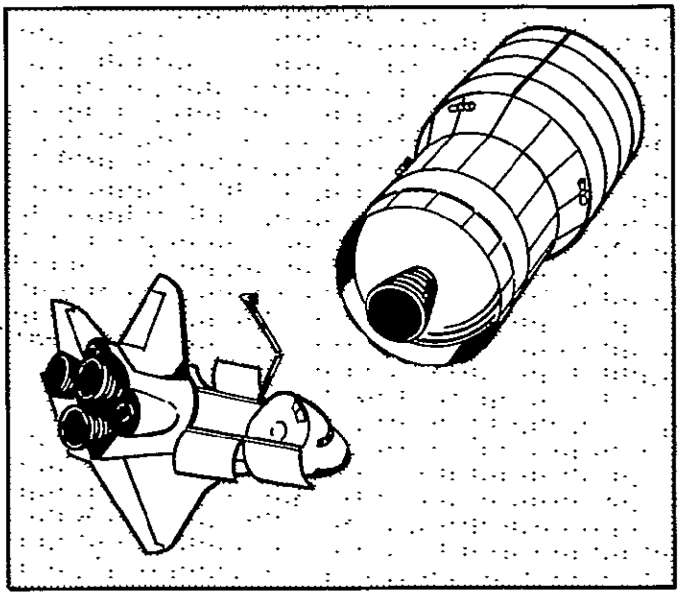
Orbit Transfer Vehicle(OTV) Engine Phase "A" Study

Contract NAS 8-32999
Bi-Monthly Status Report 32999-M2
15 October 1978

Prepared For:
NASA - George C. Marshall Space Flight Center



Aerojet
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Company

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Report 32999-M2

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ORBIT TRANSFER VEHICLE (OTV) ENGINE PHASE "A" STUDY

Bi-Monthly Status Report No. 2

1 August 1978 to 30 Sept 1978

Contract NAS 8-32999

Prepared for:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

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FOREWORD

This bi-monthly status report is submitted for the Orbit Transfer Vehicle (OTV) Engine Phase "A" Study per the requirements of Contract NAS 8-32999, Data Procurement Document No. 559, Data Requirement No. MA-02. This work is being performed by the Aerojet Liquid Rocket Company for the NASA-Marshall Space Flight Center. The study authority to proceed date was 10 July 1978.

This study program consists of parametric trades and system analysis which will lead to conceptual designs of the OTV engine for use by the OTV systems contractor.

The NASA/MSFC COR is Mr. D. H. Blount. The ALRC Program Manager is Mr. L. B. Bassham, and the Study Manager is Mr. J. A. Mellish.

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I. INTRODUCTION

The Space Transportation System (STS) includes an Orbit Transfer Vehicle (OTV) that is carried into low Earth orbit by the Space Shuttle. The primary function of this OTV is to extend the STS operating regime beyond the Shuttle to include orbit plane changes, higher orbits, geosynchronous orbits and beyond. The NASA and DOD have been studying various types of OTV's in recent years. Data have been accumulated from the analyses of the various concepts, operating modes and projected missions. The foundation formulated by these studies established the desirability and the benefits of a low operating cost, high performance, versatile OTV. The OTV must be reusable to achieve a low operating cost. It is planned that an OTV have an Initial Operating Capability (IOC) in 1987.

The OTV has as a goal the same basic characteristics as the Space Shuttle, i.e., reusability, operational flexibility, and payload retrieval along with a high reliability and low operating cost. It is necessary to obtain sufficient data, of a depth to assure credibility, from which comparative systems analyses can be made to identify the development, costs, and program requirements for OTV concepts. The maximum potential of each concept to satisfy the mission goals will be identified in the OTV systems studies to be initiated in FY-79.

An assessment of the above factors will be made by the NASA to determine the candidate approaches for matching the OTV concepts to mission options within resource and schedule requirements. This study will provide the necessary data on OTV engine concept(s) based upon 1980 technology which is required to objectively select, define, and design the preferred OTV engine, and is being conducted in very close concert with the NASA.

I, Introduction (cont.)

The major objective of this Phase "A" engine study is to provide design and parametric data on the OTV engine for use by NASA and the OTV systems contractors. These data and the systems analyses will ultimately lead to the identification of the OTV engine requirements so that the conceptual design phase can be initiated. Specific study objectives are:

- Review the OTV engine requirements identified in the statement of work, make recommendations and iterate with NASA/MSFC.
- Conduct trade studies and system analyses necessary to define the engine concept(s) which meets the OTV engine requirements.
- Generate parametric OTV engine data and provide this data in suitable format for use by the OTV system contractors.
- Prepare a final report at the completion of the study which documents the technical and programmatic assessments of the OTV engine concepts studied.

To accomplish the program objectives, a study program consisting of seven major technical tasks and a reporting task is being conducted. These tasks are:

- Task I: Engine Requirement Review
- Task II: Engine Concept Definition
- Task III: Parametric Engine Data
- Task IV: Engine Off-Design Operation
- Task V: Work Breakdown Structure
- Task VI: Programmatic Analysis and Planning
- Task VII: Cost Estimate
- Task VIII: Reports Requirements

II. SUMMARY

This second bi-monthly status report covers the period from 1 August to 30 September 1978. Major effort during this reporting period was placed upon Tasks I and II.

The review of the engine requirements set forth in the statement of work was continued and trade studies on staged combustion, expander and gas generator engine cycles are being conducted to define an engine concept which meets the OTV engine requirements.

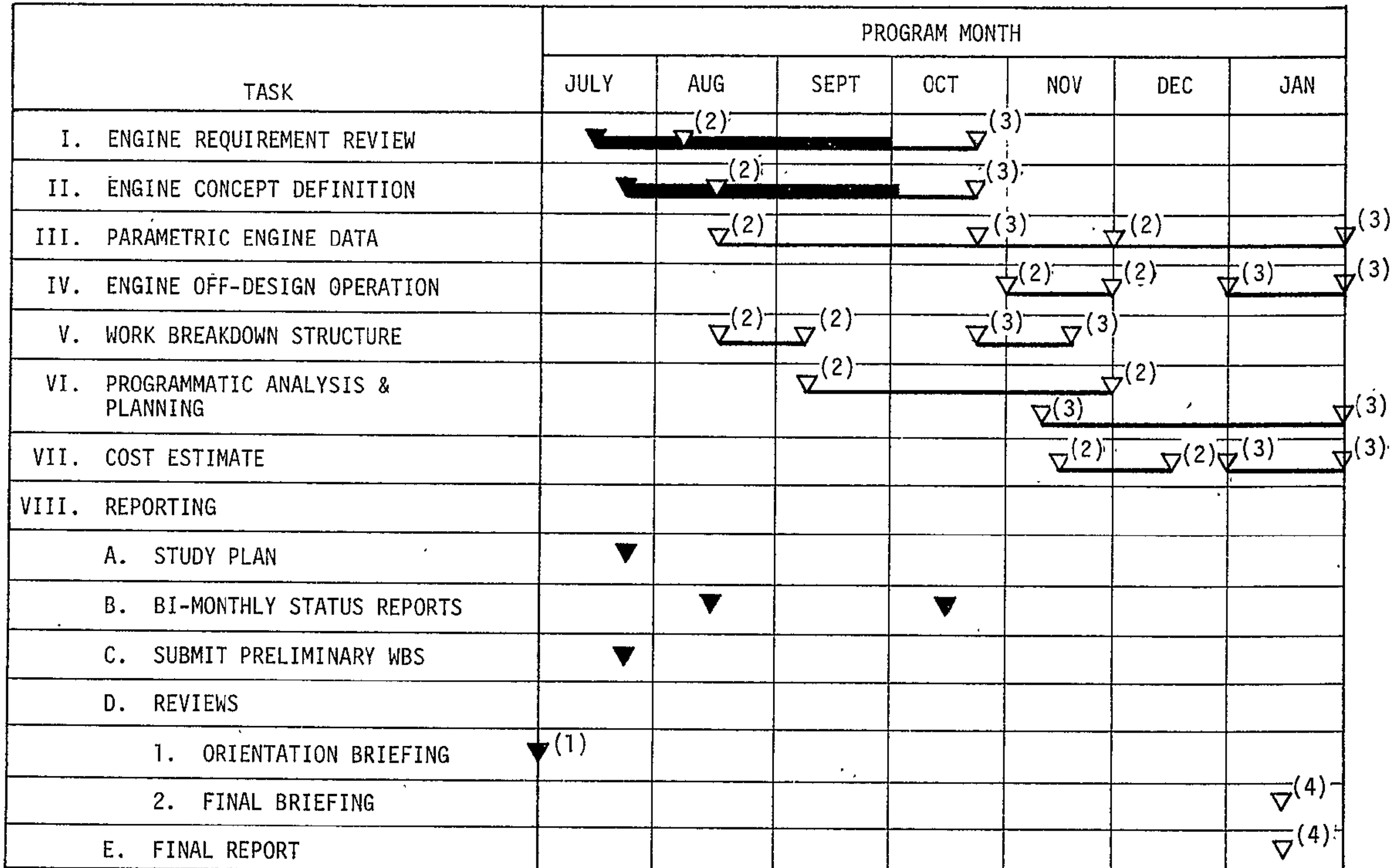
During the performance of Tasks I and II, it became obvious that an intelligent engine concept and cycle selection could not be made without at least preliminary parametric performance, weight, envelope, programmatic and cost data on all three engine cycles under consideration for the OTV application. Because of funding limitations, only one engine cycle was planned to be analyzed in Tasks III through VII under the contract. Therefore, a company sponsored effort was initiated to obtain the required data on all cycle candidates. This has resulted in schedule problems as shown on Figure 1 although the contract will benefit from a more thorough study.

The payload, specific impulse and engine weight trade-off results to date for single engine installations have shown that:

- Staged combustion cycle engines have the highest payload capability.

- Expander cycle engines can deliver approximately the same payload as staged cycle engines in an 8K to 15K lbf thrust range.

- Gas generator cycle engines result in payload penalties over the total thrust range.



(1) 28 June 1978
(2) Original Schedule
(3) Current Schedule
(4) To Be Rescheduled

Figure 1. Study Program Milestone Schedule

II, Summary (cont.)

Programmatic and life cycle cost considerations are being factored into the analysis. The cycle finally recommended to be carried throughout the remaining study tasks will be selected on the basis of all the technica programmatic and cost data.

The Task I and II review has been scheduled for 24 October 1978 at NASA/MSFC. This date has been mutually agreed upon by the NASA/COR and ALRC. All contract and ALRC in-house study results shall be reviewed at this time and an engine concept and cycle recommended for Task III through VII analyses.

III. TECHNICAL PROGRESS

A. TASK I - ENGINE REQUIREMENT REVIEW

The major Phase A OTV engine requirements are shown on Figures 2 and 3 and the parametric ranges under consideration are shown on Figure 4. The study has shown that the major "drivers" in these requirements are the life cycle, man-rating and specific impulse requirements.

The life cycle requirement limits the maximum operating pressure of the staged combustion cycle engine over the whole thrust range. The expander and gas generator cycle engines are pressure limited by this requirement at low thrust.

The man-rating requirement imposes valve redundancy requirements which result in engine weight penalties.

The specific impulse requirement results in high area ratio nozzles. This establishes the required chamber pressure for any given engine length with the extendible nozzle in the stowed position. The chamber pressures and nozzle area ratios required to meet the minimum specific impulse requirements for a staged combustion cycle engine are shown on Figure 5 and Table I. Chamber length requirements are different for the various cycles and the effect this has on the pressure and area ratio design points is shown on Figure 6 and Table II.

Analyses were then undertaken in Task II to see if the engine cycles could operate at the required chamber pressures.

- PROPELLANTS: HYDROGEN AND OXYGEN
- TECHNOLOGY BASE: 1980 STATE-OF-THE-ART
- ENGINE MIXTURE RATIO: NOMINAL = 6.0 RANGE = 6.0 TO 7.0
- PROPELLANT INLET CONDITIONS:

		H_2	O_2
BOOST PUMP	NPSH, FT	15	2
	TEMP., °F	37.8	162.7

- SERVICE LIFE BETWEEN OVERHAULS: 300 CYCLES & 10 HRS
- ENGINE NOZZLE: CONTOURED BELL WITH EXTENDIBLE/RETRACTABLE SECTION
- GIMBAL ANGLE: +15°, -6° PITCH
  ±6° YAW
- PROVIDE GASEOUS HYDROGEN & OXYGEN TANK PRESSURIZATION
- MAN-RATED WITH ABORT RETURN CAPABILITY
- THRUST CHAMBER PRESSURE: TBD
- ENGINE WEIGHT: TBD
- ENGINE ENVELOPE: TBD
- ENGINE SPECIFIC IMPULSE: MINIMUM REQUIREMENTS AS SPECIFIED ON NEXT FIGURE.

Figure 2. Phase A OTV Engine Requirements

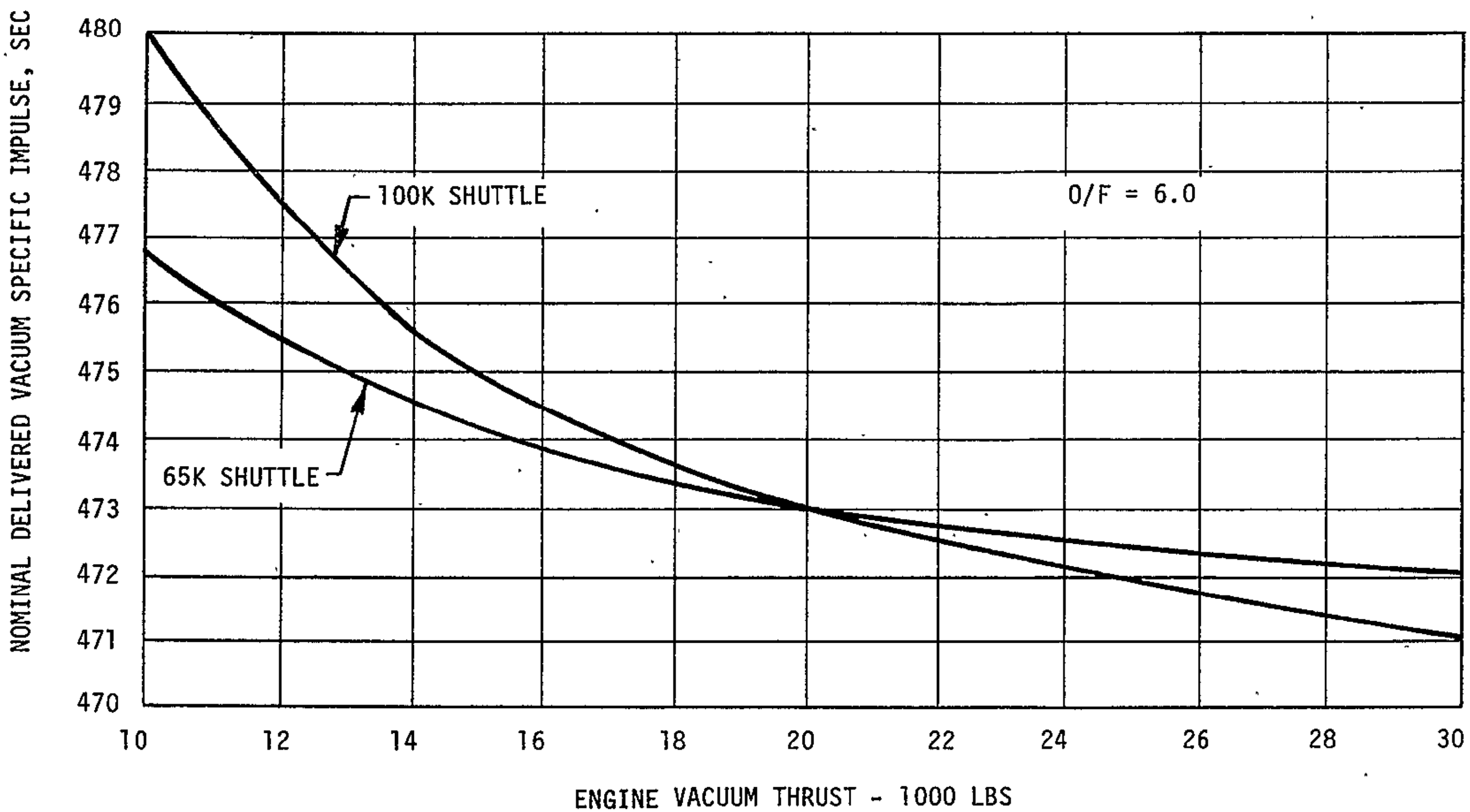


Figure 3. OTV Engine Nominal Specific Impulse vs Engine Vacuum Thrust

- THRUST LEVEL: 10,000 TO 30,000 LB[1]
- MAXIMUM RETRACTED LENGTH: 50, 60 & 70 INCHES
- NOZZLE AREA RATIO: TBD

NOMINAL THRUST = 20,000 LB

NOMINAL RETRACTED LENGTH = 60 IN.

NOMINAL EXTENDED LENGTH = 120 IN.

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(1) Investigated as Low as 8K lb_f For The Concept Review

Figure 4. Phase A OTV Parametric Ranges

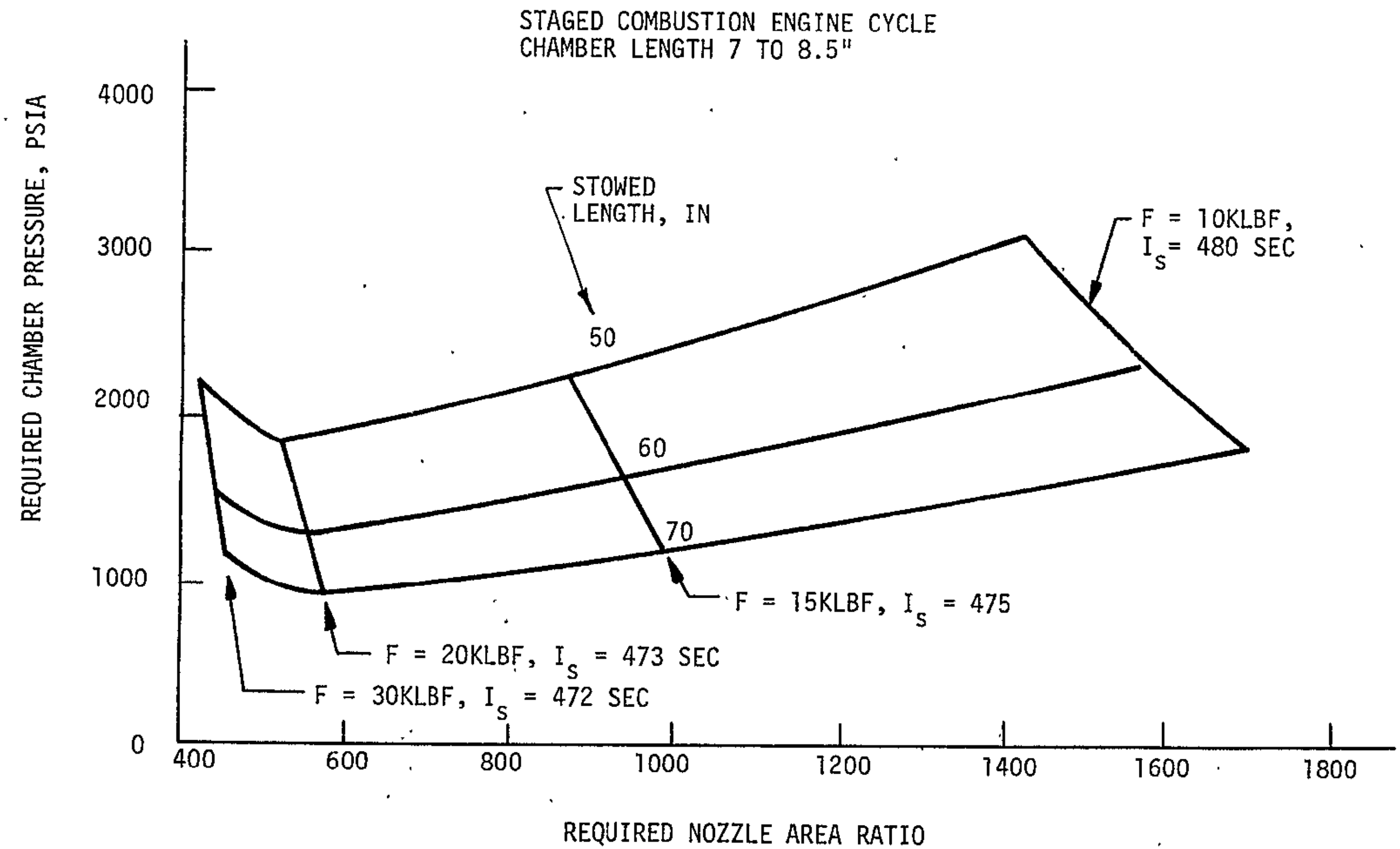


Figure 5. Sensitivity of Engine Design Point To Performance and Stowed Length Requirements.

TABLE I

REQUIRED STAGED COMBUSTION ENGINE CYCLE DESIGN POINTS TO MEET PERFORMANCE AND MAXIMUM LENGTH REQUIREMENTS

THRUST, K LB	MINIMUM REQUIRED I_s SEC	MAX. RETRACTED LENGTH, IN.	REQUIRED CHAMBER PRESSURE, PSIA	REQUIRED AREA RATIO
10	480	50	3120	1421
↓	↓	60	2359	1572
↓	↓	70	1850	1698
20	473	50	1847	522
↓	↓	60	1281	548
↓	↓	70	945	569
30	472	50	2245	415
↓	↓	60	1550	439
↓	↓	70	1124	454

CHAMBER LENGTHS: 7 TO 8.5 IN.

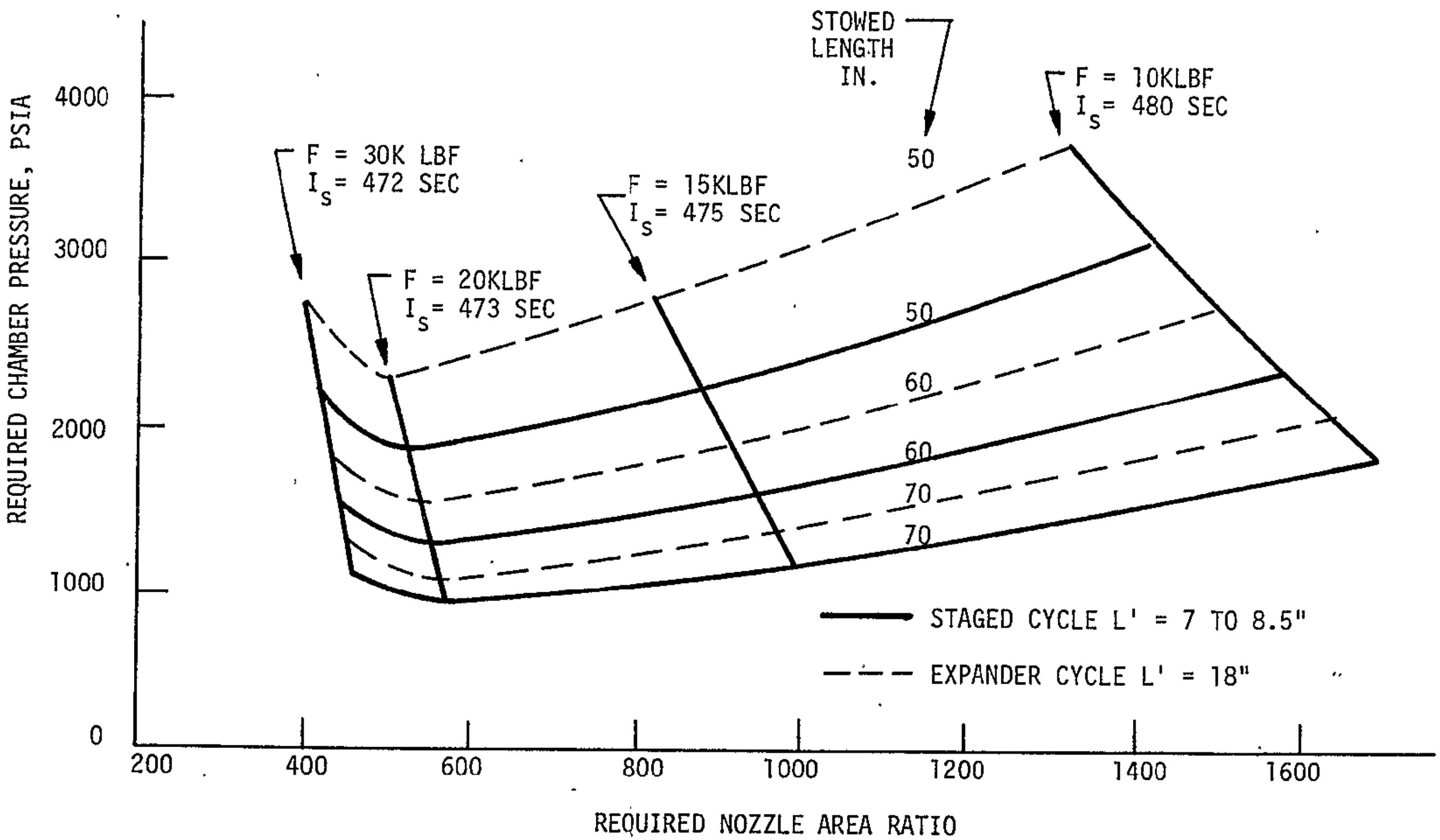


Figure 6. Effect of Chamber Length Requirement Upon Required Chamber Pressure and Area Ratio

TABLE II

REQUIRED EXPANDER CYCLE ENGINE DESIGN POINTS TO MEET PERFORMANCE AND MAXIMUM LENGTH REQUIREMENTS

THRUST K LB	MINIMUM REQUIRED I_S SEC	MAX. RETRACTED LENGTH, IN.	REQUIRED CHAMBER PRESSURE, PSIA	REQUIRED AREA RATIO
10	480	50	3699	1315
↓	↓	60	2745	1491
		70	2117	1640
20	473	50	2285	499
↓	↓	60	1531	535
		70	1084	556
30	472	50	2785	396
↓	↓	60	1852	429
		70	1303	447

CHAMBER LENGTH = 18 IN.

B. TASK II - ENGINE CONCEPT DEFINITION

Engine cycle power balance, heat transfer and performance/weight/payload tradeoffs were conducted to establish chamber pressure limitations and relative capability of the various cycles.

The baseline orbit transfer vehicle characteristics and the payload/I_s and payload/engine weight sensitivities used in the analyses are shown on Figure 7.

The staged combustion maximum operating pressure is life limited. The expander cycle engine is power balance limited except at low thrust (about 8K) where it becomes life limited. Due to the performance loss associated with the turbine exhaust, the gas generator cycle is performance limited except at low thrust were it also becomes life limited. The limiting chamber pressures are shown on Table III as a function of thrust.

The gas generator cycle engine performance and weight data and chamber pressure optimization are shown on Figures 8 and 9, respectively.

The performance, weight and relative payload capability for the various engine cycles is shown on Table IV. The table shows that the staged cycle engine has the highest payload capability although expander cycle engines are competitive at low thrust. Gas generator cycle engines result in payload losses over the entire thrust range.

- MAN-RATED
- INITIAL OPERATING CAPABILITY - 1987
- DESIGN MISSION - 4 MAN, 30 DAY SORTIE TO GEOSYNCHRONOUS ORBIT
- ROUND TRIP PAYLOAD - 13,000 LB
- INITIAL OTV IGNITION WEIGHT = 97,300 LB
- AEROMANEUVERING ORBIT TRANSFER VEHICLE (AMOTV) PAYLOAD SENSITIVITIES:

$$\frac{\Delta W_{PL}}{\Delta I_S} = 73 \text{ LB/SEC}$$

$$\frac{\Delta W_{PL}}{\Delta W_{ENG}} = -1.1 \text{ LB/LB}$$

Figure 7. Baseline Orbit Transfer Vehicle Characteristics

TABLE III

MAXIMUM ENGINE OPERATING PRESSURES

CYCLE	VACUUM THRUST, K LB	THRUST CHAMBER PRESSURE, PSIA	LIMITATION
STAGED COMBUSTION	8	1400	CHAMBER CYCLE LIFE
↓	10	1500	↓
↓	20	2000	↓
↓	30	2350	↓
EXPANDER	8	1400	CHAMBER CYCLE LIFE
↓	10	1300	POWER BALANCE
↓	20	1000	↓
↓	30	850	↓
GAS GENERATOR	8	1400	CHAMBER CYCLE LIFE
↓	10	1500	PERFORMANCE
↓	20	1500	↓
↓	30	1500	↓

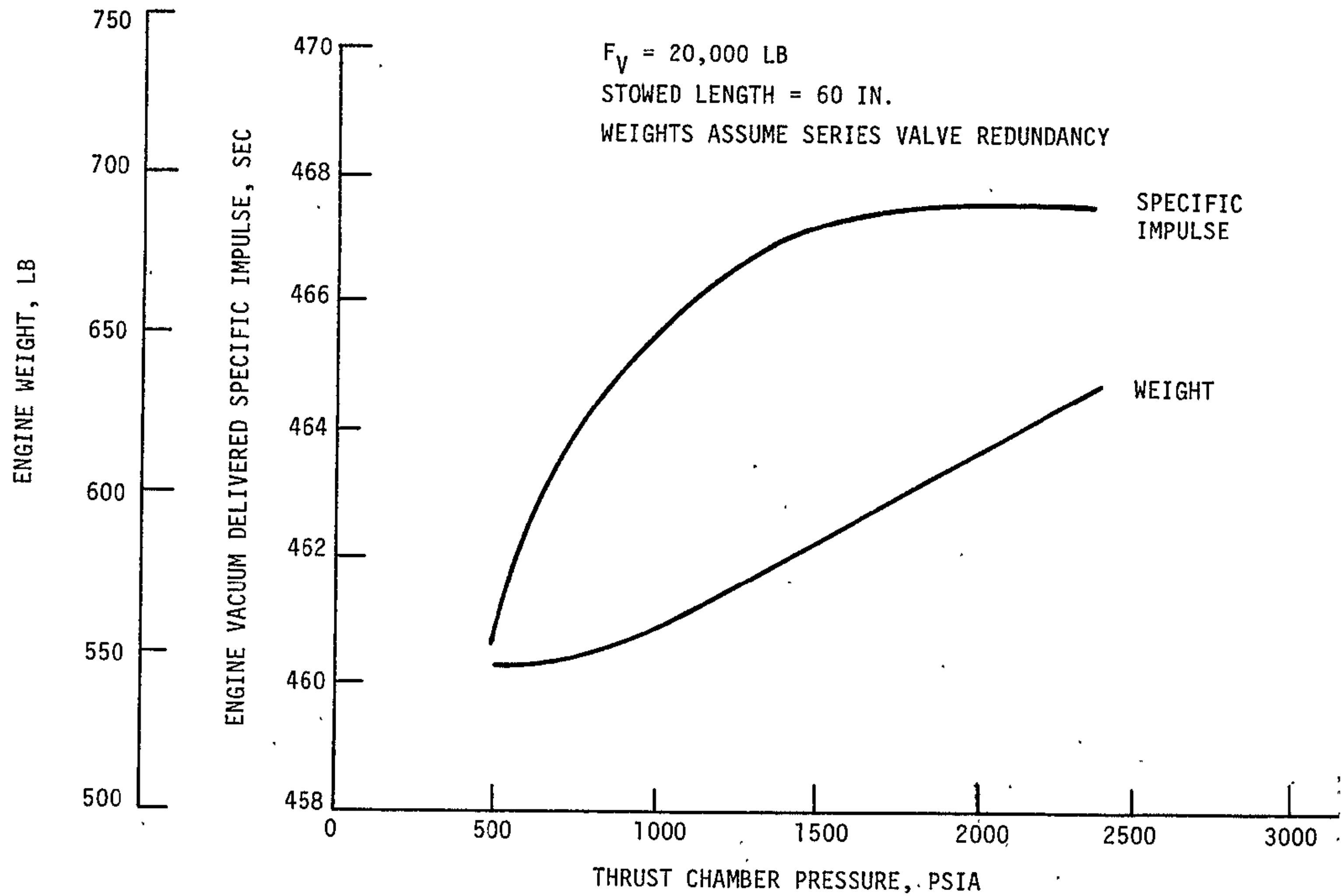


Figure 8. Gas Generator Cycle Engine Performance and Weight Data

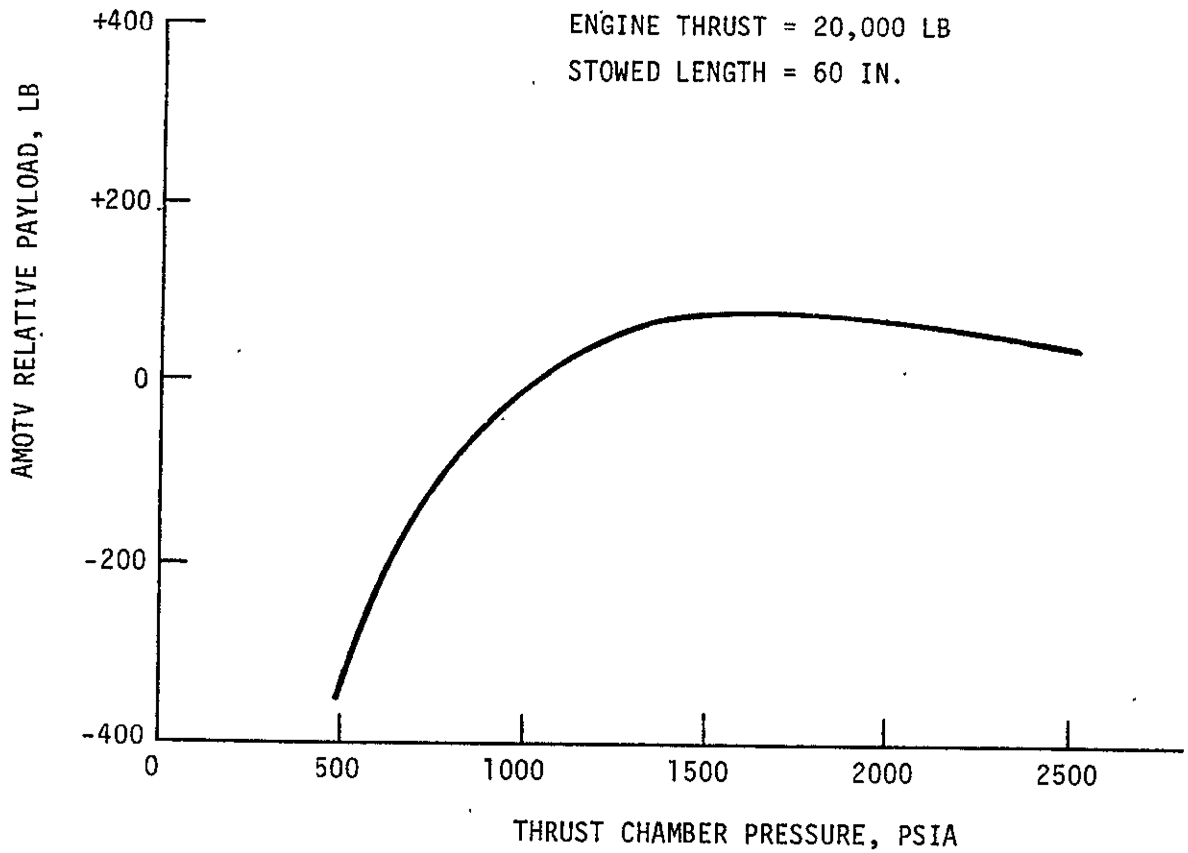


Figure 9. Gas Generator Cycle Chamber Pressure Optimization

TABLE IV

ENGINE CYCLE COMPARISONS - SINGLE ENGINE INSTALLATIONS

(STOWED ENGINE LENGTH = 60 IN.)

CYCLE	THRUST, LB	MIN. REQ. I_s SEC	CHAMBER PRESSURE, PSIA	NOZZLE AREA RATIO	VACUUM DELIVERED SPECIFIC IMPULSE, SEC	ENGINE DRY WEIGHT,[2] LB	AMOTV RELATIVE PAYLOAD,[1] LB
STAGED COMB.	8K	488	1400	1034	477.2	469	-515
↓	10K	480	1500	938	477.0	514	+5
(BASELINE)	20K	473	2000	699	476.5	718	+256
↓	30K	472	2350	552	475.7	899	+71
EXPANDER	8K	488	1400	898	476.2	424	-538
↓	10K	480	1300	782	475.1	462	-76
↓	20K	473	1000	309	469.4	580	-111
↓	30K	472	850	186	464.9	691	-489
GAS GENERATOR	8K	488	1400	968	470.8	434	-943
↓	10K	480	1500	858	470.0	470	-457
↓	20K	473	1500	486	467.2	617	-312
↓	30K	472	1500	327	464.6	741	-566

(1) COMPUTED FOR MIN I_s REQUIREMENT AT EACH THRUST LEVEL
BASE ENGINE WEIGHT = 718 LB.

(2) ASSUMES QUAD. MAIN ENGINE VALVES

C. TASK III - PARAMETRIC ENGINE DATA

Initiation of this task has been delayed until an engine cycle is selected.

D. TASK IV - ENGINE OFF-DESIGN OPERATION

No activity scheduled.

E. TASK V - WORK BREAKDOWN STRUCTURE

The WBS will be updated when an engine concept has been selected.

F. TASK VI - PROGRAMMATIC ANALYSIS AND PLANNING

Initiation of this task has been delayed until an engine cycle is selected.

G. TASK VII - COST ESTIMATE

No scheduled activity.

H. TASK VIII - REPORTS REQUIREMENTS

The Task I and II review was rescheduled with NASA concurrence to 24 October 1978.

IV. CURRENT PROBLEMS

The program is approximately 1-1/2 months behind schedule as shown on Figure 1. This delay has been created by the extension of the concept definition phase and scope of work with ALRC in-house funds. Attempts to make up some of the schedule slip will be made in the months following the concept review.

V. WORK PLANNED

The work planned for the next two months under the revised schedule is discussed for each task in the paragraphs which follow.

A. TASK I - ENGINE REQUIREMENT REVIEW

Complete the review of the OTV engine requirements, make recommendations and iterate with NASA/MSFC.

B. TASK II - ENGINE CONCEPT DEFINITION

Complete the tradeoff analyses to select an engine cycle and concept which best meets the engine requirements. Conduct a review of the trades, rationale and selection with NASA.

C. TASK III - PARAMETRIC ENGINE DATA

Conduct the technical effort to define the engine performance, weight and envelope parametric data for the selected engine concept.

D. TASK IV - ENGINE OFF-DESIGN OPERATION

No activity scheduled.

V, Work Planned (cont.)

E. TASK V - WORK BREAKDOWN STRUCTURE

Update the WBS for the selected engine concept. Review the WBS dictionary and iterate with NASA.

F. TASK VI - PROGRAMMATIC ANALYSIS AND PLANNING

Initiate effort to define the engine DDT&E schedule and component test requirements.

G. TASK VII - COST ESTIMATE

No activity scheduled.

H. TASK VIII - REPORTS REQUIREMENTS

Conduct the engine requirement and engine concept definition review with NASA on 24 October 1978.

VI. MAN-HOUR EXPENDITURES

The planned vs actual man-hours expended during this reporting period are shown on Figure 10. The low actual expenditure rate reflects the delay in the initiation of Tasks III, V and VI.

National Aeronautics and Space Administration
Contractor Man Hour Management Report

Report for Month Ending: 1 October 1978 (19 days)

To: Financial Management Office
George C. Marshall Space Flight Center, NASA
Marshall Space Flight Center, AL 35812

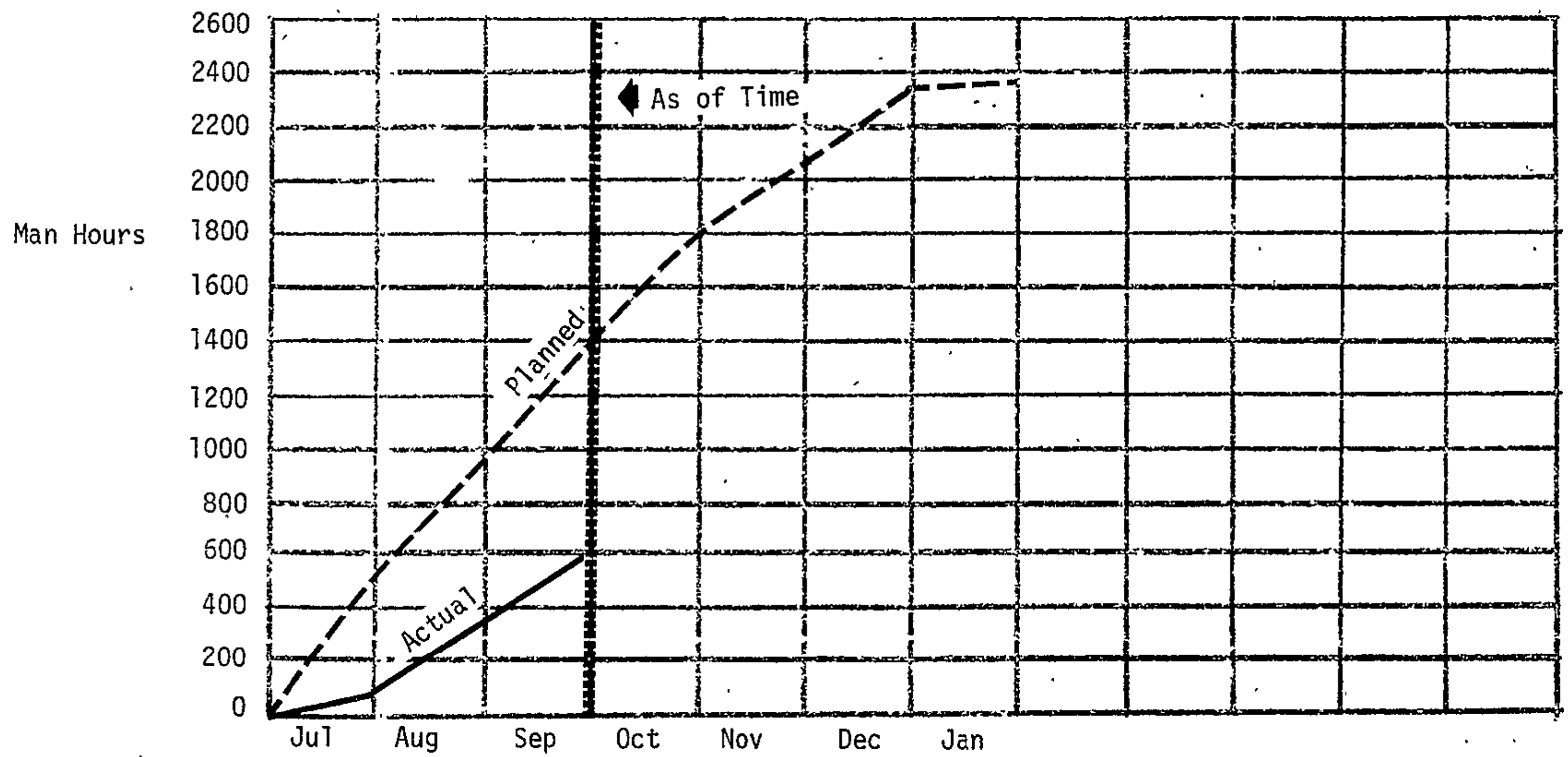
From: Aerojet Liquid Rocket Co.
Post Office Box 13222
Sacramento, California 95813

Type: CPFF

Contract No. NAS 8-32999

Contract Description: Scope of Work: Orbit Transfer Vehicle Engine Study, Phase A

Auth. Contr. Rep. Date:



Planned Hours (Cum)	561	983	1401	1827	2072	2346	2357					
Actual Hours (Cum)	86		592									

Figure 10. Contractor Man-Hour Management Report