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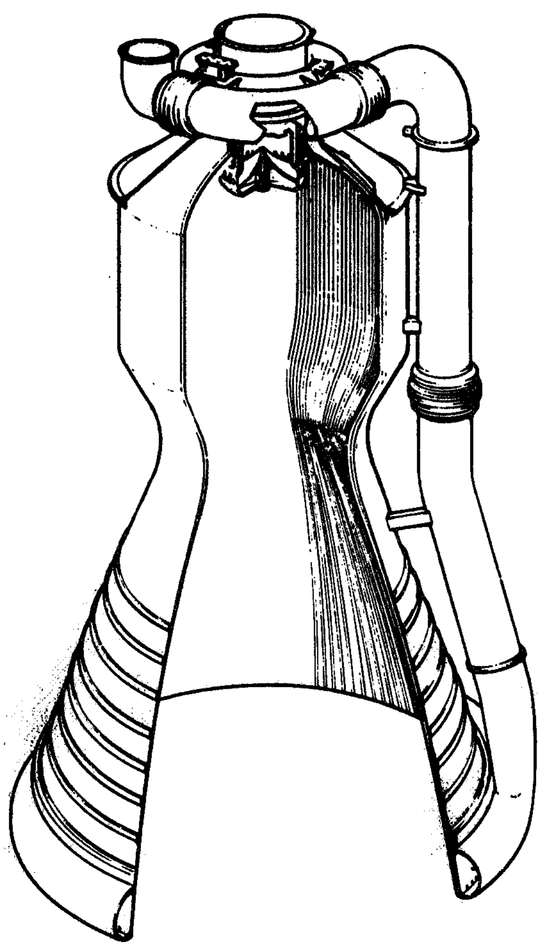
PART II



FEASIBILITY STUDY OF A PRESSURE-FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

VOLUME III

PROGRAM ACQUISITION PLANNING PROGRAM COSTS

15 MARCH 1972

PREPARED FOR
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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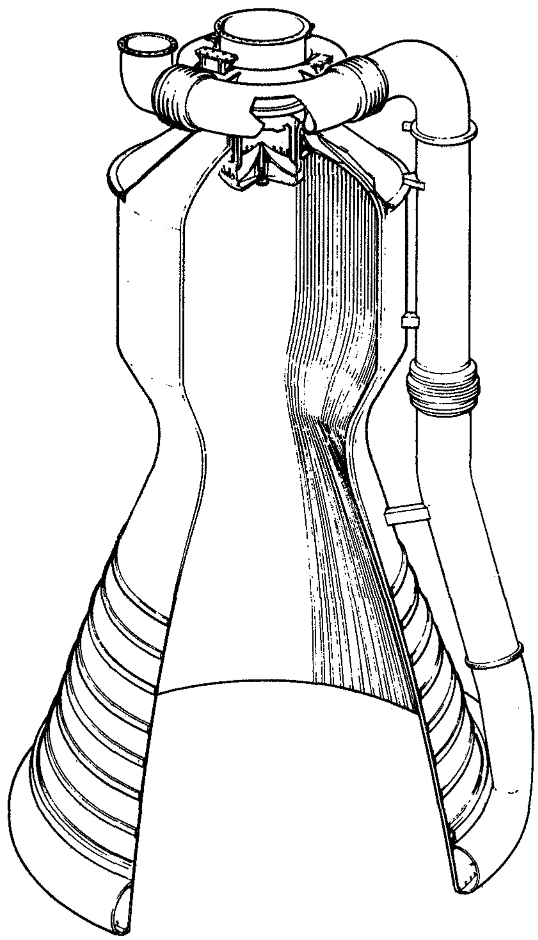
PART II



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VOLUME III

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15 MARCH 1972

DRD MA-05

PREPARED FOR

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PHASE A/B FINAL COST ESTIMATES DOCUMENT FOR FEASIBILITY STUDY OF A PRESSURE-FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

DPD 303 DR MA 05

15 March 1972

Prepared for

National Aeronautics and Space Administration

George C. Marshall Space Flight Center

Huntsville, Alabama 35812

Under Contract

NAS 8-28218

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Program Manager
Pressure Fed Engine Study

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CONTENTS

This report has been prepared in partial fulfillment of NASA Contract NAS 8-28218 entitled "Feasibility Study of a Pressure Fed Engine for a Water Recoverable Space Shuttle Booster."

This volume presents the Final Cost Estimates for the engine configurations and schedules studied. It updates the data presented in the TRW 4 February 1972 briefings at the Marshall Space Center.

This volume is prepared in accordance with Data Requirements Description MF-030A. The data requested in the Additional Statement of Work is covered in Appendix A plus a summary of other cost studies conducted and additional background data related to the basic study.

The complete final report for the study is covered in six volumes:

Executive Summary	NASA No. SE-019-008-2H-A
Technical Report	SE-019-008-2H-B
Program Acquisitional Planning Part 1 and Part 2	SE-019-008-2H-C
Design Data Book	SE-019-011-2H
Preliminary Design Package	SE-019-013-2H
Mass Properties Report	SE-019-015-2H

1.0 COSTING APPROACH, METHODOLOGY AND RATIONALE

1.1 COSTING APPROACH

A detailed engineering approach was used in generating the cost data and was based on consideration of the engine configuration, program plan, specified engine deliveries and estimated spares and support requirements for the flight program.

1.2 GROUND RULES

1.2.1 Configurations Costed

The configurations of the Pressure Feed Space Shuttle Booster Engine which were costed in detail included the following primary characteristics:

Thrust Level:	1, 200 K lbs. and 600 K lbs.
Chamber Cooling:	Regenerative and Duct
Thrust Control:	Fixed and Throttlable
Thrust Vector Control:	LITVC (LOX as injectant) Head End 2 axis Gimbal c.g. 1 axis Gimbal (Hinge)

Hot gas injection for thrust vector control (GITVC) was considered, however, technical considerations led to the conclusion that GITVC was too high a risk program to meet program objectives and costs were, therefore, not prepared.

The detailed cost of the two axis and single axis gimballed configurations were within a few percent of each other and, therefore only one set of costs are presented in the summaries.

The 1, 200 K lb. thrust regenerative chamber, gimballed engine was used as a baseline for costing purposes.

1.2.2 Schedules Costed

1.2.2.1 Alternate FMOF Schedules

Three schedules were costed. The baseline with the First Manned Orbital Flight (FMOF) on March 1, 1978, a maximum success schedule with the FMOF on August 1, 1977 and a most probable schedule with the FMOF on January 1, 1979. Only the baseline configuration was used in costing the maximum success and most probable schedules.

1.2.2.2 Flight Models

The baseline flight schedule, 445 flights, used in the costing is shown in Table 1-1 also shown are the alternate flight schedules ranging from 10 flights to 60 flights maximum per year whose operational costs were estimated.

Table 1-1

Baseline and Alternate Flight Schedules

CY Year	1978	79	80	81	82	83	84	85	86	87	88	Total
Baseline	6	15	24	32	41	50	59	60	60	60	38	445
Option 1	6	10	10	10	10	10	10	10	10	10	-	96
2	6	15	20	20	20	20	20	20	20	20	-	181
3	6	15	24	32	40	40	40	40	40	40	-	317
4	6	15	24	32	41	50	59	60	60	60	-	407

1.2.2.3 Engine Deliveries

The costs for delivered hardware were based on the following delivery of vehicle sets (7 engines per set for the 1, 200 K lb. thrust program and 10 engines for the 600 K thrust program).

	Schedule		
	Baseline	Max. Success	Most Probable
Sys. Dev. Veh., PTA*	1-1-75	1-1-75	4-1-75
Flight Dev. Veh.	3-1-76	3-1-76	11-1-76
Dynamic Test Veh.**	6-1-76	-	5-1-77
Flight Veh. No. 1	7-1-78	10-1-76***	4-1-79
2	1-1-77***	4-1-77	10-1-77***
3	7-1-77	10-1-77	4-1-78
4	1-1-78	4-1-78	10-1-78
5	1-1-79	10-1-78	10-1-79
6	7-1-79	4-1-79	4-1-80
7	1-1-80	10-1-79	10-1-80
8	7-1-80	4-1-80	4-1-81
9	1-1-81	10-1-80	10-1-81
10	7-1-81	4-1-81	4-1-82
Spare 1	-	-	-
Spare 2	-	-	-

* 5 engines for 600 K lb. thrust program

** Dummy Engines

*** Engine for FMOF

The cost for the System Development, Flight Development, and Dynamic Test and No. 1 flight vehicles were included in the non-recurring costs, the balance in the Investment Phase.

1.3 WORK BREAKDOWN STRUCTURE

The work breakdown structure is shown pictorially in Fig. 1-1 and the cost methodology for each level 5 cell in Table 1-2.

1.4 QUANTITIES OF HARDWARE

The number of engines included in the costs were as follows:

	Program	
	1,200 K lb. Thrust	600 lb Thrust
Non-recurring		
Development		
Engine Development	5	5
PFC	11	11
FFC	8	8
Deliverable		
PTA	7	5
FFC	7	10
Flight No. 1	7	10
Recurring		
Deliverable	77	110

1.5 VENDOR SURVEY

The vendors from whom quotes were received are listed in Table 1-3. The quotes were evaluated by increasing apparently low quotes, reducing those that appeared excessive, and averaging others.

1.6 REFURBISHMENT

In considering the cost of refurbishment, it was assumed that engines would not be removed from the vehicle. It was also assumed that only those components which were active would wear out and need replacement. The components considered as active are starred on Table 1-4 which also shows the hardware breakdown used in costing. It was assumed that from the standpoint of cost, each active component would be replaced once in 50 missions. (This assumption is considered conservative.) As the rate of wear out would decrease as the number

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LEVEL 2	PRESSURE FED ENGINE 10 CONFIGURATION:					
3	10100 NON-RECURRING				10200 RECURRING	
4	1010010 DEVELOPMENT	1010020 DELIVERABLE HARDWARE	1010030 OVERHAUL AND REFURBISHMENT PARTS	1010040 PROPELLANT	1020010 INVESTMENT	1020020 OPERATIONS
5	1 101001010 PROGRAM MANGT ENGINEERING	101002010 COMPONENTS AND PURCHASED PARTS	101003010 OVERHAUL AND REFURBISHMENT PARTS	101004010 DEVELOPMENT	102001010 DELIVERABLE ENGINES	102002010 FLIGHT SUPPORT
	2 101001020 COMPONENT	101002020 ASSEMBLY		101004020 PFC	GSE 102001020	102002020 OPERATIONS
	3 101001030 DEVELOPMENT HARDWARE PROCUREMENT	101002030 PRODUCT ASSURANCE		101004030 FFC	102001030 INITIAL SPARES	102002030 OVERHAUL AND REFURBISHMENT PARTS
	4 101001040 ENGINE TEST	101002040 ACCEPTANCE TESTS		101004040 ACCEPTANCE	102001040 ACCEPTANCE TEST PROPELLANTS	102002040 PROPELLANTS AND ANCILLARY FLUIDS
	5 101001050 SITE ACTIVATION					
	6 101001060 GSE PROCUREMENT					
	7 101001070 TOOLING					
	8 101001080 FIELD SUPPORT					

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Figure 1-1. Work Breakdown Structure

Table 1-2. Cost Methodology

Identification Number	WBS Identification	How Estimated	Comments
		DEVELOPMENT	
xx 100 10 10	Program Management and Engineering	Direct Manhours	
xx 100 10 20	Component Development	Vendor and TRW estimates	Covers Development through bench qualification.
xx 100 10 30	Development Hardware Procurement	Vendor estimates for parts. TRW Direct Manhours assembly and checkout.	Hardware through FFC. (See Section 1.4 for quantities.)
xx 100 10 40	Engine Test	Direct Manhours	
xx 100 10 50	Site Activation	Architect and Engineering Firm for structual modifications. TRW Manhours for installation of wiring, etc.	Covers activation and modifications of EAFB Test Facility.
xx 100 10 60	GSE Procurement	TRW estimate	Design engineering in xx 100 10 10.
xx 100 10 70	Tooling	Vendor estimate and TRW manufacturing estimate.	
xx 100 10 80	Field Support	Direct Manhours.	
		DELIVERABLE HARDWARE	
xx 100 20 10	Components and Purchased Parts	Vendor and TRW estimates	
xx 100 20 20	Assembly	Direct Manhours per engine.	TRW assembly
xx 100 20 20	Product Assurance	5 percent of Vendor and assembly cost.	
xx 100 20 30	Acceptance Test	Direct Manhours	
		OVERHAUL AND REFURBISHMENT PARTS	
xx 100 30 10	Overhaul and Refurbished Parts	Percent of Deliverable hardware	
		PROPELLANT	
xx 100 40 10	Development	Seconds of firing time $300/second at 1, 200 K lb thrust	Includes other fluids and gases and losses. N_2 at 1.8^c/gal. LOX at 1.8^c/gal. RP at 7.4^c/gal.
xx 100 40 20	PFC	Seconds of firing time $300/second at 1, 200 K lb thrust	
xx 100 40 30	FFC	Second of firing time $300/second at 1, 200 K lb thrust	
		INVESTMENT	
xx 200 10 10	Deliverable Engines	Vendor and TRW estimates	
xx 200 10 20	GSE	TRW manufacturing estimate	Covers GSE delivered to Launch Site
xx 200 10 30	Initial Spares	Percent of Deliverable engines	
xx 200 10 40	Acceptance Test Propellants	15 seconds of firing time per engine at $300/second at 1, 200 K lb thrust engine.	
		OPERATIONS	
xx 200 20 10	Flight Support	Direct Manhours	
xx 200 20 20	Operations	Direct Manhours	
xx 200 20 30	Overhaul and Refurbishment Parts	Percent of initial engine cost based on wear out rate estimate	
xx 200 20 40	Propellants and Ancillary Fluids	Estimated losses from flushing system.	Primarily fluids for flushing engines.

Table 1-3. Vendor Survey

SHUT OFF VALVES WHITTAKER PARKER POSI-SEAL	ENGINE PARTS FORGINGS LADISH ARCTURUS
SURGE SUPPRESSION (SCALED SHUT OFF)	SHELL LADISH GRANO CENTRAL WESTERN
LITVC SHUTOFF VALVE (SCALED SHUT OFF)	
CONTROL, ELECTRONICS TRW	
ACTUATORS (GIMBAL AND THROTTLING) MOOG (ELECTRIC HYDRAULIC) HYDRAULIC RESEARCH (ELECTRIC HYDRAULIC) BENDIX (ELECTRIC-MECHANICAL)	TUBES LA FEIL BRAZED ASSEMBLY RYAN AERO SOLAR ROHR
LITVC SERVO INJECTOR MOOG LTV	ABLATIVES HITCO
APU AIRESEARCH	

Table 1-4. Hardware Items Costing Breakout

* CONTROL, ELECTRONIC AND WIRING	CHAMBER
* INSTRUMENTATION	THRUST RING
* LOX SHUTOFF VALVE	* GIMBAL, RING/HINGE
* LOX TRIM VALVE	SHELL (AND RINGS)
* LOX DUCT	MANIFOLD (REGEN INLET)
* RP SHUTOFF VALVE	TUBES
* RP TRIM VALVE	COLLECTOR RING (INJECTOR INTERFACE)
* RP DUCT	ASSEMBLY, BRAZE AND NDT
* IGNITER	
INJECTOR	LITVC (LOX)
* ACTUATOR	* SHUTOFF VALVES
* ACTUATOR ARM	DUCT
* ACTUATOR MOUNT	MANIFOLD (VALVE INLET)
TOROID, FUEL	* VALVES
* PARTS AND ASSEMBLY	CHAMBER MANIFOLD

* ACTIVE ITEMS FOR SPARES COSTING

of missions per engine is decreased, in order to calculate the refurbishment parts for the various mission models (paragraph 1.2.2.2) the logarithmic wear out curve shown in Fig. 1-2 was constructed. From this curve it can be seen that for the 96 flight mission model, the replacement parts drop to 2.69 from the 100% used for the 445 flight model. Parts required for damage in recovery are covered by the Investment Phase initial spares.

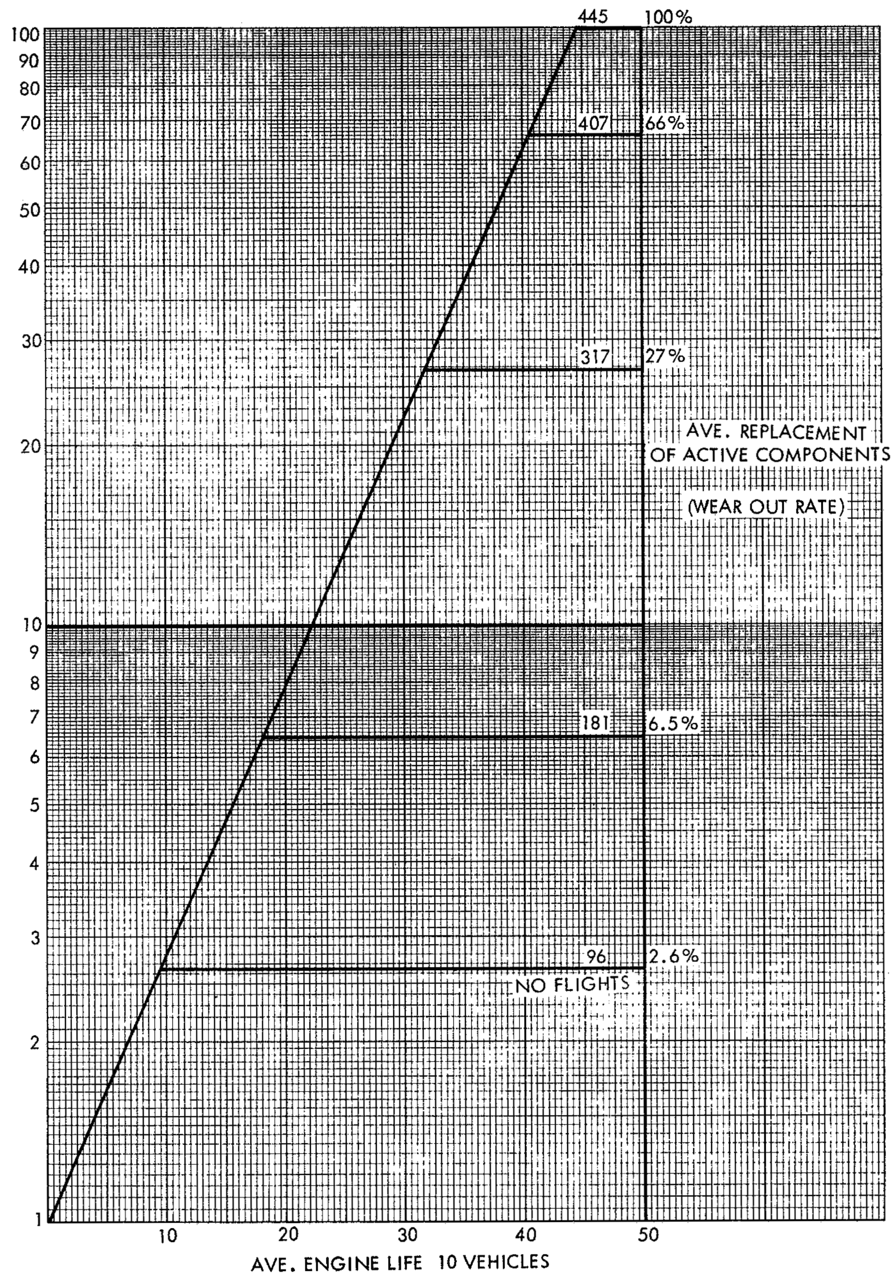

Figure 1-2. Cost Wear Curve for Replacement

1.7 FEE

All costs in this volume include fee (at 8%) unless otherwise noted.

2.0 COST SUMMARY

2.1 BASELINE SCHEDULE

The total program and non-recurring costs are summarized below for the baseline schedule.

Configuration 1200 K	Total Program $M	Non-Recurring $M
A - Regenerative, Fixed Thrust, Gimbal TVC	252	114
B - Regenerative, Throttable, LITVC	296	133
C - Regenerative, Throttable, Gimbal TVC	275	127
D - Duct, Fixed Thrust, Gimbal TVC	230	104
600 K		
E - Regenerative Fixed Thrust Gimbal TVC	230	91

From the above it is seen that the duct chamber configuration results in the lowest cost program although not significantly lower than the comparable regenerative engine in non-recurring costs.

A comparison of configuration B and C shows that LITVC results in approximately a 9 percent increase in total funding costs. This results from the high total cost of the 32 LITVC values used in that configuration. In earlier studies, it was shown that if the APU and actuator were included, the gimballed configurative would be the more expensive.

In comparing configuration A and C, it is seen that throttling results in a 9 percent increase in total program costs over the fixed thrust configuration.

For equivalent configuration (A and E), the 600 K lb thrust program has lower total costs than the 1200 K lb thrust program, primarily the result of lower hardware and propellant costs in development.

2.2 MAXIMUM SUCCESS AND MOST PROBABLE SCHEDULE

For the baseline configuration (Regenerative, Fixed Thrust, Gimbal TVC), the effect of schedule changes to the 445 flight program was as follows:

Schedule	Total Program $M	Non-Recurring $M
Baseline	252	114
Maximum Success	271	129
Most Probable	263	127

Both schedule modifications result in higher costs than the baseline. The maximum success has higher costs to provide for more redundancy in development. The most probable schedule program cost increase over the baseline on the assumption that the level of development effort would be maintained for the added 9 months.

2.3 EFFECT OF VARYING THE NUMBER OF FLIGHTS

The effect of varying the number of flights in the program (see Section 1.2.2.2) on the recurring operational costs, assuming the baseline configuration, is shown below. The operational cost of the first 5 flights is covered in the non-recurring costs.

		Recurring Phase		
Total No. Flights	Flight Rate (max.)	No. Flights	Cost ($M)	Average Cost Per Flight ($M)
96	10	91	22.28	0.24
181	20	176	33.20	0.19
317	40	312	53.24	0.17
407	60	402	75.60	0.19
445	60	440	81.56	0.19

The average cost per flight is essentially the same for each schedule. Although the overhaul and refurbishment parts cost decrease as per the percentage shown in Section 1.6 with the decreasing number of flights, the reduced labor efficiency compensates resulting in the essentially equal costs. The costs of the 96 flight model reflect the costs of minimum staffing.

3.0 COST ESTIMATE BY WBS ELEMENT

3.1 PROGRAM COST SUMMARY

The program total funding requirements for the key configurations and schedules costed are presented in Table 3-1 to level 5 except for non-recurring costs which are summarized at level 4. The configurations represent for the baseline schedule: (1) the 1200 K lb thrust baseline configuration, fixed thrust, regenerative, gimballed; (2) the lowest cost program, the fixed thrust, duct, gimballed engine; (3) the highest cost program, the throttable, regenerative, LITVC configuration; and (4) the throttable, regenerative, gimballed engine. Also shown to the baseline schedule is the 600 K lb thrust baseline configuration. The costs for the three schedules; baseline, maximum success and most probable, are shown for the baseline configuration. The level 5 breakdown of the level 4 cell DEVELOPMENT is given in table 3-2.

3.2 ENGINE COSTS

3.2.1 No. of Engines

The number of all up engines costed in the program were as follows:

Level	WBS No.	Identification	No. of Engines
5	xx 100 10 30	Development Hardware Procurement	24
4	xx 100 20	Deliverable Hardware	21
5	xx 200 10 20	Deliverable Engines	77

3.2.2 Sequence Number

The production sequence number of the first unit used in the recurring phase is 37 for the 1200 K lb thrust program and 50 for the 600 K lb thrust program. (34th unit from the standpoint of application of learning curve for 1200 K lb thrust engine and 40th unit for the 600 K lb thrust engine.)

3.2.3 Reference Unit Costs

The unit costs of the reference units for the configurations costed are given in Table 3-3 along with the first unit costs.

Table 3-1. Funding Requirement Summary

W.B.S. LEVEL	W.B.S. NUMBER	SCHEDULE / FMOF / THRUST / CONFIGURATION	BASELINE 3-1-78 1200K REGENERATIVE FIXED THRUST GIMBAL	BASELINE 3-1-78 1200K REGENERATIVE THROTTABLE LITVC	BASELINE 3-1-78 1200K REGENERATIVE THROTTABLE GIMBAL	BASELINE 3-1-78 1200K DUCT FIXED THRUST GIMBAL	BASELINE 3-1-78 600K REGENERATIVE FIXED THRUST GIMBAL	MAXIMUM SUCCESS 8-1-77 1200K REGENERATIVE FIXED THRUST GIMBAL	MOST PROBABLE 1-1-79 1200K REGENERATIVE FIXED THRUST GIMBAL
2	XX 1X	TOTAL FUNDS M $	251.92	295.89	274.78	229.88	229.75	271.15	262.97
3	XX 100	NON-RECURRING	(114.33)	(133.19)	126.64	(104.36)	(91.49)	(129.41)	(126.83)
4	XX 10010	DEVELOPMENT	69.80	80.97	79.13	63.23	60.12	86.34	80.38
4	XX 10020	DELIVERABLE HDWRE.	15.51	18.36	17.33	13.09	13.15	16.01	15.51
4	XX 10030	OVERHAUL AND REFURBISH PARTS	9.79	12.63	10.30	8.81	8.51	6.98	10.00
4	XX 10040	PROPELLANTS	19.23	21.23	19.88	19.23	9.71	20.08	20.94
3	XX 200	RECURRING	(137.59)	161.65	148.14	(125.52)	(138.26)	(141.74)	(136.14)
4	XX 20010	INVESTMENT	(56.03)	(70.99)	(61.30)	(48.21)	(52.79)	(56.00)	(56.00)
5	XX 2001010	DELIVERABLE ENGINES	46.73	61.50	52.13	39.40	42.37	46.70	46.70
5	XX 2001020	GSE	0.76	0.80	0.78	0.72	0.86	0.76	0.76
5	XX 2001030	INITIAL SPARES	7.85	7.80	7.70	7.40	9.07	7.85	7.85
4	XX 2001040	ACCEPTANCE PROPELLANTS	0.69	0.89	0.69	0.69	0.49	0.69	0.69
5	XX 20020	OPERATIONS	(81.56)	(90.66)	(86.84)	(77.31)	(85.47)	(85.74)	(80.14)
5	XX 2002010	FLIGHT SUPPORT	23.08	24.76	24.00	23.08	23.05	23.85	21.98
5	XX 2002020	OPERATIONS	30.04	30.02	30.46	28.02	36.12	30.64	29.38
5	XX 2002030	OH AND REFURBISH PARTS	28.06	35.50	32.00	25.83	25.99	30.87	28.40
5	XX 2002040	PROPELLANTS	0.38	0.38	0.38	0.38	0.28	0.38	0.38
		DIFFERENCE IN $	BASE	43.97	22.86	-22.04	-18.04	19.23	11.05

445 FLIGHTS

3/10/72

Table 3-2. Level 5 Breakdown of Development Costs (1200 lb thrust)

	Configuration											
Chamber	Regenerative						Duct					
Thrust Control	Fixed			Throttable			Fixed			Throttable		
Thrust Vector Control	LITVC	Gimbal		LITVC	Gimbal		LITVC	Gimbal		LITVC	Gimbal	
		2 Axis	1 Axis		2 Axis	1 Axis		2 Axis	1 Axis		2 Axis	1 Axis
W.B.S.	Cost $M											
xx 100 10 10 Program Management and Engineering	23.372	24.164	24.164	24.828	25.620	25.620	22.580	23.372	23.372	24.036	24.828	24.828
xx 100 10 20 Component Development	2.930	2.420	2.420	3.230	2.720	2.720	2.670	2.160	2.160	2.792	2.460	2.460
xx 100 10 30 Hardware	27,350	22.210	22.370	31.080	25.580	25.740	22.860	18.000	18.160	25.100	22.090	22.250
xx 100 10 40 Engine Test	7.681	7.681	7.681	8.131	8.131	8.131	7.681	7.681	7.681	8.131	8.131	8.131
xx 100 10 50 Site Activation	3.171	3.171	3.171	3.171	3.171	3.171	3.171	3.171	3.171	3.171	3.171	3.171
xx 100 10 60 GSE Procurement	1.080	1.080	1.080	1.220	1.220	1.220	1.080	1.080	1.080	1.220	1.220	1.220
xx 100 10 70 Tooling	5.044	5.074	5.074	5.314	5.344	5.344	3.743	3.773	3.773	4.014	4.044	4.044
xx 100 10 80 Field Support	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
xx 100 10 10 Development	74.628	69.800	69.960	80.974	75.786	75.946	67.785	63.237	63.397	72.464	69.944	70.104

Table 3-3. Reference Unit and First Unit Costs

	Configuration							
Chamber	Regenerative				Duct			
Thrust Control	Fixed		Throttable		Fixed		Throttable	
Thrust Vector Control	LITVC	Gimbal	LITVC	Gimbal	LITVC	Gimbal	LITVC	Gimbal
1200 K lb Thrust								
First Unit Cost K$	1,075	895	1,170	1,000	906	753	1,000	808
Reference Unit Cost K$	76	639	835	714	647	538	714	577
600 K lb Thrust								
First Unit Cost K$	795	640	866	720	653	535	732	612
Reference Unit Cost K$	561	451	611	507	461	377	516	432
Ratio First Unit Cost 1200 T/600 T	1.35	1.40	1.35	1.39	1.39	1.41	1.37	1.32

Also shown is the ratio of the first unit cost of the 1200 K lb thrust to the 600 K lb thrust engines which varies between 1.32 and 1.41. It is noted that the ratio of engines per vehicle set 10/7 is 1.43, therefore, there is not a large differential in the cost of delivered engines for the two configurations. The ratio of the thrust chamber cylindrical sections for the two thrust levels is 1.41, the engine cost for a given configuration therefore, scale approximately with the chamber diameter.

3.2.4 Learning Curve

A 95 percent straight line cumulative average learning curve was used in calculating the engine cost.

3.2.5 Confidence Level

A confidence rating of 3, medium high, has been applied to the estimates. All criteria for this level of rating are met, except a prototype engine of the thrust levels specified, have not been fabricated.

3.2.6 First Unit Cost

The first unit costs are shown in Table 3-3. This cost was applied to the first unit for PFF program and the learning curve applied to subsequent units. Development and PTA engines were costed at the first unit cost. A further breakdown of the first unit cost of the baseline configuration is given in Table 3-4.

Table 3-4. First Unit Cost TRW PFE (Baseline Schedule and 1200 K lb Thrust Configuration)

Part	Cost (K$)		
Electrical Controls Instrumentation and Wiring	72.0		
LOX shut off and trim valves	39.3		
RP shut off and trim valves	19.7		
Propellant lines and bellows	110.5		
Ignition system	8.0		
Injector Assembly	40.0		
Chamber Assembly	254.7		
Thrust mount and gimbal ring	83.8		
Sub-Total Components		628.0	
QC, engine assembly and test		161.0	
G and A and fee		106.0	
Total first unit			895.0

4.0 TECHNICAL CHARACTERISTICS DATA

The primary parameters of the technical characteristics which may have a significant effect on cost are listed below for the baseline configuration

Sizing	Weight
Performance	Isp delivered (90% of theoretical)
	Combustion Stability
Complexity	Number of missions (50 missions required - 100 mission goal)

No particular problem is anticipated with the above parameters. The basic design philosophy was that of low cost. The weights derived in the study are therefore considered conservative. Arriving at an Isp 90 percent of theoretical has not been a problem in scaling the basic injector design up to 250 K lbs thrust from 50 K lbs thrust and none is anticipated in scaling further to the thrust levels required. Although the single axial injector studied has been proven stable in a large number of tests and is considered stable from a theoretical point of view, it is listed as a TCD parameter only because it has not been demonstrated at the 600 K and 1200 K lb thrust levels. The number of missions of the chamber will impact costs primarily because of the extent of the test program required to demonstrate its life.

In the LITVC configuration the maximum thrust vector angle will impact costs as it determines the valve size which tends to increase exponentially with the larger sizes up to the maximum thrust vector angle obtainable. If the thrust vector angle specified is close to the maximum obtainable, it may also require a significant number of tests to determine the maximum position and angle.

5.0 TOTAL PROGRAMMING FUNDING SCHEDULES

5.1 BASELINE SCHEDULE

The time phased costs for the key configurations and the baseline schedule (FMOF 3-1-78) are shown in Tables 5-1 through 5-4.

5.2 ALTERNATE SCHEDULES

The time phased costs for the maximum success schedule (FMOF 8-1-77) is shown in Table 5-5 and for the most probable schedule (FMOF 1-1-79), see Table 5-6.

5.3 ALTERNATE FLIGHT MISSION MODELS

The time phased costs for the alternate flight mission models are shown in Table 5-7. (See Table 1-1 for Mission Models.)

5.4 MANPOWER REQUIREMENTS

The time phased TRW direct manpower requirements for the program are given in Table 5-8. These requirements exclude manpower directly associated with development of some engine components which were estimated as TRW make decisions, i.e., the electrical controls and injector assembly. Also excluded are clerical and other supporting personnel.

Table 5-1

SPACE SHUTTLE
ENGINE FUNDING REQUIREMENTS

CONTRACT NO. NAS 8-28218
TRW SYSTEMS
15 MAR 1972

CONFIGURATION 1.2 M LB THRUST
PRESSURE FED PROPELLANTS

CHAMBER	THROTTLEABLE	TVC	SCHEDULE
Regen.	No	Gimbal	Base line

CY	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	TOTAL ($M)
FLIGHTS								Δ FMOF 3-1-78 6	15	24	32	41	50	57	60	60	60	38	445
ENGINE DEVELOPMENT																			
ENGINE DELIVERY																			
TOL REQ M$		10.13	19.72	23.61	26.08	28.52	22.62	19.21	20.08	18.25	15.34	9.70	8.29	7.07	6.73	6.54	6.54	3.43	251.92
NON-RECURRING		10.13	19.72	23.61	25.85	22.21	10.41	2.40											114.33
DEVELOPMENT		9.00	12.00	14.13	14.00	12.00	7.38	1.29											69.80
DELIVERABLE HDW			3.00	3.26	4.75	4.50													15.51
O H+REFURB PARTS				1.50	2.00	2.50	2.75	1.04											9.79
PROPELLANT		1.13	4.72	4.72	5.10	3.21	0.28	0.07											19.23
RECURRING					0.23	6.31	12.21	16.81	20.08	18.25	15.34	9.70	8.29	7.07	6.79	6.54	6.54	3.43	137.59
INVESTMENT					0.23	6.31	12.21	11.34	10.94	9.08	5.92								56.03
DEL. ENGINES						5.34	9.14	8.90	8.80	8.69	5.86								46.73
GSE					0.23	0.30	0.23												0.76
PARTS						0.60	2.70	2.30	2.00	0.25									7.85
ACCEPT PROP.						0.07	0.14	0.14	0.14	0.14	0.06								0.68
OPERATIONS								5.47	9.14	9.17	9.42	9.70	8.29	7.07	6.79	6.54	6.54	3.43	81.56
FLIGHT SUPPORT								1.65	2.50	2.41	2.41	2.41	2.41	2.14	2.05	2.05	2.05	1.00	23.08
OPERATIONS								1.26	2.08	2.32	2.58	2.86	3.16	3.42	3.48	3.48	3.48	1.92	30.04
O H+ REFURB PARTS								2.42	4.42	4.42	4.42	4.42	4.42	1.50	1.25	1.00	1.00	0.50	28.06
PROPELLANT								0.14	0.14	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.38
1	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	

Table 5-2

SPACE SHUTTLE
ENGINE FUNDING REQUIREMENTS

CONTRACT NO. NAS 8-28218
TRW SYSTEMS
15 MAR 1972

CONFIGURATION 1.2 M LB THRUST
PRESSURE FED PROPELLANTS

CHAMBER	THROTTLEABLE	TVC	SCHEDULE
Regen.	Yes	LITVC	Baseline

CY	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	TOTAL ($M)
FLIGHTS								Δ FMOF 3-1-78 6	15	24	32	41	50	57	60	60	60	38	445
ENGINE DEVELOPMENT																			
ENGINE DELIVERY																			
TOL REQ M$		13.29	19.83	25.73	29.67	35.06	29.80	24.81	24.66	22.74	18.96	11.45	8.75	6.74	6.69	6.71	6.71	3.49	295.09
NON-RECURRING		13.29	19.83	25.73	29.43	27.14	14.68	3.09											133.14
DEVELOPMENT		11.60	11.60	15.46	15.46	15.46	10.10	1.29											80.97
DELIVERABLE HDW			3.16	3.00	6.30	5.90													18.36
O H+REFURB PARTS				2.20	2.20	2.20	4.30	1.73											12.63
																			—
PROPELLANT		1.69	5.07	5.07	5.47	3.58	0.28	0.07											21.23
RECURRING					0.24	7.92	15.12	21.72	24.66	22.74	18.96	11.45	8.75	6.74	6.69	6.71	6.71	3.49	161.90
INVESTMENT					0.24	7.92	15.12	14.58	13.77	11.82	7.79								71.24
DEL. ENGINES						7.10	12.00	11.70	11.60	11.40	7.70								61.50
GSE					0.24	0.32	0.24												0.80
PARTS						0.40	2.70	2.70	2.00	0.25									8.05
ACCEPT PROP.						0.10	0.18	0.18	0.17	0.17	0.09								0.89
OPERATIONS								7.14	10.89	10.92	11.17	11.45	8.75	6.74	6.69	6.71	6.71	3.49	90.66
FLIGHT SUPPORT								1.70	2.67	2.58	2.58	2.58	2.58	2.31	2.22	2.22	2.22	1.10	24.76
OPERATIONS								1.26	2.08	2.32	2.58	2.86	3.16	3.42	3.46	3.48	3.48	1.92	30.02
O H+ REFURB PARTS								4.04	6.00	6.00	6.00	6.00	3.00	1.00	1.00	1.00	1.00	0.46	35.50
PROPELLANT								0.14	0.14	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.38
1	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	

Table 5-3

SPACE SHUTTLE
ENGINE FUNDING REQUIREMENTS

CONTRACT NO. NAS 8-28218
TRW SYSTEMS
15 MAR 1972

CONFIGURATION 1.2 M LB THRUST
PRESSURE FED PROPELLANTS ______

CHAMBER	THROTTLEABLE	TVC	SCHEDULE
Duct	No	Gimbal	Baseline

CY	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88		TOTAL ($M)
FLIGHTS								Δ FMOF 3-1-78 6	15	24	32	41	50	57	60	60	60	38		445
ENGINE DEVELOPMENT																				
ENGINE DELIVERY																				
TOL REQ M$		9.53	18.12	21.69	22.50	27.97	20.94	16.54	16.55	16.44	14.18	9.10	8.00	6.33	6.30	6.30	6.30	3.09		229.88
NON-RECURRING		9.53	18.12	21.69	21.98	20.61	10.28	2.15												104.36
DEVELOPMENT		8.40	10.40	13.20	11.36	11.20	7.38	1.29												63.23
DELIVERABLE HDW			3.00	2.27	4.02	3.80														
O H+REFURB PARTS				1.50	1.50	2.40	2.62	0.79												8.81
PROPELLANT			1.13	4.72	4.72	5.10	3.21	0.2												19.23
RECURRING					0.52	7.36	10.66	14.39	16.55	16.44	14.18	9.10	8.00	6.33	6.30	6.30	6.30	3.09		125.52
INVESTMENT					0.52	7.36	10.66	9.63	7.59	7.47	4.98									48.21
DEL. ENGINES						4.50	7.71	7.49	7.45	7.33	4.92									39.40
GSE					0.22	0.29	0.21													0.72
PARTS					0.30	2.50	2.60	2.00												7.40
ACCEPT PROP.						0.07	0.14	0.14	0.14	0.14	0.06									0.69
OPERATIONS								4.76	8.96	8.97	9.20	9.10	8.00	6.33	6.30	6.30	6.30	3.09		77.31
FLIGHT SUPPORT								1.65	2.50	2.41	2.41	2.41	2.41	2.14	2.05	2.05	2.05	1.00		23.08
OPERATIONS								1.12	1.98	2.20	2.44	2.68	2.96	3.18	3.24	3.24	3.24	1.74		28.02
O H+ REFURB PARTS								1.85	4.34	4.34	4.34	4.00	2.62	1.00	1.00	1.00	1.00	0.34		25.83
PROPELLANT								0.14	0.14	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.38
I	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89		

Table 5-4

SPACE SHUTTLE
ENGINE FUNDING REQUIREMENTS

CONTRACT NO. NAS 8-28218
TRW SYSTEMS
15 MAR 1972

CONFIGURATION 0.6 M LB THRUST
PRESSURE FED PROPELLANTS

CHAMBER	THROTTLEABLE	TVC	SCHEDULE
Regen	No	Gimbal	Base line

CY	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	TOTAL ($M)
FLIGHTS							Δ FMOF 3-1-78 6	15	24	32	41	50	57	60	60	60	38		445
ENGINE DEVELOPMENT																			
ENGINE DELIVERY																			
TOL REQ M$		8.87	13.04	17.31	19.74	23.96	23.98	18.68	19.92	17.79	14.89	9.89	8.99	7.25	7.23	7.23	7.23	3.75	229.75
NON-RECURRING		8.87	13.04	17.31	19.48	18.44	12.11	2.24											91.49
DEVELOPMENT		8.15	9.95	9.95	12.10	10.90	7.71	1.36											60.12
DELIVERABLE HDW			0.79	3.31	3.31	3.54	2.20												13.15
O H+REFURB PARTS				1.50	1.50	2.70	2.02	0.79											8.51
PROPELLANT		0.72	2.30	2.55	2.57	1.30	0.18	0.09											9.71
RECURRING					0.26	5.52	11.87	16.44	19.92	17.79	14.89	9.89	8.99	7.25	7.23	7.23	7.23	3.75	138.26
INVESTMENT					0.26	5.52	11.87	11.34	10.49	8.24	5.03	0.04							52.79
DEL. ENGINES						4.42	8.32	8.50	8.00	8.17	4.96								42.93
GSE					0.26	0.34	0.26												0.86
PARTS						0.72	3.20	2.75	2.40										9.07
ACCEPT PROP.						0.04	0.09	0.09	0.09	0.07	0.07	0.04							0.49
OPERATIONS								5.10	9.43	9.55	9.86	9.85	8.99	7.25	7.23	7.23	7.23	3.75	85.47
FLIGHT SUPPORT								1.65	2.50	2.41	2.41	2.41	2.41	2.14	2.05	2.05	2.05	1.00	23.08
OPERATIONS								1.51	2.50	2.78	3.10	3.43	3.79	4.10	4.17	4.17	4.17	2.40	36.12
O H+ REFURB PARTS								1.85	4.34	4.34	4.34	4.00	2.78	1.00	1.00	1.00	1.00	0.34	25.99
PROPELLANT								0.09	0.09	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.28
I	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	

Table 5-5

SPACE SHUTTLE
ENGINE FUNDING REQUIREMENTS

CONTRACT NO. NAS 8-28218
TRW SYSTEMS
15 MAR 1972

CONFIGURATION 1.2 M LB THRUST
PRESSURE FED PROPELLANTS ______

CHAMBER	THROTTLEABLE	TVC
Regen.	No	Gimbal

SCHEDULE
Max. Success

CY	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	TOTAL ($M)
FLIGHTS							FMOF 8-1-77												445
ENGINE DEVELOPMENT																			
ENGINE DELIVERY																			
TOL REQ M$		14.43	27.12	31.01	34.80	30.10	21.08	20.33	20.65	18.93	9.76	10.00	9.05	7.13	6.79	6.54	3.43		271.15
NON-RECURRING		14.43	27.12	31.01	34.50	19.79	2.56												129.41
DEVELOPMENT		13.00	19.20	21.53	22.10	9.20	1.51												86.34
DELIVERABLE HDW			3.00	3.26	5.00	4.75													16.01
O H+REFURB PARTS				1.50	2.00	2.50	0.98												6.98
GOV'T SUPPORT																			
PROPELLANT		1.49	4.92	4.92	5.40	3.34	0.07												20.08
RECURRING					0.30	10.31	18.52	20.33	20.65	18.93	9.76	10.00	9.05	7.13	6.79	6.54	3.43		141.74
INVESTMENT					0.30	10.31	12.61	11.82	11.39	9.51	0.06								56.00
DEL. ENGINES						9.34	9.61	9.38	9.25	9.12									46.70
GSE					0.30	0.30	0.16												0.76
PARTS						0.60	2.70	2.30	2.00	0.25									7.85
ACCEPT PROP.						0.07	0.14	0.14	0.14	0.14	0.06								0.69
OPERATIONS							5.91	8.58	9.26	9.42	9.70	10.00	9.05	7.13	6.79	6.54	3.43		85.74
FLIGHT SUPPORT							1.88	2.59	2.50	2.41	2.41	2.41	2.41	2.14	2.05	2.05	1.00		23.85
OPERATIONS							1.62	2.32	2.32	2.58	2.86	3.16	3.42	3.48	3.48	3.48	1.92		30.64
O H+ REFURB PARTS							2.27	3.46	4.42	4.42	4.42	4.42	3.21	1.50	1.25	1.00	0.50		30.87
PROPELLANT							0.14	0.14	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.38
1	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	

Table 5-6

SPACE SHUTTLE
ENGINE FUNDING REQUIREMENTS

CONTRACT NO. NAS 8-28218
TRW SYSTEMS
15 MAR 1972

CONFIGURATION 1.2 M LB THRUST
PRESSURE FED PROPELLANTS

CHAMBER	THROTTLEABLE	TVC	SCHEDULE
Regen.	No	Gimbal	Most Probable

CY	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	TOTAL ($M)
FLIGHTS								FMOF ▲ 1-1-79											445
ENGINE DEVELOPMENT																			
ENGINE DELIVERY																			
TOL REQ M$		10.27	15.89	21.02	22.23	22.41	27.01	27.86	21.62	20.68	18.94	9.84	10.06	8.28	7.04	6.79	6.54	3.98/2.51	262.97
NON-RECURRING		10.27	15.89	21.02	22.23	22.18	16.77	15.25	3.22										126.83
DEVELOPMENT		7.16	11.74	13.87	14.32	14.32	10.74	7.33	0.96										80.38
DELIVERABLE HDW				3.00	3.26	2.75	2.50	4.00											15.51
O H+ REFURB PARTS					0.50	2.00	2.50	2.75	2.25										
																			10.00
PROPELLANT		3.11	4.15	4.15	4.15	3.11	1.03	1.17	0.07										20.94
RECURRING						0.23	10.24	12.61	18.40	20.68	18.94	9.84	10.06	8.28	7.04	6.79	6.54	3.98/2.51	136.14
INVESTMENT						0.23	10.24	12.61	11.82	11.39	9.51	0.14	0.06						56.00
DEL. ENGINES							9.34	9.61	9.38	9.25	9.12								46.70
GSE						0.23	0.30	0.23											0.76
PARTS							0.60	2.70	2.30	2.00	0.25								7.85
ACCEPT PROP.								0.07	0.14	0.14	0.14	0.14	0.06						0.69
OPERATIONS									6.58	9.29	9.43	9.70	10.00	8.28	7.04	6.79	6.54	3.98/2.51	80.14
FLIGHT SUPPORT									2.00	2.41	2.41	2.41	2.41	2.14	2.05	2.05	2.05	1.05/1.00	21.98
OPERATIONS									1.68	2.32	2.58	2.86	3.16	3.42	3.48	3.48	3.48	1.92/1.00	29.38
O H+ REFURB PARTS									2.76	4.42	4.42	4.42	4.42	2.71	1.50	1.25	1.00	1.00/0.50	28.40
PROPELLANT									0.14	0.14	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01/0.01	0.38
1	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89/90	

TABLE 5-7

SPACE SHUTTLE 1200 K PF ENGINE FUND ESTIMATE RECURRING OPERATIONS COST FOR ALTERNATE MISSIONS MODELS

Baseline Schedule and Configuration

	1977	FMOF * 3-1-78 1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Total
91 FLIGHT MISSION MODEL													
Operations		2.13	2.79	2.79	2.49	2.43	2.34	2.23	2.12	2.00	0.96		22.28
Flight Support		0.98	1.30	1.30	1.20	1.20	1.20	1.20	1.10	1.00	0.50		10.98
Operations		0.90	1.20	1.20	1.00	1.00	1.00	0.95	0.95	0.95	0.45		9.60
Overhaul and Refurbish Parts		0.18	0.22	0.22	0.22	0.22	0.22	0.08	0.07	0.05	0.01		1.41
Propellants		0.07	0.07	0.07	0.07	0.01							0.29
176 FLIGHT MISSION MODEL													
Operations		2.77	3.94	3.84	3.75	3.75	3.58	3.46	3.24	3.11	1.76		33.20
Flight Support		1.35	2.00	1.90	1.90	1.90	1.90	1.90	1.70	1.60	1.00		17.15
Operations		1.05	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	0.70		12.95
Overhaul and Refurbish Parts		0.27	0.44	0.44	0.44	0.44	0.27	0.15	0.13	0.10	0.05		2.73
Propellants		0.10	0.10	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.37
312 FLIGHT MISSION MODEL													
Operations		4.16	6.43	6.62	6.62	6.52	5.62	5.02	4.87	4.67	2.71		53.24
Flight Support		1.65	2.40	2.40	2.40	2.30	2.10	2.00	1.95	1.85	1.00		20.05
Operations		1.26	2.08	2.32	2.40	2.40	2.40	2.40	2.40	2.40	1.50		21.56
Overhaul and Refurbish Parts		1.18	1.81	1.81	1.81	1.81	1.11	0.61	0.51	0.41	0.20		11.26
Propellants		0.07	0.14	0.09	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.37
402 FLIGHT MISSION MODEL													
Operations		5.47	9.14	9.17	9.42	9.70	8.29	7.07	6.79	6.54	4.01		75.60
Flight Support		1.65	2.50	2.41	2.41	2.41	2.41	2.14	2.05	2.05	1.50		21.53
Operations		1.26	2.08	2.32	2.58	2.86	3.16	3.42	3.48	3.48	2.00		26.64
Overhaul and Refurbish Parts		2.42	4.42	4.42	4.42	4.42	2.71	1.50	1.25	1.00	0.50		27.06
Propellants		0.14	0.14	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.37
FY	78	79	80	81	82	83	84	85	86	87	88	89	

Table 5-8

Direct Manpower Requirements

F'Y	Non-Recurring	Man Years Recurring	Total
1973	106		106
74	148		148
75	172		172
76	172		172
77	148	13	161
78	82	19	101
79	25	84	109
80		123	123
81		127	127
82		131	131
83		126	126
84		136	136
85		140	140
86		140	140
87		140	140
88		140	140
89		75	75
Totals	853	1394	2247

6.0 WORK BREAKDOWN STRUCTURE DICTIONARY

Level	Number	Identification	Definition
2	XX	PRESSURE FED ENGINE	Total Program Requirements. XX unique number for each configuration.
3	XX	NON-RECURRING	All program effort through the support of the FMOF (Excludes in time phasing the investment costs associated with follow-on flights.)
4	XX 100 10	DEVELOPMENT	Effort required for engine development and all associated equipment and facilities and field support through FMOF.
5	XX 100 10 10	Program Management and Engineering	Program Management and Engineering functions including travel, data and configuration management.
5	XX 100 10 20	Component	Development through bench qualification of components for the engine.
5	XX 100 10 30	Development Hardware Procurement	Procurement of parts, assembly, Q.A. effort and acceptance of parts for development, FFC and FFC programs.
5	XX 100 10 40	Engine Test	Manpower for static firing tests of development, PFC and FFC programs. Also includes effort for rework of engines between tests.
5	XX 100 10 50	Site Activation	Effort required for modification and activating static test facilities at EAFB.
5	XX 10 100 10 60	GSE Procurement	Manufacturing and acceptance of GSE. Design in XX 100 10 10.

6.0 WORK BREAKDOWN STRUCTURE DICTIONARY (continued)

Level	Number	Identification	Definition
5	XX 10 100 10 70	Tooling	Tooling required for manufacture and assembly of engines.
5	XX 10 100 10 80	Field Support	Manpower and associated effort required to support PTA and flight program through FMOF.
4	XX 10 100 20	DELIVERABLE HARDWARE	Engines for PTA, FDV, Dynamic Test, and No. 1 Flight Vehicles.
5	XX 10 100 20 10	Components and Purchased Parts	Components and parts required for engine assembly.
5	XX 10 100 20 20	Assembly	Assembly of completed engine.
5	XX 10 100 20 30	Product Assurance	Inspection, acceptance and other QA functions directly related with purchase of components (XX 10 100 20 10) and assembly (XX 10 100 20 20) of engines.
5	XX 10 100 20 40	Acceptance Tests	Manpower and associated effort required for acceptance test of engines and subsequent preparation for shipment.
4	XX 10 100 30	OVERHAUL and REFURBISHMENT PARTS	Parts estimated to be required to support PTA, Flight Development and No. 1 flight vehicles.
5	XX 10 100 30 10	Overhaul and Refurbishment Parts	Same as XX 100 30
4	XX 10 100 40	PROPELLANT	Cost delivered to EAFB of N_2, LOX, and RP-1 required for the program.

6.0 WORK BREAKDOWN STRUCTURE DICTIONARY (continued)

Level	Number	Identification	Definition
5	XX 10 100 40 10	Development	N_2, LOX and RP-1 for Engine Development program.
5	XX 10 100 40 20	PFC	N_2, LOX and RP-1 for PFC program.
5	XX 10 100 40 30	FFC	N_2, LOX and RP-1 for FFC program.
5	XX 10 100 40 40	Acceptance	N_2, LOX and RP-1 for Acceptance Test of deliverable engines.
3	XX 10 200	RECURRING	All program support effort associated with flights after the FMOF and equipment for the FMOF.
4	XX 10 200 10	INVESTMENT	Direct effort associated with procurement of hardware and support equipment for FMOF and subsequent.
5	XX 10 200 10 10	Deliverable Engines	Direct effort associated with fabrication, assembly and acceptance test of engines for FMOF and subsequent.
5	XX 10 200 10 20	GSE	Ground support equipment delivered to the launch facility.
5	XX 10 200 10 30	Initial Spares	Spares required for initial installation and replacement of damaged parts due to operations (spare due to wear out on normal usage covered in 10 200 20 40)
5	XX 10 200 10 40	Acceptance Test Propellants	N_2, LOX, and RP-1 used in acceptance tests of engines.

6.0 WORK BREAKDOWN STRUCTURE DICTIONARY (continued)

Level	Number	Identification	Definition
4	XX 10 200 20	OPERATIONS	All effort associated with program support after FMOF except for Investment (procurement of engines).
5	XX 10 200 20 10	Flight Support	Program management and sustaining engineering.
5	XX 10 200 20 20	Operations	Effort associated with vehicle overhaul and refurbishment.
5	XX 100 200 20 30	Overhaul and Refurbishment Parts	Components and parts required for overhaul and refurbishment due to wear out.
5	XX 100 200 20 40	Propellants and Auxiliary Fluids	Propellants required for retest of overhauled engines and auxiliary fluids for flushing chamber (tubes, etc.) after recovery.

Appendix A

ADDITIONAL STUDIES

1.0 EFFECT ON COSTS AND SCHEDULE OF ENGINE LIFE

The effect on Development Costs (W.B.S. 10 100 10) of engine life over the range of 20 to 100 mission duty cycles are shown in Fig. A-1. The baseline program was established to demonstrate 50 mission duty cycles. Because of practical test limitations, the costs shown are not for equal levels demonstrated reliability. For example in the 20 mission duty cycle development, 13 engines would be run for 20 plus duty cycles; in the 50 mission duty cycle, 10 engines would be used to demonstrate 50 + cycles; in the 100 mission duty cycle program, 6 engines would be run for the 100 missions.

Also shown in Fig. A-1 is the difference in cost of propellant (WBS 10 100 40) which has a relatively large change as the number of demonstrated mission duty cycles is changed.

A 20 mission duty cycle program could reduce the development program time (through FFC) by 12 months and the 100 mission duty cycle program would increase the engine testing phase by 8 months.

The baseline configuration, regenerative thrust chamber, fixed thrust injector, and gimballed engine were assumed for these estimates.

2.0 REFURBISHMENT COSTS

The cost of refurbishment consists of labor, etc. (Operations W.B.S. 10 200 20 20) and overhaul and refurbishment parts (W.B.S. 10 200 20 30). The philosophy for determination of the parts costs is given in Section 1.6 of this report. Section 5.3 presents the operations costs for alternate mission models all based on 9 flight vehicles including and subsequent to the FMOF. Propagating the data in Table 5-7 and plotting against the number of mission duty cycles per engine as a percentage of the engine unit cost results in Fig. A-2.

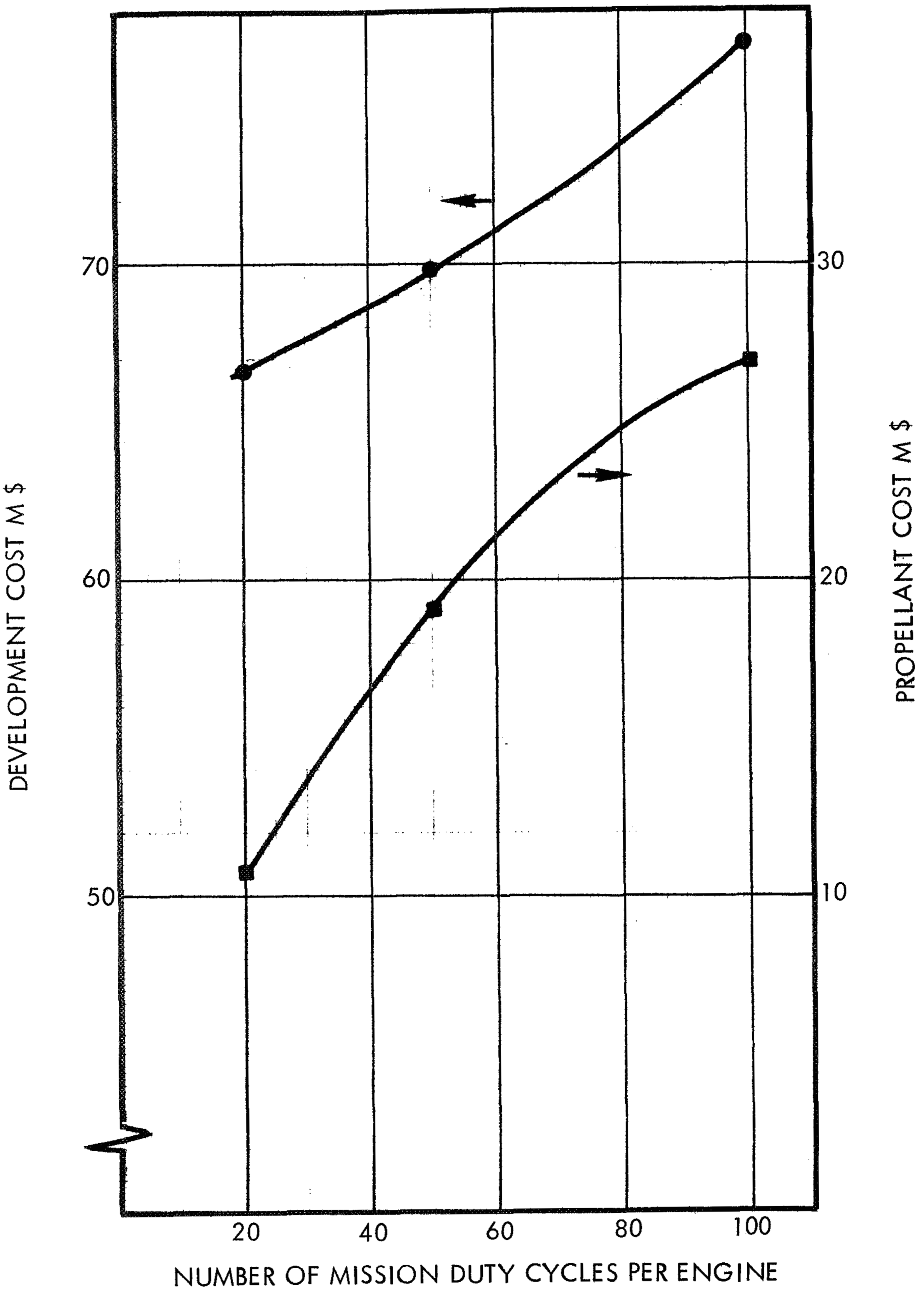

Figure A-1. Effect on Cost of Demonstrated Engine Life

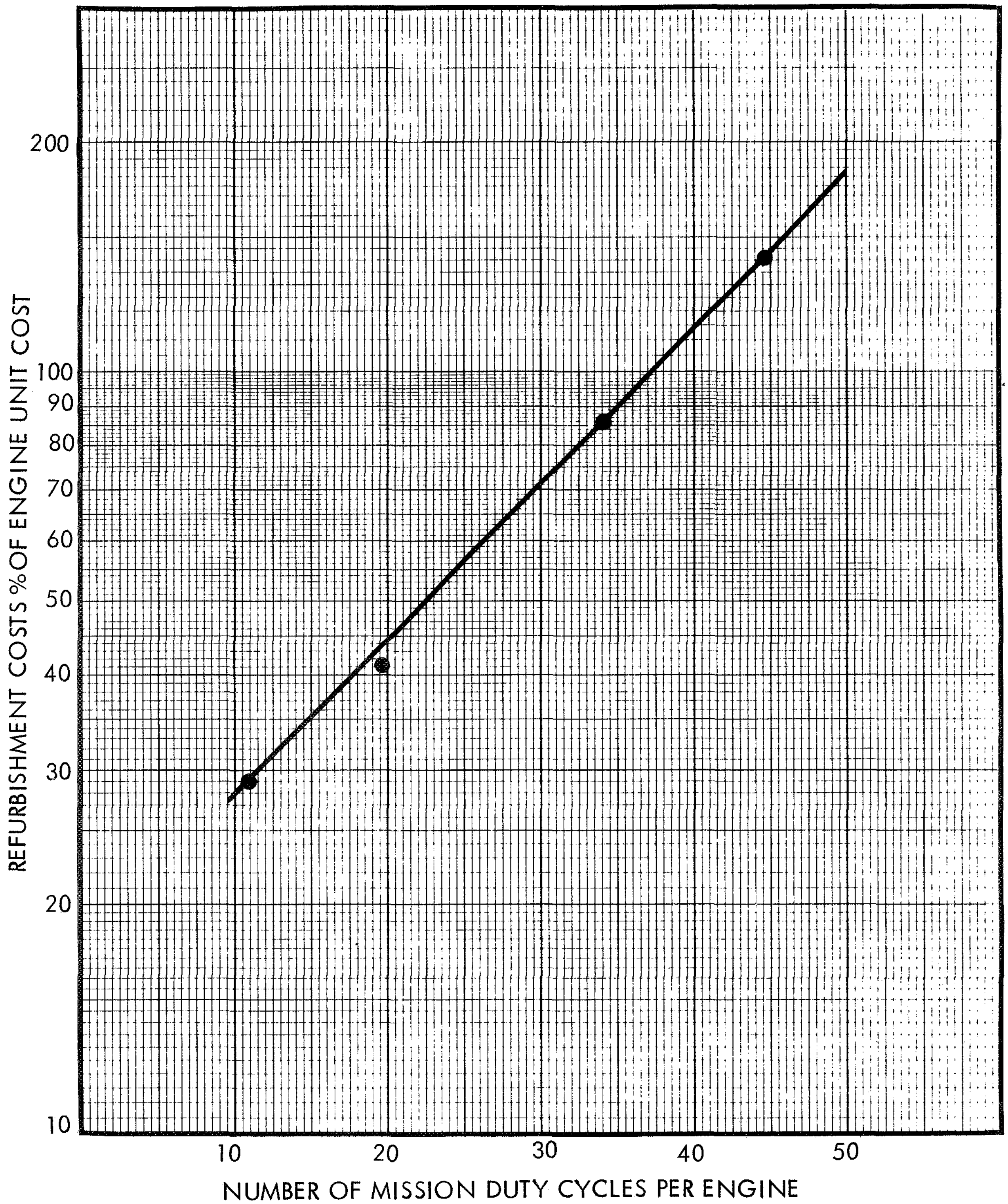

Figure A-2. Cost of Refurbishment as Percent of Engine Cost Versus Engine Life

3.0 ABLATIVE ENGINES

As an alternate to the regenerative thrust chamber configuration, the costs of programs based on an ablative thrust chamber engine were also estimated. Two types of engines were considered, 1) a reusable engine in which the chamber would be relined after each flight and 2) a "throw away" engine which included additional simplifications, i.e., single use valves. Both also assumed a fixed thrust and gimballed TVC. The first unit and program costs for these configurations are tabulated below and compared with the Baseline regenerative thrust chamber configuration and Baseline 445 flight schedule.

	First Unit Cost $K	Program Costs Total $M	Non-recurring $M
Baseline	895	252	114
Ablative Chamber	694	378	92
Throw Away Ablative Chamber	592	714	86

Although the first unit costs and non-recurring costs are reduced, the total program costs are considerably higher for the ablative engine.

4.0 FACILITIES

Review of the Edwards Rocket Test Facility, Edwards Air Force Base, California and the facilities modifications required has confirmed that the original plan for operation of test stands 2A and 1B is the most effective from a facility cost standpoint. In order to perform the injector development program on the schedule shown by the Preliminary Development Plan dated 10 February 1972, test stand 2A and its associated control center will have to be activated immediately upon initiation of the program. The costs associated with the control center are primarily for activating the recording facility. The additional increment for activating the 1B control panel and checkout of land lines was shown in the TRW labor cost for the activation of stand 1B. The costs for activating the 2A position and its control center would therefore be as follows:

TRW Labor	\$145,000
Purchased Parts	216,000
Purchased Services	
Cleaning	65,000
Metrology	107,000
Total	\$553,000

The additional cost for activating Stand 1B would be as follows:

TRW Labor	\$ 450,000
Modification to 1B	1,600,000
Water Flow Facility	150,000
Total	\$2,200,000

On 1 March 1972 a visit to the Edwards Rocket Test Facility for the purpose of reviewing engine test stands 1C and 1D as possible sites for testing of pressure fed boosters disclosed the following:

1. The test stands are in excellent condition. 1D is currently in operation while 1C is in an excellent state of preservation. The control center common to the two stands is currently in an operational status.

2. The physical separation between the two test stands will make maintenance of the test schedule easier than on stand 1B.
3. The separation distance between the stands precludes the use of a common set of run tanks.
4. The use of a common control center introduces the same scheduling problems that are presented on stand 1B.

The costs for converting stands 1C and 1D to pressure fed booster requirements are estimated to be as follows:

TRW Labor	$ 100,000
Purchased Parts	100,000
Modification of stand 1C Propellant System	1,600,000
Modification of stand 1D Propellant System	1,600,000
Installation of Water Flow Facility	150,000
	$3,550,000

Total cost for 1C, 1D and 2A is therefore $4,083,000 as compared to $2,733,000 for 1B and 2A. The costs presented above are less G&A and fee which are included in the main body of this report.

In planning the modifications of the Edwards Rocket Test Facility, TRW has been working in close association with Norman Engineering Company of Culver City, California. The costs and schedules for the modification of the 1B test stand have been prepared by them in accordance with engineering direction from TRW. The schedule is based upon the release of a purchase order for procurement of the longest lead time item, namely the propellant run tanks by the second week after go-ahead; as soon as the tank specification can be released. On 29 February the realism of the proposed schedule was discussed with Mr. E. F. Slattery, Vice President of Norman Engineering Company. As a result of this conversation Mr. Slattery contacted the Pittsburg-DesMoines Steel Company who confirmed a 9 month schedule for design, fabrication, erection, and test of the run tanks. A detail breakdown of the activities required to activate the 1B test stands is given in Part I of this report. If test stands 1C and 1D are used, the first test stand can be activated on the same schedule as shown for stand 1B; the second can be activated 3 months later.