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ACCEPTANCE-TEST TRADE STUDY
INTERIM REPORT

NERVA Program, Contract SNP-1

September 1970

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AEROJET NUCLEAR SYSTEMS COMPANY

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Contract SNP-1

September 1970

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ACCEPTANCE TEST TRADE STUDY

I. INTRODUCTION

This report is an interim report which identifies the approach toward determining the acceptance test criteria and the test candidates. Because of a lack of maturity in the engine design and acceptance criteria, only qualitative discussions of the candidate acceptance tests can be presented at this time.

A. PURPOSE OF TRADE STUDY

The purposes of this trade study are (1) to establish acceptance test criteria for the deliverable NERVA Flight Engine, and (2) to select the acceptance test, or combination of tests, that provide a high degree of confidence for demonstrating that the acceptance criteria are met. These criteria are those key characteristics (fit, form, function, and operation) of components, subsystems, and the engine which provide a basis for comparison or judgment that the deliverable engine is equivalent to engines that have successfully completed qualification testing. In determining the best acceptance test candidate(s) many other factors must be considered. These factors include safety considerations, test facilities, design impact, support equipment (TSE/AGE), support personnel, test location, associated logistics, and costs required to accomplish the acceptance test(s). In comparing the candidate acceptance tests these factors are weighed against the confidence level that a particular test, or combination of tests provides.

B. BACKGROUND INFORMATION

Several attempts to formulate an acceptance test philosophy have taken place over the past several years. However, no finalized approach toward resolution of the acceptance test philosophy was obtained. One of the primary reasons for this was the lack of adequately defined acceptance test criteria. Another major reason was the lack of maturity in engine design. The initial effort of this study has been largely oriented toward defining an approach for the definition of acceptance test criteria from which candidate acceptance tests could be compared.

II. SUMMARY

A. CRITERIA FOR DETERMINING FLIGHT ENGINE ACCEPTANCE

The basic philosophy of the approach to selecting the acceptance test(s) is one of proving that a deliverable NERVA engine is equivalent to other NERVA engines that successfully completed qualification testing. The objective is to demonstrate "equivalency" of engines without duplication of the Qualification Test Program. If this can be done with a high level of confidence, then it can be reasonably inferred that the deliverable engine also satisfies all of the functional requirements of the NERVA engine (Section III of the Engine Specification). For this approach to be successful, the criteria, or the key functional characteristics, must be established to satisfy this philosophy with a high degree of confidence. These criteria in effect become the forcing factor by which the various candidate acceptance tests can be compared.

It can be argued that the greater the number of criteria satisfied by acceptance testing at the engine level, the greater is the level of confidence. This does not preclude the possibility that other acceptance tests conducted at the subsystem or component level may also be necessary in establishing a high confidence level. In general, a greater level of confidence obtained by testing at the engine level also results in a greater impact on the factors, such as costs, facilities, personnel, handling logistics, etc. The complicity of these factors is traded against the level of confidence. Every phase of the engine buildup from component level acceptance to engine level acceptance must be considered.

Examples of acceptance test criteria are developed for a few of the important components (PSOV, TPA, BCV, BBV, Nozzle). An approach is developed for comparing the ability of various acceptance test candidates to demonstrate the criteria at the component, subsystem, and engine levels. The objective of the approach is to satisfy as many of the criteria as possible at the engine level. Because of the lack of maturity of the engine design a complete comparison is not possible, and this approach should be continued as the engine design progresses to obtain a complete comparison of the acceptance test candidates.

B. SELECTED CANDIDATE TEST(S) TO BE PERFORMED

The candidate acceptance test alternatives which have been tentatively selected include a Basic (Checkout) Test, Inert Gas Flow Test, Modified Cold Flow Test (Engine or Module), Cold Flow Test, Low Power Test, and a Full Power Test.

The Basic (Checkout) Test candidate provides a composite of a number of functional type checkout tests which form a fundamental building block for use during acceptance testing. These tests are planned to be accomplished in any event, and data provided by any other candidate alternative selected would be supplementary to the data from this basic test.

The Basic (Checkout) Test includes such items as visual inspection, dimensional and alignment checks, fit and match checks, electrical continuity (RLC), I&C continuity and readout, leak checks, valve actuation, thrust vector control operation, TPA torque break-away and running checks, and Destruct System electrical continuity.

The Inert Gas Flow Test candidate provides for the flowing of an inert gas, such as nitrogen or helium, at ambient temperature, through the engine system. The pressures and flow rates are adequate to demonstrate that normal flow is occurring throughout the system. In addition to determining that all flow passages are open, this test provides for the determination of the location of obstructions or problem areas.

The Modified Cold Flow Test (engine level) candidate provides for the functioning and/or flow check of the Propellant Feed System (PFS) and Structural Support Coolant System (SSCS), nozzle, and reflector systems without the necessity for bringing the reactor to even a low power level. This is accomplished by incorporating a means of bypassing the reactor utilizing a bypass system to exhaust the hydrogen before entering the reactor.

The Modified Cold Flow Test (module level) candidate provides for the complete functional checkout of the thrust structure module under full flow conditions with LH_2 . Since the module involves only that segment

of the engine from the lower thrust structure/pressure vessel interface to the engine stage interface the reactor would not be present and the test could be conducted without any concern of generating a radioactive environment.

The Cold Flow Test candidate provides for a test in which liquid hydrogen is circulated through the system with the reactor maintained at a constant low power level so that hydrogen reactivity is controllable. This test provides for an overall system checkout under LH_2 flow conditions and serves to verify valve sequencing and instrumentation performance. Additionally, it furnishes a flow check of the PFS, nozzle, and reflector system and verifies TPA rotation.

The Low Power Test candidate is a test which follows a normal start-up profile to a point above which program control is initiated but below the throttle point. This candidate would maintain the engine in a steady state condition at a low power level (approximately 170 MW) for a pre-determined duration followed by a ramp down through pump tailoff. This test would verify those performance requirements related to prestart and startup phases through bootstrap, a portion of the program ramp immediately after bootstrap, and a portion of pump tailoff.

The Full Power Test candidate provides for engine operation at the chamber pressure and temperature corresponding to the normal rated thrust and specific impulse. This candidate verifies the capability of the engine to perform most of its design performance requirements except, duration, restart, and operation in other than normal mode operation. However, a switch to the PFS malfunction mode could be accomplished during the shutdown phase to verify that function also.

Since the criteria have not been completely developed and all of the test related factors have not been assessed, no specific test(s) can be selected at this point in time.

A cursory examination of the candidate tests (Refer to Table I) indicates that the test program should be as extensive as possible short of involving operation at any significant power level. This is based on the fact that such operation results in a radioactive environment which presents difficulties in handling and subsequent use of the engine. In addition, discussions with the Kennedy Space Center (KSC) reveal that they prefer to receive a completely checked out and "cold" engine.

It is believed that the degree of component/subsystem acceptance testing accomplished as part of the engine assembly will assist measurably toward increasing the confidence level for engine acceptance. These component/subsystem tests combined with numerous functional checkout tests at the engine level provide a measure of confidence that the deliverable engine is equivalent to the engines that were qualified.

In using the "equivalent engine" approach it was determined that the development of the acceptance test (or combination of tests) must be carried along in conjunction with the engine development program. In other words, the acceptance test concept must also be qualified prior to being used in conjunction with the deliverable engine.

TABLE I

September 1970

COMPARATIVE SUMMARY OF CANDIDATE ACCEPTANCE TEST ALTERNATIVES

CANDIDATE TEST ALTERNATIVE	NUMBER AND % OF COMPONENT TESTS REPEATED AT ENGINE LEVEL		SAFETY MAJOR CONSIDERATION IF PERFORMED AT VARIOUS TEST SITES				RELIABILITY/CONFIDENCE LEVEL		COST FOR TESTS PERFORMED AT VARIOUS TEST SITES				SCHEDULE FOR TESTS PERFORMED AT VARIOUS TEST SITES				LOGISTICS FOR TESTS PERFORMED AT VARIOUS TEST SITES				DESIGN IMPACT POTENTIAL	ADVANTAGES	DISADVANTAGES	COMMENTS
	NUMBER	%	NRDS	MICHOU/MTF	KSC	OTHERS	IMPROVED	NOT MARKEDLY IMPROVED	NRDS	MICHOU/MTF	KSC	OTHERS	NRDS	MICHOU/MTF	KSC	OTHERS	NRDS	MICHOU/MTF	KSC	OTHERS				
BASIC (CHECKOUTS)	TBD	TBD	NO NEW PROBLEMS	REQUIRES ANALYSIS PROBABLY OK	REQUIRES ANALYSIS PROBABLY OK		✓		TBD	TBD	TBD		TBD	TBD	TBD		ENGINE SHIPPING CONTAINER REQUIRED	ENGINE SHIPPING CONTAINER REQUIRED	ENGINE SHIPPING CONTAINER NOT REQUIRED ONLY IF ASSEMBLY AT KSC		NONE KNOWN AT THIS TIME	1. PROVIDES A MARKED MEASURE OF CONFIDENCE THAT THE SYSTEM WILL FUNCTION AS PREVIOUSLY QUALIFIED ENGINES. 2. NO ENGINE RADIATION PROBLEM, AND THEREFORE MINIMUM PERTURBATION IN HANDLING AND SHIPPING	1. DOES NOT COMPLETELY DEMONSTRATE IN ACCORDANCE WITH THE USUAL CLASSICAL DEFINITION OF ACCEPTANCE THAT THE ENGINE WILL MEET ALL ITS RATED PERFORMANCE REQUIREMENTS.	THIS TEST FORMS ONE OF THE PRIMARY BUILDING BLOCKS TO WHICH DATA FROM ANY OTHER SELECTED CANDIDATE ALTERNATIVE(S) WOULD BE ADDED.
INERT GAS FLOW	TBD	TBD	MIGHT REQUIRE SOME ANALYSIS PROBABLY OK	REQUIRES ANALYSIS PROBABLY OK	REQUIRES ANALYSIS PROBABLY OK		✓		TBD	TBD	TBD		TBD	TBD	TBD		ENGINE SHIPPING CONTAINER REQUIRED	ENGINE SHIPPING CONTAINER REQUIRED	ENGINE SHIPPING CONTAINER NOT REQUIRED ONLY IF ASSEMBLY AT KSC		NONE KNOWN AT THIS TIME	1. PROVIDES MEANS TO CHECK THAT NO FOREIGN OBJECTS, PROTECTIVE CLOSURES, ETC. LEFT IN FLOW PASSAGES. 2. PROVIDES STIMULUS OF THOSE ENGINE TRANSDUCERS CAPABLE OF SENSING SMALL PRESSURE DIFFERENTIALS. 3. PROVIDES A FUNCTIONAL CHECK OF VALVES WHERE EFFECT ON FLOW RATE OF SUFFICIENT MAGNITUDE.	1. EXPENSE OF GSE REQUIRED 2. ORIFICE BLOCKAGE IN FUEL ELEMENTS NOT DISCLOSED 3. SPECIAL PROVISIONS REQUIRED FOR VENTING AND/OR DISPOSAL OF THE EXIT GAS.	THE UTILITY AND NEED FOR THIS TEST, AIMED AT DISCLOSING ABNORMAL FLOW CONDITIONS CAUSED BY FOREIGN OBJECTS OR IMPROPER ASSEMBLY, WOULD BE NEGATED TO THAT DEGREE TO WHICH A GOOD QUALITY CONTROL AND ASSURANCE SYSTEM WAS IMPLEMENTED AND CARRIED OUT. IT IS BECAUSE OF THE POSSIBILITY THAT QA HAS NOT BEEN 100% EFFECTIVE THAT THIS CANDIDATE NEEDS TO BE CONSIDERED.
MODIFIED COLD FLOW	TBD	TBD	REQUIRES ANALYSIS PROBABLY OK	REQUIRES ANALYSIS	REQUIRES ANALYSIS			✓	TBD	TBD	TBD		TBD	TBD	TBD		ENGINE SHIPPING CONTAINER REQUIRED	ENGINE SHIPPING CONTAINER REQUIRED	ENGINE SHIPPING CONTAINER NOT REQUIRED ONLY IF ASSEMBLY AT KSC		YES - SINCE REQUIRES THE MODIFICATION OF TDL FOR BYPASS OF H ₂	1. NO ENGINE RADIATION PROBLEM, SINCE ENGINE IS NOT LEFT "HOT" 2. PROVIDES CONFIDENCE PFS, NOZZLE, AND I & C SUBSYSTEM OPERATING	1. REQUIRES ENGINE MODIFICATION AND PROBABLE INCREASE IN WEIGHT 2. MODIFICATION COULD INVALIDATE ENGINE PERFORMANCE DATA. 3. WILL REVEAL ONLY GROSS ENGINE LEAKS ALREADY DETECTED BY STATIC LEAK TEST 4. CORE TEMPERATURE INSTRUMENTATION NOT AFFECTED OR STIMULATED 5. PRESSURES TOO LOW FOR RELIABLE CHECK OF PRESSURE TRANSDUCERS, EXCEPT IN PUMP INLET LINE 6. TPA PERFORMANCE INFORMATION LIMITED TO INITIAL BOOTSTRAP REGION. CHANGE IN ENGINE CONFIGURATION WOULD AFFECT TPA PERFORMANCE. 7. REASSEMBLY OF TDL WOULD REQUIRE SUBSEQUENT ADDITIONAL CHECKOUTS.	SINCE THIS TEST PROVIDES ONLY A PARTIAL FUNCTIONAL CHECK OF PFS, AN INCOMPLETE SYSTEM FLOW CHECK (CORE IS EXCLUDED), AND A TEMPERATURE INSTRUMENTATION STIMULUS CHECK IN THE FLOW PASSAGES, BUT DEGRADES ENGINE PERFORMANCE BY ADDITION OF UNNECESSARY WEIGHT AND POTENTIAL LEAKS IN DESIGN, IT IS FELT THAT INFORMATION PROVIDED BY THIS TEST CAN BE BETTER OBTAINED BY OTHER MEANS.
COLD FLOW	TBD	TBD	MIGHT REQUIRE SOME ANALYSIS PROBABLY OK	REQUIRES ANALYSIS	REQUIRES ANALYSIS	THESE SITES ARE NOT AEC APPROVED AND MUST BE EQUIPPED TO COPE WITH MAXIMUM CREDIBLE ACCIDENT IF ANY LH ₂ FLOW IS PLANNED	✓		TBD	TBD	TBD		TBD	TBD	TBD		MINOR RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING	MINOR RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING	MINOR RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING		NONE KNOWN AT THIS TIME	1. TEST DOES NOT LEAVE ENGINE "HOT" 2. PROVIDES ADDITIONAL MEASURE OF CONFIDENCE THAT ENGINE WILL MEET PERFORMANCE REQUIREMENTS 3. EXTENSIVE FACILITIES NOT REQUIRED 4. VERIFIES VALVE SEQUENCING AND INSTRUMENTATION PERFORMANCE	1. ONLY GROSS LEAKS DETECTED WHICH STATIC LEAK TESTS SHOULD DISCLOSE 2. PROVIDES A RELIABLE CHECK IN DETERMINING THE CRITICAL DRUM ANGLE WITH HYDROGEN IN THE CORE AND STEMS 3. TPA PERFORMANCE INFORMATION LIMITED TO INITIAL BOOTSTRAP REGION. MEASURABLE ACCEPT/REJECT LIMITS FOR PERFORMANCE IN THIS REGION NARROW AND ARBITRARY	TOTAL SYSTEM CHECKOUT PROVIDED AT CRYOGENIC FLOW CONDITIONS WITHOUT ANY SIGNIFICANT POWER LEVEL REACTOR OPERATION. PROVIDES OPPORTUNITY FOR VALVE SEQUENCING AND INSTRUMENTATION PERFORMANCE (EXCLUDING HIGH RANGES), AND OVERALL ENGINE SYSTEM SHAKEDOWN
LOW POWER	TBD	TBD	MIGHT REQUIRE SOME ANALYSIS PROBABLY OK	REQUIRES ANALYSIS	REQUIRES ANALYSIS	THESE SITES ARE NOT AEC APPROVED AND MUST BE EQUIPPED TO COPE WITH MAXIMUM CREDIBLE ACCIDENT IF ANY LH ₂ FLOW IS PLANNED	✓		TBD	TBD	TBD		TBD	TBD	TBD		RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING	RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING	RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING		NONE KNOWN AT THIS TIME	1. VERIFIES SEVERAL ENGINE PERFORMANCE REQUIREMENTS RELATED TO PRESTART AND STARTUP PHASES THROUGH BOOTSTRAP AND A SMALL PORTION OF PROGRAM RAMP BEYOND BOOTSTRAP. 2. VERIFIES LOOP CLOSURE SINCE T _c REACHES APPROXIMATELY 1400°R 3. PERMITS SOME CALIBRATION OF THE NSS. THE CRITICAL DRUM ANGLE ESTABLISHED BUT THIS WOULD BE DONE NORMALLY PRIOR TO ANY FLOW OF LH ₂ . 4. DEMONSTRATES TPA RESPONSE (SPINUP), AND PRESSURE AND TEMPERATURE INSTRUMENTATION RESPONSE	1. TEST VERIFIES ONLY REQUIREMENTS RELATED TO PRESTART AND BOOTSTRAP PORTION OF STARTUP PHASE. 2. CONTROLLING P _c OR T _c ALONG PROGRAM RAMP, OR ACHIEVING RATED CONDITIONS, OR SHUTDOWN NOT VERIFIED. 3. ALTHOUGH POST-TEST RADIATION LEVELS PERMIT PERSONNEL ACCESS TO ENGINE, STAGE AND VEHICLE ACTIVITIES WOULD BE HAMPED. 4. NECESSARY TO REPLACE POISON WIRES IN CORE. 5. PROVIDES A RELIABLE CHECK IN DETERMINING THE CRITICAL DRUM ANGLE WITH HYDROGEN IN THE CORE AND STEMS	THIS TEST WOULD YIELD ONLY SLIGHTLY MORE INFORMATION THAN COLD FLOW. ALTHOUGH A MEASURE OF CONFIDENCE IN CONTROL SYSTEM OBTAINABLE UP TO POINT OF TEST TERMINATION, TEST DOES NOT VERIFY P _c RAMP RATE, RATED THRUST, I _{sp} , DURATION, ETC. ADDITIONALLY NSS CALIBRATION WOULD NORMALLY BE OBTAINED WITHOUT A FLOW TEST.
FULL POWER	TBD	TBD	MIGHT REQUIRE SOME ANALYSIS PROBABLY OK	REQUIRES ANALYSIS	REQUIRES ANALYSIS	THESE SITES ARE NOT AEC APPROVED AND MUST BE EQUIPPED TO COPE WITH MAXIMUM CREDIBLE ACCIDENT IF ANY LH ₂ FLOW IS PLANNED	✓		TBD	TBD	TBD		TBD	TBD	TBD		SEVERE RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING	SEVERE RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING	SEVERE RADIO-ACTIVITY PROBLEM IN SHIPPING AND HANDLING		NONE KNOWN AT THIS TIME	1. VERIFIES THE CAPABILITY OF THE ENGINE TO MEET MOST OF THE PERFORMANCE REQUIREMENTS, EXCEPT DURATION, RESTART, AND OPERATIONS IN OTHER THAN NORMAL MODE. (PFS MALFUNCTION MODE COULD BE PICKED UP DURING SHUTDOWN PHASE) NOTE: THRUST MAY BE AN ADDITIONAL REQUIREMENT WHICH THE CURRENT FACILITIES DO NOT HAVE ANY PROVISIONS FOR MEASURING	1. PROBLEMS ASSOCIATED WITH POST-TEST HIGH RADIATION LEVEL 2. NECESSARY TO REPLACE POISON WIRES IN CORE 3. TEST WOULD REDUCE THE AVAILABLE ENGINE LIFE 4. ADDITIONAL ANALYSES WOULD STILL BE REQUIRED 5. DURATION, AMONG OTHER REQUIREMENTS NOT VERIFIED 6. MOST COSTLY OF ALL CANDIDATES - COST DECREASE WITH LESSER SEVERITY TEST.	WHILE A FULL POWER TEST DEMONSTRATES OPERATION AT RATED PERFORMANCE, NOT ALL PERFORMANCE REQUIREMENTS CAN BE VERIFIED, AND THE SEVERE PROBLEMS IMPOSED BY RESIDUAL RADIOACTIVITY MAKE THIS TEST HIGHLY IMPRACTICAL. THERE SHOULD BE NO NEED TO RE-DO PERFORMANCE TESTS WHICH HAVE ALREADY BEEN ACCOMPLISHED IN THE ENGINE DEVELOPMENT QUALIFICATION TESTING PROGRAM.

III. SCOPE

This initial trade study effort presents a preliminary evaluation of candidate acceptance test alternatives. A necessary part of this evaluation involves the definition of acceptance test criteria for the components, subsystems, and engine. The component and subsystem criteria are considered because the nature of the overall system acceptance test depends, in part, on the degree of testing performed to verify the proper functioning of individual components or subsystems. The relative advantages and disadvantages of the candidate alternative approaches to acceptance testing are reviewed considering such factors as reliability/confidence level, safety, design impact, logistics, schedule and costs.

The trade study will ultimately make recommendation and provide supporting justification for specific acceptance test requirements which can be shown to satisfy the established criteria. However, the current assessment is incomplete and no recommendations can be made at this time.

IV. TECHNICAL DISCUSSION

A. DEFINITION OF ACCEPTANCE TESTING

AFSCM 375-1 defines acceptance testing as the formal inspection, testing and/or analysis accomplished in accordance with Part II of a uniform specification to verify the performance and adequacy of an item of supply at the time of its delivery and acceptance by the government. From the AFSCM instructions regarding the preparation of the CEI Part II Specification, it can be seen that their objective for the acceptance testing is to establish the quality of a Contract End Item (CEI) as manufactured.

In the course of pursuing the work to be accomplished, the NERVA engine development program and, therefore, the engine qualification program will necessarily have been completed prior to reaching the point of delivery of an engine. This means that the engine design will have been proven capable (to the maximum extent possible) of satisfying all the requirements specified in the CEI Specification, Part I, "Performance/Design and Qualification Requirements".

Basically, then the goal to be accomplished in acceptance testing is to provide as high a level of confidence as possible in demonstrating to the satisfaction of the customer that the deliverable engines are equivalent to those earlier assembled engines which have successfully completed the Qualification Phases of the engine development program. However, providing proof of this equivalence does not necessarily require repeating the same tests that will have been accomplished in the Qualification Program to demonstrate performance.

The approach and methodology for achieving the high level of confidence desired as pertaining to the demonstrating of the equivalence of the deliverable engine to those engines previously qualified during the development program form the subject of this trade study.

B. PHILOSOPHY OF ACCEPTANCE TESTING

The NERVA engine presents a new problem in the area of acceptance testing rocket propulsion units. Since the engine is a nuclear engine, there is the problem of residual radiation which is present and emitted after the engine (reactor) has been operated at any appreciable power level. The

resultant radiation hazards and safety problems associated with the expected levels of radiation effect personnel access to the engine. The restrictions related to personnel accessibility to the engine also apply toward creation of additional problems in transporting the engine, should that be necessary.

As inferred above, post-operation access limitations vary, depending upon the radiation dose rate present. For short duration runs, the dose rate is proportional to the power-time integral of reactor operation. Tests in which the reactor is operated barely above the point of criticality, (as in a dry criticality test) result in a relatively small amount of radiation, and minor access limitations, while tests at near rated power, even for a few seconds, raise the radiation level high enough to impose stringent limitations for a long period of time. Estimated dose rates for a 20 second full power run are shown in Table IV, which is discussed in greater detail under Full Power Test.

1. Other Programs

The radiation problem and cost of the nuclear engine makes it impractical to follow the conventional acceptance testing procedures utilized for typical liquid or solid rocket engines. Liquid engines, such as the Titan, have traditionally been acceptance tested by the hot firing of each engine for a predetermined time to obtain directly the necessary measurements for verifying performance characteristics. This firing is usually at full power (or thrust) and is followed by an inspection and servicing of the engine.

In the case of solid rocket motors, the acceptance testing generally includes a functional checkout of each motor, but with the performance characteristics such as thrust, Isp, and duration, being verified by the firing of samples from the production line.

Acceptance testing the NERVA engine in a fashion similar to the liquid engines would connote conducting tests which operate the engine at full power rated performance, resulting in sacrificing a portion of the engine life in addition to the problems related to radiation and safety hazards previously mentioned. Although this is not an impossibility, at present it portends some serious disadvantages which will necessarily have to be considered.

Acceptance testing of the NERVA engine in a manner similar to that used for the solid rocket engines implies the discard of a tested engine which is prohibitive from the standpoint of the high costs of engines as well as the limited number of engines that would be produced. Also, the qualification of a number of engines during the engine development program will have served to provide a sampling of sorts of engines typical of the production engine, and at that time, most of the performance and functional requirements will have been demonstrated. For the deliverable flight engines, there should not be any need to re-do even portions of this previously accomplished Engine Qualification Program. The Acceptance Test should instead demonstrate that the deliverable engine has all the critical characteristics similar to the engines that successfully completed qualification testing.

2. NERVA Program

The NERVA Program Requirements Document (NPRD) currently states that "the engine assembly will be accepted on the basis of successful functional and cold flow tests, together with a review of the production and test history of those components in the assembly and all other related components in the program". This provides only a partial basis or guideline requirement, and indicates that all of the documentation, such as the records generated for the deliverable components/subsystems during the testing, shipping, receiving, and inspection manufacturing, processes may be used as part of the CEI acceptance test. The accumulation of these data will provide a basic package which is a positive addition toward proving the equivalence of the deliverable engines to those which have successfully completed the Qualification Program.

However, the goals of the actual testing to be conducted as part of the acceptance test which serve to provide the sufficiency of the level of confidence in assuring this equivalence must ensure accomplishing this objective without creating unnecessary radiation/safety hazards, or sacrificing engine life. These criteria are fundamental to the initiation of the detailed acceptance test criteria which must necessarily be established in order to provide a basis for evolving of the acceptance testing to be performed. Once the detailed acceptance testing criteria has been established the type and extent of testing to be performed for acceptance of the engine will be fairly well determined.

Eventually the requirements and the tests/verifications for Engine Acceptance will be contained in the CEI Specification, Part II, "Production Configuration and Acceptance Test Requirements", which must be completed before First Article Configuration Inspection (FACI). Although preparation of this Part II Specification will not begin for some time, answers regarding acceptance test requirements are needed for facilities and logistics planning. Additionally, the early development of a NERVA Acceptance Testing Program would be beneficial in that it would afford the opportunity for trying and proving out the acceptance testing concepts during the engine development program. The acceptance test should also be qualified as a part of the Qualification Program, and should remain the same for the deliverable engines. This is illustrated in Figure 1, which displays an overall inter-relationship of the activities leading to the establishment of a formal acceptance test program.

C. ANALYTICAL METHOD FOR COMPARATIVE EVALUATION OF
CANDIDATE ACCEPTANCE TEST ALTERNATIVES

It is anticipated that the complete set of acceptance testing criteria will evolve as the NERVA program progresses. The primary objective of the initial trade study effort is to perform a preliminary evaluation of the acceptance test alternatives. As stated earlier a necessary part of this evaluation is the definition of the acceptance test criteria for the components and subsystems that make up the engine system. The component and subsystem criteria must be considered because the nature of the overall system acceptance test depends in part, on the degree of testing performed to verify the proper functioning of the individual components or subsystems. The extent of the acceptance tests required on the completed engine assembly will be influenced by the extent of acceptance testing already conducted at the component and subsystem level. Conversely, the engine acceptance testing requirements could influence the amount of testing to be done on the component level by decreasing or increasing the number of tests to be performed. Furthermore, the data generated at the component/subsystem level is expected to be sufficient to verify its similar quality and acceptability, and since the component/subsystem will have been accepted prior to engine assembly in accordance with the provisions of Part II component specifications (it is anticipated that no component acceptance testing per se will be performed at the engine level), the documentation from these tests, along with documentation previously mentioned, will be available for use in the engine acceptance testing/verification program.

AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET - GENERAL

ACTIVITIES LEADING TO THE ESTABLISHMENT OF A FORMAL ACCEPTANCE TEST PROGRAM FOR THE DELIVERABLE NERVA ENGINE

September 1970

A sequential flow diagram showing the various components and sub-assemblies as related to one another in leading toward the different sub-assemblies and modules which eventually are integrated into the NERVA engine is shown as Figure 2. Also displayed in this figure are the flow and accumulation of the data packages and a number of control and verification checks and tests at various stages of the components/subsystems integration into a total engine assembly. Additionally, a tentative selection of items to be included in a Basic Acceptance Testing Package for the engine is shown along with preliminary candidate acceptance test alternatives for possible addition to create the total acceptance test program. Additional visibility as to what types of tests might be included with each of the candidate alternative acceptance tests is shown in Figure 1 and is further detailed in the individual descriptions and discussions for each of the candidates in following sections of this report.

At this point in time, because of the incipient state of design which most of the engine components are in, the development of the acceptance test criteria and consequently the acceptance testing requirements for the components have not been initiated as yet. However, in accordance with the philosophy expressed herein the importance of examining the acceptance test criteria for the components/subsystems in attempting to predict the types and kinds of acceptance tests to which the components/subsystems would be exposed, made it mandatory to provide for an investigation into this area without regard to the current status of component design.

1. Assumption of Component Verification Testing Based on Earlier Phases of NERVA Program.

AFSCM 375-1 provides for Part II of the Component Specifications to define the acceptance requirements and criteria for each component. The writing of Part II of the Component Specifications, as inferred above is not planned to be accomplished for some time. However, reasonable assumptions regarding the acceptance testing of components and subassemblies can be made based on common practices established in earlier phases of the NERVA Program, as well as in other rocket programs.

An overall view of what will be known of a candidate NERVA Flight Engine results from component level acceptance testing prior to final engine assembly. Special test equipment and tooling will be built and used to perform the tests as required. It must be remembered that the tests listed are only reasonable assumptions for use in this study. The component

COMPONENT/SUBASSEMBLY INTEGRATION FOR ENGINE ASSEMBLY SHOWING TENTATIVE CHECKOUTS, VERIFICATIONS, AND TESTS FOR ENGINE ACCEPTANCE

September 1970

specifications, when prepared, may or may not include such requirements. Experience gained in the development and qualification programs will also have a considerable effect on the selection of the acceptance tests.

The assumptions regarding acceptance testing of various components is detailed in the following paragraphs:

a. Valve/Actuator Acceptance

(1) Valves

Before being mated to the appropriate actuator, valves will be subjected to limited dimensional and functional tests to verify size and interface dimensions and correct torque values over the full range of travel. Stroke measurements will be taken, especially on control valves. Proof and leak tests will be conducted. In general, this type of testing will be performed on all engine valves including check valves. There will probably be no cryogenic tests at this level of assembly (except for check valves with no actuators).

(2) Actuators

Before being mated to the appropriate valve, actuator operation will be thoroughly tested under simulated load conditions. The type of tests performed will vary according to whether the actuator is a binary type, or a control (analog) type. The appropriate continuity, insulation breakdown (megger) and functional electrical checks will be performed. Test equipment will be built for these tests.

(a) Binary Type

Open/close rates and response times under simulated load will be verified at ambient temperature under simulated operating loads.

(b) Analog Type

Slew rates, frequency response, threshold checks and positioning accuracy checks will be verified under simulated operating load, at ambient temperature, for both normal and emergency modes.

(3) Valve Assembly Tests

After valves and actuators are mated additional tests will be performed. In the case of valve modules, these tests may be performed on a complete module. Tests are expected to include the following:

- (a) Functional checkout at ambient temperature.
- (b) Proof and leak test for internal and external leakage, combined with a functional checkout, at ambient temperature.
- (c) Cryogenic tests including leak tests and functional checkout. Test conditions may progress from LN_2 to LH_2 and will probably simulate the operating environment the valve will see in service.
- (d) Cryogenic Flow Tests (at various increments of travel for control valves).
- (e) Measurement of purge gas flow.
- (f) Ambient functional and electrical checks prior to packaging.
- (g) Accountability, and buy-off

b. Turbopump Assembly (TPA)

It can be assumed that the candidate flight TPA's will be subjected to a "green test" before engine assembly. In this test the TPA would be operated at conditions simulating rated operation in the normal mode, as well as the single turbopump operational mode (PFS Malfunction Mode.) It may be desirable to verify specification extreme performance also. The complete startup and shutdown profile could be duplicated, although this would depend on the facility control system capability. It may be feasible to include the TPA module valves in the "green test" to provide additional assurance of their proper operation.

In conducting the green test, the following information on the TPA would be of particular interest.

- (1) Break-away Torque
- (2) Head vs Flow Characteristics (pump and turbine)
- (3) Instrumentation performance
- (4) Others

c. Propellant Lines

For this discussion, all lines of the propellant feed system except the engine purge unit are considered propellant lines.

Normally, at the completion of fabrication, lines are proof tested to the pressure specified on the drawings. Dye penetrant tests, X-Ray of welds, and other inspections will also be performed as a normal part of the manufacturing process. These tests are performed at ambient temperature.

a. Engine Purge Unit

The engine purge unit acceptance testing will include proof and leak tests of the purge unit valves at ambient temperature as well as functional tests at ambient temperature. Cryogenic tests may also be performed to assure proper operation in the event of exposure to cryogenic conditions during operation. Proof and leak tests may be performed on the purge distribution lines. Flow Tests may be conducted to preclude blockage.

e. Nozzle Assembly Subsystem

The nozzle and the nozzle extension, which comprise the nozzle assembly subsystem, will be acceptance tested separately.

(1) Nozzle

Numerous tests will be performed on the nozzle to verify its structural integrity and compliance with fabrication drawings. Chemical hot firing tests simulating its operating environment are possible, but are not planned at this time. Such tests were conducted on early NRX nozzles, but were discontinued for XE because of several types of operational problems which resulted in damage to the nozzle. The following is a list of tests which will probably be conducted on the NERVA nozzle prior to engine assembly. In addition to actual tests, documentation of the manufacturing processes will be part of the acceptance package.

(a) H_2O flow tests through individual tubes to verify that each one is open and free flowing and to determine K value.

(b) H_2O flow tests through the cooling system, to determine the water K value.

(c) Titration tests to determine the volume of the coolant tubes and the tube cross sections at various stations. This will verify that the tube is at the proper depth in its groove, and that the proper coolant velocities will be attained.

(d) Leak tests for internal and external leakage.

(e) Proof test of tubes

(f) Proof test of nozzle chamber upstream of the throat.

(g) Inspections, including radiography for chips and obstructions in flow passages, and dye penetrant checks.

(h) Dimensional check throat, interfaces, misalignment

(2) Nozzle Extension

The flight nozzle extension will be accepted on the basis of the quality control documentation of the manufacturing process (including conformance to drawings) and by inspection and analysis. Proof and leak tests would not be meaningful as the aft end of the nozzle extension is too large and the use of a mechanical plug closer to the joining interface presents difficulties. The flight version is not currently considering the use of any strain gage, pressure, temperature, or other instrumentation and therefore eliminates the need for any instrumentation checkouts. The loads that would be experienced by the flight nozzle extension are primarily thermal and vibrational and will have been compensated for in the design. Techniques such as ultrasonic or X-Ray examination would be employed as part of the Quality Assurance operations in its manufacture. The extension would be self-aligning having registered diameters. Therefore, upon its assembly to the nozzle, visual inspection and dimensional checks should suffice.

f. Instrumentation and Control Subsystem

(1) NERVA Digital Instrumentation and Control Electronics

The acceptance testing of the NDICE will probably include a complete checkout of input vs output, using some type of a simulator, to verify that the unit is functioning properly. The object of this type of test is to verify that all the various circuits function as specified, over the specified ranges.

Another test that will probably be performed, especially for the first flight units, is to play the NDICE with the Common Analog Model (CAM), to actually simulate the engine over the full operating cycle, from startup to shutdown. Various malfunction conditions might be simulated also. This type of test would verify the NDICE design. Since the qualification program will be completed by this time, this test may be of minor importance compared to the more comprehensive type mentioned above.

(2) Wiring Harness

Acceptance testing of the wiring harness at the component level, before engine assembly, will probably be limited to standard electrical checks (resistance, continuity, impedance and insulation breakdown). A trial mating of connectors at the interfaces for the various portions of the harness itself may be performed. If so, electrical checks of the combined portions would then be performed also.

(3) Engine Instrumentation

Engine instrumentation includes all the various transducers, thermocouples, etc. that go into the engine, except for those identified as Nuclear Subsystem Instrumentation, and those which are provided

as an integral part of other engine components. Acceptance testing of the individual components of the engine instrumentation will include the standard electrical checks, and calibration tests. Where applicable, proof and leak tests will be performed.

g. Thrust Structure Subsystem

The acceptance testing of both the upper and the lower thrust structures will probably include proof loading at ambient conditions. Documentation of dimensional checks (including gages), material certifications, Weight, radiography, etc. during and at the completion of fabrication is expected to be required also. Vibration testing will probably not be performed on the deliverable units.

h. External Shield

Acceptance testing of the external shield will probably be limited to trial fit-up of the various segments, with backup provided by documented results of dimensional measurements, weights, materials certification, etc., accumulated during fabrication.

i. Gimbal Pivot

Acceptance tests of the gimbal pivot can be expected to include proof loading, with backup documentation including records of dimensional checks, materials certifications, absence of residual magnetism, etc. Results of tests conducted at lower levels of assembly, such as angular movement of the flexure pivot, will also be a part of the acceptance package. As with the thrust structures, vibration testing will probably not be performed on deliverable units.

j. Gimbal Actuators

Acceptance testing of the gimbal actuators is expected to include verification of the insulation resistance and dielectric strength of electrical components, proof loading, and the verification of actuator position control requirements. This would include output force, stroke, rate of travel, acceleration, step command response (displacement vs time) under simulated load, overshoot, settling time, positioning accuracy, threshold, and deceleration under simulated load. These results would probably be measured at both upper and lower limits of input voltage. Verification of (TBD) coolant flow to the actuator is also a probable test, and would likely be done concurrently with some of the operations named above.

k. Pressure Vessel and Closure

Several pressurization cycles at ambient conditions to the proof pressure specified by the component drawings can be expected as part of the acceptance requirements for the pressure vessel cylinder and closure.

Documentation of the manufacturing history, including the materials certifications, dimensional checks, verification of cleaning, weight, etc. will be a part of the acceptance package.

l. Nuclear Subsystem (to be determined)

m. Electromagnetic Interference (EMI)

EMI tests will be conducted on selected components. The manner in which these tests will be conducted will need to be determined, depending upon the particular component selected, its size, etc.

n. Summary

It can be seen based on the earlier phases of the NERVA Program that a considerable amount of testing can and will be performed on the components prior to their assembly into the engine. An interesting speculation concerned with component tests is that the test conditions imposed will probably be of greater severity than the conditions imposed in an engine system test. Also, interactions between components operating in a system will not be revealed in component tests. However, because identical components will have gone through the engine qualification program, there is a basis for assuming that the interactions between assembled accepted flight components will be the same. Additionally, the acceptance criteria defined in Phase II of the component specifications will have been met by each of the components before it is placed on the engine assembly, unless it is not possible to verify (by test, analysis or inspection) a particular requirement until it is tested as part of the engine. If any of these requirements exist, they must be identified before engine acceptance tests can be defined.

2. Component Verification Tests Repeated During an Engine Level Test

In continuing to pursue the objective of determining the kinds and number of component tests repeatable at the engine level, the items which comprise the Specification Tree were selected as a starting point. A review was initiated to select as many readily apparent functional characteristics of each item as possible as potential characteristics or requirements that might be verified at either a component, subsystem, or engine level. Several forms were developed as part of the technique for categorizing and itemizing the component tests which might be repeated at the engine level for various candidate acceptance test alternatives as compared to similar tests performed at the component or subsystem level. The first of these forms is shown as Table II. In this form each component was identified and associated with its next higher assembly, and testing information tabulated. Additional examples of the form filled in with data are shown in the Appendix B for those components for which data have been partially accumulated.

TABLE II
SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT _____
A PART OF _____

PAGE _____ OF _____
DATE _____

FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUT	INERT GAS FLOW TEST	COLD* FLOW TEST	LOW POWER TEST	FULL POWER TEST	
<p>* MCF after entry indicates Modified Cold Flow Testing Alternative CF after entry indicates Cold Flow Testing Alternative</p>									

II As can be seen by examination of the form shown in Table III, the first column is used to designate a particular functional characteristic or requirement of a component which might be demonstrated or verified at a component, subsystem/module, or engine level as shown by information provided in the next three columns. There are several facets to this portion of the data which can be examined from the point of view of determining first, the one or more levels at which a component test can be conducted and second, if more than one level, determining the preferential level at which to conduct the test to obtain the particular item of data. Following this an examination would be made of each one of the functional characteristics with reference to the particular candidate acceptance test alternative which would be required as an engine test for its demonstration. This would be indicated by the placing of a check mark in the appropriate columns under the candidate alternatives. [It should be noted that the conduct of any of the candidate acceptance test alternatives other than the Basic Checkouts implies that those tests associated with this latter candidate would be conducted in addition to rather than instead of the other candidate test.]

3. Distribution of Engine Level Tests Among Candidate Alternatives

A second form, shown as Table III, has been prepared to total and indicate the quantitative distribution of the repeated component tests conducted at the engine level among the various candidate acceptance test alternatives. The first column of this form is used to itemize the various individual components which were detailed separately on the previous form shown as Figure 3. The second column simply provides a place for listing the total number of all engine level tests, again as shown on the previously filled in form for a particular component. The additional columns are for splitting up this total number of engine level tests conducted into a distribution showing the number conducted by performing any one of the particular candidate alternative tests. [Totalization of the number of tests in each category and the relative distribution would then provide an indication of which of the candidate acceptance test alternatives provide a preponderance of encompassing and repeating a determination of functional characteristics and requirements such as were determined previously on an individual component level. This then provides one basis for trade-off against the advantages and disadvantages of conducting a particular candidate acceptance test alternative.]

FANTASTIC!

TOTAL COMPONENT TESTS PERFORMED AT ENGINE LEVEL
FOR ENGINE ACCEPTANCE

COMPONENT	TOTAL NO. OF TESTS	DISTRIBUTION OF COMPONENT TESTS AS PERFORMED BY THE VARIOUS CONDITIONS					REMARKS
		BASIC CHECKOUT	INERT GAS FLOW TEST	COLD* FLOW TEST	LOW POWER TEST	FULL POWER TEST	
* MCF after entry indicates Modified Cold Flow Testing Alternative CF after entry indicates Cold Flow Testing Alternative							

4. Comparative Matrix of Candidate Alternatives for Component Engine Level Tests

(Not completed at this time)

NOTE: This matrix will present a tabulation of the candidate acceptance test alternatives showing the % of component verification tests which each candidate demonstrates along with a listing of their advantages and disadvantages.

5. Effect of Candidate Acceptance Test on Component and/or Total Engine Reliability

(No work efforts have been expended in this area as yet)

6. Effect of Candidate Acceptance Test on Component and/or Subsystem Operational Life

(No work efforts have been expended in this area as yet)

7. Recommended Simulated Tests

(Not completed at this time)

NOTE: The type of simulated tests which would be accumulated and detailed in this section would be concerned with candidate acceptance test alternatives which utilize non-conventional tests with component and/or engine hardware other than that of the deliverable engine itself. For example, in the case of the reactor it might be possible to demonstrate operating life by preparing a few fuel elements from the same batch as the flight reactor fuel elements, and subjecting them to long duration furnace tests. This would correspond roughly to propellant batch testing utilized for solid rocket motors.

D. PRELIMINARY SELECTION OF ACCEPTANCE TEST CRITERIA

1. Basis for Criteria

As shown in Figure 1, there are a number of factors which contribute toward the establishment of acceptance test criteria. Among these factors, some of which have been previously discussed, are such items as current and past rocket engine practices, the number and types of simulated tests that it might be possible to conduct, and the engine level tests which involve flow or no flow which may or may not be feasible to conduct. The current reactor technology coupled with the analyses that can

be made are important factors for consideration. Additionally, the constraints which may be imposed by facilities considerations even to involving the availability of suitable or permissible facilities would also need to be taken into account. Finally, it is quite probable that a number of requirements will emanate from the customer which will have to be negotiated, resolved, and in the final analysis satisfied.

E. CANDIDATE ACCEPTANCE TEST ALTERNATIVES

1. Basic (Checkout) Acceptance Test

This particular test is a composite of a number of functional type checkout tests, and forms a fundamental building block in acceptance testing. The tests included in this checkout are planned to be accomplished in any event. The data obtained from any of the other selected candidate alternatives would be utilized to supplement the data from these basic checkout tests.

a. Preparatory Component Acceptance Testing

Before the assembly of the engine can be started it would first be necessary to provide for the acceptance testing of all the components and subassemblies. After components and subassemblies have been accepted, they will be transported to the assembly site - (TBD). Shipping will be accomplished using approved shipping containers and methods, in accordance with a shipping plan. At the assembly site, the components will undergo an inspection for possible shipping damage. Assuming the inspections reveal no damage, the components will be approved for installation on the engine. Engine assembly will be accomplished in accordance with the appropriate assembly drawings, using approved procedures. Product Assurance Verifications will be obtained during the receiving inspection and assembly process.

It is contemplated that the nozzle extension would be shipped directly to Kennedy Space Center (KSC) rather than the engine assembly site should these two sites not be coincident, since the nozzle extension is not required for engine acceptance testing for the reasons previously stated under C.1.e.(2). The size of the nozzle extension and the increased length this would add to the engine, coupled with the fact that it would not provide any real contribution to the acceptance testing of the engine, reinforce its acceptance based on similarity and conformance to drawing.

In order to show that no degradation of the components has occurred since the last previous test (before shipment) certain functional checks will be required. The checks to be performed will be determined based on an evaluation of the possible effects of the shipping environment. It is assumed that procedures will be written and approved for the inspections which will probably include functional checks. The successful completion of the pre-assembly inspections will verify the acceptability status of the components and release them for assembly.

During the assembly steps, quality assurance will be employed to monitor the work as it is accomplished. The types of inspections that will probably be utilized are briefly described as follows:

(1) Configuration

Evidence of component acceptance and the correct component part number documented for each component before installation.

(2) Mechanical

Use of the proper fastening devices, proper torque values, lockwire installation, etc., in the mechanical joining of the components verified and documented. This is normally done throughout the assembly phase.

(3) Electrical

All electrical connections and terminations verified. This will be done progressively as the engine is built up by performing electrical checks at the interfaces. Electrical checks will be specified in the assembly drawings/procedures, and will include checks for resistance, capacitance, continuity, etc.

(4) Fluid

The proper mate-up of all flow passage joints verified. To a large degree, this can be accomplished by leak test. However, there will be some semi-permanent and/or permanent joints (not yet defined) which will require some additional test/verifications. In addition to leak testing, visual inspection, radiography, dye penetrant checks and analysis will probably form the basis for acceptance of these joints. Proof testing of the assembly to operating pressure will probably not be attempted.

(5) Functional Checks

Functional checks such as valve cycling, and TPA torque checks, may be performed during the course of the assembly.

(6) Dimensional Checks

There will be some dimensional requirements to be verified, especially at the engine/stage interface. Alignment and engine length will require verification also.

It is anticipated that the complete records of the engine assembly process, including the quality assurance certifications, as-built drawings, assembly procedures and any other required documents will be maintained as part of the engine documentation package.

Once the engine assembly has been accomplished, the checkout of the completed engine assembly then constitutes a basic candidate acceptance test alternative as detailed below:

b. Description

The basic acceptance test consists of all inspections, checkouts, and functional tests which would normally be required prior to an operational test. The basic acceptance test consists of the following:

(1) Electrical Checkout

- (a) RLC measurements
- (b) Transducer stimulus checks
- (c) Transducer shunt calibration
- (d) Insulation resistance leakage (megger check)

NOTE: During these high voltage checks, it is necessary to disconnect all sensitive electronic elements to avoid damaging them.

- (e) Electrical continuity
- (f) Short circuit check

NOTE: Electrical checks from the point where the wiring harness interfaces with the stage will be performed, and the results compared with allowables.

(2) Leak Check

All external joints in the flow paths will be checked for leakage. This will probably be performed using helium as the pressurant, at approximately 50 psia, and an approved leak detector. A nozzle plug is required to pressure check the entire engine.

(3) Functional Checkout

Functional checks of all actuators will be performed. The NDICE should be used for this check, especially if done in conjunction with the engine acceptance test. Actuation rates will be recorded for comparison with the last previous values for determination of any degradation that may have occurred during the assembly phase, along with other items of data in the following list:

- (a) Valve/actuator response
- (b) Actuator command and position feedback

- (c) Current versus position
- (d) Applied voltage
- (e) TPA breakaway torque
- (f) Control drum control response
- (g) Control drum feedback response
- (h) Control drum feedback calibration check
- (i) Gimbal actuator response and angular displacement
- (j) Optical alignment
- (k) Gimbal actuator feedback response
- (l) Gimbal actuator feedback calibration
- (4) Inspections
 - (a) Visual
 - (b) Dimensional
- (5) Documentation Analysis
 - (a) Engine assembly and checkout records
 - (b) Transportation records
 - (c) Trend Data Analysis

The data on the engine components that has been accumulated from the manufacturing of the components through the completed engine assembly checks will be examined for indication of any trends which would indicate deviations from expected performance by any component.

- (6) Test Conditions
 - (a) Pressure - The engine will be static leak checked at 50 psig.
 - (b) Flow - N/A
 - (c) Temperature - Ambient
 - (d) Duration - Time to measured leak or pressure decay.
 - (e) Power Level - N/A

c. Test Objectives

The objectives that would be realized from this candidate test are:

- (1) Certification of proper assembly.
- (2) Certification of piping system integrity.
- (3) Certification of proper valve actuation at ambient conditions.
- (4) Certification of electrical integrity.

(5) Certification that engine records and trend data do not indicate any apparent incipient failure.

d. Functional Description

Upon completion of engine assembly a complete checkout (leak, electrical, and functional) is usually accomplished. In this case, however, these tests would constitute a portion of the formal acceptance and would be conducted along the appropriate guidelines and under the proper surveillance required for formal acceptance. The tests defined in Paragraph E.1.b. could be performed at the assembly site and probably in the assembly fixture. Therefore, no special facilities or transportation functions would be associated with these tests.

e. Facility Requirements

(1) Mechanical

The simplicity of the checkout test does not require engine handling, assuming that the test will be performed at the assembly site. Therefore, the tools and other facility support equipment used in assembly are sufficient to support the candidate test.

(2) Civil Structures

The same civil structures required for assembly will be sufficient to support this candidate test.

(3) Fluids

Inert gas shall be required as follows:

(a) GN_2 per MIL-P-27401: 50 psig @ 100 scfm, with a total supply of 880 scf (minimum).

(b) GHe per MIL-P-27407: 50 psig @ 100 scfm, with a total supply of 880 scf (minimum).

(4) Electrical

Electrical power is required as follows: 115 vac, 40 amps, 60 Hz

(5) Location

No special location requirements are imposed by this candidate test. It is assumed that the test would be performed at the engine assembly site.

(6) Personnel

(to be supplied)

f. GSE/TSE Requirements

(1) Mechanical

There is a requirement for engine assembly and checkout equipment, and such special items as a nozzle plug.

(2) Electrical

There would be a requirement for appropriate type test equipment such as a Functional Checker (Valve, Instrumentation and Controls) or an Electrical Test Set that would supply 28 vdc.

(3) Pneumatic

(To be determined)

g. Special Considerations

(1) Safety

During the performance of the test the reactor would be fully poisoned, therefore, only the safety precautions normally required during engine assembly and checkout would apply.

(2) Reliability

(To be supplied)

(3) GSE/TSE Cost Estimates

A preliminary cost estimate was prepared in Mid-July of CY69 to determine the ROM¹ Ground Support Equipment (GSE) costs necessary to support the basic (checkout) acceptance test at the three alternate test locations as shown in the tabulation below.

	<u>Assemble and Test at NRDS</u>	<u>Assembled Michoud Test at MTF</u>	<u>Assemble and Test at KSC</u>
Transport and Handling GSE/TSE	282K**	560K**	534K**
Checkout GSE/TSE	-	878K	516K*
TOTAL COST AT SITE	282K	1438K	1050K
TOTAL PROGRAM COST	798K	1945K	1050K

* 516K checkout GSE/TSE must be provided at KSC in any case.

** 225K cost of engine transporter is not included since assembly and testing performed at same test site, and this equipment not required for intra-site movement.

¹ ROM is the abbreviation for Rough Order of Magnitude

- (4) Facility Costs
(To be Determined)
- (5) Post-Test Radiation Evaluation
Not required.
- (6) Quality Assurance
(To be supplied)
- (7) Logistics
(To be supplied)

h. Advantages/Disadvantages

(1) Advantages

(a) This candidate provides a marked measure of confidence that the engine system will function and meet its performance requirements to the same extent as those engines which had previously been qualified during the engine development program.

(b) The testing associated with this candidate does not present any post-test radiation problem, and therefore results in a minimum perturbation in handling and shipping of the engine after completion of the tests.

(2) Disadvantages

(a) This candidate acceptance test alternative does not completely demonstrate, in accordance with the usual classical definition of acceptance testing, that the engine will meet all its rated performance requirements.

(3) Summary

(a) This candidate forms a basic building block which is planned to be accomplished as part of the acceptance testing in any event and to which data from any other selected candidate alternative(s) would be added.

2. Inert Gas Flow Test

A first candidate acceptance test alternative is the inert gas flow test detailed in the following paragraphs.

a. Description

An inert gas flow test involves flowing an inert gas (GH_e or GN_2 at ambient temperature) through the engine system at flow rates and pressures (near 30 psia) measured at the propellant inlet line adequate to demonstrate that normal flow is occurring throughout the system. It would be desirable to obtain impedance data for the system and analysis would probably be required to determine if flow rates adequate to produce this data are permissible, or feasible. The test would be performed on the completed engine assembly, and might necessitate that all poison wires be removed from the core. However, control drums would remain fully in and locked.

Valves would be cycled in a planned sequence to obtain the most data for the least number of cycles and gas utilization.

(1) Test Conditions

(a) Propellant Inlet Line (each) at engine/stage interface

- 1 Gas used: GN_2 or GH_e
- 2 Pressure: Tank Pressure $\pm$ TBD psi, max
- 3 Temperature: ambient
- 4 Flow Rate TBD lb/sec max

(b) Cooldown Line at engine/stage interface

- 1 Gas used: GN_2 or GH_e
- 2 Pressure: Tank Pressure $\pm$ TBD psi, max
- 3 Temperature: Ambient
- 4 Flow Rate: TBD lb/sec max.

(c) Nozzle Exit:

- 1 The exit gas would require a TBD micron filter and would be vented into facility exhaust.

(d) Reactor Poison

1 The order of preference for poison wire status would be:

- (1) Core Fully poisoned
- (2) Core partially poisoned
- (3) All poison wires removed from core

The selection would be based on analyses, considering a number of factors such as flow rates, safety, poison wire retaining devices, etc.

(e) Flow Measurement

1 Measurements would be obtained from instrumentation furnished as part of the GSE equipment.

(f) Engine Instrumentation

1 Engine instrumentation would be utilized to measure effects of pressure, flow and temperature (to the extent possible, considering the small values to be measured).

b. Test Objectives

The test objectives of an inert gas flow test are to provide the following:

(1) Demonstrate that the engine has been assembled properly, and ascertain that foreign objects, which would obstruct the flow of propellant, had not been left in the system.

(2) Permit a functional check of valves, and would provide a means for measurement of the resulting effect on flow.

(3) Provide a stimulus check for those transducers of low enough range to detect the small pressure changes.

(4) Provide for a gross leak check.

c. Functional Description

Prior to conducting this test on a deliverable engine, it would be necessary to obtain base line reference data on identical engines in the development program, for data comparison.

This test would be conducted at the engine assembly facility, upon completion of assembly operations. Poison wires would be removed as required, and in accordance with safety regulations established for the operation. A vent and filter would be attached to the nozzle exit at the 24:1 location.

inert gas would be introduced at the propellant inlet lines and the cooldown line, individually and/or simultaneously, while the valves are cycled according to a planned sequence and the flow measurements are obtained upstream of the engine, in the GSE equipment. Pressures and temperatures in the engine will be recorded to the extent possible with the installed instrumentation. Upon completion of the test, poison wires would be reinstalled as required.

d. Facility Requirements

(1) Mechanical

The following mechanical equipment is required for an inert gas flow test:

(a) Engine holding stand (could be the same as the engine assembly stand).

(b) Nozzle vent system with filter (TBD Micron)

(c) Gas supply and distribution system

(2) Civil Structures

The inert gas flow test could be performed in the engine assembly building, provided the (TBD), exhaust flow can be safely vented.

(3) Fluids

Fluid requirements for an inert gas flow test are:

(a) GN_2 per MIL-P-27401: TBD scf or

(b) GH_e per MIL-P-27407: TBD scf

(4) Electrical

Electrical requirements for an inert gas flow test are:

(no special requirements known)

(5) Location

Since the reactor will not be brought to critical for this inert gas flow test (as described herein), the safety restrictions are expected to be similar to those applicable to any non-nuclear Engine Assembly Site, in the sense that it does not present the necessity for remote handling. However, since the NERVA engine is a nuclear engine, the facility for this test would still be required to be an AEC approved nuclear engine test facility. Therefore, the location for an inert gas flow test could be considered at any location being considered for engine assembly. This could include

(a) Sacramento - TBD

(b) NRDS - No modifications required

(c) MTF - TBD

(d) KSC - TBD

(e) Huntsville - TBD

(6) Personnel

(To be supplied)

e. GSE/TSE Requirements

(1) Mechanical

The following mechanical equipment would be required to support inert gas flow testing:

- (a) Engine transporting device
- (b) Engine environmental monitoring equipment (for storage)
- (c) Leak test closures
- (d) Poison wire reinsertion equipment (manual)

(2) Electrical

The following electrical equipment would be required to support inert gas flow testing:

- (a) Functional/Electrical Checkout Unit
- (b) Leak Detector

(3) Pneumatic

The following pneumatic equipment would be required to support inert gas flow testing:

- (a) Leak Test Pressurizing Unit
- (b) Engine Inert Gas Flow Test Unit

f. Special Considerations

- (1) Safety (To be supplied)
- (2) Reliability (To be supplied)
- (3) GSE/TSE Cost Estimates

A preliminary cost estimate was prepared in Mid-July of CY69 to determine the ROM Ground Support Equipment (GSE) costs necessary to support the inert gas flow acceptance test at the three alternate test locations as shown in the tabulation below.

	Assemble and Test at NRDS	Assemble Michoud Test at MTF	Assemble and Test at KSC
Transport and Handling GSE/TSE	282K**	560K**	534K**
Checkout GSE/TSE	-	878K	516K*
TOTAL COST AT SITE	282K	1438K	1050K

* 516K checkout GSE/TSE must be provided at KSC in any case.

** 225K cost of engine transporter is not included since assembly and testing performed at same test site, and this equipment not required for intra-site movement.

Total Program Cost	798K	1956K	1050K
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- (4) Facility Costs
(To be determined)
- (5) Post-Test Radiation Evaluation
None Required
- (6) Quality Assurance
(To be supplied)
- (7) Logistics
(To be supplied)

g. Advantages/Disadvantages

(1) Advantages

(a) This test would provide an additional measure of confidence that the no foreign objects, protective closures, etc. were left in the flow passages during the manufacturing and assembly procedures.

(b) Additional benefits of this test are (1) stimulus of those engine transducers which are capable of sensing the small pressure differentials resulting from this test, (2) a functional check of valves wherein an effect on flow rate is detectable.

(2) Disadvantages

(a) Considerable expense will be involved in the GSE required for this test and in a vent for the exit gas.

(b) Establishment of accept/reject criteria for this test may be difficult and expensive. Also, tests might need to be run on assemblies with known flow restrictions to verify the effectiveness of this test in accomplishing its purpose.

(c) It is extremely doubtful that any orifice blockage in fuel elements would be disclosed by this test.

(d) Accept/Reject criteria cannot be assigned based on engine instrumentation performance in this test.

(3) Summary

This test is primarily aimed at disclosing abnormal flow conditions in the engine system, caused by foreign objects or improper assembly as well as leakage. The degree of confidence in the operating personnel and inspectors, the administrative controls, and the quality of the procedures are the things to be considered in determining the relative value of this test.

Engine Instrumentation response data from this test cannot be used in an accept/reject determination. However, it would provide an additional source of information which would be additive toward establishing a level of confidence.

3. Modified Cold Flow Acceptance Test

A second candidate acceptance test alternative is the modified cold flow test described in the following paragraphs.

a. Description

A modified cold flow test is defined as a test during which sensible energy is not added to either the test article or the flow stream within the test article from chemical or nuclear reactions.

Safety requirements pertaining to available shut-down reactivity preclude flowing hydrogen through the reactor without bringing the reactor to a low power level so that hydrogen reactivity is controllable. Therefore, a cold flow test of the complete engine (including reactor) is not possible without evolving the test into some level of low power type test requiring special facilities.

By incorporating a method of bypassing the reactor, as shown in Figure 3, the PFS could be functioned for a modified cold flow test. A design modification of the engine would be required to allow installation of a bypass system to exhaust the gas before entering the reactor. Liquid hydrogen would be provided at the PSOV-to-propellant tank interface of the assembled engine, at normal operational temperature and pressure. Upon command, programmed valve operation would be initiated to start the test. All valves would be operated in as near their design environment as practicable simulating bootstrap start. The test would be terminated a short time after reaching maximum turbine speed. Valves not normally cycled during bootstrap could be cycled afterwards to demonstrate their operability.

There would not be any flow of liquid hydrogen through the reactor in this modified cold flow test, and the core would contain all (both central and peripheral) of the poison wires. The Structural Support Coolant Assembly (SSCA) valves could be functioned during this test, even though the core support stems filled with liquid hydrogen since the fully poisoned core (all wires inserted) would override the stem reactivity available.

(1) Test Conditions

(a) Pressure (P_c) - The chamber pressure, P_c , is not applicable to this test. The only pressure requirement is 30 psia propellant pressure at the PSOV's.

(b) Flow - 0 to TBD lbs/sec maximum.

(c) Temperature (T_c) - The chamber temperature, T_c , is not applicable to this test. The only temperature requirement is 40°R propellant temperature at the PSOV's.

Figure 3

Acceptance Testing
Trade Study No. 1004

AEROJET NUCLEAR SYSTEMS COMPANY
A DIVISION OF AEROJET - GENERAL

September 1970

TEST SYSTEM LINES
LINE REMOVED OR
OTHERWISE BYPASSED

MODIFIED COLD FLOW TEST SETUP

(d) Duration - The test will be terminated when turbine speed begins to decrease as a result of engine chilldown which would be approximately TBD seconds after initiation of flow.

(e) Power Level - N/A

b. Test Objectives

The test objectives of a modified cold flow test would provide the following:

(1) Demonstration of valve and piping operation under conditions which approximate those existing during the initial engine startup.

(2) Stimulus check of PFS temperature instrumentation. Pressure rise may be enough to stimulate some of the PFS pressure transducers also.

(3) Demonstration of turbine response (spinup) under simulated initial startup conditions.

(4) Demonstration of flow through the main branches of the PFS.

c. Functional Description

Upon completion of engine assembly and assembly checkout, the engine must be removed from the assembly fixture and installed in a transporting device. The type of transporting device will depend, to a large extent, on the distance and mode of transporting to the test site. Upon arrival at the test site, if remote from the assembly site, provisions must be made to house the engine in an environmentally controlled structure to perform pre-test operations. The engine must then be transported to, and installed in, a test stand that will accommodate a modified cold flow test as described in Paragraph 3.a. Upon completion of the test the engine must be removed from the test stand and returned to the environmentally controlled structure for post-test operations and preparation for shipment to KSC.

d. Facility Requirements

(1) Mechanical

Equipment required for accomplishing modified cold flow testing and all associated operations is listed below. The equipment list does not include equipment, normally required and used at the engine assembly site.

(a) Modified cold flow test stand.

(b) Liquid run tank and associated lines.

(2) Civil Structures

The following civil structures are required at or near the test stand.

(a) Test control and instrumentation building.

(b) Environmentally controlled engine receiving and storage building.

(c) On-site rail or improved road system.

(3) Fluids

Fluid requirements for modified cold flow testing are as follows:

(a) GN_2 per MIL-P-27401: 880 scf (minimum).

(b) GHe per MIL-P-27407: 880 scf (minimum).

(c) LH_2 per MSFC-SPEC-356: 350 lbs (minimum).

(4) Electrical

Electrical requirements for the modified cold flow test are as follows:

(a) Test command and programming instrumentation.

(b) Test monitoring instrumentation.

(5) Location

The following is a list of possible locations for performing a modified cold flow test along with comments regarding their present capability:

(a) Sacramento - Existing test facility adequate with some modification.

(b) NRDS - Existing test facility adequate with minor modification.

(c) MTF - Existing test facility adequate with some modification.

(d) KSC - Major modification of test facility required.

(e) Huntsville - Existing test facility adequate with some modification.

(6) Personnel

(To be supplied)

e. GSE/TSE Requirements

(1) Mechanical

The following mechanical equipment would be required for a modified cold flow testing:

(a) Engine transporting device.

(b) Engine environmental monitoring equipment.

(c) Engine-to-test stand installation equipment.

(d) Leak test closures.

(2) Electrical

The following electrical equipment would be required for modified cold flow testing:

(a) Functional/Electrical checkout unit.

(b) Leak detector.

(3) Pneumatic

(a) Leak test pressurizing unit.

f. Special Considerations

(1) Safety

The safety aspects of diverting core flow and the potential leakage of hydrogen from the reflector system and the SSCS into the core would require analysis.

(2) Reliability

(To be supplied).

(3) GSE/TSE Cost Estimates

A preliminary cost estimate was prepared in Mid-July of CY69 to determine the ROM¹ Ground Support Equipment (GSE) costs necessary to support the modified cold flow test at the three alternate test locations as shown in the tabulation below.

	Assemble and Test at NRDS	Assemble Michoud Test at MIF	Assemble and Test at KSC
Transport and Handling GSE/TSE	282K **	560K **	534K **
Checkout GSE/TSE	-	878K	516K *
TOTAL COST AT SITE	282K	1438K	1050K
TOTAL PROGRAM COST	798K	1954K	1050K

* 516K checkout GSE/TSE must be provided at KSC in any case.

** 225K cost of engine transporter is not included since assembly and testing performed at same test site, and this equipment not required for intra-site movement.

(4) Facility Costs
(To be determined)

(5) Post-Test Radiation Evaluation

Not applicable.

(6) Quality Assurance

(To be supplied)

(7) Logistics

(To be supplied)

g. Advantages/Disadvantages

(1) Advantages

(a) This test would provide some confidence that the PFS, Nozzle, and I&C Subsystem are operating (to the extent stated in Paragraph 2.b.).

¹ ROM is the abbreviation for Rough Order of Magnitude

(b) This test would not leave the engine "hot".

(c) This test would not require a facility as extensive as ETS-1, but ETS-1 could be used if performed at NRDS.

(2) Disadvantages

(a) This test would require an engine modification which would probably increase weight by the addition of two line flanges and at the same time add two potential sources of leakage. These modifications would possibly degrade engine performance in order to perform the test.

(b) The information to be gained is not identifiable with any engine performance requirement.

(c) This test yields no information about the NSS except a flow check of the Structural Support Coolant System and reflector shield assemblies.

(d) The information to be gained regarding valve operation is of less value than a complete functional checkout. The valves will have already been functionally checked at full load and at operating temperature in component acceptance tests. Except for PSOV, the load on the valves in this test will not begin to approach operating conditions. Also, not all of the valves would be cycled during a modified cold flow bootstrap. In order to flow propellant through all valves, additional functional checks would be required over and above the bootstrap operation.

(e) Reassembly of the turbine exhaust line will necessitate further checkout afterwards.

(f) This test will reveal no engine leaks except gross ones, and they would have been detected already in a static leak check. In a hydrogen flow test only remote means of leak detection are available.

(g) Temperature instrumentation in the core would be stimulated in this test at the low end, LH₂ ranges only.

(h) Pressure transducers would not see pressures large enough for a reliable stimulus check in this test, except for those in the pump inlet line.

(1) TPA performance information

available from this test is limited to the initial bootstrap region. Measureable accept/reject limits for performance in this region would be narrow. A manual torque check at ambient temperature would have previously furnished some useful data and this would supplement. Also, the engine configuration is different because the core is bypassed. Pressure drop across the turbine would be different and the heat transfer between core exit gas and nozzle coolant flow would be absent. These factors would change TPA performance, but this data would still be useful.

(j) As a flow check of the engine system, this test is not complete. The reactor core is not included.

(k) Practically no information on the engine control system is obtained from this test. Simulator runs would be required which would have nothing to do with the modified cold flow test.

(3) Summary

This test is primarily a partial functional check of the PFS, a system flow check (exclusive of the core), and a stimulus check of the temperature instrumentation in the flow passages, and for core temperature instrumentation at the low, LH_2 range.

This test would degrade engine performance by causing the addition of unnecessary weight and potential leaks in the design.

Most of the information yielded by this test can also be obtained by other means (functional checks, simulator (electronic) runs).

3a. Modified Cold Flow Acceptance Test - Module

There is a second possible modified cold flow candidate alternative which cannot be considered on the same level as a total engine test since it involves only that segment of the engine from the lower thrust structure/pressure vessel interface to the engine/stage interface. This module could be assembled and acceptance tested as a unit. It could be subjected to full flow conditions with LH_2 to provide complete functional checkout (without the concern of generating a radioactive environment) of the following:

Thrust Structure Module (TSM) consisting of:

- (a) Upper Thrust Structure (UTS)
- (b) Lower Thrust Structure (LTS)
- (c) Cooldown Supply Line (CSL)
(Below Station 0.00)
- (d) Engine Purge Unit (Below Station 0.00)
- (e) Turbopump Assembly (TPA) and
Valves Modules

- 1 Pump Discharge Block Valves (PDBV) and Actuators
- 2 Turbine Throttle Valves (TTV) and Actuators
- 3 Pump Discharge Valves (PDV) and Actuators
- 4 Turbine Block Valves (TBV) and Actuators
- 5 Pump Discharge Check Valves (PDKV)
- 6 Turbine Discharge Block Valves (TDBV) and Actuators
- 7 Turbopump Assembly Module Interconnecting Lines
- 8 Turbopump Assemblies
- (f) Turbine Bypass Modules
 - 1 Bypass Control Valves (BCV) and Actuators
 - 2 Bypass Block Valves (BBV) and Actuators
- (g) Structural Support Module
 - 1 Structural Support Block Valves (SSBV) and Actuators
 - 2 Structural Support Coolant Valves (SSCV) and Actuators
 - 3 Structural Support Coolant Line (SSCL) (PDL to SSBV)
- (h) Gimbal Assembly Subsystem
 - 1 Gimbal Bearings
 - 2 Gimbal Actuators
- (i) Propellant Inlet Lines (PIL)
- (j) Wiring Harness/Engine Instrumentation (Internal to TSM)
- (k) Stage Tank Pressurization Line and Check Valve
- (l) Turbine Bypass Line
- (m) Turbine Inlet Line (Upper Segments)

Upon completion of the acceptance of this assembly as a module, it would still be necessary to integrate the module into the engine assembly and complete the acceptance testing of the engine. However, the type and extent of testing which treatment as a separate module affords would provide for a greatly increased measure of confidence that the engine is indeed equivalent to those engines which have successfully completed the Qualification Phase during the engine development program.

4. Cold Flow Acceptance Test

A third candidate acceptance test alternative, which if selected would be utilized in conjunction with the basic (checkout) acceptance test candidate, is the cold flow test described in the following paragraphs.

a. Description

A cold flow test is defined as a test in which liquid hydrogen is circulated through the system with the reactor maintained at a constant low power level of approximately * KW so that the hydrogen reactivity is controllable.

The purpose of the cold flow test is to provide for an overall system checkout under LH₂ flow conditions and to verify valve sequencing and instrumentation performance. Liquid hydrogen would be provided at the PSOV - to - propellant tank interface of the assembled engine, at normal operational temperature and pressure. Upon command, valve operation would be programmed in sequence with rotation of the control drums to start the test.

All valves would be operated in as near their design environment as practical simulating bootstrap start.

(1) Test Conditions

(a) Pressure (Pc) - The chamber pressure, Pc, will be limited to approximately * psia.

(b) Flow - 0 to TBD lbs/sec or as limited by the predetermined feedback reactivity ceiling established.

(c) Temperature (Tc) - The chamber temperature, Tc, is not applicable to this test. The only temperature requirement is 40°R propellant temperature at the PSOV's.

(d) Duration - The test will be terminated when a predetermined feedback reactivity limit of * is reached.

(e) Power Level - Maximum power level will be limited to approximately * KW, as required to establish the desired operating conditions.

b. Test Objectives

The test objectives of the cold flow test would provide the following:

* To Be Determined

- (1) Provide for a general system checkout under LH₂ flow conditions
- (2) Demonstration of flow through main branches of PFS.
- (3) Demonstration of turbine response (spinup) under simulated initial startup conditions.
- (4) Verification of valve sequencing and instrumentation performance. (Excluding high temperature and pressure ranges)
- (5) Provide data on cold start condition
- (6) Demonstration of bootstrap
- (7) Provide for check of drum angle
- (8) Provide for check of reactivity
- (9) Provide for electrical, leakage, and overall functional and operational check of total engine system.

c. Functional Description

Upon completion of engine assembly and assembly checkout, the engine must be removed from the assembly fixture and installed in a transporting device. The type of transporting device will depend, to a large extent, on the distance and mode of transporting to the test site. Upon arrival at the test site, if remote from the assembly site, provision must be made to house the engine in an environmentally controlled structure to perform pre-test operations. The pre-test operations would consist of removing the engine from the transporting vehicle, removing special monitoring equipment used only for transporting, performing pretest checkout, and removing poison wires. The engine would then be transported to, and installed in, a test stand. Upon completion of the test the engine would be removed from the test stand using a remote handling device and returned to the environmentally controlled structure for post-test operations (insertion of poison wires) and preparation for shipment to KSC.

d. Facility Requirements

(1) Mechanical

Equipment required for accomplishing a cold flow test is listed below:

- (a) Nuclear Engine Test Stand
- (b) Liquid Run Tank Associated Lines
- (c) Remote Handling Facilities

(2) Civil Structures

The following civil structures are required at or near the test stand:

- (a) Test Control and Instrumentation Building
- (b) Environmentally Controlled Engine Receiving and Storage Building

(3) Fluids

Fluid requirements for the cold flow test and associated checkout are as follows:

- (a) GN_2 per MIL-P-27401: 880 scf (minimum)
- (b) GHe MIL-P-27407: scf (minimum)
- (c) LH_2 per MSFC-SPEC-356: ____ lbs (minimum)

(4) Electrical

Electrical requirements for the cold flow test are as follows:

- (a) Test command and programming instrumentation
- (b) Test monitoring instrumentation
- (c) Nuclear instrumentation and monitoring equipment

(5) Location

The following is a list of possible locations for performing the cold flow test along with comments regarding their present capability: (The only location which has AEC approval is NRDS. All other locations considered as candidate locations for Nuclear Engine testing would have to be AEC approved as a result of a test site safety analysis before a final selection could be made).

- (a) NRDS - minor modification required
- (b) MTF - major modification required
- (c) KSC - complete test facility required

(6) Personnel

(To be supplied)

e. GSE/TSE Requirements

(1) Mechanical

The following mechanical equipment would be required to support cold flow testing:

- (a) Engine transporting device
- (b) Engine environmental monitoring equipment
- (c) Engine-to-test stand installation equipment
- (d) Engine test stand adapter
- (e) Leak test closures
- (f) Remote engine handling device
- (g) Poison wire reinsertion equipment

(2) Electrical

The following electrical equipment would be required to support cold flow testing:

- (a) Functional/Electrical Checkout Unit
- (b) Leak Detector

(3) Pneumatic

The following pneumatic equipment would be required to support cold flow testing:

- (a) Leak Test Pressurizing Unit

f. Special Considerations

- (1) Safety - TBD
- (2) Reliability - TBD
- (3) GSE/TSE Cost Estimates

A preliminary cost evaluation was prepared in Mid-July to determine the ROM Ground Support Equipment (GSE) costs necessary to support the cold flow acceptance test at the three alternate test locations as shown in the tabulation below.

	Assemble and Test at NRDS	Assembly Michoud Test at MTF	Assemble and Test at KSC
Transport and Handling GSE/TSE	282K**	560K**	534K**
Checkout GSE/TSE	-	878K	516K*
Remote Handling Equipment	-	1500K	1500K
TOTAL COST AT SITE	282K	2938K	2550K
Total Program Cost	798K	3454K	2550K

* 516K checkout GSE/TSE must be provided at KSC in any case.

** 225K cost of engine transporter is not included since assembly and testing performed at same test site, and this equipment not required for intra-site movement.

- (4) Facility Costs
(To be determined)

- (5) Post-Test Radiation Evaluation
(To be determined)
- (6) Quality Assurance
(To be supplied)
- (7) Logistics
(To be supplied)

g. Advantages/Disadvantages

(1) Advantages

(a) The post-test radiation level would be sufficiently low, so there would be no severe engine radiation problems with which to contend.

(b) This test would provide an additional measure of confidence that the engine will function as those engines previously qualified during the engine development program.

(c) This test would set the "cold" critical drum angle.

(d) This test would not require a facility as extensive as ETS-1, but ETS-1 could be used if performed at NRDS.

(e) This test provides for the verification of valve sequencing and instrumentation performance. (Excluding the higher ranges).

(2) Disadvantages

(a) The overriding of the control drums is possible and extremely dangerous.

(b) This test will only detect gross leaks which would have been found during the static leak checks.

(c) TPA performance information is limited to the initial bootstrap region. Measureable accept/reject limits for performance in this region would be narrow. (A manual torque check at ambient temperature would be performed and provide some basic information).

(3) Summary

This test permits a total system checkout under cryogenic flow conditions without entailing operation of the reactor at any significant power level with the completing of the test as planned. Therefore, there would not be any of the penalties associated with the problems of a large amount of residual radioactivity.

The test provides for a bootstrap start and limited operation of valves and controls. Opportunity is presented for gross checks for leakage, electrical continuity, and a general shakedown.

NSS calibration is independent of a flow test, and this candidate would not be required to obtain this type of data. However, this test helps in that it provides a reliable check in determining the critical drum angle with hydrogen in the core and stems.

5. Low Power Acceptance Test

A fourth candidate acceptance test alternative is the low power test detailed in the following paragraphs.

a. Description

A low Power NERVA Engine Test is defined, for the purpose of acceptance testing, as a test which follows a normal startup profile to a point above which program control is initiated but below the throttle point. The engine is maintained in a steady state condition at the low power level for a predetermined duration, then ramped down through pump tailoff.

(1) Test Conditions

(a) Pressure (P_c) - The chamber pressure, P_c , will be limited to approximately 75 psia.

(b) Flow - as required to reach the desired operating point ($T_c = 1400^\circ R$, $P_c = 75$ psia), utilizing normal startup mode, and shutdown.

(c) Temperature (T_c) - The chamber temperature, T_c , will be limited to approximately 1400 degrees R.

(d) Duration - Approximate times of the various phases of operation will be as follows:

Temperature conditioning	- TBD seconds
Bootstrap start	- 15 seconds
Steady state low power	- TBD seconds
Pump tailoff	- TBD seconds

(e) Power Level - Maximum power level will be limited to approximately 170 MW, or as required to establish the desired operating conditions.

b. Test Objectives

The test objectives of a lower power test would provide the following:

- (1) Demonstration of proper valve and piping operation through the bootstrap phase and the first part of the program ramp.
- (2) Demonstration of pressure and temperature instrumentation response.
- (3) Demonstration of TPA response (spinup) under operational conditions.
- (4) Verification of capability to perform pre-start operations.*
- (5) Verification of capability to temperature condition within TBD sec.*
- (6) Verification of less than TBD lbs propellant used in temperature conditioning.*
- (7) Verification of capability of engine to bootstrap.**
- (8) Verification of controllability requirements applicable to bootstrap (to $\text{TBD } ^\circ\text{R } T_c$ and $\text{TBD } \text{psia } P_c$).

c. Functional Description

Upon completion of engine assembly and assembly checkout, the engine must be removed from the assembly fixture and installed in a transporting device. The type of transporting device will depend, to a large extent, on the distance and mode of transporting to the test site. Upon

* These three objectives would be achieved also by utilization of either the modified cold flow or the cold flow candidate alternatives.

** This objective would be achieved also by utilization of the cold flow candidate alternative.

arrival at the test site, if remote from the assembly site, provision must be made to house the engine in an environmentally controlled structure to perform pre-test operations. The pre-test operations would consist of removing the engine from the transporting vehicle, removing special monitoring equipment used only for transporting, performing pretest checkout, and removing poison wires. The engine would then be transported to, and installed in, a test stand. Upon completion of the test the engine would be removed from the test stand using a remote handling device and returned to the environmentally controlled structure for post-test operations (insertion of poison wires) and preparation for shipment to KSC.

d. Facility Requirements

(1) Mechanical

Equipment required for accomplishing a low power test is listed below:

1. Nuclear Engine Test Stand
2. Liquid Run Tank and Associated Lines
3. Remote Handling Facilities

(2) Civil Structures

The following civil structures are required at or near the test stand:

1. Test Control and Instrumentation Building
2. Environmentally Controlled Engine Receiving and Storage Building.

(3) Fluids

Fluid requirements for the low power test and associated checkout are as follows:

1. GN_2 per MIL-P-27401: 880 scf (minimum)
2. GHe MIL-P-27407: scf (minimum)
3. LH_2 per MSFC-SPEC-356: TBD lbs (minimum)

(4) Electrical

Electrical requirements for the low power test are as follows:

1. Test command and programming instrumentation.
2. Test monitoring instrumentation.
3. Nuclear instrumentation and monitoring equipment.

(5) Location

The following is a list of possible locations for performing the low power test along with comments regarding their present capability: (The only location which has AEC approval is NRDS. All other locations considered as candidate locations for Nuclear Engine testing would have to be AEC approved as a result of a test site safety analysis before a final selection could be made).

- (a) NRDS - minor modification might be required.
- (b) MTF - major modification required.
- (c) KSC - complete test facility required.

(6) Personnel

(To be supplied)

e. GSE/TSE Requirements

(1) Mechanical

The following mechanical equipment would be required to support low power testing:

1. Engine transporting device
2. Engine environmental monitoring equipment
3. Engine-to-test stand installation equipment
4. Engine test stand adapter

5. Leak test closures
6. Remote engine handling device
7. Poison wire reinsertion equipment (Remote)

(2) Electrical

The following electrical equipment would be required to support low power testing:

1. Functional/Electrical Checkout Unit
2. Leak Detector

(3) Pneumatic

The following pneumatic equipment would be required to support low power testing:

1. Leak Test Pressurizing Unit

f. Special Considerations

- (1) Safety
(To be supplied)
- (2) Reliability
(To be supplied)
- (3) GSE/TSE Cost Estimates

A preliminary cost estimate was prepared in Mid-July of CY69 to determine the ROM¹ Ground Support Equipment (GSE) costs necessary to support the low power acceptance test at the three alternate test locations as shown in the tabulation below.

¹ ROM is the abbreviation for Rough Order of Magnitude

	Assemble and Test at NRDS	Assembled Michoud Test at MTF	Assemble and Test at KSC
Transport and Handling GSE/TSE	282K**	560K**	534K**
Checkout GSE/TSE	-	878K	516K*
Remote Handling Equipment	-	1500K	1500K
TOTAL COST AT SITE	282K	2938K	2550K
TOTAL PROGRAM COST	798K	3454K	2550K

* 516K checkout GSE/TSE must be provided at KSC in any case.

** 225K cost of engine transporter is not included since assembly and testing performed at same test site, and this equipment not required for intra-site movement.

- (4) Facility Costs
(To be determined)
- (5) Post-Test Radiation Evaluation
(To be supplied)
- (6) Quality Assurance
(To be supplied)
- (7) Logistics
(To be Supplied)

g. Advanatages/Disadvantages

(1) Advantages

(a) This test would verify three engine performance requirements (CEI Part I Spec) relative to the prestart and startup phases through bootstrap, a portion of the program ramp immediately after bootstrap, (see Figure 4), and a portion of pump tailoff.

(b) Other information could be provided which might be of use in analyses to verify other requirements.

(c) This test would permit some calibration of the nuclear subsystem. The critical drum angle with hydrogen in the core would be established, and other checks could be performed as necessary.

(2) Disadvantages

(a) This test would only verify requirements relative to prestart, the bootstrap, a portion of the startup phase and pump tailoff. None of the other performance requirements of the engine are touched upon. For example, the engine performance requirements for controlling Pc and Tc along the program ramps, achieving rated conditions and holding within the

required tolerances, and engine shutdown can only be partially verified by this test. The same is true for all other engine requirements except those directly concerned with prestart and the bootstrap portion of the startup phase.

(b) While the post-test radiation level would be low enough for limited personnel access to the engine, the stage and vehicle assembly activities would be hampered to some degree. After TBD weeks the radiation level at TBD would be approximately TBD.

(c) After the test it would be necessary to replace poison wires in the core, if the test were to be performed at a location other than the launch site. This would probably require remotely operated equipment and/or removal of the nozzle. It might also be at the risk of damage to the nozzle and/or core.

(3) Summary

(a) This test would yield slightly more information than the cold flow test in Section IV.E.4. The prestart and bootstrap performance requirements could be verified, and program control would be in effect for a few seconds, (see Figure 4) providing a measure of confidence in the control system up to the point of test termination. However, important performance requirements such as Thrust, Isp, the Pc Ramp Rate, and Duration, cannot be verified by this test. These requirements could only be verified indirectly by analysis and simulator runs.

(b) In light of the above, indirect verification of the startup requirements should also be considered.

(c) Information to be gained in this test which is not verification of a requirement, and which is needed to support analysis, or correlation with the qualification engines, can probably be obtained other means without starting the engine.

Acceptance Testing
Trade Study No. 1004

STARTUP PHASE OF NERVA ENGINE OPERATION INDICATING MAXIMUM LOW POWER PRESSURE, TEMPERATURE, AND FLOW RATE PARAMETERS

AEROJET NUCLEAR SYSTEMS COMPANY
A DIVISION OF AEROJET - GENERAL

6. Full Power Acceptance Test

A fifth candidate acceptance test alternative is the full power test which is described and discussed in the following paragraphs:

a. Description

A Full Power NERVA Engine Test is defined as a test of engine operation at the chamber pressure and temperature corresponding to the normal rated thrust and specific impulse.

(1) Test Conditions

(a) Pressure (P_c) - The maximum chamber pressure, P_c , will be the nominal full power (rated thrust) pressure of 450 psia.

(b) Flow - As required to attain nominal rated conditions of P_c and T_c utilizing normal operating modes for the steady state flow rate at rated conditions will be approximately 90 lbs/sec. Propellant for the cooldown period will be supplied in pulses totaling approximately TBD lbs.

(c) Temperature (T_c) - The maximum chamber temperature, T_c , will be the nominal full power (rated thrust) temperature of 4250 degrees R.

(d) Duration - Duration of the test at steady state rated thrust will be approximately 20 seconds, or less.

(e) Power Level - The power level at steady state rated thrust will reach approximately TBD MW.

b. Test Objectives

The test objectives of a full power test are to demonstrate/verify engine capability to perform most of its design performance requirements. Obvious exceptions are:

- (1) Endurance (10 hours at rated temperature)
- (2) Performance in the Malfunction and Emergency Modes (However, a switch to malfunction mode could be made after attaining rated conditions, for partial demonstration of this requirement).
- (3) Restart capability

c. Functional Description

Upon completion of engine assembly and assembly checkout, the engine must be removed from the assembly fixture and installed in a transporting device. The type of transporting device will depend, to a large extent, on the distance and mode of transporting to the test site. Upon arrival at the test site, if remote from the assembly site, provision must be made to house the engine in an environmentally controlled structure to perform pre-test operations. The pre-test operations would consist of removing the engine from the transporting vehicle, removing special monitoring equipment used only for transporting, performing pre-test checkout, and removing poison wires. The engine would then be transported to, and installed in, a test stand. Upon completion of the test the engine would be removed from the test stand using a remote handling device and returned to the environmentally controlled structure for post-test operations (insertion of poison wires) and preparation for shipment to KSC.

d. Facility Requirements

(1) Mechanical

Equipment required for accomplishing a full power test is listed below:

- (a) Nuclear Engine Test Stand.
- (b) Liquid Run Tank and Associated Lines
- (c) Remote Handling Facilities

(2) Civil Structures

The following civil structures are required at or near the test stand:

- (a) Test Control and Instrumentation Building
- (b) Environmentally Controlled Engine Receiving and Storage Building

(3) Fluids

Fluid requirements for the full power test and associated checkout are as follows:

- (a) GN_2 per MIL-P-27401: 880 scf (minimum)
- (b) GHe per MIL-P-27407: 880 scf (minimum)
- (c) LH_2 per MSFC-SPEC-356: _____ lbs (minimum)

(4) Electrical

Electrical requirements for the full power test are as follows:

- (a) Test command and programming instrumentation
- (b) Test monitoring instrumentation
- (c) Nuclear instrumentation and monitoring equipment

(5) Location

The following is a list of possible locations for performing the full power test along with comments regarding their present capability: (The only location which has AEC approval is NRDS. All other locations considered as candidate locations for Nuclear Engine testing would have to be AEC approved as a result of a test site safety analysis before a final selection could be made).

- (a) NRDS - minor modification might be required.
- (b) MTF - major modification required.
- (c) KSC - complete test facility required.

(6) Personnel

(To be supplied)

e. GSE/TSE Requirements

(1) The following mechanical equipment would be required to support full power testing:

- (a) Engine transporting device
- (b) Engine environmental monitoring equipment
- (c) Engine-to-test stand installation equipment
- (d) Engine test stand adapter
- (e) Leak test closures
- (f) Remote engine handling device
- (g) Poison wire reinsertion equipment (Remote)

(2) Electrical

The following electrical equipment would be required to support full power testing:

- (a) Functional/Electrical Checkout Unit
- (b) Leak Detector

(3) Pneumatic

The following pneumatic equipment would be required to support full power testing:

- (a) Leak Test Pressurizing Unit

f. Special Considerations

- (1) Safety
(To be supplied)
- (2) Reliability
(To be supplied)
- (3) GSE/TSE Cost Estimates

A preliminary cost estimate was prepared in Mid-July of CY69 to determine the ROM¹ Ground Support Equipment (GSE) costs necessary to support the full power acceptance test at the three alternate test locations as shown in the tabulation below.

	Assemble and Test at NRDS	Assembled Michoud Test at MTF	Assemble and Test at KSC
Transport and Handling GSE/TSE	282K**	560K**	534K**
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* 516K checkout GSE/TSE must be provided at KSC in any case.

** 225K cost of engine transporter is not included since assembly and testing performed at same test site, and this equipment not required for intra-site movement.

¹ ROM is the abbreviation for Rough Order of Magnitude

- (4) Facility Costs
(To be supplied)
- (5) Post-Test Radiation Evaluation
(To be supplied)
- (6) Quality Assurance
(To be supplied)
- (7) Logistics
(To be supplied)

g. Advantages/Disadvantages

(1) Advantages

(a) A full power test would verify the capability of the engine to meet most of the performance requirements, except duration, restart, and perhaps operation in other than normal mode. However, a switch to the PFS Malfunction Mode could be performed during the shutdown phase to verify that function also.

(2) Disadvantages

(a) The radiation level after a full power test is high enough to severely complicate subsequent activities. Assuming a normal startup, 20 second hold at rated conditions and a normal shutdown, with a 10 sec hold at the throttle point, the radiation level would be approximately as shown by Table I.

(b) Poison Wire replacement after the test would be required. Remotely operated equipment for nozzle removal, wire reinsertion, and nozzle replacement might be required. If reinsertion of the poison wires could not be accomplished without removal of the nozzle the complexity of performing these tasks remotely would present a risk of damage to the components.

(c) As with other acceptance tests involving engine start-up, crosscountry shipping of the "hot" engine afterwards becomes a major problem.

(d) This test would reduce the operating time available for mission performance.

(e) Even a full power test cannot fully verify directly all the engine requirements. For example, the full operating range of the gimbal assembly cannot be checked at ETS-1 while the engine is operating due to test stand limitations. The restart requirements can only be verified directly by a restart. Duration can only be verified by analysis for obvious reasons. Additional testing would be required to verify some of the off-design requirements.

(3) Summary

(a) A full power test is the only test that will demonstrate directly any of the engine performance requirements relative to rated operation, or the ability of the individual components to perform through the full range of actual engine operation.

(b) The severe personnel access limitations and other problems imposed by the residual radioactivity make this test impractical.

(c) Except for the post-test radiation problems, this test would be the most satisfactory one to demonstrate engine acceptability. Since the test is impractical, the next logical step is to look for other ways of imposing the same conditions on the components, and show by analysis that the quality of the engine fulfills the requirements.

(d) Consideration could be given to a short duration trial startup to rated power after the engine is placed in orbit, if the analytical method does not suffice.

TABLE IV

Approximate Fission Product Gamma Dose Rates (Rem/hr)
for 20 sec operation at Rated Conditions
(with ten sec. hold at throttle point)*

<u>Time After Shutdown (days)</u>	<u>Radial Traverse - Axial Centerline Distance From Pressure Vessel Surface (feet)</u>				
	<u>1</u>	<u>5</u>	<u>10</u>	<u>30</u>	<u>100</u>
0.96	2,200	430	140	19	2.1
9.24	328	64	21	2.9	0.3
23.1	125	25	7.6	1.1	0.95
46.	47.	9.3	2.9	0.43	0.036
93.	16	3.2	1.0	0.15	0.012
115.	12	2.4	0.75	0.11	0.009
231.	3.9	0.76	0.24	0.035	0.0029
463.	0.49	0.096	0.03	0.004	0.0004

* Based on compilation extracted from the Flight Engine Profile (FEP) run included in the 30 April 1970 issue of the Data Item S-130, NERVA Reference Data

TABLE IV(continued)

<u>Time After Shutdown (days)</u>	<u>Axial Traverse Toward Nozzle - Radial Centerline Distance Below Core Support (feet)</u>			
	<u>5</u>	<u>10</u>	<u>30</u>	<u>100</u>
0.96	280	93.	12.0	1.1
9.2	46	14.	2.1	0.14
23.	17	5.6	0.76	0.056
46	6.4	2.1	0.29	0.021
93	2.2	0.74	0.10	0.0073
115	1.7	0.56	0.074	0.0055
231	0.53	0.18	0.024	0.0024
463	0.067	0.022	0.003	0.0002

NOTES TO TABLE IV

1. Standard limits of exposure for personnel at NTO have been 300 mrem/week, with higher limits acceptable under certain conditions. In some situations, 1 rem/week may be authorized. For operations which may be planned, 3 rem/quarter or 5 rem/year are the limits which have been observed.
2. Emergency situations allow for higher doses.
3. Applying the 300 mrem/week standard, and the values from Table I, a person could work 5 feet from the side of the pressure vessel, for the following times:

<u>Time after Test</u>	<u>Working Time</u>
46 days	1.9 Min/wk
93 days	5.6 Min/wk
231 days	24 Min/wk
463 days	187 Min/week

F. TENTATIVE SELECTION OF CANDIDATE ACCEPTANCE TEST(S) ALTERNATIVE

1. Candidate Selected
(To be determined)

NOTE: Since the criteria have not been completely developed and all of the test related factors have not been assessed, no specific test(s) can be selected at this point in time.

2. Factors Determining Selection

A cursory examination of the candidate tests was made, and all of the currently available data which relates to the factors which need to be considered in selecting a candidate acceptance test(s) are compared for the various alternatives presented herein and shown in Table I. (page 6)

The factors which are considered for comparison for the candidates include such items as reliability/confidence level, safety, costs, logistics, design impact, and schedule. In addition to these factors, the major advantages and disadvantages for each candidate alternative are shown.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

No finite conclusions can be drawn at this time because of the level of maturity and insufficiency of data available.

B. RECOMMENDATION

No final recommendations can be made until the acceptance test criteria will have been more fully developed and established to provide the basis for the evolving of an acceptance test for the deliverable NERVA flight engine.

APPENDIX A
SUMMARY OF COMPONENT TESTS REPEATED AT ENGINE LEVEL

A detailed evaluation has been initiated to disclose as many of the functional characteristics or requirements which would be verified for each component or sub-assembly during its individual acceptance testing to provide a comparison of the comprehensiveness of the candidate acceptance test alternatives in repeating some numbers of these tests on the engine level. This in effect is a forcing factor for the early development of Part II of the Component Specification, which provides the verification and acceptance testing requirements for the components. It is anticipated that most of the acceptance test requirements for the components will have been satisfied prior to their assembly into the engine. However, there is the possibility that some requirement might exist which can only be verified after the component has been assembled into the engine. If any such requirement becomes known, therefore, it will be identified and segregated from the other tests listed.

A summary tabulation of the functional characteristics or requirements which have been completed for a number of components showing the level at which the characteristic is capable of being demonstrated, i.e. component, subsystem/module, or engine and a comparative summary showing which candidate acceptance test alternative provides for repeating each particular test is included in this Appendix A.

The total list of the various components grouped into the subsystems with which they are associated for which this type of tabulation will need to be completed is included in the following listing:

I.	NERVA Engine	CP90290	<u>Status</u>
A.	Propellant Feed Subsystem	EC90218	
1.	Turbopump Assembly	EC90149	Initiated
2.	Propellant Shutoff Valve & Actuator	EC90117	Initiated
3.	Bypass Control Valve & Actuator	EC90122	Initiated
4.	Bypass Block Valve & Actuator	EC90257	Initiated
5.	Turbine Block Valve & Actuator	EC90121	
6.	Pump Discharge Check Valves	EC90246	

APPENDIX A

7. Cooldown Supply Control Valve & Actuator EC90258
8. Cooldown Shutoff Valve & Actuator EC90276
9. Turbine Discharge Block Valve and Actuator EC90281
10. Structural Support Block Valve & Actuator EC90261
11. Turbine Throttle Valve and Actuator EC90283
12. Stage Tank Pressurization Line & Check Valve DS90263
13. Engine Purge Unit DS90264
14. Propellant Lines DS90284
- B. Destruct Subsystem EC90242
- C. Nozzle Assembly Subsystem EC90151
 1. Nozzle DS 90196 Initiated
 2. Nozzle Extension DS90176
- D. Instrumentation & Control Subsystem EC90214
- E. Thrust Structure Subsystem EC90152
 1. Upper Thrust Structure DS90267
 2. Lower Thrust Structure DS90269
- F. External Shield Subsystem EC90243
- G. Gimbal Assembly Subsystem EC90244
 1. Gimbal Actuator DS90251
- H. Pressure Vessel & Closure Subsystem EC90154
- I. Nuclear Subsystem CP677555
 1. Structural Support Coolant Assembly EC677575
 2. Structural Support Coolant Valve EC90192
 3. Structural Support Coolant Valve Actuator EC677576
 4. Fuel Elements EC677566

APPENDIX A

5. Cluster Hardware EC677558
6. Core Periphery EC677564
7. Support Plate & Plena EC677561
8. Internal Shield EC677562
9. Reflector Assembly EC677559
10. Control Drum Drive Assembly EC677585
11. Nuclear Subsystem Instrumentation

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
'COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT PSOV & Actuator (EC90117)

PAGE 1 OF 3

A PART OF Propellant Feed Subsystem (EC90218)

DATE Sept 1970

FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
1. PSOV (valve only)									Current Selection is poppet type valve NOTE: Characteristics involving valve only or actuator only will not be applicable at higher levels of assembly, hence N/A in those columns.
a. Correct force required over full travel range.	Yes	N/A	N/A						
b. Stroke measure- ments.	Yes	N/A	N/A						
c. Proof pressure at ambient temperature.	Yes	N/A	N/A						
d. Leakage									
(1) Internal	Yes	N/A	N/A						
(2) External	Yes	N/A	N/A						
2. PSOV Actuator									Binary Actuator
a. Open/Close rate at ambient temp.									
(1) No load	Yes	N/A	N/A						
(2) Simulated operating load	Yes	N/A	N/A

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT PSOV & Actuator (EC90117)
A PART OF Propellant Feed Subsystem (EC90218)

PAGE 2 OF 3
DATE Sept 1970

FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
3. PSOV/Actuator Assy									Should be done at upper and lower voltage limits.
a. Electrical Check	Yes	Yes	Yes	X					
b. Open/Close Rate									Flow would likely be intro- duced after proof & leak, other tests (see 3.e.)
(1) Ambient Temp no load.	Yes	Yes	Yes	X					
(2) Simulated op temp.press, no flow(may be graduated from LN ₂ to LH ₂ .	Yes	No	No						
c. Proof Pressure at ambient temp. with valve exer- cised.	Yes	No	No						
e. Leakage									
(1) At ambient temp. with valve ex- ercised.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT PSOV & Actuator (EC90117)

PAGE 3 OF 3

A PART OF Propellant Feed Subsystem (EC90218)

DATE Sept 1970

FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
(a) Internal	Yes	No	No						At engine level, leak test would normally be with no flow.
(b) External	Yes	No	Yes	X					
(2) At operating temp and press., no flow, with valve exer- cised.									
(a) Internal	Yes	No	No						In service, PSOV will not be closed against high flow rate, so a cold flow would impose normal load.
(b) External	Yes	No	No						
e. Open/Close rate at operating temp., press., and flow rate.	Yes	No	Yes			X (see remarks)			
f. Purge gas flow measurement	Yes	Yes	Yes	X					PSOV will be visible on engine assembly therefore visual inspection would probably verify no obstruc- tions.
g. Flow path not obstructed	No	No (see remarks)	No

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT TPA (EC90149)

PAGE 1 OF 2

A PART OF Propellant Feed Subsystem (EC90218)

DATE Sept 1970

FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
1. Leakage									
a. Operating	Yes	No	No						
b. Non-operating	Yes	Yes	Yes	X					
2. Electrical Check	Yes	Yes	Yes	X					For engine level, can be done at low pressure only due to propellant inlet line/PSOV limitations
3. Rotor Torque Require- ments (breakaway and rolling)	Yes	Yes	Yes	X					
4. Instrumentation Response *	Yes	Yes (partial)	Yes			X (temp only)	X (temp & pressure)		Pressure transducer re- sponse requires pump operation.
5. Chillydown Time	Yes	No	Yes			X			
6. Head vs Flow characteristics over operating range, (for normal and single TPA operation) at simulated operating temps.	Yes	No	Yes					X	May be obtained from same basic data as Item No. 7.
* TPA will probably be equipped with internal instrumentation.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT TPA (EC90149)

PAGE 2 OF 2

A PART OF Propellant Feed Subsystem (EC90218)

DATE Sept 1970

FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
7. Startup and Shut- down Transient Performance at sim- ulated operating conditions, for pump and turbine.	Yes	No	Yes					X	
8. No obstructions in flow paths.	Yes	Yes	Yes		X				At component level, this characteristic would be demonstrated in other flow tests listed above.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT BCV and Actuator (EC90122)
A PART OF Propellant Feed Subsystem (EC90218)

PAGE 1 OF 5
DATE Sept 1970

FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
1. BCV, Valve only, at ambient temp.									Current selection is sleeve type valve.
a. Correct moving force over full travel range.	Yes	N/A	N/A						
b. Stroke measure- ments.	Yes	N/A	N/A						
c. Proof Pressure	Yes	N/A	N/A						
d. Leakage									
(1) Internal	Yes	N/A	N/A						
(2) External	Yes	N/A	N/A						Analog type actuator
2. BCV Actuator									
a. Slew Rate at ambient Temp.									
(1) No load	Yes	N/A	N/A						
(2) Simulated load	Yes	N/A	N/A

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT BCV and Actuator (EC90122)

PAGE 2 OF 5

A PART OF Propellant Feed Subsystem (EC90218)

DATE Sept 1970

FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
b. Frequency re- sponse at ambient Temp.									
(1) No load	Yes	N/A	N/A						
(2) Simulated load	Yes	N/A	N/A						
c. Threshold, at ambient Temp.									
(1) No load	Yes	N/A	N/A						
(2) Simulated load	Yes	N/A	N/A						
d. Positioning accuracy at ambient Temp.									
(1) No load	Yes	N/A	N/A						
(2) Simulated load	Yes	N/A	N/A

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT BCV and Actuator (EC90122)
A PART OF Propellant Feed Subsystem (EC90218)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
3. BCV/Actuator Assy									
a. Slew Rate *									
(1) Ambient Temp. No load	Yes	Yes	Yes	X					
(2) Operating Temp., Press and Flow	Yes	No	Yes					X	
b. Frequency Response *									
(1) Ambient Temp. No load	Yes	Yes	Yes	X					
(2) Operating Temp., Press and Flow	Yes	No	Yes					X	
c. Threshold *									
(1) Ambient Temp., No load	Yes	Yes	Yes	X					
* Component level tests and higher level ambient checks should be done at upper and lower voltage limits.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT BCV and Actuator (EC90122)
A PART OF Propellant Feed Subsystem (EC90218)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
(2) Operating Temp., Press and Flow	Yes	No	Yes					X	This test could be per- formed only if instrumen- ted to monitor stem position
d. Positioning Accuracy *									
(1) Ambient Temp., no load	Yes	Yes	Yes	X					
(2) Operating Temp., Press and Flow	Yes	No	Yes					X	Proof test would probably be among the first to be performed
e. Proof Pressure at ambient temp. with valve exercised	Yes	No	No						
f. Leakage									
(1) Ambient Temp with valve exercised									
* Component level tests and higher level ambient checks should be done at upper and lower voltage limits.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT BCV and Actuator (EC90122)
A PART OF Propellant Feed Subsystem (EC90218)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
(a) Internal	Yes	No	No						Propellant inlet line will not withstand high pressure leak checks of PFS.
(b) External		Yes (at low press)	Yes (at low press)	X					
(2) Simulated Operating temp and press no flow, with valve exercised									
(a) Internal	Yes	No	No						
(b) External	Yes	No	No						
g. Purge gas flow measurement	Yes	Yes	No						
h. Electrical Checks	Yes	Yes	Yes	X					
i. No obstructions in flow path	No (see remarks)	Yes	Yes		X				At component level, a visual inspection will suffice.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT BBV and Actuator (EC90257)
A PART OF Propellant Feed Subsystem (EC90218)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
1. BBV, Valve only at ambient temperature									Current selection is poppet type valve. NOTE: Characteristics involving valve only or actuator only will not be applicable at subsystem/ module level or engine level, hence N/A in those columns.
a. Correct moving force over full travel range	Yes	N/A	N/A						
b. Stroke measure- ment	Yes	N/A	N/A						
c. Proof Pressure	Yes	N/A	N/A						
d. Leakage									
(1) Internal	Yes	N/A	N/A						
(2) External	Yes	N/A	N/A						Binary type actuator
2. BBV Actuator									
a. Open/Close Rate at ambient temp.									
(1) No load	Yes	N/A	N/A						
(2) Simulated Operating load	Yes	N/A	N/A

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT BBV and Actuator (EC90257)

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A PART OF Propellant Feed Subsystem (EC90218)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
3. BBV/Actuator Assy									
a. Open/Close Rate*									
(1) Ambient Temp no load	Yes	Yes	Yes	X					
(2) Simulated Operating temp, press and flow	Yes	No	Yes						
b. Proof Pressure at ambient temp with valve exercised	Yes	No	No						Proof test would likely be among the first performed (at component level)
c. Leakage									
(1) At ambient temp with valve exer- cised									Engine level leakage can only be determined at low pressure, using an inert gas at near ambient temperature, except for gross leaks which would be detected by data inconsistencies during engine operation. This is not con- sidered to be the type of leak test done for engine acceptance.
(a) Internal	Yes	No	No						
* Component level tests and higher level ambient checks should be done at upper and lower voltage limits

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT BBV and Actuator (EC90257)
A PART OF Propellant Feed Subsystem (EC90218)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
(b) External	Yes	Yes	Yes	X					Electrical measurements will be compared for trends prior to engine acceptance as well as after.
(2) At simulated operating temp press, no flow with valve exercised									
(a) Internal	Yes	No	No						
(b) External	Yes	No	No						
d. Electrical measurements	Yes	Yes	Yes						
e. Purge Gas Flow Measurements	Yes	Yes	Yes	X					
f. No obstruction inflow path (see remarks)	No	Yes	Yes		X				At component level, a visual inspection will suffice.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT Nozzle (DS90196)

A PART OF Nozzle Assembly Subsystem (EC90151)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
1. Each tube open and free flowing	Yes	No	No (see remarks)						Engine level demonstration would require hot firing and inspection for damage.
2. Flow coefficient (water) nozzle tube system.	Yes	No	No						
3. Coolant Velocities	Yes	No	No (see remarks for Item 1 above)						
4. Leakage									Will be calculated based on determination of tube volume and cross section at various stations, from component level tests
a. Internal	Yes	No	No						
b. External	Yes	No	Yes	X					
5. Proof Pressure									Low pressure gas (He) leak check limited by propellant inlet line.
a. Tubes	Yes	No	No						
b. Chamber (up- stream of throat)	Yes	No	No						
									A throat plug will be used for proofing chamber. Pres- sure in divergent portion will be very small, and probably will not require demonstration.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT Nozzle (DS90196)

A PART OF Nozzle Assembly Subsystem (EC90151)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
6. Gas flow characteristics for producing thrust.	No	No	No						This information will be known very closely from nozzle dimensions and should not require demonstration. Also, hot firing with 100:1 extension installed is not practical as full expansion of gas cannot be obtained with presently planned facilities. Hot testing should not be planned for demonstrating this function.

SUMMARY OF COMPONENT TESTS PERFORMED AT THE ENGINE LEVEL FOR ENGINE ACCEPTANCE
COMPARED WITH SIMILAR TESTS PERFORMED AT COMPONENT AND SUBSYSTEM LEVEL

COMPONENT Nozzle Extension (DS90176)

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A PART OF Nozzle Assembly Subsystem (EC90151)

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FUNCTIONAL CHARACTERISTIC OR REQUIREMENT	LEVEL AT WHICH CHARACTERISTIC DEMONSTRATED			TEST REQUIRED FOR ENGINE LEVEL DEMONSTRATION					REMARKS
	COMPONENT	SUBSYSTEM /MODULE	ENGINE	BASIC CHECKOUTS	INERT GAS FLOW TEST	COLD FLOW TEST	LOW POWER TEST	FULL POWER TEST	
1. Withstand (simulated) launch and boost vibration	Yes (see remarks)	No	No						While possible, vibrational tests on deliverable units may not be necessary. Quality Assurance data on manufacturing processes may be sufficient to assure performance.
2. Proof Pressure	No (see remarks)	No	No						A proof pressure test is not meaningful. The loads are primarily vibrational and thermal. Wall pressures will vary from approximately 2 psi at the inlet to approximately 0.3 psi at the exit during operation.
3. Leakage	No	No	No (see remarks)						The only meaningful leak test would be to determine leakage at the interface with the nozzle. This will be considered for the engine assembly checkout, but is not considered a likely test at this time.