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ORBIT TRANSFER VEHICLE (OTV)ENGINE

PHASE "A" STUDY
EXTENSION 1

FINAL REPORT

VOLUME III: STUDY COST ESTIMATES

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA

CONTRACT NAS 8-32999

20 AUGUST 1980

AEROJET LIQUID ROCKET COMPANY

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FOREWORD

This report volume presents program cost and planning data, based on 1980 technology and shown in 1979 dollars, for a 20K lb Thrust Staged Combustion Cycle Engine and compares these data with those for the Advanced Expander Cycle Engine at 10K lb and 20K lb thrust levels.

These data are prepared in accordance with the requirements of Contract NAS 8-32999, Data Procurement Document (DPD) No. 559, Data Requirement (DR) No. MA-05.

The NASA/MSFC Contracting Officer Representative was Mr. Dale H. Blount, and Mr. R. L. Klan was the NASA Programmatics and Cost Manager.

This report was prepared by Mr. K. L. Christensen. Mr. L. B. Bassham was the ALRC Program Manager, and Mr. J. A. Mellish was the ALRC Study Manager.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

2. Costing Approach, Methodology and Rationale

This section (Part III of this volume) is divided into two parts. The first part (A. Approach) describes in detail the costing methodology used in generating the cost estimates and data for this study. The cost approach for DDT&E, production, and operations is each covered separately and includes the data sources, estimating steps, estimating techniques, cost comparisons, and parametric applications.

The second part (B. Guidelines and Assumptions) includes a listing of guidelines furnished to ALRC by NASA/MSFC for use in planning and projecting costs for this study. In addition, a listing of assumptions made by ALRC, which were used in the planning and cost projections, is presented.

3. Work Breakdown Structure Dictionary

The WBS section (Part IV) displays the entire task/costing structure for each of the program phases to the lowest level and presents the WBS dictionary which fully defines the composition of each element. In addition, the WBS for each program phase is shown at the third, or cost display, level.

4. Cost Estimates

This section (Part V) presents the DDT&E, production and operations cost estimate summaries, detailed cost breakdown by WBS element, and time-phased cost summaries for a 20K lb thrust staged combustion cycle engine.

II. SUMMARY

A. DDT&E PROGRAM

1. Estimated Costs

Cost estimate covering design, development, test, and evaluation (DDT&E) of the 20K lb thrust staged combustion cycle engine is $322.0 million dollars.

2. Major Assumptions

a. DDT&E Program duration will be 5.75 years.

b. The program is nominal (average number of development problems).

c. All costs are in 1979 dollars.

d. Costs do not include contractor fee.

e. DDT&E Program will be preceded by technology programs.

f. 17 engines will be required for DDT&E.

g. All propellants will be government furnished.

B. PRODUCTION PROGRAM

1. Estimated Costs

Cost estimates covering the production of the 20K lb thrust staged combustion cycle engine to support both the AMOTV and APOTV mission models are shown below. Costs include main engines, initial spares, facility maintenance, sustaining engineering, and project management.

II, B, Production Program (cont.)

AMOTV Production Cost in Millions of Dollars	APOTV Production Cost in Millions of Dollars
$137.0	$161.9

2. Major Assumptions

a. Both mission models will require two engines per vehicle.

b. AMOTV production run will consist of 44 engines (22 sets).

c. APOTV production run will consist of 56 engines (28 sets).

d. After delivery of first flight-qualified engines on 31 December 1987, production is planned at the rate of one engine per month.

e. A 90% learning curve was used to project the cost of the main engines.

f. All costs are in 1979 dollars.

g. Costs do not include contractor fee.

h. All propellants will be government furnished.

C. OPERATIONS PROGRAM

1. Estimated Costs

Cost estimates covering the operations of the 20K lb thrust staged combustion cycle engine to support both the AMOTV and APOTV mission models are displayed below. Costs include inplant support, field support, major engine overhaul, facility maintenance, follow-on spares, and project management.

AMOTV Operations Cost in Millions of Dollars	APOTV Operations Cost in Millions of Dollars
$60.2	$68.6

2. <u>Major Assumptions</u>:

a. Operations program duration will be 10 years.

b. AMOTV operations will service 6 engines (3 sets) per year.

c. APOTV operations will service 8 engines (4 sets) per year.

d. Operations costs vary slightly with engine cycle and thrust. (Theoretrical First Unit [TFU] Cost is influenced by engine cycle and thrust. TFU, in turn, determines follow-on spares cost, which is part of operations cost.)

e. All costs are in 1979 dollars.

f. Costs do not include contractor fee.

g. All propellants will be government furnished.

III. COSTING APPROACH, METHODOLOGY AND RATIONALE

A. APPROACH

1. DDT&E

During the course of this study contract, the DDT&E costing was performed through a parametric approach. Initial overall program costs were estimated based upon Space Tug Engine study data shown in "Space Tug System Data Package," Addendum 1, Propulsion System Control Data NASA/MSFC, 1 August 1973.

The Space Tug cost data were expressed in fiscal year 1973 dollars. A NASA-supplied chart showing escalation indices was employed to convert the costs into 1979 dollars. These escalated cost data were then used to estimate the approximate overall cost for an expander cycle engine DDT&E program. The costs were allocated to the third Work Breakdown Structure (WBS) level, then to the fourth WBS level to evaluate their validity.

Cost comparisons between expander cycle engine DDT&E estimates and previous ALRC DDT&E programs (Titan and OMS) were then made. The estimated cost allocations were then tailored to conform with historical relationships within areas of similarity and with the OTV engine DDT&E schedule and test requirements. Figure 1 shows the 20K lb thrust staged combustion cycle engine DDT&E schedule which is spread over five and three quarters (5.75) years and was derived to meet the OTV schedule requirement.

Parametrics were then employed to estimate the 20K lb thrust staged combustion cycle engine DDT&E costs. These costs were established by assessing the differences between the program and component requirements of the staged combustion cycle engine and the expander cycle engine.

An ALRC cost estimation computer program was then used to divide the staged combustion cycle engine DDT&E costs between Engineering

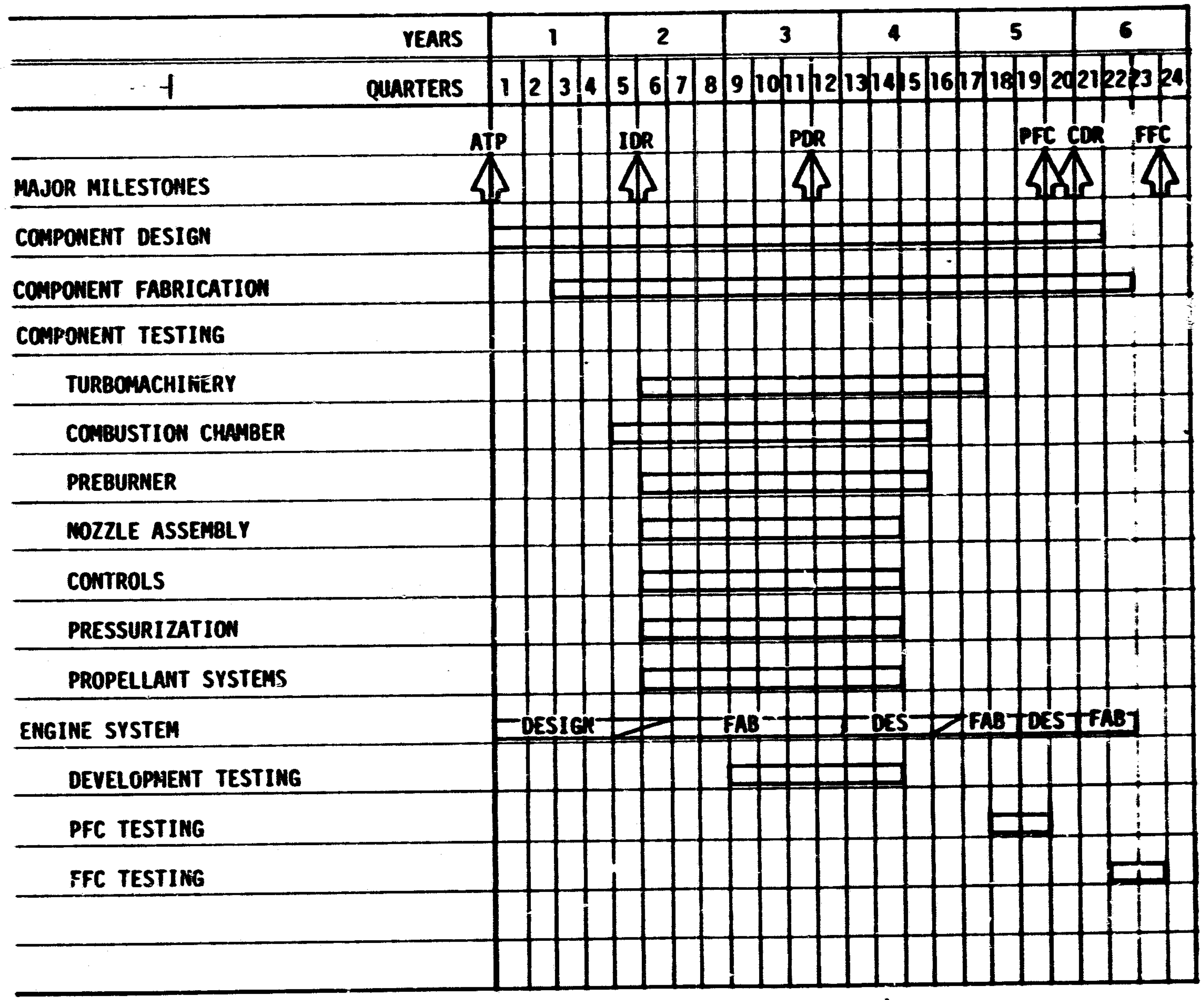

Figure 1. Staged Combustion Cycle Engine
Nominal DDT&E Schedule (5.75 years)

Manufacturing, and Materiel at all WBS levels. By programming each WBS cost task to identify the duration in program months, the beginning month, the spread function ogive curve, the salary and hourly labor hour relationahips, the applicable 1979 wage rates, and the manufacturing to engineering slip time, several meaningful computer printouts were created. These printouts describe, in detail, the prime cost elements of the DDT&E program. Each DDT&E WBS cost task was displayed in terms of dollars, as well as in salary and hourly hours, for both the engineering and manufacturing pools by month, year, and in total. In addition, manpower for both labor pools was displayed hourly and in salary, by month, year, and in total. Table I contains the type of basic information that was programmed into the computer to create the aforementioned printouts.

The computer printouts provided the costing profiles which allowed each WBS cost task to be objectively evaluated by prime cost element, as well as by manpower requirements at task start, peak and tail-off. This was the test for the reasonableness of the DDT&E cost estimates.

It was assumed that consumable propellants would be government furnished; therefore, these values were estimated and expressed in terms of millions of pounds of propellants required.

2. Production

Production costing techniques employed during this study used both the detailed estimating approach and that of parametrics. Actual cost history for Titan II, Gemini, and Titan III were analyzed along with projected cost data for the OMS program. The data from these programs were compared with each other and with the requirements for the staged combustion cycle OTV engine.

TABLE I

DDT&E PROGRAMMING INFORMATION FOR COMPUTERIZED SPREAD

	Dur. in Mo.	Plcm't fm End in Mo.	Ogive Spread Funct.	% Total Cost			Sal/Hrly Rel.		Sal/Hrly Rates		Mfg. Slip in Mo.
				Eng.	Mfg.	Matl.	Eng.	Mfg.	Eng.	Mfg.	
Component Part	*	*	*	70	20	10	93/7	50/50	33.72/18.54	47.42/36.44	6
Assy. & Checkout	21	36	50/50	10	80	10	93/7	50/50			C
Tooling	39	54	80/20	0	70	30	-	20/80			0
Project Mgmt.	54	54	LOE	75	15	10	91/9	90/10			3
Development Testing	*	*	60/40	20	70	10	93/7	50/50			0
Ground Support	*	*	50/50	80	-	20	90/10	-			0
Facilities	39	54	70/30	-	60	40	-	30/70			0

*Varies by component or type

Actual experience from the Gemini program was selected as the base upon which to project the cost for the main engines. This selection was based on several key considerations: (1) similarity of components, (2) ability to project configuration and size differences, (3) the Gemini engines were man-rated.

The Gemini historical cost data were in 1965 dollars, and the cost per system included three engines. The data were first converted to cost per engine, then the actual manufacturing cost for a Gemini bare engine was transformed through a normalizing process to the cost of an OTV expander cycle engine. This process consisted of two major steps: (1) the bare engine manufacturing costs were divided into two categories (one was costs unaffected by the conversion from Gemini to OTV expander cycle and the other was costs impacted by the conversion) and (2) a parametric formula (cost estimation relationship, CER) was applied to the two categories. The Gemini ablative skirt and start cartridge costs were replaced by detailed estimates for a columbium nozzle and controls/pumps, respectively, for the expander cycle engine. Thus, the estimated cost of an OTV expander cycle engine was developed for engine numbers 430 through 465 (the respective number of engines of the Gemini configuration [36] following a production run of 429 Titan II engines) in FY 1965 dollars.

The numbers of engines to produce were determined to support the AMOTV and APOTV mission models shown on Tables II and III, respectively. These mission models were extracted from NASA TMX-73394 and provided by NASA/MSFC as study guidelines. A total quantity of 44 (22 sets) engines was established for the AMOTV mission model. This includes 2 (1 set) engines for prototype delivery, 2 (1 set) engines for pre-flight certification (PFC), 4 (2 sets) first flight-qualified engines, and 36 (18 sets) engines for production deliveries. The APOTV mission model requires more engine deliveries. There are 12 (6 sets) additional engines for production deliveries, for a total quantity of 56 (28 sets) engines.

<u>TABLE II</u>

NOMINAL AMOTV MISSION MODEL, 100,000 LB SHUTTLE

Units	Program	Calendar Year										Remarks
		86	87	88	89	90	91	92	93	94	95	
Shuttle Launches (Mission Weight)	Station Elements	2	3	2	3	3	3					
	Station Cargo		2	1	4	7	6	2	1	2	1	
	SPS - Test/Development Hardware	2	3	3	3	2						
	Space Construction Base Miscellaneous			3				4	2	5		
	PSP			2	2	3	1	2	1	2	1	
	Solar Terrestrial Observatory (STO)	2					1		1			
	PSP and STO Miscellaneous		1		1		1		1		2	
	Automated or Cluster Payload	1	1	2	2	2	2	3	2	3	3	
	Subtotal	7	10	13	15	17	14	11	8	12	7	
Shuttle Launches (Mission Flights)	4-Man Crew Transfer		4	4	6	8	12					Carried on Crew Transfer Launch or after 1991 on HLLV
	Station Supplies											
	12-Man Crew Transfer							4	8	12	24	
	4-Man Sortie	2	2	1	2	1	2	1	2	4	6	
	Planetary	2	1	2	0	2	1	2	2	2	2	
	Lunar	1	1	1	1	2	2	1	1	2	1	
	High Altitude and Heliocentric	1			1			1			1	
	Subtotal	6	8	8	10	13	17	9	13	20	34	
	Program Total	13	18	21	25	30	31	20	21	32	41	252 TOTAL

TABLE III

NOMINAL APOTV MISSION MODEL, 100,000 LB SHUTTLE

Units	Program	Calendar Year										Remarks
		86	87	88	89	90	91	92	93	94	95	
Shuttle Launches (Mission Weight)	Station Elements	4	5	4	5	5	5					Dual Launches
	Station Cargo		3	5	8	13	10	3	2	3	2	
	SPS - Test/Development Hardware	3	6	5	6	4						
	Space Construction Base Miscellaneous			5				7	4	8		
	PSP			3	4	4	2	3	2	4	1	
	Solar Terrestrial Observatory (STO)	4					1		1			
	PSP and STO Miscellaneous		1		1		1		3		2	
	Automated or Cluster Payload	2	2	4	3	4	3	5	4	5	5	
	Subtotal	13	17	26	27	30	22	18	16	20	10	
Shuttle Launches (Mission Flights)	4-Man Crew Transfer		4	4	6	8	12	12	24	36	48	Dual Launches
	Station Supplies		4	4	6	8	12					
	12-Man Crew Transfer											
	4-Man Sortie	4	4	2	4	2	4	2	4	8	12	
	Planetary	2	1	2	0	2	1	2	2	2	2	
	Lunar	1	1	1	1	2	2	1	1	2	1	
	High Altitude and Heliocentric	1			1			1			1	
	Subtotal	8	14	13	18	22	31	18	31	48	64	
	Program Total	21	31	39	45	52	53	36	47	68	74	466 TOTAL

A production schedule for the AMOTV engines was devised (see Figure 2). The schedule was constructed so that the 36 engines for production deliveries would be produced at a rate of one engine per month. This type of continuous production led to the selection of a 90% learning curve to project first unit and total quantity costs. This delivery rate results in a low production cost. A slower rate would increase the total production cost.

A NASA-supplied chart displaying escalation indices was employed to convert the estimated cost of an OTV expander cycle engine into FY 1979 dollars. Utilizing a 90% learning curve, the first unit cost (T^1) was projected and came to $2.665 million dollars. Total production cost for the expander cycle main engines was projected on a 90% learning curve. These engine costs were applicable to an engine thrust level of 10,000 pounds. Engine costs for thrust levels of 20,000 and 30,000 pounds were estimated by applying a parametric cost estimation relationship.

Delta costs for the staged combustion cycle engine were established by estimating the component differences between the two engine cycles.

The basis for the cost of initial spares was provided by NASA and amounts to 50% of the theoretical first unit cost (TFU).

Facility maintenance, sustaining engineering, and project management were manloaded on the basis of OMS and Titan data, then costed in FY 1979 dollars.

Consumables were estimated and expressed in millions of pounds of government-furnished propellants.

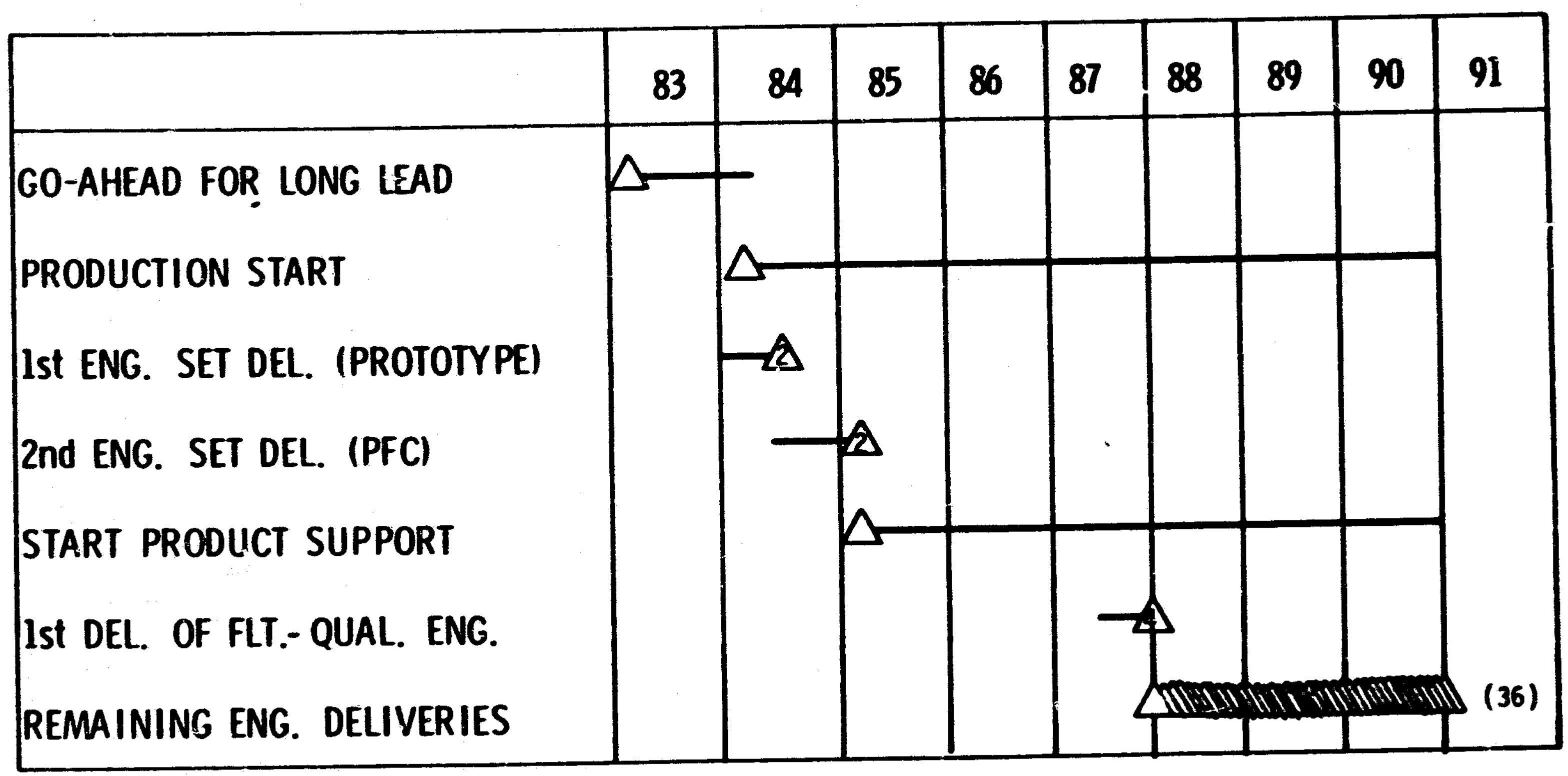

Figure 2 - AMOTV Engine Production Schedule

3. Operations

Detailed estimates based on manpower requirements to perform the required functions were used to derive annualized costs for inplant support, field support, facility maintenance, and project management. The requirements for engine turnaround maintenance are based on a turnaround cycle of 29.5 hours. Figure 3 displays the detailed tasks and time frames for routine and corrective engine maintenance. Figure 4 shows the Engine Maintenance Plan. AMOTV operations costs assume that six engines per year will be serviced, whereas APOTV operations will service eight engines per year.

Major engine overhaul costs are based on labor only; all material and parts will be available from spares stock. Labor hours to overhaul an engine are based on 150% of the manufacturing and quality control hours, including shop support, for assembly of an engine. This includes the effort for disassembly.

Labor hours to overhaul components, such as valves and pumps, were estimated as a factor of engine acquisition cost, based on Titan III experience for overhaul of returned products.

There is only one primary difference between the annualized cost of operations for the AMOTV, as opposed to the APOTV mission model, and that is the number of missions for each model.

The follow-on spares cost was computed as 4.5 times the theoretical first unit cost (TFU) and divided by 10 obtain an average cost for one year. The 4.5 factor is a guideline provided by NASA.

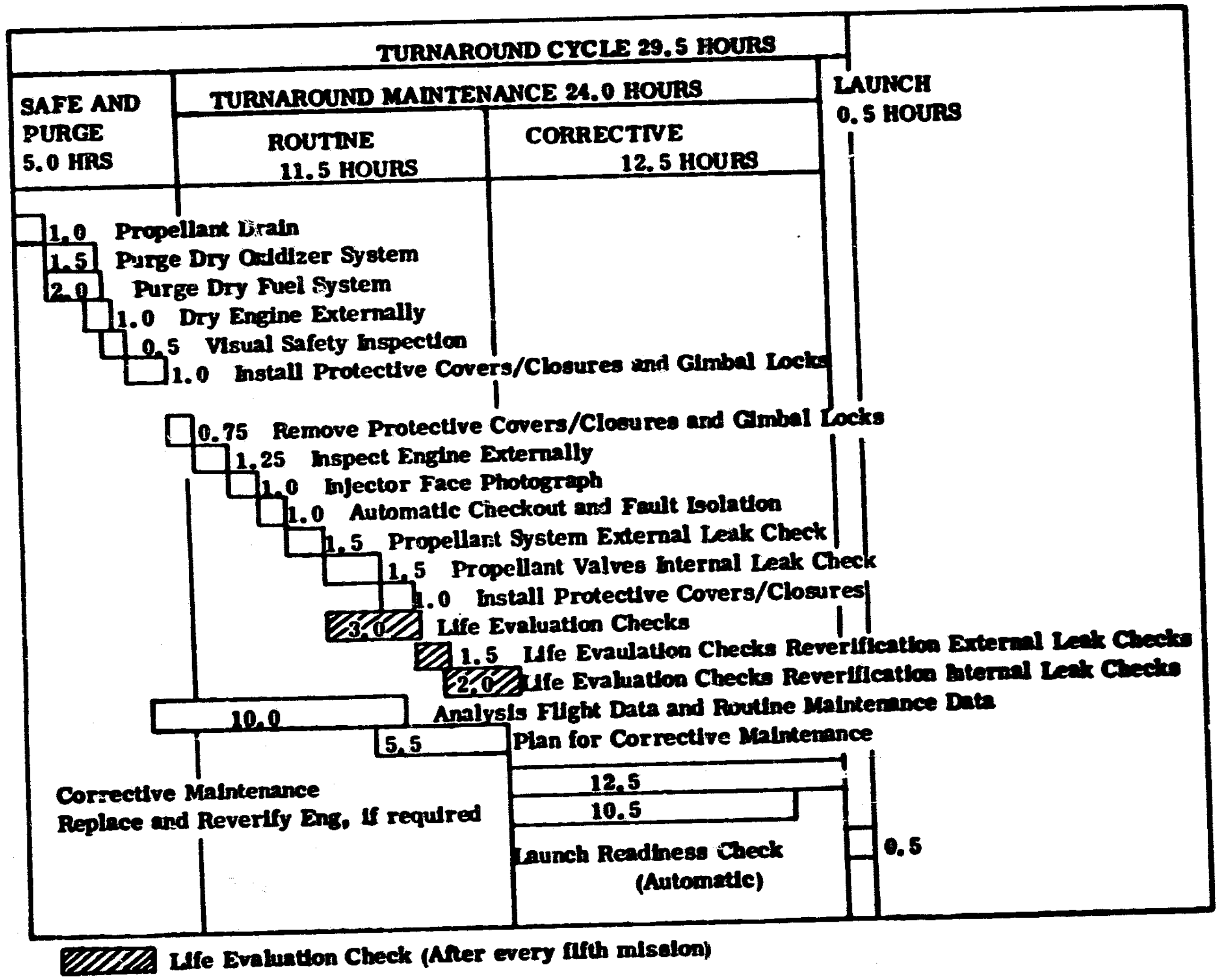

Figure 3 - Engine Turnaround Cycle Timeline

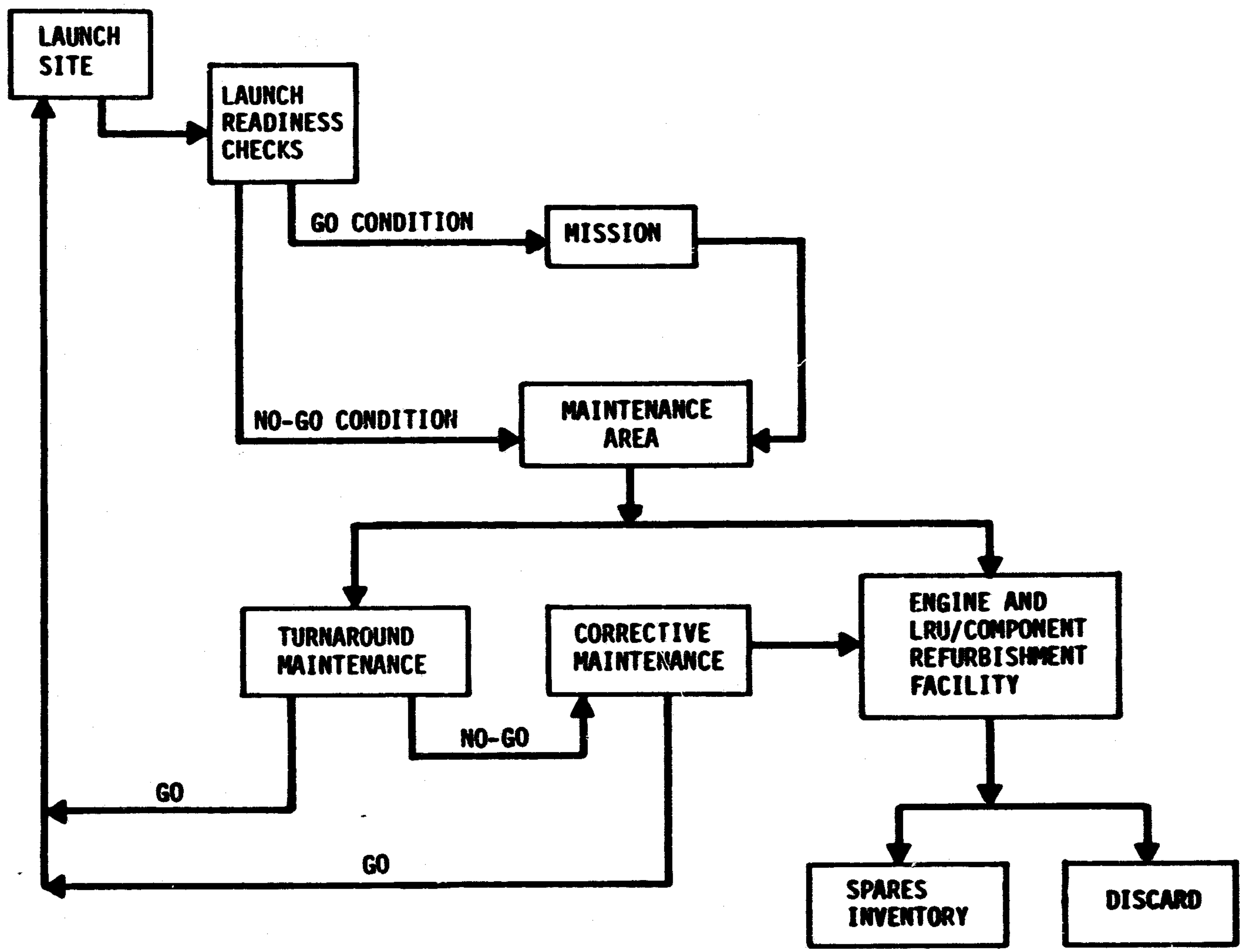

Figure 4 - Engine Maintenance Plan

Consumables were estimated and expressed in millions of pounds of government-furnished propellants.

B. GUIDELINES AND ASSUMPTIONS

1. NASA/MSFC furnished key guidelines to ALRC which were used as the basis for planning and projecting costs for this study. These guidelines are itemized below.

a. Cost estimates shall be developed to the lowest Work Breakdown Structure (WBS) level for which hardware elements are defined.

b. Costing will be presented at the third (3rd) WBS level.

c. All costs will be expressed in FY 1979 dollars without regard to escalation.

d. The Aerojet Liquid Rocket Company (ALRC) fee will not be added to the costs.

e. Utilize NASA-supplied escalation indices to convert costs from previous years to FY 1979 dollars.

f. The nominal program mission models contained in NASA TMX-73394 should be used for both APOTV and AMOTV engine program cost analysis.

g. The engine is to be man-rated.

h. Engine development testing will be conducted at ALRC test facilities.

i. For costing, put mock-ups in assembly and checkout.

j. Pre-flight test and checkout should be included in engine overhaul.

k. Initial spares cost should be 50% of the cost of the theoretical first unit (TFU).

l. Follow-on spares cost should be 4.5 times the theoretical first unit cost.

m. Flights are to be evenly spaced throughout each year, from tables.

n. Special emphasis shall be given to low-cost operations and minimum program costs.

o. Select learning curve based upon production rate.

p. Authority to proceed will be 1 January 1982.

q. First flight engine need date is 1 April 1985.

r. Initial operational capability is 31 December 1987.

s. Spread DDT&E and production costs by year.

t. Base operations cost on one year.

u. The consumables will be government-furnished propellants.

2. In addition to NASA/MSFC-furnished guidelines, ALRC made certain assumptions and analyses which were used for planning and projecting costs for this study. The results of these assumptions and analyses are as follows:

a. Two (2) engines will be required per OTV.

b. Prior to the Engine Development Phase, the Engine Concept Definition Studies (Phase A), Engine Point Design, Critical Technology, and Phase B Design Efforts will have been completed.

c. The Engine DDT&E Phase will be a five and three quarters (5-3/4) year nominal program with the following key elements:

(1) Seventeen (17) engines will be required by DDT&E testing.

(2) Engine development testing will be completed mid-way through the second quarter of 1986.

(3) Pre-Flight Certification (PFC) testing will be completed on 28 September 1986.

(4) Final Flight Certification (FFC) testing will be completed on 28 September 1987.

d. The Engine Production Phase will start on 31 March 1984 and will run through the last quarter of 1990 for the AMOTV and through the last quarter of 1991 for the APOTV.

(1) Full production support will start in the first quarter of 1985.

(2) The total AMOTV production run will consist of 44 engines (22 sets) and will include two (2) prototype engines (1 set), two (2) pre-flight certification (PFC) engines (1 set), four (4) first flight-qualified engines (2 sets), and 36 production delivery engines (18 sets).

(3) The total APOTV production run will consist of 56 engines (28 sets) and will include two (2) prototype engines (1 set), two (2) PFC engines (1 set), four (4) first flight-qualified engines (2 sets), and 48 production delivery engines (24 sets).

(4) Production deliveries will be at the rate of one (1) engine per month for 36 months for AMOTV or 48 months for APOTV.

e. For a production rate of one (1) engine per month, the learning curve slope will be 90%.

f. Operations program duration will be ten (10) years.

g. AMOTV operations will service six (6) engines (3 sets) per year.

h. APOTV operations will service eight (8) engines (4 sets) per year.

i. The OTV engine turnaround cycle time will be a total of 29.5 hours.

(1) The safe-and-purge portion of the OTV engine turnaround cycle time will be five (5) hours.

(2) Turnaround maintenance time will average 24 hours, which includes 11.5 hours for routine maintenance actions and 12.5 hours allotted for corrective maintenance, if required.

(3) Launch preparation time will be one-half (1/2) hour.

(4) Life evaluation checks will be conducted after every fifth (5th) mission.

(5) Corrective actions requiring more than 12.5 hours will be cause for engine replacement.

(6) Refurbishment activity will normally be accomplished at depot level.

m. The useful life of an engine will average 18 missions for the APOTV and 21 missions for the AMOTV before requiring a major overhaul. This is based upon the 10-hour service life.

n. Expendable planetary missions will be flown with engines which are at the end of their service lives.

IV. WORK BREAKDOWN STRUCTURE DICTIONARY

A. WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure (WBS) used throughout this study for cost estimating purposes was structured in concert with NASA/MSFC.

The WBS Number for the Main Engines is 1.0; DDT&E is 1.1, Production is 1.2, and Operations is 1.3. This WBS summary is shown in Figure 5.

A separate WBS was used for each of the program phases: DDT&E, Production, and Operations. These are displayed as follows:

1.0 Main Engine

1.1 DDT&E

1.1.1 Turbomachinery
1.1.1.1 Main Fuel Pump
1.1.1.2 Main Oxidizer Pump
1.1.1.3 Fuel Boost Pump
1.1.1.4 Oxidizer Boost Pump
1.1.1.5 Assembly and Checkout

1.1.2 Main Combustion Chamber
1.1.2.1 Injector
1.1.2.2 Chamber
1.1.2.3 Upper Nozzle (fixed)
1.1.2.4 Igniter
1.1.2.5 Gimbal Assembly
1.1.2.6 Assembly and Checkout

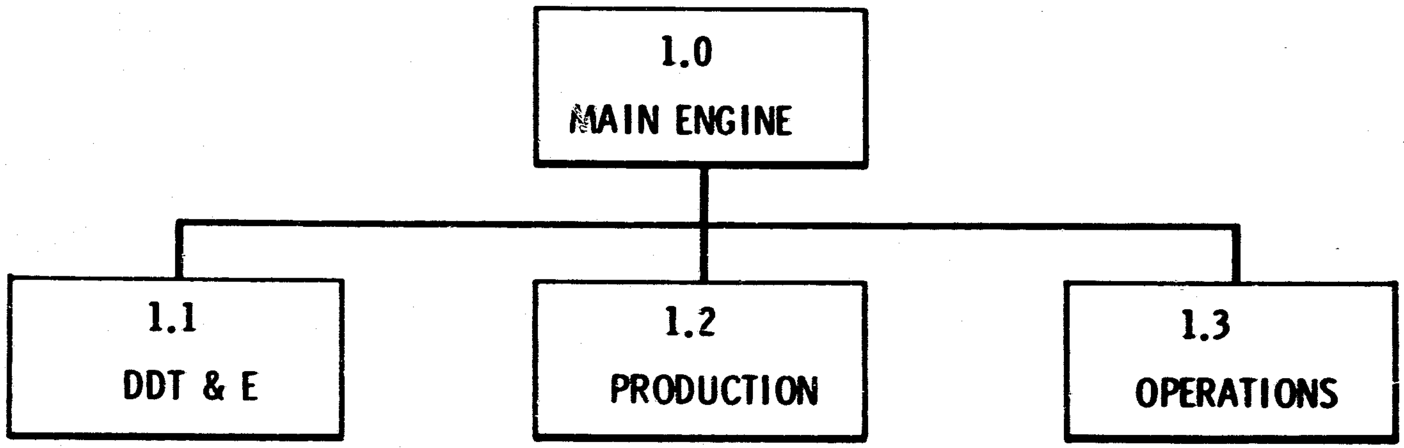

Figure 5 - Work Breakdown Structure (WBS) Summary

IV, A, Work Breakdown Structure Dictionary (cont.)

1.1.3	Preburner/Gas Generator
1.1.3.1	Injector
1.1.3.2	Combustor
1.1.3.3	Igniter
1.1.3.4	Assembly and Checkout
1.1.4	Nozzle Assembly
1.1.4.1	Lower Nozzle (Extendable)
1.1.4.2	Extension/Retraction Mechanisms
1.1.4.3	Assembly and Checkout
1.1.5	Controls
1.1.5.1	Engine Controller & Electrical Harness
1.1.5.2	Control Valves
1.1.5.3	Instrumentation & Electrical Harness
1.1.5.4	Assembly and Checkout
1.1.6	Pressurization
1.1.6.1	Heat Exchangers
1.1.6.2	Assembly and Checkout
1.1.7	Propellant Systems
1.1.7.1	Feed, Fill, Vent, Abort Dump, and Drain
1.1.7.2	Assembly and Checkout
1.1.8	Initial Tooling
1.1.9	Ground Support Equipment
1.1.9.1	Handling and Protective Equipment
1.1.9.2	Checkout and Maintenance Equipment
1.1.9.3	Assembly and Checkout

IV, A, Work Breakdown Structure Dictionary (cont.)

1.1.10 Test
1.1.10.1 Development Testing
1.1.10.2 PFC Testing
1.1.10.3 FFC Testing

1.1.11 System Engineering and Integration
1.1.11.1 Integration of DDT&E Activities
1.1.11.2 Engine Assembly and Checkout
1.1.11.3 Engine/Vehicle Interface

1.1.12 Project Management

1.1.13 Facilities

1.1.14 Consumables

1.2 Production

1.2.1 Main Engines
1.2.1.1 Turbomachinery
1.2.1.2 Combustion Devices
1.2.1.3 Controls
1.2.1.4 Pressurization
1.2.1.5 Propellant Systems
1.2.1.6 Engine Assembly

1.2.2 Initial Spares

1.2.3 Facility Maintenance
1.2.3.1 Manufacturing and Test Facilities

IV, A, Work Breakdown Structure Dictionary (cont.)

1.2.3.2 Sustaining Tooling
1.2.3.3 GSE

1.2.4 Sustaining Engineering

1.2.5 Project Management

1.2.6 Consumables

1.3 <u>Operations</u>

1.3.1 Inplant Support
1.3.2 Field Support
1.3.2.1 Launch Support
1.3.2.2 Flight Support
1.3.2.3 Refurbishment and Maintenance
1.3.2.4 Checkout

1.3.3 Major Engine Overhaul

1.3.4 Facility Maintenance

1.3.5 Follow-on Spares

1.3.6 Project Management

1.3.7 Comsumables

Cost estimating for this study was performed at the lowest level of the WBS. The costs displayed in Part V.A., Cost Summaries, are shown at the third WBS level per NASA instructions. Figures 6, 7, and 8 represent the WBS for DDT&E, Production, and Operations, respectively, at the third WBS level.

1.1.1	TURBOMACHINERY
1.1.2	MAIN COMBUSTION CHAMBER
1.1.3	PREBURNER/GAS GENERATOR*
1.1.4	NOZZLE ASSEMBLY
1.1.5	CONTROLS
1.1.6	PRESSURIZATION
1.1.7	PROPELLANT SYSTEMS
1.1.8	INITIAL TOOLING
1.1.9	GROUND SUPPORT EQUIPMENT
1.1.10	TEST
1.1.11	SYSTEM ENGINEERING
1.1.12	PROJECT MANAGEMENT
1.1.13	FACILITIES
1.1.14	CONSUMABLES

*STAGED/GAS GEN. CYCLES ONLY

Figure 6 - Work Breakdown Structure (WBS) Engine DDT&E

1.2.1 MAIN ENGINES

1.2.2 INITIAL SPARES

1.2.3 FACILITY MAINTENANCE

1.2.4 SUSTAINING ENGINEERING

1.2.5 PROJECT MANAGEMENT

1.2.6 CONSUMABLES

Figure 7 - Work Breakdown Structure (WBS) Engine Production

1.3.1 INPLANT SUPPORT

1.3.2 FIELD SUPPORT

1.3.3 MAJOR ENGINE OVERHAUL

1.3.4 FACILITY MAINTENANCE

1.3.5 FOLLOW-ON SPARES

1.3.6 PROJECT MANAGEMENT

1.3.7 CONSUMABLES

Figure 8 - Work Breakdown Structure (WBS) Engine Operations

IV. Work Breakdown Structure Dictionary (cont.)

B. WBS DICTIONARY

This dictionary defines the work scope composition of each WBS element. These definitions were used as the basis for assigning estimated costs to specific tasks associated with each WBS element. The definitions were provided by Mr. R. L. Klan, NASA/MSFC Cost and Programmatics Manager.

WORK BREAKDOWN STRUCTURE
DICTIONARY

1.0 MAIN ENGINES

This is the top level of the Work Breakdown Structure (WBS) and covers the total project. The efforts include: Non-recurring Design, Development, Test and Evaluation (DDT&E), Recurring Production, and Recurring Operations.

1.1 DDT&E (NON-RECURRING EFFORT)

This task includes the total effort of designing, developing, testing and evaluating the engine system. The DDT&E task may overlap the production and operational tasks because of design modifications, production lead times, site activations, etc. Specifically included in this task are design/development support and engineering, test hardware, ground support equipment, design and acquisition of tooling and special test equipment (STE), and other efforts not associated with repetitive production.

1.1.1 TURBOMACHINERY

This element covers all efforts associated with the design and development of the turbomachinery (low and high pressure LOX and fuel turbopumps).

Specifically included are tasks to define and conduct test programs to verify and demonstrate component and complete package adequacy. Conduct supporting technology programs as required.

1.1.1.1 MAIN FUEL PUMP

This element covers all efforts associated with the design, development, test & evaluation of the main fuel pump. Specifically included are tasks to conduct supporting technology as required. Define and conduct test programs to verify, qualify and demonstrate component and complete package adequacy.

1.1.1.2 MAIN OXIDIZER PUMP

This element covers the same efforts as those described under WBS 1.1.1.1 (Main Fuel Pump).

1.1.1.3 BOOSTER FUEL PUMP

This element covers the same efforts as those described under WBS 1.1.1.1 (Main Fuel Pump).

1.1.1.4 BOOSTER OXIDIZER PUMP

This element covers the same efforts as those described under WBS 1.1.1.1 (Main Fuel Pump).

1.1.1.5 ASSEMBLY AND CHECKOUT

This element covers all efforts associated with the assembly of the component parts into a turbomachinery system and with the checkout of this system prior to installation into the engine. Included are mock-ups of the turbomachinery system and subsystems.

IV, B, WBS Dictionary (cont.)

1.1.2 MAIN COMBUSTION CHAMBER

This element covers all efforts associated with the design and development of the main combustion chamber (including injector, chamber, upper nozzle [fixed], igniter and gimbal assembly). Specifically included are tasks to define and conduct test programs to verify and demonstrate component and complete system adequacy. Conduct supporting technology programs as required.

1.1.2.1 INJECTOR

This element covers all efforts associated with the design, development, test, and evaluation of the injector. Specifically included are tasks to conduct supporting technology as required. Define and conduct test programs to verify, qualify and demonstrate component and complete package adequacy.

1.1.2.2 CHAMBER

This element covers the same efforts as those described under WBS 1.1.2.1 (Injector).

1.1.2.3 UPPER NOZZLE(FIXED)

This element covers the same efforts as those described under WBS 1.1.2.1 (Injector).

1.1.2.4 IGNITER

This element pertains to the igniter for the main combustion chamber and covers the same efforts as those described under WBS 1.1.2.1 (Injector).

1.1.2.5 GIMBAL ASSEMBLY

This element covers the same efforts as those described under WBS 1.1.2.1 (Injector).

1.1.2.6 ASSEMBLY AND CHECKOUT

This element covers all efforts associated with the assembly of the component parts into a main combustion system and with the checkout of this system prior to installation into the engine. Included are mock-ups of the main combustion chamber and its subsystems.

1.1.3 PREBURNER/GAS GENERATOR

This element covers all efforts associated with the design and development of either the preburner system or gas generator system (determined by engine design). Specifically included are tasks to define and conduct test programs to verify and demonstrate component and complete system adequacy. Conduct supporting technology programs as required.

1.1.3.1 INJECTOR

This element pertains to the injector for the preburner or gas generator and covers all efforts associated with its design, development, test, and evaluation. Specifically included are tasks to conduct supporting technology as required. Define and conduct test programs to verify, qualify and demonstrate component and complete package adequacy. Conduct supporting technology programs as required.

1.1.3.2 COMBUSTOR

This element covers the same efforts as those described under WBS 1.1.3.1 (Injector).

1.1.3.3 IGNITER

This element covers the same efforts as those described under WBS 1.1.3.1 (Injector).

1.1.3.4 ASSEMBLY AND CHECKOUT

This element covers all efforts associated with the assembly of the component parts into a preburner or gas generator system and with the checkout of the system prior to installation into the engine. Included are mock-ups of the preburner or gas generator and its subsystems.

1.1.4 NOZZLE ASSEMBLY

This element includes all efforts associated with the design, development, test & evaluation of the nozzle assembly (includes the lower extendable nozzle plus the extension/retraction mechanisms). Specifically included are tasks to conduct supporting technology as required. Define and conduct test programs to verify, qualify and demonstrate component and complete package adequacy.

1.1.4.1 LOWER NOZZLE (EXTENDABLE)

This element covers all efforts associated with the design, development, test & evaluation of the extendable lower nozzle. Specifically included are tasks to conduct supporting technology as required. Define and conduct test programs to verify, qualify and demonstrate component and complete package adequacy.

1.1.4.2 EXTENSION/RETRACTION MECHANISMS

This element covers the same efforts as those described under WBS 1.1.4.1 (Lower Nozzle Extendable).

1.1.4.3 ASSEMBLY AND CHECKOUT

This element covers all efforts associated with the assembly of the component parts into a nozzle assembly system and with the checkout of the system prior to installation into the engine. Included are mock-ups of the nozzle assembly and its subsystems.

1.1.5 CONTROLS

This element covers all efforts associated with the design, development, test & evaluation of the main engine controls (engine controller & electrical harness, control valves, and the instrumentation with associated electrical harness). Specifically included are tasks to define and conduct test programs to verify, qualify and demonstrate component and complete system adequacy. Conduct supporting technology programs as required.

1.1.5.1 ENGINE CONTROLLER & ELECTRICAL HARNESS

This element covers all efforts associated with the design, development, test & evaluation of the engine controller, including the associated electrical harness. Specifically included are tasks to define and conduct test programs to verify, qualify and demonstrate component and complete package adequacy. Also included are tasks to conduct supporting technology as required.

1.1.5.2 CONTROL VALVES

This element covers the same efforts as those described under WBS 1.1.5.1 (Engine Controller & Electrical Harness). This element incorporates the main propellant valves plus other valves, including feed, fill, vent, abort dump, and drain.

1.1.5.3 INSTRUMENTATION & ELECTRICAL HARNESS

This element covers the same efforts as those described under WBS 1.1.5.1 (Engine Controller & Electrical Harness).

1.1.5.4 ASSEMBLY AND CHECKOUT

This element covers all efforts associated with the assembly of the component parts of the main engine control system and with the checkout of the system prior to installation into the engine. Included are mock-ups of the engine control system and its subsystems.

1.1.6 PRESSURIZATION

This element covers all efforts associated with the design, development, test & evaluation of the pressurization system. Specifically included are tasks to define and conduct programs to verify, qualify and demonstrate component and complete system adequacy. Also included are tasks to conduct supporting technology as required.

1.1.6.1 HEAT EXCHANGERS

This element covers all efforts associated with the design, development, test & evaluation of the heat exchangers. Specifically included are tasks to define and conduct test programs to verify, qualify and demonstrate component and complete system adequacy. Also included are tasks to conduct supporting technology as required.

1.1.6.2 ASSEMBLY AND CHECKOUT

This element covers all efforts associated with the assembly of the component parts into a pressurization system and with the checkout of the system prior to installation into the engine. Included are mock-ups of the pressurization system and its subsystems.

1.1.7 PROPELLANT SYSTEMS

This element covers all efforts associated with the design, development, test & evaluation of the propellant systems. Specifically included are tasks to define and conduct test programs to verify, qualify and demonstrate component and complete system adequacy. Also included are tasks to conduct supporting technology as required. The propellant system includes lines and ducts, but it excludes valves (included under WBS 1.1.5.2).

1.1.7.1 FEED, FILL, VENT, ABORT DUMP, AND DRAIN

This element covers all efforts associated with the design, development, test & evaluation of the feed, fill, vent, abort dump, and drain systems. (Includes lines & ducts but excludes valves) Specifically included are tasks to define and conduct test programs to verify, qualify and demonstrate component and complete system adequacy. Also included are tasks to conduct supporting technology as required.

1.1.7.2 ASSEMBLY AND CHECKOUT

This element covers all efforts associated with the assembly of the component parts into a feed, fill, vent, abort dump and drain system and with the checkout of the system prior to installation into the engine. Included are mock-ups of the system and its subsystems.

1.1.8 INITIAL TOOLING

This element covers all efforts associated with the planning, design, fabrication and modification of all tools and special test equipment (STE) in support of the development and manufacture of the main engine.

1.1.9 GROUND SUPPORT EQUIPMENT

This element covers all efforts associated with the design, fabrication, and qualification of all GSE required for the main engine. Included are the handling and protective equipment plus the checkout and maintenance equipment. Specifically included are tasks to define and conduct test programs to verify, qualify and demonstrate the adequacy of the Ground Support Equipment.

1.1.9.1 HANDLING AND PROTECTIVE EQUIPMENT

This element incorporates all efforts associated with the design, development, test & evaluation of the handling and protective equipment required in support of the main engine. Included are tasks to define and conduct test programs to verify, qualify and demonstrate the adequacy of the handling and protective equipment.

1.1.9.2 CHECKOUT AND MAINTENANCE EQUIPMENT

This element incorporates all efforts associated with the design, development, test & evaluation of the checkout and maintenance equipment required in support of the main engine. Included are tasks to define and conduct test programs to verify, qualify and demonstrate the adequacy of the checkout and maintenance equipment.

1.1.9.3 ASSEMBLY AND CHECKOUT

This element covers all efforts associated with the assembly of the component parts into a complete ground support equipment system and with the checkout of complete system.

IV, B, WBS Dictionary (cont.)

1.1.10 TEST

This element covers all major tests through FFC. Major tests are defined as complete engine tests or any test utilizing multiple subsystems. Specifically included are tasks to define and conduct tests to verify, qualify and demonstrate the adequacy of the main engine.

1.1.10.1 DEVELOPMENT TESTING

This element covers all major engine development tests. These are tests utilizing complete engines or multiple subsystems. Component and subsystem tests are excluded here but are included under the various subsystem WBS elements. Special tests dictated to complete PFC or FFC are excluded here but are included under WBS 1.1.10.2 and 1.1.10.3.

1.1.10.2 PFC TESTING

This element covers all efforts associated with procedure development and special tests dictated expressly for PFC. All related activities are incorporated, including manufacture and test.

1.1.10.3 FFC TESTING

This element covers all efforts associated with procedure development and special tests dictated expressly for final flight certification testing. All related activities are incorporated, including manufacturing and testing.

1.1.11 SYSTEM ENGINEERING AND INTEGRATION

This element incorporates the overall integration of DDT&E activities. Included are establishment of engineering design characteristics;

determination for design review; establishment of procedures for testing components and systems; development procedure for engine maintenance; quality/reliability planning and administration engineering; verifying the compatibility of design with requirements; technology utilization assessment; technical risk assessment; safety assessment; and configuration requirements analysis. Also included are assembly of all subsystems into a complete engine and the checkout of the engine, plus assurance of engine/vehicle interface.

1.1.11.1 INTEGRATION OF DDT&E ACTIVITIES

This element covers the integration of all DDT&E activities. Included are establishment of engineering design characteristics; establishment of procedures for testing components and complete systems; development or procedures for engine maintenance; quality/reliability planning and administration engineering; verifying the compatibility of designs with requirements; assuring technology utilization; technical risk assessment; safety engineering; and configuration control analysis.

1.1.11.2 ENGINE ASSEMBLY AND CHECKOUT

This element covers the overall responsibility for merging the engine subsystems into the total engine assembly. Includes engine assembly and checkout and subsystem-to-subsystem interfaces. Also included are mock-ups of the main engine.

1.1.11.3 ENGINE/VEHICLE INTERFACE

This element includes all efforts associated with the engine/vehicle interface. Included are analysis, design, test and evaluation to ensure the efficient integration of the engine to the Orbit Transfer Vehicle (OTV), and implementation and maintenance of interface control documents.

IV, B, WBS Dictionary (cont.)

1.1.12 PROJECT MANAGEMENT

This element summarizes the management activities of planning, organizing, directing, coordinating, controlling and approval actions required to accomplish overall engine project objectives. Cost/Performance management and information management are also included under this element.

1.1.13 FACILITIES

This element covers facilities (new and/or modifications to existing ones) for manufacture, test, maintenance, refurbishment, and launch support of an operational program. This effort includes facility planning and maintenance during the DDT&E phase of the program.

1.1.14 CONSUMABLES

This element covers all propellants and gases consumed by the engines during the DDT&E phase of the program.

1.2 PRODUCTION

This task includes the total effort of acquiring additional facilities (if needed), equipment, and flight engines. Specifically included are the cost of the flight engines and initial spares, the cost of sustaining the manufacturing and test facilities, tooling and GSE. Also included are the management and sustaining engineering effort in support of the production phase of the program.

1.2.1 MAIN ENGINES

This element includes the total effort of manufacturing reusable engines in quantities required to accommodate the Orbit Transfer Vehicle Operational Program.

1.2.1.1 TURBOMACHINERY

This element covers the total effort of manufacturing turbomachinery in quantities required to accommodate the Orbit Transfer Vehicle Operational Program.

1.2.1.2 COMBUSTION DEVICES

This element covers the total effort of manufacturing combustion devices in quantities required to accommodate the Orbit Transfer Vehicle Operational Program.

1.2.1.3 CONTROLS

This element covers the total effort of manufacturing engine controls in quantities required to accommodate the Orbit Transfer Vehicle Operational Program.

1.2.1.4 PRESSURIZATION

This element covers the total effort of manufacturing engine pressurization systems in quantities required to accommodate the Orbit Transfer Vehicle Operational Program.

1.2.1.5 PROPELLANT SYSTEMS

This element covers the total effort of manufacturing engine propellant systems in quantities required to accommodate the Orbit Transfer Vehicle Operational Program.

1.2.1.6 ENGINE ASSEMBLY

This element covers the total effort to assemble and checkout complete engines from the subsystems manufactured (WBS 1.2.1.1 through WBS 1.2.1.5).

1.2.2 INITIAL SPARES

This element covers the manufacturing of spare parts for the initial spares stock required for operations. Follow-on spares are purchased during the operational phase, but these initial spares provide the stockpile needed during the early operations for infantile failures.

1.2.3 FACILITY MAINTENANCE

This element covers the maintenance of the manufacturing and test facilities acquired for the production phase of the program. Also included are the maintenance of the GSE and all efforts required to sustain the tooling.

1.2.3.1 MANUFACTURING AND TEST FACILITIES

This element covers all efforts for maintaining the manufacturing and test facilities acquired for the production phase of the engine program.

1.2.3.2 SUSTAINING TOOLING

This element covers all efforts required to sustain the tooling acquired for the production phase of the engine program.

1.2.3.3 GSE

This element covers all effort to maintain the GSE acquired for the production phase of the engine program.

1.2.4 SUSTAINING ENGINEERING

This element covers all engineering effort in direct support of manufacturing. Included are the coordination of various manufacturing activities (interdepartmental, subcontractors and vendors). Also includes the continued engineering analysis of test results and other supporting activities.

1.2.5 PROJECT MANAGEMENT

This element covers all efforts associated with the centralized program management in the areas of program planning, control and administration. Includes all phases of management in engineering, manufacturing, quality assurance, test and product support to assure an efficient program.

1.2.6 CONSUMABLES

This element covers all propellants and gases consumed by the engines during the production phase of the program.

1.3 OPERATIONS

This task covers all effort associated with operating and maintaining the engines, facilities and equipment developed and produced during the DDT&E and production phases of the program.

1.3.1 INPLANT SUPPORT

This element covers all efforts associated with inplant liaison engineering support of operational activities. The tasks covered herein usually occur after the first OTV launch. Included are product improvement characterized by engineering changes. These changes may occur as a result of user recommendations or operational experience. Anomaly resolution is also included. Excluded are efforts pertaining to major hardware modifications required to meet new performance specifications.

1.3.2 FIELD SUPPORT

This element covers the activities centered at the launch site in support of the Orbit Transfer Vehicle Engine Operations.

1.3.2.1 LAUNCH SUPPORT

This element covers activities during pre-flight checkout, actual countdown, and launch operations. Included are review of the flight data, assisting in pre-flight performance predicitons, and anomaly analysis as necessary.

1.3.2.2 FLIGHT SUPPORT

This element covers activities through mission completion and return. Includes such functions as assisting in processing and analyzing engine telemetry & communications data during flight.

1.3.2.3 REFURBISHMENT AND MAINTENANCE

This element covers activities to restore the reusable OTV Engine after each flight to a readiness condition for subsequent missions. Inspection, replacement of necessary parts, maintenance, and testing are included.

1.3.2.4 CHECKOUT

This element covers the checkout of the refurbished engines. This activity is completed when the OTV is ready for launch operations.

1.3.3 MAJOR ENGINE OVERHAUL

This element covers all efforts associated with periodic (frequency to be determined) major engine overhauls. These will normally be accomplished at the engine contractor's facility.

1.3.4 FACILITY MAINTENANCE

This element covers the activities to maintain engine facilities, equipment & GSE to support the launch operations.

1.3.5 FOLLOW-ON SPARES

This element includes activities to procure and/or manufacture engine-related spares (other than initial spares) to support the launch program.

1.3.6 PROJECT MANAGEMENT

This element covers the efforts associated with managing the engine program during the operations phase. Included are planning, scheduling, and all phases of management support required to assure an efficient program.

1.3.7 CONSUMABLES

This element covers all propellants and gases consumed by the engines during the operational phase of the program.

V. COST ESTIMATES

The objectives of this task were to provide the following cost summaries and estimates for a 20K lb thrust staged combustion cycle engine: (1) DDT&E, Production, and Operations cost summaries; (2) time-phased cost estimates to the third WBS level; (3) a detailed cost estimate to the lowest WBS level for which hardware elements are defined.

A. COST SUMMARIES

The DDT&E cost estimates for the 20K lb thrust staged combustion cycle engine at the third WBS level are shown in Table IV. The costs are shown in millions of 1979 dollars and do not include the contractor's fee. The consumables are assumed to be government-furnished propellants and, at the direction of NASA, are shown in millions of pounds.

The costs associated with the engine production necessary to support the AMOTV nominal mission model are shown in Table V. The AMOTV nominal mission model has 236 reusable missions and 16 expendable planetary missions. The expendable planetary missions govern the number of engines required. It was estimated that 40 engines (20 sets) are required to support the mission model. In addition, 4 engines (2 sets) are required for the first two OTV's for a total of 44 engines. A production rate of one engine (subassembly) a month was used. The initial spares cost was computed as 50% of the theoretical first unit cost (TFU), which was a guideline provided by NASA. A 90% learning curve was used to project the costs.

The operations costs to support the AMOTV mission model are shown in Table VI. It was estimated that six engines (3 sets) per year would be overhauled. Costs are shown for one year only and are assumed to be spread evenly over 10 years. The follow-on spares cost was computed as 4.5 times the theoretical first unit cost and divided by 10 to obtain an average cost for one year. The 4.5 factor was guideline provided by NASA.

TABLE IV

DDT&E WBS COSTS

		MILLIONS OF DOLLARS 20K LB THRUST STAGED COMBUSTION CYCLE ENGINE
1.1.1	TURBOMACHINERY	39.4
1.1.2	MAIN COMBUSTION CHAMBER	37.6
1.1.3	PREBURNER/GAS GENERATOR	30.2
1.1.4	NOZZLE ASSEMBLY	7.3
1.1.5	CONTROLS	26.4
1.1.6	PRESSURIZATION	13.3
1.1.7	PROPELLANT SYSTEMS	10.7
1.1.8	INITIAL TOOLING	20.5
1.1.9	GROUND SUPPORT EQUIPMENT	16.6
1.1.10	TEST	60.8
1.1.11	SYSTEM ENGINEERING	17.1
1.1.12	PROJECT MANAGEMENT	25.3
1.1.13	FACILITIES	16.8
1.1.14	CONSUMABLES (IN MILLIONS OF LBS)	55.0
	TOTAL COST	322.0

TABLE VI

AMOTV OPERATIONS WBS COSTS

- 44 ENGINE FLEET
- SERVICE 6 ENGINES/YEAR

1.3.1	INPLANT SUPPORT	0.87
1.3.2	FIELD SUPPORT	1.14
1.3.3	MAJOR ENGINE OVERHAUL	1.77
1.3.4	FACILITY MAINTENANCE	0.15
1.3.5	FOLLOW-ON SPARES	1.89
1.3.6	PROJECT MANAGEMENT	0.20
1.3.7	CONSUMABLES (IN MILLIONS OF LBS)	(0.20)
		6.02 M/YEAR
	TOTAL PROGRAM 6.02 M X 10 YEARS	60.2 M

The engine production costs for the APOTV are shown in Table VII. The APOTV nominal mission model has 450 reusable missions and 16 expendable planetary missions. It was estimated that 52 engines (26 sets) would be required to support the nominal APOTV mission model. In addition, 4 engines (2 sets) are required for the first two OTV's for a total of 56 engines. The APOTV engine production is also at a rate of 1 per month, which, compared to the AMOTV, extends this production program 12 months and results in increased costs.

The operations costs to support the APOTV mission model are shown in Table VIII. It was estimated that 8 engines (4 sets) per year would be overhauled. This number is higher than for the AMOTV because of the higher mission frequency and results in greater costs for items 1.3.2 and 1.3.3.

B. DETAILED COST ESTIMATE

A detailed cost estimate was prepared for the 20K lb thrust staged combustion cycle engine for the DDT&E, production, and operations phases. This estimate was prepared to the lowest identified WBS level. The data is presented in Tables IX, X and XI for the DDT&E, production, and operations phases, respectively.

C. TIME-PHASED COSTS

The DDT&E and production program funding schedules are presented in Tables XII and XIII. The funding schedule summary and overlap of the DDT&E and production programs are shown in Table XIV. The operations phase is shown for one year only per NASA instructions.

TABLE VII

APOTV PRODUCTION WBS COSTS

- 2 ENGINE VEHICLE
- 56 ENGINE PRODUCTION RUN

		Staged Combustion
1.2.1	MAIN ENGINES	142.8
1.2.2	INITIAL SPARES	2.1
1.2.3	FACILITY MAINTENANCE	4.6
1.2.4	SUSTAINING ENGINEERING	4.8
1.2.5	PROJECT MANAGEMENT	7.6
1.2.6	CONSUMABLES (IN MILLIONS OF LBS)	3.8
	TOTAL COST	161.9

MILLIONS OF DOLLARS

TABLE VIII

APOTV OPERATIONS WBS COSTS

- 56 ENGINE FLEET
- SERVICE 8 ENGINES/YEARS

1.3.1	INPLANT SUPPORT	0.87
1.3.2	FIELD SUPPORT	1.49
1.3.3	MAJOR ENGINE OVERHAUL	2.26
1.3.4	FACILITY MAINTENANCE	0.15
1.3.5	FOLLOW-ON SPARES	1.89
1.3.6	PROJECT MANAGEMENT	0.20
1.3.7	CONSUMABLES (IN MILLIONS OF LBS)	(0.25)
		6.86 M/YEAR
TOTAL PROGRAM 6.86 M X 10 YEARS		68.6 M

TABLE IX

20K LB THRUST STAGED COMBUSTION CYCLE ENGINE
DDT&E COST ESTIMATE
(NON-RECURRING)

WBS IDENT. NO.	WBS IDENTIFICATION	WBS LVL	EXPECT. COST	T (D)	T (S)	SPREAD FUNCT.
1.0	MAIN ENGINE	1	.0	0	0	
1.1	ENGINE DDT+E	2	322.0	69	69	
1.1.1	TURBOMACHINERY	3	39.4	57	69	
1.1.1.1	MAIN FUEL PUMP	4	9.1	54	69	70-30
1.1.1.2	MAIN OXIDIZER PUMP	4	9.0	54	69	70-30
1.1.1.3	FUEL BOOST PUMP	4	4.7	54	69	60-40
1.1.1.4	OXIDIZER BOOST PUMP	4	4.7	54	69	60-40
1.1.1.5	ASSEMBLY & CHECKOUT	4	11.9	39	51	50-50
1.1.2	MAIN COMBUSTION CHAMBER	3	37.6	57	69	
1.1.2.1	INJECTOR	4	7.7	54	69	70-30
1.1.2.2	CHAMBER	4	7.5	54	69	70-30
1.1.2.3	UPPER NOZZLE (FIXED)	4	5.7	54	69	70-30
1.1.2.4	IGNITER	4	3.9	54	69	70-30
1.1.2.5	GIMBAL ASSEMBLY	4	3.7	54	69	60-40
1.1.2.6	ASSEMBLY + CHECKOUT	4	9.1	39	51	50-50
1.1.3	PREBURNER/GAS GENERATOR	3	30.2	57	69	
1.1.3.1	INJECTOR	4	9.1	54	69	70-30
1.1.3.2	COMBUSTOR	4	8.8	54	69	70-30
1.1.3.3	IGNITER	4	4.6	54	69	70-30
1.1.3.4	ASSEMBLY + CHECKOUT	4	7.7	39	51	50-50
1.1.4	NOZZLE ASSEMBLY	3	7.3	57	69	
1.1.4.1	LOWER NOZZLE (EXTENDIBLE)	4	2.6	54	69	60-40
1.1.4.2	EXT./RETRACT. MECH.	4	2.5	54	69	60-40
1.1.4.3	ASSEMBLY & CHECKOUT	4	2.2	39	51	50-50
1.1.5	CONTROLS	3	26.4	57	69	
1.1.5.1	CONTROLLER + HARNESS	4	9.3	57	69	60-40
1.1.5.2	CONTROL VALVES	4	6.7	57	69	60-40
1.1.5.3	INSTRUMENTATION + HARNESS	4	2.7	57	69	60-40
1.1.5.4	ASSEMBLY + CHECKOUT	4	7.7	39	51	50-50
1.1.6	PRESSURIZATION	3	13.3	57	69	
1.1.6.1	HEAT EXCHANGERS	4	6.8	57	69	60-40
1.1.6.2	ASSEMBLY & CHECKOUT	4	6.5	39	51	50-50
1.1.7	PROPELLANT SYSTEMS	3	10.7	57	69	
1.1.7.1	FEED,FILL,VENT,ABORT DUMP + OR	4	5.2	57	69	60-40
1.1.7.2	ASSEMBLY + CHECKOUT	4	5.5	39	51	50-50
1.1.8	INITIAL TOOLING	3	20.5	57	69	80-20
1.1.9	GROUND SUPPORT EQUIP.	3	16.6	57	69	
1.1.9.1	HANDLING & PROTECTIVE EQUIP.	4	5.8	57	69	50-50
1.1.9.2	CHECKOUT & MAINT. EQUIP.	4	8.4	57	69	50-50
1.1.9.3	ASSEMBLY & CHECKOUT	4	2.4	39	51	50-50
1.1.10	TEST	3	60.8	69	69	
1.1.10.1	DEVELOPMENT TESTING	4	21.4	52	69	60-40
1.1.10.2	PFC TESTING	4	18.3	21	33	60-40
1.1.10.3	FFC TESTING	4	21.1	15	15	60-40
1.1.11	SYSTEM ENGR. + INTEGRATION	3	17.1	69	69	
1.1.11.1	INTEG. OF DDT+E ACTIVITIES	4	6.8	69	69	50-50
1.1.11.2	ENGINE ASSY. + CHECKOUT	4	5.2	39	51	50-50
1.1.11.3	ENGINE/VEHICLE INTERFACE	4	5.1	39	51	50-50
1.1.12	PROJECT MANAGEMENT	3	25.3	69	69	LOE
1.1.13	FACILITIES	3	16.8	57	69	70-30
1.1.14	CONSUMABLES(MILLIONS OF LBS)	3	55.0	54	54	60-40

TABLE X

20K LB THRUST STAGED COMBUSTION CYCLE ENGINE PRODUCTION COST ESTIMATE (RECURRING)

WBS IDENT. NO.	WBS IDENTIFICATION	WBS LVL	EXPECT. COST
1.2	PRODUCTION	2	137.0
1.2.1	MAIN ENGINES	3	119.3
1.2.1.1	TURBOMACHINERY	4	29.8
1.2.1.2	COMBUST. DEVICES	4	25.2
1.2.1.3	CONTROLS	4	27.4
1.2.1.4	PRESSURIZATION	4	11.9
1.2.1.5	PROPELLANT SYSTEMS	4	11.9
1.2.1.6	ENGINE ASSEMBLY	4	13.1
1.2.2	INITIAL SPARES	3	2.1
1.2.3	FACILITY MAINTENANCE	3	4.1
1.2.3.1	MFG. & TEST FACIL.	4	1.0
1.2.3.2	SUSTAIN TOOLING	4	2.1
1.2.3.3	GSE	4	1.0
1.2.4	SUSTAIN ENGINEERING	3	4.4
1.2.5	PROJECT MANAGEMENT	3	7.1
1.2.6	CONSUMABLES (POUNDS)	3	3.0

1ST UNIT COST = 4.2 MILLION DOLLARS

NO. OF UNITS = 44

TABLE XI

20K LB THRUST STAGED COMBUSTION CYCLE ENGINE OPERATIONS COST ESTIMATE (RECURRING)

Identification Number	WBS Identification	WBS Level	Expect Cost
1.3	Operations	2	6.02
1.3.1	Inplant Support	3	.87
1.3.2	Field Support	3	1.14
1.3.2.1	Launch Support	4	.14
1.3.2.2	Flight Support	4	.12
1.3.2.3	Refurb. & Maint.	4	.53
1.3.2.4	Checkout	4	.35
1.3.3	Major Eng. Overhaul	3	1.77
1.3.4	Facility Maintenance	3	.15
1.3.5	Follow-on Spares	3	1.89
1.3.6	Project Management	3	.20
1.3.7	Consumables	3	(.20 million lbs)

TABLE XII

DDT&E FUNDING SCHEDULE

DDT&E COSTS (THOUSANDS OF DOLLARS)

20K STAGED COMBUSTION CYCLE ENGINE

WBS Identification	WBS IDENT. NO.	COST CATEGORY	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	TOTAL
DDT&E	1.1	TOTAL	35879.0	79536.1	85084.6	69419.2	36179.8	15901.2	321999.9
TURBOMACHINERY	1.1.1	TOTAL	4574.7	11273.2	12669.5	8296.0	2586.6	.0	39400.0
MAIN COMBUSTION CHAMBER	1.1.2	TOTAL	4990.9	11816.4	11467.0	7126.2	2199.5	.0	37600.0
PREBURNER/GAS GENERATOR	1.1.3	TOTAL	4061.0	9544.2	9005.0	5797.5	1792.3	.0	30200.0
NOZZLE ASSEMBLY	1.1.4	TOTAL	709.6	1885.6	2617.8	1590.2	496.8	.0	7300.0
CONTROLS	1.1.5	TOTAL	2370.7	6350.8	9388.2	6162.6	2127.8	.0	26400.0
PRESSURIZATION	1.1.6	TOTAL	862.1	2578.3	4759.8	3812.6	1287.2	.0	13300.0
PROPELLANT SYSTEMS	1.1.7	TOTAL	659.2	2010.1	3832.5	3140.4	1057.8	.0	10700.0
INITIAL TOOLING	1.1.8	TOTAL	4362.2	9719.2	4097.8	1493.3	827.6	.0	20500.0
GROUND SUPPORT EQUIPMENT	1.1.9	TOTAL	1696.5	3797.0	5494.8	4206.2	1405.5	.0	16600.0
TEST	1.1.10	TOTAL	3615.0	7786.3	7192.0	15388.2	14622.7	12195.8	60800.0
SYS. ENG. & INTEGRATION	1.1.11	TOTAL	599.3	2007.0	5539.4	6034.3	2537.1	382.9	17100.0
PROJECT MANAGEMENT	1.1.12	TOTAL	4257.5	4430.0	4430.0	4430.0	4430.0	3322.5	25300.0
FACILITIES	1.1.13	TOTAL	3120.4	6338.0	4590.8	1941.7	809.1	.0	16800.0
CONSUMABLES	1.1.14	TOTAL	.0	5371.7	16799.4	20319.4	9282.8	3226.7	55000.0

TABLE XIII

PRODUCTION FUNDING SCHEDULE

PR[illegible] [illegible]TION C[illegible]STS ([illegible]S OF DOLLARS)

20K STAGED COMBUSTION CYCLE ENGINE

IDENT. NO.	WBS IDENTIFICATION	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	TOTAL
1.2	PRODUCTION	2397.5	9110.[illegible]	10617.5	12672.5	23358.5	29934.5	29345.5	19563.5	137800.0
1.2.1	MAIN ENGINES	2087.7	7935.4	9245.7	11035.2	20340.6	26067.3	25424.9	16165.2	119300.0
1.2.1.1	TURBOMACHINERY	521.5	1981.	[illegible].5	2756.5	5080.9	6511.[illegible]	6500.7	4037.9	29806.0
1.2.1.2	COMB. DEVICES	441.0	1675.6	1[illegible].0	2331.0	4296.6	5506.2	5581.8	3414.6	25200.0
1.2.1.3	CONTROLS	479.5	1822.1	[illegible].5	2534.5	4671.7	5986.9	6069.1	3712.7	27400.0
1.2.1.4	PRESSURIZATION	208.2	791.[illegible]	922.2	1100.7	2028.9	2600.1	2635.8	1612.5	11900.0
1.2.1.5	PROPELLANT SYSTEMS	208.2	791.[illegible]	922.2	1100.7	2028.9	2600.1	2635.8	1612.5	11900.0
1.2.1.6	ENGINE ASSEMBLY	229.2	871.[illegible]	[illegible].2	1211.7	2233.5	2862.3	2901.6	1775.1	13100.0
1.2.[illegible]	INITIAL SPARES	36.7	139.[illegible]	16[illegible].7	194.2	358.0	458.8	465.1	284.6	2100.0
1.2.[illegible]	FACILITY MAINTENANCE	71.7	272.[illegible]	317.7	379.2	699.0	895.9	908.1	555.6	4100.0
1.2.[illegible].1	MFG. & TEST FACIL.	17.5	66.[illegible]	77.5	92.5	170.5	218.5	221.5	135.5	1000.0
1.2.[illegible].2	SUSTAIN TOOLING	36.7	139.[illegible]	162.7	194.2	358.0	458.8	465.1	284.6	2100.0
1.2.[illegible].3	GSE	17.5	66.[illegible]	77.5	92.5	170.5	218.5	221.5	135.5	1000.0
1.2.[illegible]	SUSTAIN ENGINEERING	77.0	292.[illegible]	341.0	407.0	750.2	961.4	974.6	596.2	4400.0
1.2.[illegible]	PROJECT MANAGEMENT	124.2	472.[illegible]	550.2	656.7	1210.5	1551.[illegible]	1572.6	962.1	7100.0
1.2.[illegible]	CONSUMABLES (POUNDS)	52.5	199.5	232.5	277.5	511.5	655.5	664.5	406.5	3000.0

TABLE XIV

FUNDING SCHEDULE SUMMARY (MILLIONS OF DOLLARS)

Project WBS Items	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	Total
Engine DDT&E	35.9	79.5	85.1	69.4	36.2	15.9				322.0
Production		2.4	9.1	10.6	12.7	23.4	29.9	30.3	18.6	137.0
Operations (1 yr only)										6.02

VI. COMPARISONS

The cost data shown in the 29 June 1979 Cost Estimate Report on the Advanced Expander Cycle Engine were presented at ALRC's recommended 10K lb thrust level. In order to provide a consistent comparison between the staged combustion and expander cycle engines, cost data were also calculated at the 20K lb thrust level for the expander cycle engine. The 10K expander cycle engine data presented in June of 1979 are also shown to summarize the cost analyses results completely.

Cost comparisons between expander staged combustion cycle engines are shown in Figures 9 through 13 for DDT&E, Production and Operations. Conclusions drawn from the cost analyses are shown in Figure 14. Operations costs for the two engines would be the same, except for the guideline used to calculate the follow-on spares as a function of the theoretical first unit cost (TFU).

		MILLIONS OF DOLLARS		
		20K LBF STAGED COMBUSTION	10K LBF EXPANDER	20K LBF EXPANDER
1.1.1	TURBOMACHINERY	39.4	30.2	32.9
1.1.2	MAIN COMBUSTION CHAMBER	37.6	22.4	24.4
1.1.3	PREBURNER/GAS GENERATOR	30.2	0.0	0.0
1.1.4	NOZZLE ASSEMBLY	7.3	5.6	6.1
1.1.5	CONTROLS	26.4	13.6	14.8
1.1.6	PRESSURIZATION	13.3	10.2	11.1
1.1.7	PROPELLANT SYSTEMS	10.7	6.6	7.2
1.1.8	INITIAL TOOLING	20.5	12.6	13.8
1.1.9	GROUND SUPPORT EQUIPMENT	16.6	12.7	13.8
1.1.10	TEST	60.8	39.6	43.2
1.1.11	SYSTEM ENGINEERING	17.1	11.8	12.9
1.1.12	PROJECT MANAGEMENT	25.3	17.5	19.1
1.1.13	FACILITIES	16.8	11.6	12.7
1.1.14	CONSUMABLES (IN MILLIONS OF LBS)	(55.0)	(21.7)	(43.4)
	TOTAL COST	322.0	194.4	212.0

Figure 9. DDT&E WBS Costs Compared

- 2 ENGINE VEHICLE
- 44 ENGINE PRODUCTION RUN

		MILLIONS OF DOLLARS		
		20K LBF STAGED COMBUSTION	10K LBF EXPANDER	20K LBF EXPANDER
1.2.1	MAIN ENGINES	119.3	76.8	90.0
1.2.2	INITIAL SPARES	2.1	1.3	1.5
1.2.3	FACILITY MAINTENANCE	4.1	3.5	4.1
1.2.4	SUSTAINING ENGINEERING	4.4	3.7	4.3
1.2.5	PROJECT MANAGEMENT	7.1	6.0	7.1
1.2.6	CONSUMABLES (IN MILLIONS OF LBS)	3.0	(1.5)	(3.0)
	TOTAL COST	137.0	91.3	107.[illegible]

MILLIONS OF DOLLARS

Figure 10. AMOTV Production WBS Costs Compared

- 2 ENGINE VEHICLE
- 56 ENGINE PRODUCTION RUN

		20K LBF STAGED COMBUSTION	10K LBF EXPANDER	20K LBF EXPANDER
1.2.1	MAIN ENGINES	142.8	94.4	110.7
1.2.2	INITIAL SPARES	2.1	1.3	1.5
1.2.3	FACILITY MAINTENANCE	4.6	4.0	4.7
1.2.4	SUSTAINING ENGINEERING	4.8	4.2	4.9
1.2.5	PROJECT MANAGEMENT	7.6	6.7	7.9
1.2.6	CONSUMABLES (IN MILLIONS OF LBS)	3.8	(1.9)	(3.8)
	TOTAL COST	161.9	110.6	129.7

MILLIONS OF DOLLARS

Figure 11. APOTV Production WBS Costs Compared

- 44 ENGINE FLEET
- SERVICE 6 ENGINES/YEAR

		20K LBF STAGED COMBUSTION	10K LBF EXPANDER	20K LBF EXPANDER
1.3.1	INPLANT SUPPORT	0.87	0.87	0.87
1.3.2	FIELD SUPPORT	1.14	1.14	1.14
1.3.3	MAJOR ENGINE OVERHAUL	1.77	1.77	1.77
1.3.4	FACILITY MAINTENANCE	0.15	0.15	0.15
1.3.5	FOLLOW-ON SPARES	1.89	1.20	1.35
1.3.6	PROJECT MANAGEMENT	0.20	0.20	0.20
1.3.7	CONSUMABLES (IN MILLIONS OF LBS)	(0.20)	(0.20)	(0.20)
		6.02 M/YR	5.33 M/YR	5.48 M/YR
	TOTAL PROGRAM = 10 YEARS	60.2 M	53.3 M	54.8 M

Figure 12. AMOTV Operations WBS Costs Compared

- 56 ENGINE FLEET
- SERVICE 8 ENGINES/YEARS

		20K LBF STAGED COMBUSTION	10K LBF EXPANDER	20K LBF EXPANDER
1.3.1	INPLANT SUPPORT	0.87	0.87	0.87
1.3.2	FIELD SUPPORT	1.49	1.49	1.49
1.3.3	MAJOR ENGINE OVERHAUL	2.26	2.26	2.26
1.3.4	FACILITY MAINTENANCE	0.15	0.15	0.15
1.3.5	FOLLOW-ON SPARES	1.89	1.20	1.35
1.3.6	PROJECT MANAGEMENT	0.20	0.20	0.20
1.3.7	CONSUMABLES (IN MILLIONS OF LBS)	(0.25)	(0.25)	(0.25)
		6.86 M/YR	6.17 M/YR	6.32 M/YR
	TOTAL PROGRAM = 10 YEARS	68.6 M	61.7 M	63.2 M

Figure 13. APOTV Operations WBS Costs Compared

- ELIMINATION OF PREBURNER LOWERS DDT&E COSTS
- FEWER COMPONENTS LOWER EXPANDER CYCLE PRODUCTION COSTS
- THE EXPANDER CYCLE ENGINE IS THE LOWER RISK AND LOWER COST OPTION

Figure 14. Cost Analysis Conclusions