

NASA Technical Memorandum

NASA TM-100382

MAIN PROPULSION SYSTEM TEST REQUIREMENTS FOR THE TWO-ENGINE SHUTTLE-C

By E.E. Lynn and G.K. Platt

Propulsion Systems Division
Propulsion Laboratory

December 1989

(NASA-TM-100382) MAIN PROPULSION SYSTEM
TEST REQUIREMENTS FOR THE TWO-ENGINE
SHUTTLE-C (NASA) 24 p CSCL 21H

N90-14282

Unclass
63/20 0253826



National Aeronautics and
Space Administration

George C. Marshall Space Flight Center



ERRATA

NASA TECHNICAL MEMORANDUM-100382

**MAIN PROPULSION SYSTEM TEST REQUIREMENTS FOR
THE TWO-ENGINE SHUTTLE-C**

By E.E. Lynn and G.K. Platt

February 1990

Delete page 6 and insert new page 6.





Report Documentation Page

1. Report No. NASA TM-100382		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Main Propulsion System Test Requirements for the Two-Engine Shuttle-C		5. Report Date December 1989		6. Performing Organization Code	
		8. Performing Organization Report No.		10. Work Unit No.	
7. Author(s) E.E. Lynn and G.K. Platt		11. Contract or Grant No.		13. Type of Report and Period Covered Technical Memorandum	
		14. Sponsoring Agency Code			
9. Performing Organization Name and Address George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546			
15. Supplementary Notes Prepared by Propulsion Systems Division, Propulsion Laboratory, Science and Engineering Directorate.					
16. Abstract <p>The Shuttle-C is an unmanned cargo-carrying derivative of the space shuttle with optional two or three space shuttle main engines (SSME's), whereas the shuttle has three SSME's. Design and operational differences between the Shuttle-C and shuttle were assessed to determine requirements for additional main propulsion system (MPS) verification testing. Also, reviews were made of the shuttle main propulsion test (MPT) program objectives and test results and shuttle flight experience.</p> <p>It was concluded that, if significant MPS modifications are not made beyond those currently planned, then main propulsion system verification can be concluded with an on-pad propellant loading and countdown demonstration test plus a long duration on-pad flight readiness firing.</p>					
17. Key Words (Suggested by Author(s)) Shuttle-C Propulsion System Testing Requirements			18. Distribution Statement Unclassified - Unlimited		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of pages 24	22. Price NTIS

PREPARATION OF THE REPORT DOCUMENTATION PAGE

The last page of a report facing the third cover is the Report Documentation Page, RDP. Information presented on this page is used in announcing and cataloging reports as well as preparing the cover and title page. Thus it is important that the information be correct. Instructions for filling in each block of the form are as follows:

Block 1. Report No. NASA report series number, if preassigned.

Block 2. Government Accession No. Leave blank.

Block 3. Recipient's Catalog No. Reserved for use by each report recipient.

Block 4. Title and Subtitle. Typed in caps and lower case with dash or period separating subtitle from title.

Block 5. Report Date. Approximate month and year the report will be published.

Block 6. Performing Organization Code. Leave blank.

Block 7. Author(s). Provide full names exactly as they are to appear on the title page. If applicable, the word editor should follow a name.

Block 8. Performing Organization Report No. NASA installation report control number and, if desired, the non-NASA performing organization report control number.

Block 9. Performing Organization Name and Address. Provide affiliation (NASA program office, NASA installation, or contractor name) of authors.

Block 10. Work Unit No. Provide Research and Technology Objectives and Plans (RTOP) number.

Block 11. Contract or Grant No. Provide when applicable.

Block 12. Sponsoring Agency Name and Address. National Aeronautics and Space Administration, Washington, D.C. 20546-0001. If contractor report, add NASA installation or HQ program office.

Block 13. Type of Report and Period Covered. NASA formal report series; for Contractor Report also list type (interim, final) and period covered when applicable.

Block 14. Sponsoring Agency Code. Leave blank.

Block 15. Supplementary Notes. Information not included elsewhere: affiliation of authors if additional space is re-

quired for block 9, notice of work sponsored by another agency, monitor of contract, information about supplements (film, data tapes, etc.), meeting site and date for presented papers, journal to which an article has been submitted, note of a report made from a thesis, appendix by author other than shown in block 7.

Block 16. Abstract. The abstract should be informative rather than descriptive and should state the objectives of the investigation, the methods employed (e.g., simulation, experiment, or remote sensing), the results obtained, and the conclusions reached.

Block 17. Key Words. Identifying words or phrases to be used in cataloging the report.

Block 18. Distribution Statement. Indicate whether report is available to public or not. If not to be controlled, use "Unclassified-Unlimited." If controlled availability is required, list the category approved on the Document Availability Authorization Form (see NHB 2200.2, Form FF427). Also specify subject category (see "Table of Contents" in a current issue of STAR), in which report is to be distributed.

Block 19. Security Classification (of this report). Self-explanatory.

Block 20. Security Classification (of this page). Self-explanatory.

Block 21. No. of Pages. Count front matter pages beginning with iii, text pages including internal blank pages, and the RDP, but not the title page or the back of the title page.

Block 22. Price Code. If block 18 shows "Unclassified-Unlimited," provide the NTIS price code (see "NTIS Price Schedules" in a current issue of STAR) and at the bottom of the form add either "For sale by the National Technical Information Service, Springfield, VA 22161-2171" or "For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402-0001," whichever is appropriate.

TABLE OF CONTENTS

	Page
INTRODUCTION.....	1
APPROACH USED IN THIS STUDY	1
DESIGN AND OPERATING CONDITIONS.....	2
SHUTTLE MAIN PROPULSION TEST PROGRAM.....	2
SHUTTLE FLIGHT EXPERIENCE.....	8
EVALUATION OF CANDIDATE AREAS FOR TEST VERIFICATION.....	8
MAXIMUM ON-PAD FRF DURATION.....	12
SUMMARY	12
APPENDIX – SHUTTLE MPT STATIC FIRING SUMMARY.....	15

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Shuttle-C reference configuration	3
2.	Shuttle-C propulsion subsystem	4

LIST OF TABLES

Table	Title	Page
1.	Shuttle MPT one- and two-engine operational history	6
2.	Main propulsion test program anomalies and failures.....	7
3.	Initial list of candidate areas for Shuttle-C propulsion system test verification.....	9

TECHNICAL MEMORANDUM

MAIN PROPULSION SYSTEM TEST REQUIREMENTS FOR THE TWO-ENGINE SHUTTLE-C

INTRODUCTION

Shuttle-C is a proposed, unmanned, cargo-carrying launch vehicle derived from the space shuttle primarily by replacing the shuttle orbiter with a cargo element and off loading the external tank (ET) propellants. The cargo element will have a much smaller mass than the shuttle orbiter and analyses indicate that Shuttle-C could deliver a target payload of approximately 100,000 lbm to low-Earth orbit with two space shuttle main engines (SSME's) and approximately 150,000 lbm to low-Earth orbit with three SSME's. The goal of minimizing development costs makes it desirable to avoid a main propulsion system (MPS) static test program, and the goal of minimizing operating costs makes it desirable to utilize only two SSME's for payloads in the 100,000-lbm class.

Therefore, a study was requested by the Marshall Space Flight Center (MSFC) Shuttle-C task team to determine whether it would be necessary to conduct a propulsion systems test program to verify the two-engine configuration or whether the new configuration could be verified by other means.

APPROACH USED IN THIS STUDY

In order to determine the need for a Shuttle-C MPS test program, the first step was to conduct detailed reviews of the following:

- Design and operating conditions, Shuttle-C versus shuttle.
- Shuttle MPT program objectives and history.
- Shuttle MPS flight experience.

After these reviews were conducted, a candidate list of MPS related hardware, software, procedures, etc., was generated to identify all areas that could possibly require Shuttle-C MPS test verification. Candidate areas were then eliminated if they could be sufficiently satisfied by the following:

- Shuttle design similarity,
- Shuttle MPT program experience, or
- Shuttle flight experience.

For each area that remained, an assessment was made to determine if it could be adequately verified by any of the following methods:

- Analytical assessment
- Component testing
- On-pad propellant loading/countdown demonstration test(s)
- On-pad flight readiness type hot firing(s)
- Baseline design changes.

DESIGN AND OPERATING CONDITIONS

The Shuttle-C reference design is similar to the shuttle's, except that it is an unmanned but "manrated" vehicle with an expendable propulsion system/payload carrier. The ET/SRB arrangement is the same as that for the shuttle. The Shuttle-C will use two standard SRB's and a standard ET. However, for a two-engine Shuttle-C the ET will have off-loaded propellants (approximately 80 percent) and relocated liquid level sensors. The two-engine version will have two standard SSME's with the SSME in position 1 removed and engine interfaces closed off and a heat shield added.

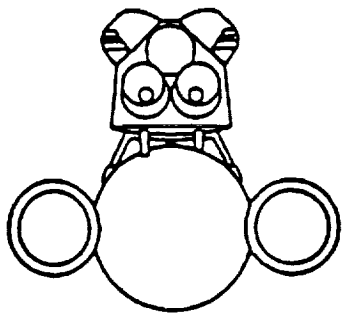
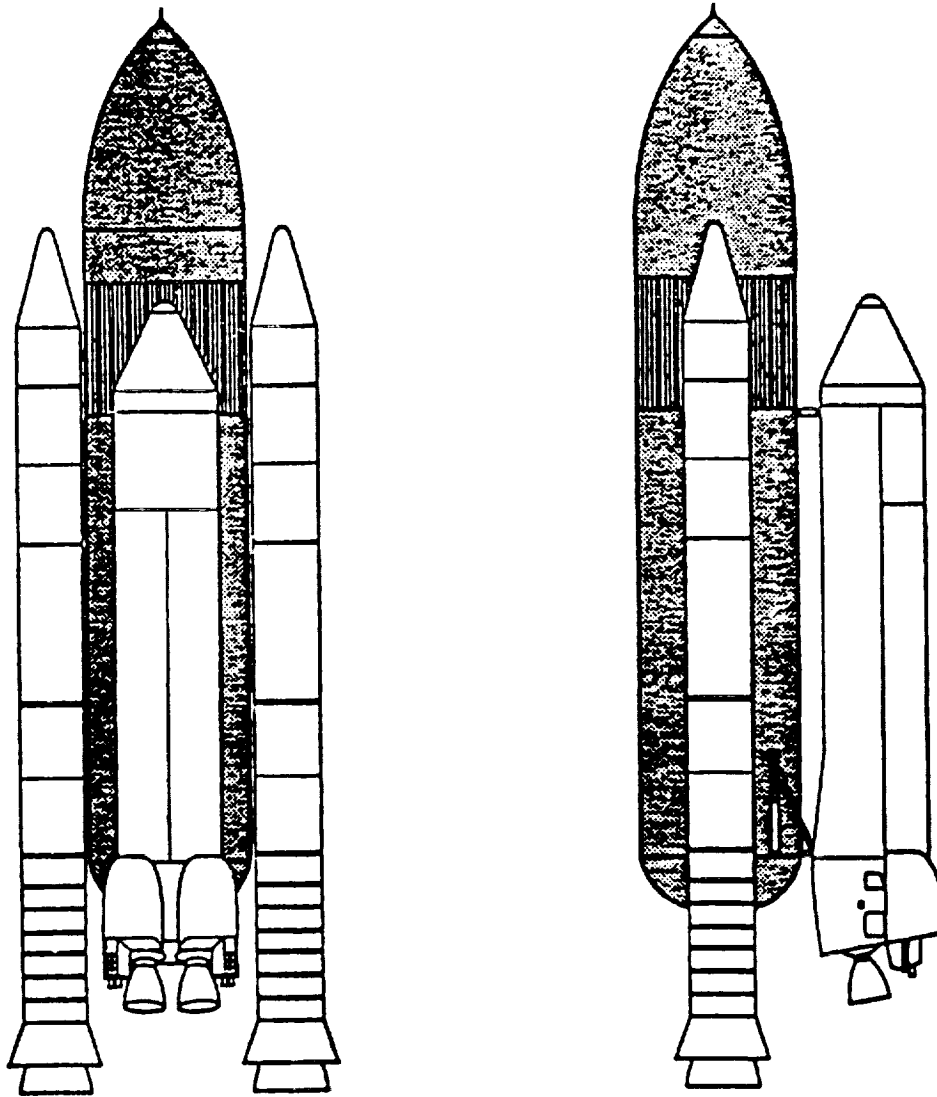
The cargo element to ET interface loads will be within nominal STS design. In flight the Shuttle-C will throttle to limit the load factor to 3 g, but will not throttle to limit the maximum dynamic pressure. There will be limited engine-out capability during the late stages of ascent. Propellant loading procedures, subsystem purges, and engine start preparation procedures will be the same or similar to those used for shuttle.

LO₂ and LH₂ conditions at the engine inlets for engine start do not completely meet Shuttle Interface Control Document requirements. However, based on test histories for engine starts, satisfactory inlet conditions for engine startup are anticipated. The inflight net positive suction pressures at the engine inlets were calculated for flight and meet the requirements.

The Shuttle-C reference configuration is shown in Figure 1. The propulsion subsystem configuration is shown in Figure 2.

SHUTTLE MAIN PROPULSION TEST PROGRAM

The primary objectives for a main propulsion system test program are to obtain data on operating characteristics to verify the design of subsystems in a systems environment, to assess the systems operating environment to the extent possible without a flight test, and to detect component deficiencies and defects.



- 82' X 15' PAYLOAD BAY
- CIRCULAR P/L CARRIER
- JETTISONABLE SHROUD
- CONICAL NOSE CONE
- MODIFIED ORBITER BOATTAIL
- 2 - 3 SSME's

Figure 1. Shuttle-C reference configuration.

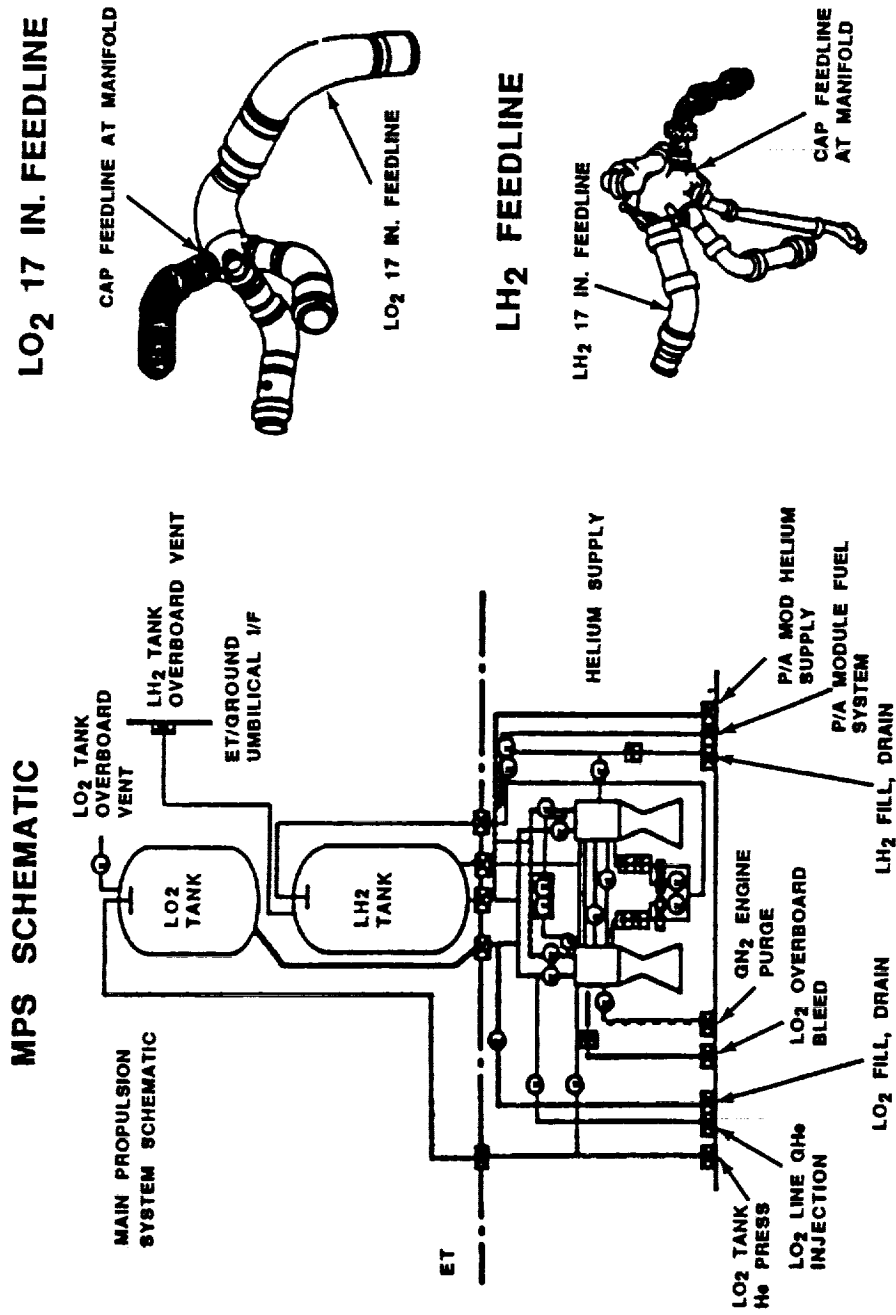


Figure 2. Shuttle-C propulsion subsystem.

The shuttle main propulsion system test program consisted of 12 MPT firings (see appendix for program history). During these firings, engines were cut off at different times for several reasons, most commonly to make the cut-off transient more conservative or to simulate engine failures. Also, these engine shutdowns were done at different power levels. These test firings helped provide for a better understanding of the propulsion system operating conditions. They also provided the means to verify system prediction capabilities. Table 1 summarizes the MPT one-engine and two-engine operational histories.

During the shuttle MPT program, a number of anomalies and failures were experienced. These are summarized in Table 2. Of these anomalies and failures, all were resolved for the shuttle flight configuration. Many were due to immaturity of components at the time of the system tests. Only those listed below were judged to have required a system test to discover them:

- 1) LO₂ and LH₂ prepressurization overshoot
- 2) LH₂ recirculation pump cavitation
- 3) Nitrogen condensation and LN₂ dripping in the engine compartment
- 4) Heat shield differential pressure exceedances caused by ignition overpressure
- 5) Inadequate ET nosecone purge
- 6) LO₂ ullage pressure overshoot.

LO₂ and LH₂ prepressurization were performed prior to test firings and the overshoots were control system problems.

Recirculation pump cavitation was a procedural problem; the pumps were well known, having been used on the S-II and S-IVB stages of the Saturn V launch vehicle.

Nitrogen purge gas commonly condenses on uninsulated or poorly insulated surfaces, and some changes usually have to be made in insulation configuration on any launch vehicle.

Ignition overpressure has been observed in single engine tests. The phenomenon results from the fuel lead during the start transient. When LO₂ reaches the injector and ignition begins, an accumulation of hydrogen gas has already occurred in the combustion chamber and nozzle and has become mixed with ambient air. This mixture is then ignited by the combusting propellants. The solution to this problem was to provide igniters or "sparklers" near the nozzle exit to ignite the hydrogen as it mixes with air. In the main propulsion test program, a high overpressure on the orbiter baseplate occurred in one test prior to the inclusion of the external igniters.

The ET nosecone purge problem was one that could have been handled in a component test of the ET; however, the purge verification was planned for MPT instead. The solution was an increase in the nosecone purge gas heater power.



TABLE 1. SHUTTLE MPT ONE- AND TWO-ENGINE OPERATIONAL HISTORY

- SF-2
 - E1 cutoff at 18.8 s (from 70% power level)
 - E2 and E3 cutoff at 20.6 s (70%)

- SF-4
 - E2 cutoff at 90 s (70%)
 - E1 and E3 cutoff at 100 s (70%)

- SF-6-04
 - E2 cutoff at 505 s (70%)
 - E1 and E3 cutoff at 555 s (70%)

- SF-7-02
 - E2 cutoff at 520 s (70%)
 - E1 and E3 cutoff at 555 s (70%)

- SF-9-02
 - E3 cutoff at 530 s (65%)
 - E2 cutoff at 545 s (65%)
 - E1 cutoff at 574 s (65%)

- SF-11-02
 - E2 cutoff at 438 s (65%)
 - E1 and E3 cutoff at 586 s (65%)

- SF-12
 - E3 cutoff at 235 s (100%)
 - E1 and E2 cutoff at 624 s (100%)

Total 2 engine operational time = 649 s (10.8 min)

Longest 2 engine operational time = 389 s (6.5 min)

Total 1 engine operational time = 29 s (0.5 min)

Longest 1 engine operational time = 29 s (0.5 min)

TABLE 2. MAIN PROPULSION TEST PROGRAM ANOMALIES AND FAILURES

TEST SYSTEM ANOMALIES	ENGINE ANOMALIES	COMPONENT ANOMALIES	PROPULSION SYSTEM ANOMALIES
● ET ATTACH BOLTS IMPROPERLY LOADED	● MAIN FUEL VALVE RUPTURED	● LOX ENGINE CUTOFF LOW-LEVEL SENSORS HAD SLOW RESPONSE	● IGNITION OVERPRESSURE
● TEST SYSTEM COMPUTER FAILED	● POGO ACCUMULATOR BUBBLE COLLAPSED	● GOX PRESSURANT FLOW CONTROL ORIFICES CRACKED	● LN ₂ IN AFT COMPARTMENT
● ACOUSTIC MEASUREMENTS FAILED	● ENGINE STEERHORN (NOZZLE HYDROGEN MANIFOLD) RUPTURED	● ENGINE LH ₂ INLET TEMPERATURE FAILED	● LOX TANK NEGATIVE PRESSURE
● ET/ORBITER ATTACH BOLTS OVER TORQUED	● FAULTY LOX PREBURNER START	● ET/ORBITER DISCONNECT FAILED TO SEAL	● ET NOSE CAP PURGE INADEQUATE
● FAULTY HAZARDOUS GAS INDICATIONS	● ENGINE HIGH PRESSURE FUEL PUMP LIFTOFF SEAL STUCK	● GOX PRESSURANT INTERFACE TEMPERATURE TOO HIGH	● LOX TANK ULLAGE PRESSURE OVERSHOOT
● LOX TANK CAPACITANCE PROBE FAILED TO INDICATE	● ENGINE HIGH PRESSURE FUEL PUMP SEAL BROKEN	● ET HYDROGEN TANK PRESSURANT DIFFUSER FAILURE	● LOW LOX TANK ULLAGE PRESSURE DURING RUN
● LH ₂ TANK AUXILIARY DRAIN VALVE FAILED TO CLOSE	● ENGINE HIGH PRESSURE FUEL PUMP FAILED	● IR FIRE DETECTORS FAILED	● LO ₂ AND LH ₂ PREPRESSURIZATION OVERSHOOT
● LOX AUXILIARY DRAIN VALVE STUCK	● ENGINE HIGH PRESSURE OXIDIZER TURBINE SEAL FAILED	● LOX FILL AND DRAIN VALVE FAILED	● LH ₂ RECIRCULATION PUMP CAVITATION
● TWO OF 5 H ₂ BURNOFF IGNITERS FAILED TO IGNITE	● ENGINE FUEL PREBURNER BURN-THROUGH	● PROBE SEAL BROKE	
	● ENGINE LEE JET FAILURE		
	● ENGINE NOZZLE FAILURE		
	● ENGINE CONTROLLER FAILURE		

The LO₂ ullage pressure overshoot occurred briefly during the early part of firings SF-7-01 and SF-8. This occurred because a vacuum reference system was incorporated to simulate pressure drops with increasing altitude during ascent and the gaseous oxygen (GOX) flow control valves had not been reorificed to compensate for the lower reference pressures for these tests.

It can be seen that all of these anomalies/failures, except ignition overpressure and LO₂ ullage pressure overshoots, were encountered during preparation for firing. Ignition overpressure occurred at engine ignition, and LO₂ ullage pressure overshoot occurred in the early part of firing. Several of these propulsion system problems would have been made worse if one engine had been removed. The indication from these problems experienced during the MPT program is that for the Shuttle-C, critical periods affected by modifications are during propellant conditioning prior to engine start and during the early part of the firing.

SHUTTLE FLIGHT EXPERIENCE

An extensive database of propulsion system related information has been developed through the shuttle flight program that is directly applicable to Shuttle-C main propulsion system verification. In fact, the only propulsion system-related information not applicable at this time are data that would be invalidated by the removal of one SSME, by the off-loading of the propellant tanks, or by the use of foam insulation for the LH₂ feedline instead of using a vacuum-jacketed feedline.

Some two-engine operational experience has been gained through the shuttle flight program. For STS-51F, engine 3 was shutdown at T+343 s because of an high pressure oxidizer turbopump (HPOTP) discharge temperature redline violation. Engines 1 and 2 continued to operate for an additional 238 s and were cut off from a power level of 91 percent with no anomalous steady-state or shutdown transient characteristics.

All shuttle propulsion system elements have been fully operational since the developmental flight program (STS-1 through STS-4) was concluded. However, some enhancements to performance and reliability are presently being worked. These include the certification of the SSME's at 109 percent power level, the replacement of the GO₂ flow control valves with orifices, and the possible replacement of the SSME oxidizer heat exchangers with external heat exchangers. These items will be fully verified through subsystem tests and shuttle flight experience. The Shuttle-C program should not require any reverification in order to incorporate these items.

EVALUATION OF CANDIDATE AREAS FOR TEST VERIFICATION

An initial list of areas that could conceivably require verification through Shuttle-C propellant load or hot-fire testing is presented in Table 3. This list was established with major areas presented in a somewhat chronological order. The major areas were broken into applicable subsystems, components, procedures, etc., that might possibly require some Shuttle-C propulsion system test verification.

TABLE 3. INITIAL LIST OF CANDIDATE AREAS FOR SHUTTLE-C
PROPULSION SYSTEM TEST VERIFICATION

- Countdown Verification
- Propellant Loading
 - Loading procedures
 - Boiloff and replenish rates
 - Extended countdown hold effects
 - Helium inject system
 - LO₂ bleed/drainback
 - LH₂ recirculation
 - Prepressurization
 - Inlet conditions (start box)
 - Hazardous gas detection system
 - LH₂ high-point bleed
- Buildup Transient Analysis
 - Start sequence for two SSME's
 - Hold down time after SSME ignition
 - Loads transfer through thrust structure
 - Redlines
- Engine Operation
 - Throttling
 - Gimbaling
 - Angles
 - Rates
 - Nozzle and base heating
 - ME-I heat shield closeout
 - Net positive suction pressure (NPSP)
 - Loads transfer through thrust structure
 - Engine-out effects
 - Redlines
 - POGO pulsing
- Pressurization System Performance
 - LO₂ ullage pressure slump
 - Flow control operation, nominal
 - Flow control operation w/failed flow control valve(s)
 - Pressurization with engine-out
- Propellant Feed System Performance (Surges, Vibrations, etc.)
- Shutdown Analysis
 - Two engine
 - One engine (engine-out case)
 - LO₂ prevalve timing
- Post-Test Checkout and Inspection

Each area was evaluated. Consultation with NASA and contractor engineers from MSFC and Kennedy Space Center (KSC) was obtained in all areas where their experience and expertise could contribute to the identification of test requirements and alternate ways to satisfy them. Results of the evaluations are as follows.

All identified test requirements for the following areas could be satisfied with on-pad propellant loading and short duration FRF tests, similar to the tests conducted at KSC prior to the maiden flight of each space shuttle orbiter:

- Countdown demonstration
- Propellant loading
- Buildup transient analysis
- Shutdown analysis
- Post-test checkout and inspection.

Engine Operation:

- Throttling and Gimbaling — An extensive base of experience has been developed through the shuttle MPT and flight programs. However, Shuttle-C hot-fire verification would be desirable, primarily for SSME gimbaling if profiles differ significantly from those used with shuttle. Combinations of gimbal angles and rates could be tested with an on-pad flight readiness firing (FRF) of sufficient duration.
- Nozzle and Base Heating — The main components of these are radiation and convective heating. Analytical models at MSFC can accurately simulate radiation heating and its effects. Convective heating is more difficult to model. However, convective heating is most pronounced at higher altitudes as the SSME exhaust plumes expand. This condition cannot be duplicated with a sea level hot-firing. Nozzle and base heating are therefore not considered to be drivers for hot-fire testing. However, any hot-fire test that is conducted probably should be done with instrumentation to determine these effects to take advantage of the opportunity.
- ME-1 Heat Shield Closeout — Not a driver for hot-fire testing. However, the opportunity to test for heat transfer to the aft compartment and vibration should be taken on any hot-firing conducted that might reach 1 or 2 min in duration.
- Net Positive Suction Pressure (NPSP) — Can be accurately determined analytically. Any hot-firing would lack solid rocket motor (SRM) and acceleration effects.
- Loads Transfer — This should be verified. Shuttle-C should be instrumented for this. A short duration FRF would be sufficient because the critical loads occur during SSME buildup.

- Engine-out — Shuttle MPT experience with one-engine operation from SF-9-01, SF-9-02, and SF-11-01 is applicable. Therefore, single engine verification is not a driver for hot-fire verification. However, an engine-out conducted during the last stages of an on-pad FRF would provide useful data on the transient effects on various propulsion subsystems and one-engine steady-state performance of the LH₂ and LO₂ pressurization systems.
- Redlines — No requirements for special assessments of performance redlines were identified.
- POGO Pulsing — Extensive POGO testing, conducted during the shuttle MPT program, is directly applicable to Shuttle-C. The SSME POGO accumulators should need no special verification with the Shuttle-C configuration.

Pressurization System Performance:

- LO₂ Ullage Pressure Slump — The pressure drop that occurs shortly after liftoff on shuttle has been determined to be primarily a result of LO₂ tank “breathing” that is caused by SRM thrust buildup loads. The problem is more pronounced because of the small initial LO₂ ullage. Analytical models have been developed that can predict the LO₂ ullage pressure slump.
- Nominal Pressurization — Pressurization system studies indicate that LH₂ tank pressurization performance will not differ enough from shuttle to warrant any special test verification. However, LO₂ pressurization is a different matter. Studies show that with a large initial LO₂ ullage volume and two SSME’s providing GO₂ through standard heat exchangers, flow control valves, and orifices, the ullage pressure control band upper limit of 22 psid will be exceeded at about T+70 s. The pressure will peak at about 26 psid near T+100 s and start to decline and will be back inside the control band at about T+255 s. These LO₂ pressurization studies indicate that the pressurization flow control orifices will have to be resized. An analytical determination of the orifice sizes can be made. However, shuttle pressurization models are based to some extent on empirical shuttle data, and complete confidence in results of resizing the LO₂ flow control orifices would require a relatively lengthy hot-firing.

With everything considered, LO₂ pressurization becomes a prime driver for main propulsion system verification testing. A hot-firing with a duration of approximately 2 min should be adequate to verify LO₂ pressurization system performance.

- Pressurization with Failed Flow Control Valve or Engine-out — These can be determined analytically from nominal pressurization data and require no special testing.

Propellant Feed System Performance:

- No special assessments are required. The LO₂ and LH₂ feedlines to the removed engine will be blocked off flush at the respective manifolds. This should result in no significant change to overall flow dynamics.

MAXIMUM ON-PAD FRF DURATION

Analyses discussed in the preceding section indicate that requirements exist for hot-fire verification for several areas of the Shuttle-C main propulsion system. Two alternatives to conducting these test verifications exist. The first is to conduct an MPT program for Shuttle-C similar to the MPT program that was conducted for shuttle. This utilized a main propulsion test article (MPTA) for a long series of tests at the Stennis Space Center. This would be quite expensive and time consuming. The second alternative, conduct hot-fire test verifications on the pad at KSC, would provide a very significant benefit to the Shuttle-C program in terms of cost and scheduling if all requirements could be adequately satisfied.

On-pad FRF's of up to 20 s duration have been conducted for shuttle. This duration would be insufficient for Shuttle-C. A study was undertaken to determine the maximum duration that would be feasible for on-pad hot-fire testing at KSC.

The limiting factor on test duration is the amount of water available to satisfy flame deflector cooling and acoustic suppression requirements. The water storage capacities at pads 39A and 39B are 280,000 and 300,000 gallons, respectively. Required flowrates are 65,000 gallons per minute (gpm) for SSME acoustic suppression and 75,000 gpm for flame deflector cooling for a total of 140,000 gpm. For a shuttle launch, there is an additional 400,000 gpm required for solid rocket booster (SRB) related sprays which would be disabled for an extended FRF. Dividing the water capacities by the required flowrates yields a maximum duration of 120 s for pad 39A and 129 s for pad 39B. For an on-pad firing, about 4,000 gallons would have to flow through the water system before flowrates would reach acceptable levels for SSME ignition. This water requirement can be met by the amount initially in the lines below the storage tank bottom. The Firex system utilizes water from a different source and does not affect test duration.

There may be a requirement for heat shielding to protect the ET aft dome area. A heat shield is available for this purpose, although the 20 s shuttle FRF did not utilize the shield and no detrimental results occurred. Also, a study will be required to assure that heat radiated back through the launch pad SRB openings would not be a problem. Shielding could be provided if needed.

SUMMARY

While this study indicates that an MPT program is not required for Shuttle-C, at least one FRF of extended duration will be required. This is only possible because the Shuttle-C is very close to the present shuttle insofar as its propulsion system configuration is concerned. A reexamination of the shuttle MPT program showed that there were many problems uncovered that would have caused extended delays to the shuttle program if they had not been found early through the test article instead of on the first shuttle FRF. Additionally, the ignition overpressure problem experienced in the MPT program could have proven catastrophic if it had occurred in flight.

The primary conclusions of this study are summarized as follows:

1. At least one propellant loading test should be planned. A second test would serve as a contingency if additional verification were required.
2. Hot-fire verification of the main propulsion system will be required.
3. The maximum on-pad FRF duration is approximately 2 min and is limited by the water supply for cooling and acoustic suppression. This matter should be thoroughly evaluated since this greatly exceeds any previous shuttle FRF duration. A water flow test should be conducted to verify the time required to consume the entire water supply.
4. LO₂ tank pressurization has been identified as the most likely area for which a full 2 min duration FRF may be required.
5. It is considered a reasonable goal to verify the Shuttle-C main propulsion system without a separate main propulsion test program, but to rely on propellant loading tests and FRF's at the launch site. However, consideration should be given to the fact that on-pad FRF testing should be success-oriented. Any anomaly that would require removal of the vehicle from the pad for repairs or modifications could severely impact the program in both cost and scheduling.

APPENDIX
SHUTTLE MPT STATIC FIRING SUMMARY

PRECEDING PAGE BLANK NOT FILMED



ORGANIZATION: MARSHALL SPACE FLIGHT CENTER
 NAME:
 CHART NO: MPT STATIC FIRING SUMMARY
 DATE:
 1-6746-9-34D

DATE	TEST NO.	DUR (SEC)	REQUIREMENTS			SPECIAL TESTS	POWER PROFILE
			MPS	GIMBAL	POGO		
4/21/78 ACTUAL	*1S-02	2.35 PLANNED 1.0 ACTUAL	● PROP. SYST. SHAKEDOWN		SUPPR. OUT	● 500 Hz POWER SUPPLY EVALUATION ● ICE FROST	
5/19/78 ACTUAL	2S	20 ACTUAL	● PROP. SYST. SHAKEDOWN		SUPPR. OUT	● FLAME BUCKET EVAL. ● TRANSIENT LOADS EVAL.. ● LOADING SYS EVAL	
6/15/78 ACTUAL	3S	42 ACTUAL		POSITIONED ● TO RUN ● TO NULL	PULSER CHECKOUT SUPPR. OUT	● FLAME BUCKET EVAL. ● LOADING SYS EVAL	
7/70/78 ACTUAL	4S	104 ACTUAL	● STARTUP EVAL THROTTLING	POSITIONED ● TO RUN ● TO NULL	PULSER (40 SEC) SUPPR. OUT	● FLAME BUCKET EVAL. ● HYDRAULIC WARMANT ● ICE FROST	

- MOD PERIOD -

5/4/79 ACTUAL	5 A F	1.5 ACTUAL	● STARTUP EVAL ● LO ₂ VENT ORIFICE ● RECIRC RESTART		SUPPR. IN	● 7 HOUR HOLD ● LOADING SYSTEMS EVAL ● 5000 GPM LO ₂ DRAIN ● HYD WARMANT ● ICE FROST	
5/12/79 ACTUAL	5F	PLANNED FULL ACTUAL 54	● PRESS SYS PERF ● FEED SYS PERF ● PNEUM SYS PERF ● INTEG. PROP SYS PERF ● LO ₂ VENT ORIFICE ● IGNITION O/P	● STEP ● FREQ. ● RAMP (130 SEC)	PULSING 265 SEC SUPPR. IN	● FLAME BUCKET EVAL ● 1400 GPM LO ₂ LOAD ● ICE FROST	
7/2/79 ACTUAL	6F-01	PLANNED FULL ACTUAL 19	● PRESS SYS PERF ● FEED SYS PERF ● PNEUM SYS PERF ● INTEG. PROP SYS PERF ● IGNITION O/P	● STEP ● FREQ. ● RAMP (250 SEC)	PULSING 130 SEC SUPPR. IN	● LO ₂ TANK PRESSURE UNDERSHOOT ● QUICK DRAIN ● ICE FROST	

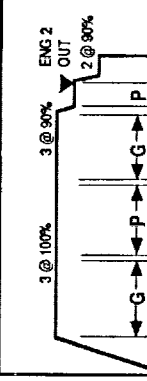
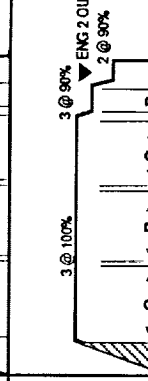
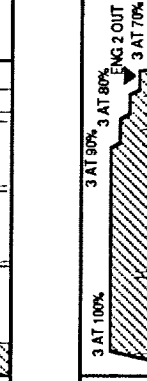
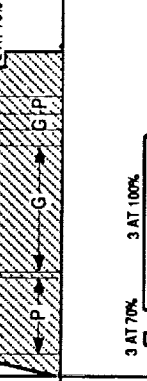
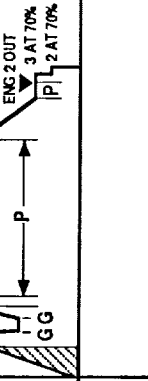
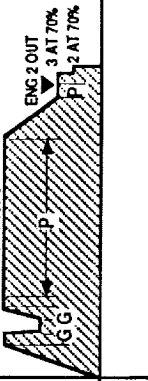
*INTERLOCKS PREVENTED IGNITION ON 16-01 WHICH WAS ATTEMPTED ON 4-11-78

REPAIR & MOD PERIOD (UNPLANNED)

MARSHALL SPACE FLIGHT CENTER
MPT STATIC FIRING
SUMMARY

ORGANIZATION:
 CHART NO:
 FILE # 1-6697-9-33D

NAME:
 DATE:

DATE	TEST NO.	DUR (SEC)	REQUIREMENTS			POWER PROFILE
			MPS	GIMBAL	POGO	
10/24/79 ACTUAL	6F-02	PLANNED FULL ACTUAL 0	<ul style="list-style-type: none"> ● PRESS SYS PERF ● FEED SYS PERF ● PNEUM SYS PERF ● HYD SYS PERF ● INTEG PROP SYS PERF ● IGNITION O/F 	<ul style="list-style-type: none"> ● STEP ● FREQ ● RAMP ● (250 SEC) 	<ul style="list-style-type: none"> ● PULSING (130 SEC) ● SUPPR, IN 	<ul style="list-style-type: none"> ● LO2 TEMP STRAT ● 1400 GPM FILL ● HELIUM BOTTLE BLOWDOWN ● SEARCH FOR LN2 IN AFT COMPARTMENT ● ICE FROST 
11/4/79 ACTUAL	6F-03	PLANNED FULL ACTUAL 10	<ul style="list-style-type: none"> ● PRESS SYS PERF ● FEED SYS PERF ● PNEUM SYS PERF ● HYD SYS PERF ● INTEG PROP SYS PERF ● IGNITION O/F 	<ul style="list-style-type: none"> ● STEP ● FREQ ● RAMP ● (250 SEC) 	<ul style="list-style-type: none"> ● PULSING (130 SEC) ● SUPPR, IN 	<ul style="list-style-type: none"> ● H2 TANK VENT FLOWRATE ● HELIUM BOTTLE BLOWDOWN ● SEARCH FOR LN2 IN AFT COMPARTMENT ● ICE FROST 
REPAIR PERIOD (UNPLANNED)						
STUB NOZZLES INSTALLED						
12/17/79 ACTUAL	6S-04	PLANNED FULL ACTUAL 555	<ul style="list-style-type: none"> ● PRESS SYS PERF ● FEED SYS PERF ● PNEUM SYS PERF ● HYD SYS PERF ● INTEG PROP SYS PERF ● FEED OUT CAL 	<ul style="list-style-type: none"> ● STEP ● FREQ ● RAMP ● (256 SEC) 	<ul style="list-style-type: none"> ● PULSING (130 SEC) ● SUPPR, IN 	<ul style="list-style-type: none"> ● QUICK DRAIN ● HELIUM BOTTLE BLOWDOWN ● SEARCH FOR LN2 IN AFT COMPARTMENT ● ICE FROST 
2/1/80 ACTUAL	7S-01	PLANNED FULL ACTUAL -5	<ul style="list-style-type: none"> ● PRESS SYS PERF ● FEED SYS PERF ● OFT-1 SIM ● LO2 LOW LVL C/O ● PNEUM SYS PERF ● INTEG PROP SYS PERF ● HYD SYS PERF 	<ul style="list-style-type: none"> ● SIMULTANEOUS RAMP AND THROTTLE (15 SEC) 	<ul style="list-style-type: none"> ● PULSING (345 SEC) ● SUPPR, IN 	<ul style="list-style-type: none"> ● SENSORS % WET CAL ● LO2 TANK VENT-DOWN WITH ORIFICE ● 2 MIN PRESSURIZED HOLD ● PREVALVE RELIEF ● SEARCH FOR LN2 IN AFT COMPARTMENT ● ICE FROST 
2/28/80	7S-02	PLANNED FULL ACTUAL -555	<ul style="list-style-type: none"> ● PRESS SYS PERF ● FEED SYS PERF ● OFT-1 SIM ● LO2 LOW LVL C/O ● PNEUM SYS PERF ● INTEG PROP SYS PERF ● HYD SYS PERF 	<ul style="list-style-type: none"> ● SIMULTANEOUS RAMP AND THROTTLE (15 SEC) 	<ul style="list-style-type: none"> ● PULSING (345 SEC) ● SUPPR, IN 	<ul style="list-style-type: none"> ● SENSORS % WET CAL ● 10 MIN SELF PRESSURIZATION OF LO2 TANK ● 2 MIN PRESSURIZED HOLD ● SEARCH FOR LN2 IN AFT COMPARTMENT ● ICE FROST 
3/28/80	8S	PLANNED FULL ACTUAL 541	<ul style="list-style-type: none"> ● PRESS SYS PERF ● FEED SYS PERF ● DIFFERENTIAL THROTTLING ● LO2 LOW LVL C/O ● 3 ENGINE SIMULTANEOUS CUTOFF 	<ul style="list-style-type: none"> ● RAMP GIMBAL (30 SEC) ● FLIGHT PROFILE (200 SEC) ● ATVC CHANNEL FAILURE SIM. (5 SEC) 	<ul style="list-style-type: none"> ● SIMULTANEOUS GIMBAL AND POGO (30 SEC) ● DWELL (285 SEC) ● SUPPR, IN 	<ul style="list-style-type: none"> ● SENSORS % WET CAL ● 10 MIN. SELF PRESS OF LH2 TANK ● HYDRAULIC WARMANT LOAD LH2 UNDER PRESS ● PREVALVE RELIEF ● LO2 TANK VENT DOWN WITH ORIFICE ● ICE FROST 

ORGANIZATION: MARSHALL SPACE FLIGHT CENTER
CHART NO: MPT STATIC FIRING SUMMARY
FILE # 1-6749-9-34D
NAME:
DATE:

DATE	TEST NO.	DUR (SEC)	REQUIREMENTS			POWER PROFILE
			MPS	GIMBAL	POGO	
4/16/80	9S-01	PLANNED FULL ACTUAL 5	<ul style="list-style-type: none"> O₂ PRESS SYS PERF INTEG. PROP. SYS. PERF. FEEDOUT CAL FLIGHT LOX LEVEL O₂ LOW LEVEL CUTOFF STS-1 CHILLDOWN DWELL THROTTLING 	<ul style="list-style-type: none"> FREQ (160 SEC) 	<ul style="list-style-type: none"> PULSING (195 SEC) SUPPR. IN 	<ul style="list-style-type: none"> ICE FROST & IR SCAN LH₂ RECIRC MANIF AND FEEDLINE RV CHECK LO₂ FEEDLINE RELIEF GH₂ FCV FAILED OPEN RTL'S DUMP SENSOR CAL AFT COMPARTMENT RECIRC PUMP RESTART
5/30/80	9S-02	PLANNED FULL ACTUAL 574	<ul style="list-style-type: none"> O₂ PRESS SYS PERF INTEG. PROP. SYS. PERF. FEEDOUT CAL FLIGHT LOX LEVEL O₂ LOW LEVEL CUTOFF STS-1 CHILLDOWN DWELL THROTTLING 	<ul style="list-style-type: none"> FREQ (160 SEC) 	<ul style="list-style-type: none"> PULSING (195 SEC) SUPPR. IN 	<ul style="list-style-type: none"> ICE FROST LH₂ RECIRC MANIF AND FEEDLINE RV CHECK LO₂ FEEDLINE RELIEF GH₂ FCV FAILED OPEN RTL'S DUMP SENSOR CAL LO₂ ECO TEST BY DRAINBACK FASCOS CHECKOUT

- MOD PERIOD -
FLIGHT NOZZLES INSTALLED

7/12/80	10F	PLANNED FULL ACTUAL 106	<ul style="list-style-type: none"> PRESS SYS. PERF ANOMALOUS COND. LO₂ LOW LVL C/O FRF SIMULATION BASE ENV EFFECTS FEEDOUT CAL FLIGHT CONTROL 	<ul style="list-style-type: none"> FREQ STEP RAMP HALTING RAMP STROKING HALTING RAMP (297 SEC) 	<ul style="list-style-type: none"> NONE SUPPR. IN 	<ul style="list-style-type: none"> ICE FROST LH₂ FEEDLINE RELIEF LH₂ TANK ULLAGE RELIEF LH₂ TANK ULLAGE PRESSURE CONTROL DURING FILL GO₂ FLOW CONTROL VALVE FAILED OPEN
11/3/80	11F-01	PLANNED FULL ACTUAL 20 SEC	<ul style="list-style-type: none"> PRESS SYS. PERF. ANOMALOUS COND. LH₂ LOW LEVEL C/O EMERG THRUST LEVEL EVAL PUMP OVERSPEED FIX EVAL FLIGHT CONTROL FEED OUT CAL 	<ul style="list-style-type: none"> FREQ STEP RAMP HALTING RAMP (322 SEC) 	<ul style="list-style-type: none"> NONE SUPPR. IN 	<ul style="list-style-type: none"> ICE FROST LH₂ ULLAGE PRESS CONTROL SHORT THROW IGNITERS FOR GH₂ BURNOFF TANK BUBBLE VOLUME TESTS F&D VALVE RELIEF GFCV FAILED CLOSED LH₂ FEEDLINE RELIEF

ORGANIZATION:

MARSHALL SPACE FLIGHT CENTER
**MPT STATIC FIRING
SUMMARY**

NAME:

CHART NO:

DATE:

1-6745-9-34D

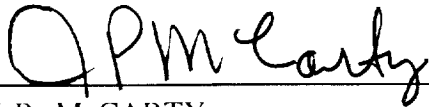
DATE	TEST NO.	DUR (SEC)	REQUIREMENTS			SPECIAL TESTS	POWER PROFILE
			MPS	GIMBAL	POGO		
12/4/80	11S-02	586	<ul style="list-style-type: none"> PRESS SYS PERF ANOMALOUS COND. LH2 LOW LEVEL C/O PUMP OVERSPEED AT CUTOFF FIX EVALUATION EMERGENCY THRUST LEVEL EVAL 	<ul style="list-style-type: none"> HALTING RAMP STEP FREQ. RESP STEP RAMP (290 SEC) 	NONE	<ul style="list-style-type: none"> ICE FROST SHORT THROW IGNITERS FOR GH2 BURNOFF 105 GPM LO2 BLEED GOX FLOW CONTROL VALVE FAILED CLOSED LO2 & LH2 FEEDLINE RELIEF LH2 DUMP VIA BLEED VALVES 	
12/17/80	12F	624	<ul style="list-style-type: none"> PRESS SYS. PERF. ANOMALOUS COND. ANTIGEYSER LINE REMOVED EARLY ENGINE OUT 2 ENG CUTOFF FROM RPL 	<ul style="list-style-type: none"> FREQ. RESP. (132 SEC) 	PULSING	<ul style="list-style-type: none"> ICE FROST LONG THROW IGNITERS FOR GH2 BURNOFF GO2 & GH2 FLOW CONTROL VALVES FAILED OPEN 	
- MOD PERIOD - UPGRADING ENGINES TO FPL CAPABILITY							
10/22/81	13F	515	<ul style="list-style-type: none"> MPS PERF. AT FPL BASE ENV. EFFECTS LOADS EVAL 	TBD	<ul style="list-style-type: none"> PULSING 	<ul style="list-style-type: none"> ICE FROST ONE LO2 AND ONE LH2 FLOW CONTR. VLV FAILED CLOSED 	
11/3/81	14F	516	<ul style="list-style-type: none"> MPS PERF. AT FPL TWO ENG CUTOFF FROM RPL ONE ENG CUTOFF FROM FPL 	<ul style="list-style-type: none"> FREQ RAMP STEP 	TBD	TBD	

APPROVAL

MAIN PROPULSION SYSTEM TEST REQUIREMENTS FOR THE TWO-ENGINE SHUTTLE-C

By E.E. Lynn and G.K. Platt

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



J.P. McCARTY

Director, Propulsion Laboratory

