two activities; (1) eliminating redundancies and (2) estimating a less conservative improvement/learning curve. The material cost retains the baseline configuration and conservative safety factors; the reductions are largely in reduction of "cushions" in the vendor quotes. With the relationship of firm-quoted material (87.4%) to the labor estimates (12.6%), it appears that further major changes to the SRM costs cannot be made without either a performance or safety factor reduction.

TOTAL RECURRING SRM PRODUCTION COSTS
BASELINE COST - REVISION 1

($ IN MILLIONS)

	BASELINE COST	COST REDUCTIONS	REVISED COST	% OF TOTAL
LABOR				
ENGINEERING	$ 6.0		$ 6.0	
MANUFACTURING	189.2	$ 63.7*	125.5↓	
PRODUCT ASSURANCE	46.4	11.0*	35.4↓	
PROGRAM MANAGEMENT	12.4	3.8*	8.6↓	
TVC, POWER & ELECTRICAL	156.9	83.3*	73.6↓	
LABOR SUBTOTAL	$ 410.9	$161.8*	$ 249.1↓	12.6*
MATERIAL				
CASE & INTERNAL INSULATION	$ 812.7	$ 57.0*	$ 755.7↓	
PROPELLANT	342.0		342.0	
NOZZLE (W/LOCKSEAL)	396.8	26.2*	370.6↓	
TVC	185.4	18.3*	167.1↓	
IGNITER	28.2	1.7*	26.5↓	
THRUST TERMINATION	36.6		36.6	
POWER & ELECTRICAL	26.1	1.8*	24.3↓	
TOOLING MAINTENANCE	4.1		4.1	
MATERIAL SUBTOTAL	$1,831.9	$105.0*	$1,726.9↓	87.4*
TOTAL SRM	$2,242.8	$266.8*	$1,976.0↓	

* NEW DISPLAY FROM BASELINE
↓ COSTS LOWER THAN PREVIOUSLY REPORTED

4.2.1 Total Recurring SRM Labor Reductions

The labor reductions from the previous page are displayed here in two categories: (1) less conservative improvement/learning curve, and (2) duplication of activities with other WBS blocks under Booster Vehicle (WBS 3.3).

The 90 percent improvement/learning curve was a conservative application after each LPC branch estimated the first production unit manhours. By comparison with both LPC experience and other SRM industry experience, the majority of past solid rocket motor programs have achieved improvement curves in the low eighties. Adding the fact that the Booster Vehicle SRM is less complex than many previous motor programs, LPC has selected a steeper curve (86%) than used in the original baseline. While this is still conservative, compared with two major weapon systems (80-85% on Minuteman and Poseidon), LPC is not prepared to reduce the motor processing costs further without more detailed study.

Two areas in the SRM labor were found which duplicated Operations activities at Kennedy Space Center. The Program Management functions were combined under SRM (WBS 3.3.2.1) since Booster Management (WBS 3.1) was deleted from the LPC costing activity. Both the SRM fabrication estimating and installation, assembly and checkout (WBS 3.3.6) estimating included Program Management costs for KSC operations. The Program Management duplication and the Product Assurance improvement costs, in the above paragraph would have been reduced further than shown, but were left at the reductions indicated on this chart to cover administration of a vendor subcontract discussed on the next chart.

The reduction shown in Power and Electrical (WBS 3.3.2.3.3) covers the labor for checkout at KSC, which is also included in WBS 3.3.6. This is a duplication and has been removed from WBS 3.3.2.3.3 under the SRM. The fabrication costs for TVC, Power and Electrical ($73.6M) shown on the previous page still appear high, but have not been analyzed at this writing.

TOTAL RECURRING SRM LABOR REDUCTIONS
BASELINE COST - REVISION 1
($ IN MILLIONS)

LEARNING CURVE REDUCTION (90 TO 86)		
MANUFACTURING	$63.7 *	
PRODUCT ASSURANCE	11.0 *	
	$74.7 *	
DUPLICATION IN KSC OPERATIONS		
PROGRAM MANAGEMENT	$ 3.8 *	
POWER & ELECTRICAL	83.3 *	
	$87.1 *	
TOTAL		$161.8 *

* NEW DISPLAY FROM BASELINE

4.2.2 Total Recurring SRM Material Reductions

Additional SRM material cost definition has been requested from the major component subcontract suppliers. A review of six items has identified the cost reductions shown on this chart. In the area of nozzle, nozzle adapter, power supply, and igniter chamber, the vendors identified the costs as shown as "cushion" in their baseline. These cusions have been removed.

The reduction in case cost ($57.0M) is the result of the deletion of an 11 percent contract handling fee which the case vendor added to the forging vendors quoted price. This has been deleted and LPC will provide the forging to the case machining vendor as CFM. The Program Management and the Product Assurance labor costs for handling this contract were discussed on the previous page.

The reduction in the Thrust Vector Control actuator costs is a result of the selected sizing of the actuator system to meet the Thrust Vector Control torque and duty cycle requirements.

All vendor quotes are at the price level and therefore include the vendor profit; LPC interpreted the NASA study requirement to mean LPC's costs which would include vendor profit. Some further reductions in material costs may be found by continued analysis which LPC is currently undertaking.

TOTAL RECURRING SRM MATERIAL REDUCTIONS
BASELINE COST - REVISION 1

($ IN MILLIONS)

CASE	$ 57.0 *
NOZZLE	22.9 *
NOZZLE ADAPTOR	3.3 *
ACTUATOR	18.3 *
POWER SUPPLY	1.8 *
IGNITER CHAMBER	1.7 *
TOTAL	$105.0 *

* NEW DISPLAY FROM BASELINE

4.3 TOTAL RECURRING STAGE PRODUCTION COST - BASELINE - REVISION 1

As of 8 March, only one area (i.e., structures) has been reviewed for cost reduction. It was found that in addition to fabrication cost, the structures WBS included assembly and checkout at KSC. This $155.7 million is a complete duplication of costs contained in WBS 3.3.6 and can be broken down into its various elements by reviewing the production WBS, paragraphs 3.3.1.1. 3.3.1.3, and 3.3.1.5 shown in Section 5.

Further reductions in both avionics and power appear available and are currently being analyzed by LPC.

TOTAL RECURRING STAGE PRODUCTION COST

BASELINE COST - REVISION 1

($ IN MILLIONS)

	BASELINE COST	COST REDUCTION	REVISED COST
LABOR			
PROG MGMT & SYSTEMS ENG	$ 2.4		$ 2.4
STRUCTURES	271.6	$155.7 *	115.9 ↓
AVIONICS	146.0		146.0
POWER	41.7		41.7
LABOR SUBTOTAL	$461.7	$155.7 *	$306.0 ↓
MATERIAL			
STRUCTURES	$113.0		$113.0
AVIONICS	38.6		38.6
POWER	9.2		9.2
MAJOR GROUND TESTS	4.0		4.0
MATERIAL SUBTOTAL	$164.8		$164.8
TOTAL	$626.5	$155.7 *	$470.8 ↓

* NEW DISPLAY FROM BASELINE

↓ COSTS LOWER THAN PREVIOUSLY REPORTED

4.4 TOTAL RECURRING OPERATIONS COST - BASELINE - REVISION 1

Major ground tests show a reduction of $98.0 million. This cost was inadvertently included in production cost due to insufficient definition of the production activity. The DDT&E major ground test costs were estimated at 10 percent of the hardware cost and this groundrule was misinterpreted to also apply to production. After redefinition, the major ground test costs for production were estimated at $18.4 million, thus producing the reduction shown. It is also possible that further reduction between SRM assembly ($123.8M) and installation assembly and checkout ($188.6M) can be accomplished and is being reviewed in more detail by LPC.

TOTAL RECURRING OPERATIONS COST

BASELINE COST - REVISION 1

($ IN MILLIONS)

	BASELINE COST	COST REDUCTIONS	REVISED COST
LABOR			
SRM ASSEMBLY	$123.8		$123.8
PROG MGMT & SYSTEMS ENG	4.1		4.1
AGE MAINTENANCE & SPARES	10.3		10.3
FLIGHT TEST SUPPORT	1.4		1.4
OPERATIONS SUPPORT	3.5		3.5
INSTALLATION, ASSEMBLY & CHECKOUT	188.6		188.6
MAJOR GROUND TEST	116.4	$98.0 *	18.4 ↓
LABOR SUBTOTAL	$448.1	$98.0 *	$350.1 ↓
MATERIAL			
AGE MAINTENANCE & SPARES	$ 15.5		$ 15.5
TRANSPORTATION	80.7	____	80.7
MATERIAL SUBTOTAL	$ 96.2	____	$ 96.2
TOTAL	$544.3	$98.0 *	$446.3 ↓

* NEW DISPLAY FROM BASELINE
↓ COSTS LOWER THAN PREVIOUSLY REPORTED

4.5 TOTAL NON-RECURRING PRODUCTION COST - BASELINE - REVISION 1

Because of the small non-recurring costs, the potential for reduction is also small and therefore has not been analyzed to date. This chart merely reflects that the original baseline and Baseline - Revision 1 are identical in the non-recurring production category.

TOTAL NONRECURRING PRODUCTION COSTS

BASELINE COST - REVISION 1

($ IN MILLIONS)

	BASELINE COST	REVISED COST	% OF TOTAL
LABOR			
SRM STARTUP COSTS (3 PPQ'S)	$ 2.4 *	$ 2.4	
OPERATIONS SYSTEM ENGR	1.0 *	1.0	
AGE DESIGN & FABRICATION	10.2 *	10.2	
STAGE SYSTEM ENGR	0.3 *	0.3	
LABOR SUBTOTAL	$13.9 *	$13.9	22.8
MATERIAL			
SRM STARTUP COSTS (3 PPQ'S)	$ 6.2 *	$ 6.2	
FACILITY COSTS	25.7	25.7	
AGE DESIGN & FAB	15.3 *	15.3	
MATERIAL SUBTOTAL	$47.2 *	$47.2	77.2
TOTAL	$61.1 *	$61.1	100.0

* NEW DISPLAY FROM BASELINE

4.6 TOTAL DEVELOPMENT COSTS - BASELINE - REVISION 1

The development program was not analyzed during the second iteration. The reductions shown here are merely "fallouts" from the production material analysis shown on chart 4.2.2. A breakdown of these costs by component is shown in the modified DDT&E WBS chart contained in Section 5.

TOTAL DDT&E COSTS
BASELINE COST - REVISION 1

($ IN MILLIONS)

	BASELINE COST	COST REDUCTION	REVISED COSTS
LABOR	$ 67.9		$ 67.9
MATERIAL	$121.9	$3.7 *	118.2↓
TOTAL	$189.8	$3.7 *	$186.1↓

* NEW DISPLAY FROM BASELINE
↓ COSTS LOWER THAN PREVIOUSLY REPORTED

4.7 REDUCED BOOSTER VEHICLE TOTAL PROGRAM COSTS - BASELINE - REVISION 1

The Baseline - Revision 1 costs summarized here reflect the reductions previously discussed in Section 4. The recurring costs per launch and total cost per launch are reduced by over one million dollars to the original LPC baseline. The Baseline - Revision 1 costs ($3,140.3B), shown on this chart, are submitted as LPC's formal position on the SRM Booster Vehicle (WBS 3.3).

Further analysis will yield more reductions in the areas of Stage and Operations. However, LPC believes that the SRM will not yield further major reductions without a change in either performance or hardware safety factors.

REDUCED BOOSTER VEHICLE TOTAL PROGRAM COSTS

BASELINE COST - REVISION 1

($ IN MILLIONS)

	REVISED TOTAL COSTS	REVISED RECURRING COST/LAUNCH	REVISED TOTAL COST/LAUNCH
RECURRING SRM PRODUCTION	$1,976.0↓	$4.5↓	$4.5↓
RECURRING STAGE PRODUCTION	470.8↓	1.1↓	1.1↓
RECURRING OPERATIONS	446.3↓	1.0↓	1.0↓
NONRECURRING PRODUCTION	61.1*	0	0.1*
DDT&E	186.1↓	0	0.4↓
TOTAL	$3,140.3↓	$6.6↓	$7.1↓

* NEW DISPLAY FROM BASELINE
↓ COSTS LOWER THAN PREVIOUSLY REPORTED

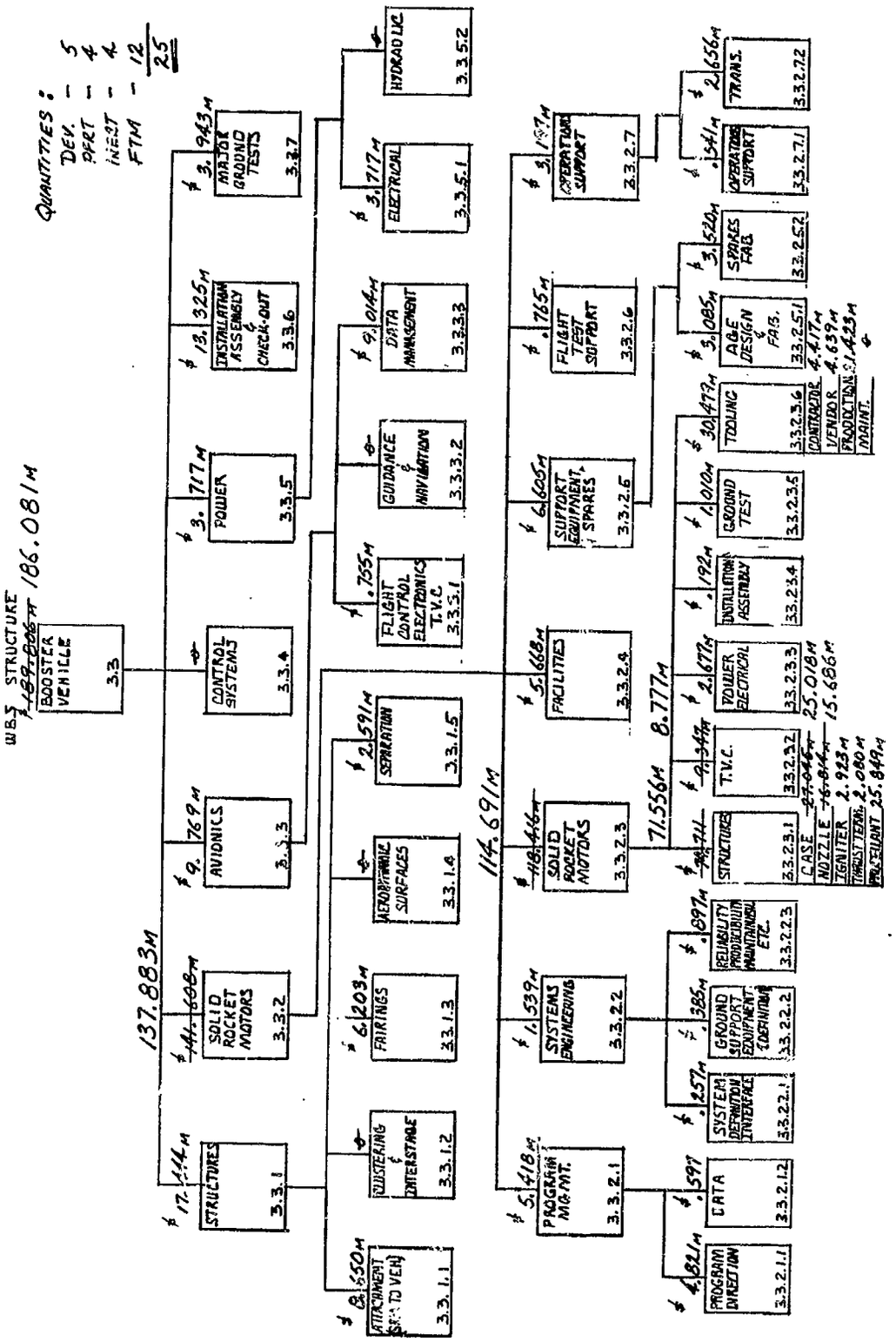
Section 5

BASELINE-REVISION 1 BACKUP DATA

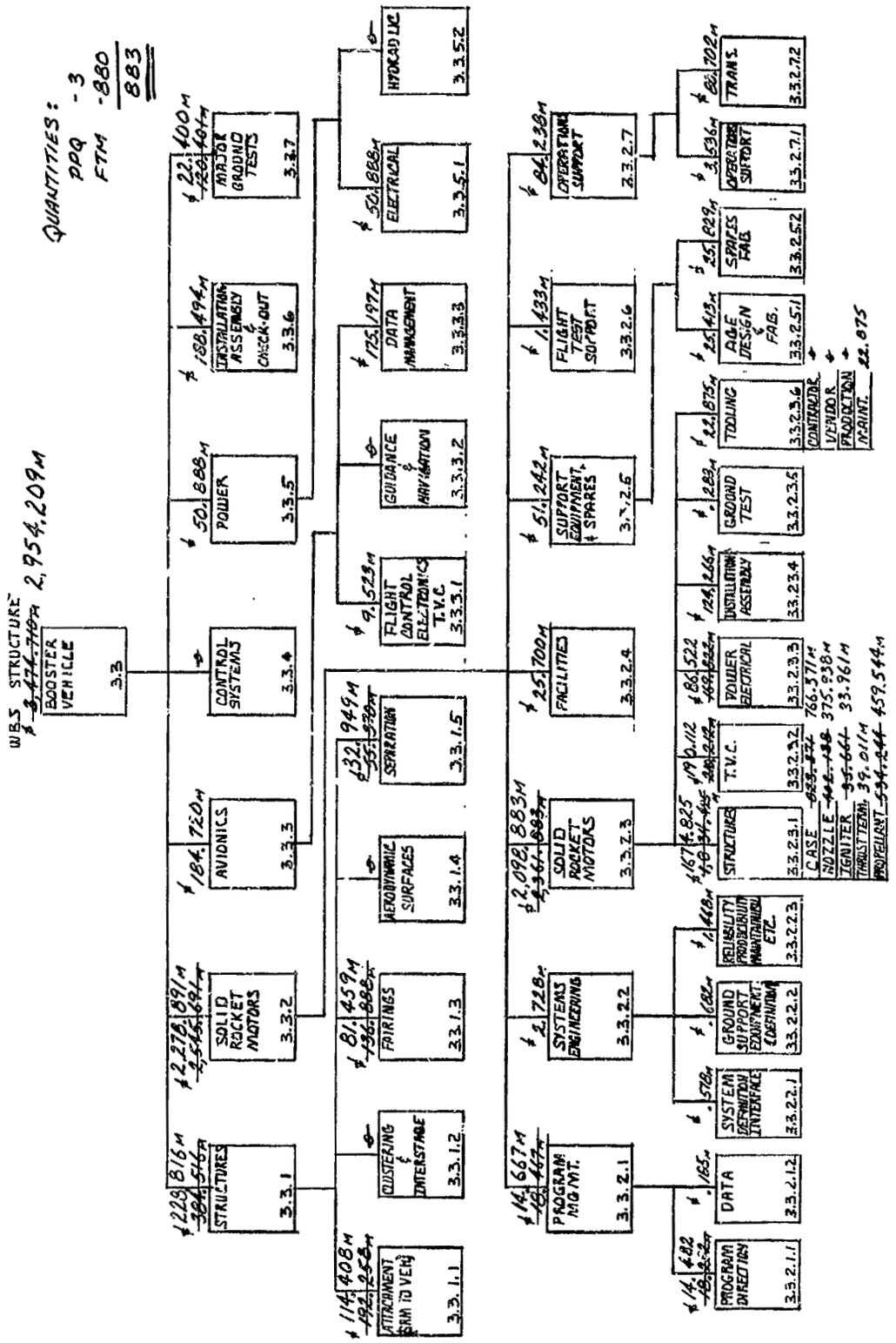
This section of the addendum includes DDT&E and Production WBS charts modified to show the reduced costs (Baseline-Revision 1) identified in Section 4. Additionally, Tables 1 and 2 to Baseline-Revision 1 costs are included.

5.1 WORK BREAKDOWN STRUCTURE - 156-7 SRM (WITH TVC AND TT)

5.1.1 Development



5.1.2 Production



5.2 PROGRAM COST ESTIMATES - TABLE 1

Cost estimates for the 156-7 SRM (Parallel W/TVC&TT), Baseline, Revision 1, are presented in table 1 format. Table 1a costs are for the SRM only and Table 1b costs are for the total program, i. e., SRM and Stage.

The definitions for DDT&E, Production and Operations are the same as in the basic report except for Program Management, Systems Engineering, and Installation, Assembly and Check-out. The SRM and Stage efforts include all costs from factory, to shipment of the hardware to KSC. The Transportation, Installation, Assembly, Check-out and the Program Management and Systems Engineering support required for this effort are now identified as Operations costs.

Program Management and Systems Engineering

Program Management and Systems Engineering was contained in Production only, it is now spread among SRM Production, Operations and Stage Production.

Installation, Assembly and Check-out

SRM Installation, Assembly and Check-out was contained in Production only for the SRMs. It is now all in Operations, except for the costs of static firing the 3 PPQs and tooling maintenance which remains in Production.

Note: Table 1a Total Program is $2.400 million lower than the amount shown on Table 1b, for SRM. The $2.400 million is for program management and systems engineering relative to Stage and is therefore excluded from SRM (Table 1a) and added to Table 1b, which includes Stage.

5.2.1 Option I Basic, Solid Rocket Motor - Table 1a

(Dollars in Millions)

SRM	DDT&E					Production	Operations	Total Program
	Engineering Design Development (EDD)	Tooling (TOOL)	Ground Test Hardware (GTH)	Flight Test Hardware (FTH)	Other (OTH)	Total (TOT)			
Program Management					$ 5.418	$ 5.418	$ 8.702	$ 3.637	$ 17.757
System Engineering					1.539	1.539	2.228	.428	4.195
SRMs									
Structures									
Case	$ 1.490	$ 7.296	$10.091	$13.437		32.314	771.424		803 738
Nozzle	3.655	2.526	5.161	6.870		18.212	377.687		395.899
Igniter	1.477	1.403	.620	.876		4.326	34.933		39.259
Thrust Termination	.984		.470	.626		2.080	39.011		41.091
Propellant	2.415	16.839	10.040	13 304		42.688	471.205		513.893
TVC	1.591	1.071	3.083	4.103		9.848	192.544		202.392
Power, Electrical, Avionics	1.110	.927	.672	.895		3.604	87.217		90.821
Installation, Assembly and C/O		.067	.081	.111		.259	.516	123.800	124.575
Ground Test	.353	.350	.657			1.360	.546		1.906
Facilities					5.668	5.668	25.700		31.368
Support Equipment and Spares								57.847	57 847
Flight Test Support								2.198	2.198
Operations Support								87.435	87 435
Total Program	$13.105	$30.479	$30.875	$40.232	$12.625	$127.316	$2,011.713	$275.345	$2,414.374

5.2.2 Option I Basic, Solid Rocket Motor and Stage - Table 1b

(Dollars in Millions)

Booster Vehicle	DDT&E					Production	Operations	Total Program
	Engineering Design Development (EDD)	Tooling (TOOL)	Ground Test Hardware (GTH)	Flight Test Hardware (FTH)	Other (OTH)	Total (TOT)			
Structures								
Attach (SRM to Vehicle)	$ 2.477	$ 2.17[illegible]		$ 3.999		$ 8.650	$ 114.108		$ 123.058
Clustering and Interstage									
Fairings	1.778	1.554		2.871		6.203	81.459		87.662
Aerodynamic Surfaces									
Separation	.738	.619		1.194		2.591	32.949		35.540
Solid Rocket Motors	13.105	30.479	$30.875	40.232	$12.625	127.316	2,014.113	$275.345	2,416.774
Avionics									
Flight Control Electronics	.399			.356		.755	9.523		10.278
Guidance and Navigation									
Data Management	4.762			[illegible].232		9.014	175.197		184.211
Control Systems									
Power									
Electrical	1.989			1.728		3.717	50.888		54.605
Hydraulic									
Installation, Assembly and C/O								201.819	201.819
Major Ground Tests							4.000	22.343	26.343
Total Program	$25.248	$34.866	$30.875	$54.632	$12.625	$158.246	$2,482.537	$499.507	$3,140.290

5.3 PROGRAM TIME PHASE FUNDINC REQUIREMENTS - TABLE 2

Baseline - Revision 1 funding requirements for the 156-7 SRM (Parallel W/TVC and TT) are presented in table 2 format. Table 2a costs are for the SRM only and Table 2b costs are for the total program, i. e. , SRM and Stage.

The Table 2s differ from the basic report in that in the basic report DDT&E was identified as non-recurring, and Production as recurring. Revision 1 segregates the costs into total Non-recurring, consisting of DDT&E non-recurring Production and Operations, and total Recurring, Production and Operations. Facilities have remained the same.

5.3.1 Option 1 Basic, Solid Rocket Motor - Table 2a

Cost Element	Fiscal Year (Dollars in Millions)																Total
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Non-Recurring Total	3.8	17.7	19.7	15.2	30.4	61.7	9.3	7.8	2.0									$ 167.628
Development																		
Development	3.8	8.6	16.2	9.6	5.2	4.3												47.737
STE/ST		9.1			7.1	14.3												30.479
Deliverable Hardware																		
Dummy Engines			1.0	2.2														3.200
Flight Engines				1.6	15.6	33.0												50.232
OS FS & Spares			2.5	1.8	2.5	10.1	9.3	7.8	2.0									35.980
Recurring Total				.4	8.7	19.9	103.4	142.5	177.8	228.1	266.0	294 0	29 5	288.3	262.4	122.9	6.5	$2,215.378
Investment																		
Deliver New Engines					7.9	17.8	94.8	128.4	160.1	205.5	239.1	262.8	260.8	256.9	231.3	104.7	5.9	1,976.013
Ground Support Equip																		
Parts								.1	.1	.1	.2	.2	.2	.2	.2	.1		1.433
Operations						.8	6.8	11.7	14.8	19.1	23.1	27.4	29.9	29.9	29.9	18.1	.6	212.103
Flight Support																		
Operations																		25 829
Parts				.4	.8	1.3	1.8	2.3	2.8	3.4	3.6	3.6	3.6	1.3	1.0			31.368
Facilities	5.7	-	8.0	17.7														
Total Program	9.5	17.7	27.7	33.3	39.1	81.6	112.7	150.3	179.8	228.1	266.0	294.0	294.5	288.3	262.4	122.9	6.5	$2,414.374

5.3.2 Option 1 Basic, Solid Rocket Motor Stage - Table 2b

Cost Element	Fiscal Year (Dollars in Millions)																Total
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Non-Recurring Total	4.8	20.7	28.0	21.9	41.8	77.1	11.7	7.8	2.0									$ 215.826
Development																		
Development	4.8	10.8	20.4	11.9	6.5	5.5												59.880
STE/ST		9.9			8.6	16.4												34.866
Deliverable Hardware																		
Dummy Engines			1.0	2.2														3 200
Flight Engines				3.1	20.1	41.4												64 632
OS FS & Spares			6.6	4.7	6.6	13.8	11.7	7.8	2.0									53 248
Recurring Total			2.9	5.8	12.7	43.4	145.2	191.6	237.0	295.7	338.9	372.1	370 4	360.8	333.7	169.3	13.6	$2.893 096
Investment																		
Deliver New Engines					9.8	22.0	117.4	159.0	200.6	254.5	293.6	323.0	320.5	313.2	286.4	139.5	7.3	2.446 837
Ground Support Equip																		
Parts																		
Operations																		
Flight Support								.1	.1	.1	.2	.2	.2	.2	.2	.1		1 433
Operations			2.9	5.4	2.1	20.1	26.0	30.2	33.5	37.7	41.5	45.3	46.1	46.1	46.1	29.7	6 3	418 997
Parts				.4	.8	1.3	1.8	2.3	2.8	3.4	3.6	3.6	3.6	1.3	1.0			25 829
Facilities	5.7	-	8.0	17.7														31.368
Total Program	10.5	20.7	38.9	45.4	54.5	120.5	156.9	199.4	239.0	295.7	338.9	372.1	370.4	360.8	333.7	169.3	13.6	$3.140 290