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AN AIRLINE STUDY OF ADVANCED TECHNOLOGY REQUIREMENTS FOR ADVANCED HIGH SPEED COMMERCIAL TRANSPORT ENGINES

III - PROPULSION SYSTEM REQUIREMENTS

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16. Abstract
The results of an airline study of the advanced technology requirements for an advanced high speed commercial transport engine are presented. This report is one in a series of three reports developed as part of the NASA Advanced Transport Technology Program. This report presents the results of the American Airlines Phase III effort and covers in a single document American's requirements and objectives for future aircraft propulsion systems. These requirements reflect the results of the Task I and II efforts and will serve as a baseline for future evaluations, specification dev[illegible]nent efforts, contract/purchase agreements, and operational plans for future subsonic commercial engines. This report is divided into five major sections:

a. Management objectives for commercial propulsion systems
b. Performance requirements for commercial transport propulsion systems
c. Design criteria for future transport engines
d. Design requirements for powerplant packages
e. Testing

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SUMMARY

This report presents the results of an airline study of the advanced technology requirements for an advanced high speed commercial transport engine. This report is one in a series of three reports developed as part of the NASA Advanced Transport Technology Program. This specific report covers the results of American Airlines' Phase III efforts and presents in a single document American's requirements and objectives for future aircraft propulsion systems. These requirements reflect the results of the Task I and II effort and will serve as a baseline for future evaluations, specification development efforts, contract/purchase agreements and operational plans for future subsonic commercial engines. This report is divided into five major sections.

a. Management Objectives - This section addresses the desired scope of the propulsion system contractor's effort, the airlines' participation in the design process and the philosophy that is recommended with respect to advanced design methods, materials, acoustics, pollution, maintainability and reliability.

b. Performance Requirements - This section addresses the performance and operability objectives for the propulsion system. The requirements for engine operating envelope, installed performance, fuel contamination levels, starting, stability, transient performance, inlet distortion, noise and pollution levels are presented.

c. Engine Design Criteria - The engine component and part design life objectives and specific engine mechanical design features desired are presented. Subsystem performance and design requirements are established for the engine fuel, oil, ignition, starting, bleed air, and instrumentation subsystems.

d. Design Requirements for Powerplant Packages - Design and performance requirements have been presented for the total powerplant package. This section covers inlet, nozzle, reverser, hydraulic, pneumatic, electrical and fuel subsystem requirements which are important to the maintenance and operation of the powerplant in commercial service.

e. Testing - The section covers specific types of tests that should be conducted prior to the entry of the propulsion system into commercial service.

Introduction

This report has been prepared to fulfill the requirements of NASA Lewis Research Center Contract NAS3-15572 with American Airlines and presents the results of studies undertaken in response to Task III of the contract. The information contained herein is directed at listing the airline management philosophy and design objectives for future commercial propulsion systems for high speed subsonic aircraft. The results of the studies conducted under Task I and Task II of the contract have been reflected in the contents of this report in the appropriate places.

The results of the ATT Propulsion System Study Contractors' investigations were a definition of the type of propulsion system required and the identification of the research programs which must be accomplished to insure the availability of the state-of-art for such a propulsion system. The intent of the report is to place the requirement to achieve these advances firmly in the hands of the manufacturers.

The requirements which future propulsion systems must meet are many and varied. The most important are significant reduction in noise and pollution emission, improvement in reliability as a system, reduction of economic burden associated with achieving the social and reliability objectives, and improvement in performance to offset the losses associated with meeting the social objectives and to provide an incentive to purchase the newer product.

The requirements and objectives subsequently listed are directed at achieving the prime objectives listed above and attempt to provide design and management guidance pertinent to achieving these objectives. The requirements are presented in a specification type format and elements of these requirements should be reflected in future engines/aircraft specifications.

This report is divided into the following sections

I. Management Objectives for Commercial Propulsion Systems.

II. Performance Requirements for Commercial Transport Propulsion Systems.

III. Design Criteria for Future Transport Engines.

IV. Design Requirements for Powerplant Packages.

V. Testing

SECTION I

MANAGEMENT OBJECTIVES FOR COMMERCIAL AIRCRAFT PROPULSION SYSTEMS

1. INTENT

The aircraft contractor must be the total systems contractor and must have the ultimate responsibility for a satisfactory aircraft in airline use. It is desired and strongly recommended that the propulsion system be contracted for as a complete subsystem of the aircraft. The purpose of this requirement is to achieve a propulsion system approach to design to insure compatibility of the engine, the engine environment and the aircraft systems that interface with the propulsion system and that the design meets all requirements for satisfactory airline usage. It is a further purpose to achieve, through the combined efforts of the aircraft contractor, the propulsion system sub-contractor and the airline customers, a higher level of system performance, reliability and of maintainability than would be possible without an integrated effort. The airlines desire to be an intimate part of the engine design process and the preliminary installation design so that their requirements and desires can be fully expressed at a point in time where their desires can be accommodated in the final product. To accomplish this objective the aircraft contractor should establish a propulsion system team including the airline technical personnel as members.

2. GENERAL

a. Responsibilities of Propulsion System Subcontractor

It is American Airlines desire that the propulsion system subcontractor have the following responsibilities:

Design, develop, test and provide for complete detail fabrication, manufacture, and delivery of the assemblies in accordance with the requirements established and reflected in the aircraft and propulsion system specification, and such other requirements as may be applicable.

Be responsible for the performance, noise level, pollution emission level, structural integrity, durability, maintainability, and reliability of the design, including responsibility for fatigue life, handling, wear, and dimensional accuracy and, further, the responsibility for any redesign, requalification, and retooling necessary to correct deficiencies in the product.

Be responsible for rapid response to, and corrective action for, in-service problems. As a part of any proposal a detailed description including an organizational flow diagram of the correction of problems which occur in service should be included. All items of the propulsion system as well as vendor components must be covered. Particular emphasis should be given to the response time of both the subcontractor and his vendors. A specific definition of a program which the subcontractor will employ to assure rapid response for correction of in-service problems of his vendor items is of major importance.

b. Coordination Requirements

It is essential that effective communication channels and forms be established. The aircraft contractor shall be responsible for establishing such procedures and requirements which most fit his needs. However, the airlines will require a preliminary design book as well as design mock-up reviews.

This book is a descriptive document containing subsystem and subassembly scope drawings, structural details, functional explanations, design parameters utilized, type and gage of material utilized, as well as brief written descriptions of the subsystems and subassemblies and their interface with the total installation. Termination of up-dating of the preliminary design book shall be mutually agreed upon.

Further, during both the preliminary and detail design phase, it will be necessary for the aircraft contractor and the subcontractor to mutually discuss the progress of the design with the airlines. Design review meetings for this purpose shall be planned at times and locations determined appropriate. Additionally, information defining the current status of the detail design shall be transmitted between the contractors themselves and the airlines by means of the preliminary design book mentioned previously.

During the preliminary and the detail design and development phase of the program, it will be necessary to conduct reviews for the airlines. It is anticipated that the mockup fixture will be the most useful tool for effective accomplishment of this objective. The data and location of these reviews will be mutually established.

3. DESIGN PHILOSOPHY & CRITERIA

a. General Design Criteria

The intended purpose of the propulsion system package is to perform all of its normal functions on the aircraft during any and all environmental conditions encountered on the ground or in flight during or following normal scheduled dispatch of the aircraft. It shall be compatible with the aircraft systems that interface with it and shall meet all requirements for certification and satisfactory airline usage. These functions include but are not necessarily limited to the following.

- Delivery of thrust levels as selected by the pilot for propulsion of the aircraft.

- Delivery of reverse thrust to the aircraft as selected by the pilot.

- Delivery of pneumatic and shaft power as required for normal or abnormal operation of accessory or support systems of the engine installation or aircraft.

The above stated purpose shall be accomplished in conjunction with meeting other power plant installation requirements such as safety, maintainability, and serviceability.

During the preliminary design phase, the design, philosophical, functional and performance requirements, pod interface definition, maintenance methods and method of handling demountable power plant will be established and mutually agreed upon with respect to all systems.

When complete definition cannot be accomplished, a program, including tests if required, will be defined and conducted by the subcontractor to supply information required to complete the definition.

b. Federal Aviation Regulations

The propulsion system shall be built to the requirements of Federal Aviation Regulation Part 25, including Amendments to the extent that Part 25 and the Amendments apply to turbofan powered transport aircraft, and also including such revisions in force up to the time of certification of the aircraft, and any special regulations and/or conditions that the FAA may deem necessary.

c. Airplane Specification

It is essential that conformity with the airplane specification exists in all respects. It shall be the responsibility of the propulsion system subcontractor to assure that this conformity is met in his design. Where other requirements would appear to dictate a design in disagreement with the requirements of the airplane specification, the aircraft contractor shall be notified forthwith and shall specify the course to follow.

d. Considerations Concerning Advanced Design Methods and Materials

The subcontractor must consider design methods and materials which may be relatively new in order to achieve optimum weight and installation arrangement within space limits and other constraints upon the overall design. Examples include consideration of acoustic treatment materials as load carrying members for access doors and structural panels, and use of lightweight materials such as plastic composites. Where use of new materials is considered, potential corrosion problems due to cleaning solvents which may be used by the airlines, elevated temperatures, etc. must be dealt with. Special attention must be given to ease of replacement and to the repairability of such materials.

e. Fire Detection

A vigorous and complete review of candidate fire and overheat detection systems shall be conducted by the subcontractor to reduce potential false warnings to an absolute minimum. Particular attention shall be given to detecting combustor burn-throughs. Consideration shall be given to the use of the fire extinguishing agent.

f. Engine Cowl Ice Protection System

The intended use of the engine cowl ice protection system is to provide acceptably aerodynamically clean engine inlets to allow safe flight during and after unlimited icing encounters as defined by FAR, Part 25. The rigid noise reduction requirements imposed may necessitate consideration of features which may be critical with respect to icing and special attention shall be given to these requirements early in the development program.

g. Pneumatic System Philosophy

The intended use of the penumatic system is to supply air of the pressure, temperature, flow rate, and contamination level required by the air conditioning, airfoil ice protection, and engine starting systems.

The aircraft manufacturer shall determine the requirements for the valves, temperature sensors, and temperature controllers for the pneumatic system in conjunction with the environmental control system of the aircraft. Aircraft growth and possible long range problems demand that the engine be capable of supplying at least 150% of initially defined requirements without adverse effect on engine life and without the replacement of parts.

h. Philosophy on Propulsion System Condition Monitoring

The engine manufacturer shall recommend key engine parameters providing measurable and interpretable data for diagnostic and fault isolation purposes to the aircraft manufacturer and using airlines. Upon mutual agreement on significant parameters, provisions for mounting sensors for monitoring of these parameters will be made at discreet locations as an integral part of the developed engine. Prototype sensors will be installed during engine development test programs to confirm sensor reliability and sensitivity and to establish baseline data for diagnostic and fault isolation procedures to be prepared and provided by the engine manufacturer.

4. COMPONENT SELECTION POLICY

a. General

The subcontractor shall be responsible for the evaluation, selection and procurement of all components required for the demountable power plant installation, unless otherwise agreed.

b. Procedure

The procedure for the selection of components shall be mutually agreed upon by the aircraft contractor and the subcontractor.

c. Qualification of Components

All components which make up the product, to be supplied by the subcontractor should be fully qualified. Where a T.S.O.* exists for a component or system the part/system must meet the requirements of the T.S.O. or have approved FAA deviation and each part should be so identified in an approved manner. The subcontractor must qualify all components prior to the time of initial delivery to the aircraft contractor for installation in the airplane. (T.S.O. approval will not necessarily be a satisfactory basis for qualification. The required test program should consider the environment in which it must perform and should be rigorous enough to insure a high confidence level that good service life and reliability will be achieved without service changes.) "Qualified" shall mean that the component is physically, functionally, and environmentally suitable for its intended usage and has completed an approved qualification test, or have been proven by successful prior usage of the part on a similar installation. All qualification test reports (or other substantiation) must be furnished to the aircraft contractor for approval.

d. Component Installation Environment

Where components of the propulsion system are supplied by the aircraft contractor, the two parties must agree on the temperature environment in which each of the components is to be installed. The subcontractor should specify the vibration environment of each component and must provide the mutually specified temperature environment. The subcontractor should be required to incorporate sufficient instrumentation to determine during flight test that the specified environments have been achieved and should accomplish any modification or rework necessary to meet the specified temperature and vibration levels.

e. Airline Participation

The airline customers will expect to participate in the selection of vendors for critical components. The subcontractor will be advised of these items.

f. Overhaul and Repairability of Components

Heavy consideration shall be given to ease of overhaul and repairability in this selection of components.

*Technical Service Order

5. ACOUSTICS POLICY

Due to the state-of-the-art and degree of uncertainty concerning acoustic performance predictions, the subcontractor is advised to have a detailed recovery plan for achieving the guaranteed levels, assuming that his initial design is deficient by as much as 3 PNdb. The subcontractor shall provide adequate sound suppression in the mounted propulsion system package.

If the suppression material or materials have not previously been proven suitable for the use by adequate service experience, the subcontractor shall provide sufficient material and arrange for incorporation in an existing installation for service test as early in the program as possible.

6. WEIGHT CONTROL POLICY

The maximum guaranteed weight for each complete propulsion system package, including the engine and engine manufacturer's supplied accessories and components shall be determined and agreed upon prior to contractual execution.

The total weight should be adjusted for any changes to the basic specification resulting from customer special requirements and for any departures from allowed weight for aircraft contractor furnished items. Additional requirements for weight control shall be specified by the aircraft contractor.

7. MOCKUPS

a. General

To adequately coordinate the design and development of the propulsion system packages, duplicate mockup assemblies will be required, at both the subcontractor's plant and at the aircraft contractor, following development of the initial preliminary installation mockups by mutual effort of aircraft contractor, subcontractor and airlines during the conceptual design phase. The subcontractor should maintain the mockups in an up-to-date status throughout the program, until terminated by mutual agreement between the aircraft contractor and the subcontractor.

b. Preliminary Mockup

Since the conceptual design effort should take place at the aircraft contractor, the initial mockups for the power plant installation should, of necessity, be developed at the aircraft contractor's facility. To permit this to be accomplished, the subcontractor should furnish the aircraft contractor wood and/or metal mockups of the basic engine, to be used in the installation mockups.

These mockups should be used to determine the preliminary arrangement of accessories, piping, wiring, ducting, etc., within the pod, help establish clearances and demonstrate accessibility and maintainability.

Further, these units should aid in the establishment of the detailed pod/pylon interface, and in the determination of the final loft lines.

c. Accurate Mockup

After completion of the conceptual design phase, using the preliminary mockups, accurate mockups should be developed whereby such tasks as piping and wiring development, realistic installation clearances, and bracket development are accomplished. Complete, demountable power plant assembly mockups shall be assembled by the subcontractor at his facility, and as detailed parts and their installation are developed these shall be accurately represented. These mockups must be maintained by the subcontractor as the master mockups to serve as the basis for such items as fit checks and development changes.

8. INTERFACE CONTROL

The interface definition should be established by mutual agreement as soon as practical in the design phase.

Where systems or structural assemblies cross the separation boundary between the powerplant (or other major subcontractor assemblies) and the airframe, the subcontractor should assume responsibility for parts on the airframe side which are closely related to the powerplant.

Further, during the conceptual design phase, it may appear advantageous to locate some propulsion system components outside the physical boundaries of the nacelle for environmental or space considerations. In cases of this type, the procurement of, and responsibility for, these components should remain with the subcontractor.

An engineering drawing defining the interface should be prepared and maintained by the aircraft contractor and used throughout the program for coordination purposes. The tolerances to be utilized for disconnect and pierce points should be controlled by means of this drawing.

9. RELIABILITY REQUIREMENTS FOR INCORPORATION IN FUTURE CONTRACTS

a. Reliability Program Plan

The contractor should prepare and submit a Reliability Program Plan specifically oriented to the requirements of the propulsion system package. The plan shall also identify the organization and responsibilities for managing the Reliability Program. It will provide specific information as to how the contractor will meet the reliability requirements during design, development, production, and test phases. An extremely critical inclusion shall be specific vendor-supplier controls to be implemented by the contractor. Guidelines provided in MIL-STD-785 can be used for the preparation of the Program Plan.

b. Reliability Guarantees

The contractor shall agree on guaranteed reliability values which the propulsion system package will meet or exceed during the last six months of the second year and the last six months of the third year that the aircraft is in commercial service. The first year shall commence with the introduction of the first certificated aircraft into commercial service.

(1) Proposed "Dispatch Reliability Guarantee"

As a design goal, total "mechanical" delays over 15 minutes, plus "mechanical" cancellations and air interruptions, shall not exceed an average of 1% of scheduled departures caused by the propulsion system during the last six months of the second year after initial scheduled service; i.e., aircraft dispatch reliability shall then average at least 98%. During the last six months of the third year, this DR shall average at least 99.5% with respect to the propulsion system.

(2) As a design goal, total "mechanical" delays over one hour, plus "mechanical" cancellations and air interruptions caused by the propulsion system, shall not exceed an average of .25% of scheduled departures during the last six months of the second year after initial service; i.e., aircraft dispatch reliability shall then average at least 99.5%. During the last six months of the third year, this DR shall average at least 99.90%.

(3) The above DR goals shall be based on a scheduled ground time of 20 minutes for "Through Flights" and 30 minutes for "Turnaround Flights", assuming an average flight of 2.6 hours block time (2.3 hours flight time). (See Note 1)

c. Desired Engine Quantitative Reliability Objectives

The minimum quantitative reliability objectives for the engine as installed in an aircraft are:

Reliability Parameter	Value (hrs.)
Mean-time-between-in-flight shut downs (MTBIFS)	25,000 Requirement
Mean-time-between-unscheduled engine removal (MTBUER)	5,000 Objective

d. Definition of Parameters

(1) Mean-time-between-in-flight shutdowns:

$$\text{MTBIFS} = \frac{\text{Cumulative Block Time}}{\text{Total Number of Shutdowns}}$$

Block Time - Includes total operating time from beginning of taxi-out through taxi-in.

In-Flight Shutdown - The stoppage of an engine which is necessary in the judgment of the pilot or flight crew to prevent or eliminate airframe damage, engine damage, and/or personnel hazard which is later confirmed to be a direct result of an independent engine failure.

(2) Mean-time-between-unscheduled-engine removals:

$$MTBUER = \frac{\text{Cumulative Block Time}}{\text{Total Number of Unscheduled Removals}}$$

Block Time - Includes total operating time from beginning of taxi-out through taxi-in.

Unscheduled Removal - A failure or malfunction which is directly chargeable to the engine and which necessitates, due to requiring more than 6 elapsed hours to repair, an unscheduled removal.

e. Corrective Action

If the actual reliability values experienced in service are less than the reliability values guaranteed, the contractor shall at his expense repair, modify, consign spares and re-design the equipment as necessary to obtain six months of operation within the guaranteed value.

Note 1: For the purpose of applying these criteria/goals it should be assumed that there will be 20 minutes available on scheduled through flights and thirty minutes on turnarounds. This means that fault diagnosis and repair must not exceed 45 minutes. Where such action does exceed 45 minutes it shall be considered a delay. It should also be assumed for an ATT transcontinental aircraft that the average flight time will be on the order of 2.6 hours and that there will be a 40% - 60% split on through stops and turnarounds.

10. MAINTAINABILITY REQUIREMENTS FOR FUTURE CONTRACTS

It is intended that the propulsion system and its components have equal or lower maintenance costs than corresponding systems and/or components now in airline service. These objectives must be met through increased time between inspection, servicing, repair, replacement and/or overhaul; minimum number of personnel, skill levels and time to accomplish the maintenance functions mentioned; and by reduced spares/replacement parts requirements.

The maintainability objectives for the system and its components must be achieved through an engineering approach which translates maintenance requirements into definitive design and equipment requirements. The contractor's trade-off and/or design reviews shall assure that maintainability is given equal consideration with other design factors and that commonality, simplicity, and aircraft dispatch keynote maintenance considerations. Complexity is to be avoided wherever possible.

Consideration shall be given in the design of maintainability features in the propulsion system package to ensure that they are integrated with the maintainability features of, and access to, the engine and result in the optimum overall configuration. For example, consideration shall be given to provisions in the pod for engine support during various stages of partial engine disassembly.

Materials utilized shall be compatible with normal field service repair procedures and equipment insofar as practical. Where new materials or manufacturing methods not in airline service, are employed, the contractor shall develop and provide appropriate repair procedures.

a. <u>Specific Engine Maintainability Requirements</u>

The following criteria shall be met:

(a) Avoid placing components, accessories, plumbing, and wiring on the upper arc of the engine where they are inaccessible for maintenance. Parts of the engine requiring routine service-checking, adjustment, or replacement shall be made readily accessible for servicing without teardown of the engine or removal of any major part, component, or accessory.

(b) Make all instrumentation probes and thermocouples, ignitors and fuel nozzles inspectable and replaceable individually from the outside periphery of the engine.

(c) Provide inspection provisions to permit adequate inspection of the combustor, compressor, and turbine sections as installed.

(d) Provide for remote engine trimming by flight and ground crews.

(e) It shall not be necessary to remove one accessory or engine component item to repair or replace another.

(f) The mating points of the propulsion system shall be controlled to maintain full interchangeability.

(g) Interchangeable component or accessory items of the propulsion system shall be so located such that the rapid removal or installation of these component accessories is facilitated.

(h) Items requiring similar maintenance function shall be grouped together in the same area.

(i) The engine interface relative to the airframe shall be defined so that it will be possible to remove and install the engine with the minimum number of disconnections. These disconnection points shall be controlled to maintain full interchangeability.

(j) All proposed propulsion interface changes shall be coordinated to assure that maintainability, reliability, and performance are not adversely affected.

(k) A maximum capability shall be provided to perform all engine maintenance while aircraft installed.

Further, the design of the handling and attachment features provided in the basic engine shall permit;

(l) Air, truck, and rail transportability so that the main engine mount points can be made accessible for engine handling and installation at the destination.

(m) Shop maintenance in the horizontal or vertical position.

(n) Complete and efficient disassembly of the engine for repairs or heavy maintenance with minimum disassembly of other portions of the engine that do not require maintenance or repair.

b. <u>Maintainability Elements</u>

(a) <u>Predictability</u> - The unit/system shall be analyzed for the predictability of failure modes. Methods and/or means shall be documented and provided by the contractor.

(b) <u>Postponeability</u> - It is desired that the unit/system be analyzed to determine its ability to be isolated or to continue operation when a failure/inoperative mode is imminent or has occured, but shall not compromise safe flight as defined by the FAA or aircraft contractor.

(c) <u>Fault Indication</u> - Means shall be provided to indicate and/or detect each fault in the system in some manner, i.e., improper performance obvious to crew, indicators, test means/equipment or ground inspection where delayed indication does not compromise safety and economy.

(d) <u>Fault Isolation</u> - A system for fault isolation shall be developed which enables rapid and positive isolation of malfunctions and failures to single major, removable components and to the single line replaceable unit (LRU) at fault. The elapsed time and manhours to accomplish this identification shall be specified together with the equipment (built-in or portable) and procedures necessary to accomplish the tasks within specified time periods (see "Unscheduled Maintenance Programs," page 17).

(e) <u>"Aids"/"Bite"</u> - To minimize flight cancellations and delays, each system in the propulsion system package should be designed, analyzed and instrumented in accordance with the following:

1. <u>Dispatch Inoperative</u> - The system should be capable of safe dispatch with the maximum number of components inoperative. This is especially important for components where impending failure cannot be predicted or which cannot be replaced or repaired within 30 minutes total elapsed time, as is necessary to avoid delay in departure. Some redundancy is permissible to achieve this objective. It is assumed that parts capable of inoperative dispatch will be replaced or repaired the evening of the day of the failure. (Inoperative flight time 7 flights or 12 hours).

2. <u>Predictability</u> - All units of the system having failure modes that give warning of impending failure by degraded performance, internal leakage, increased vibration or sound

level, or other means, should be analyzed to determine the optimum means for warning maintenance personnel of impending failure. For those units having very gradual "wear-out" modes, ground tests are permissible if not required more frequently than 600 flight hours. Ground inspection or very simple checks are permissible at 150 hour intervals. Sensors for ground tests should be installed if aircraft sensors are inadequate.

For units having more rapid failure modes after initial detection, sensors should be installed (if normal aircraft sensors are inadequate) and means provided to warn of impending failure at least 16 flight hours in advance of failure. A recommendation should be made as to the use of BITE (Built-In Test Equipment) versus AIDS (Central Airborne Information Data System). The final choice will be made jointly by the appropriate contractors.

3. Repairability - When the LRU is required for dispatch and when failure is not predictable in advance, rapid replacement or repair (within 30 minutes) is necessary to avoid delay in dispatch. One essential to rapid repair is rapid fault isolation to the faulty LRU within the system. Forsuch components, means should be provided for rapid (2 to 3 minutes), accurate, fault isolation. A system fault isolation analysis should be made and the necessary sensors provided to enable such fault isolation through the use of ground equipment, BITE or AIDS. A recommendation as to the optimum method should be made. Generally, BITE or AIDS are preferred for systems when components will be stocked at many stations. When spares will be kept only at main repair bases, ground test fault isolation is permissible.

c. General Maintenance Requirements, Guarantees & Design Objectives

Maintenance Parts Cost Warranty - The mean direct maintenance cost for parts and materials for the engine including reverser per engine block hour shall not exceed four dollars per one hundred thousand dollars of the initial price for the initial ten years of airline operation, and shall be suitably guaranteed.

Maintenance Manhours -

a/ The mean direct manhours required for scheduled major maintenance when necessary, shall not exceed 2000.

b/ The mean direct maintenance manhours per engine block hour shall not exceed 1.60. These manhours are the summation of those expended for all line, dock, shop and overhaul maintenance, both scheduled and unscheduled.

Unscheduled Maintenance Programs - (System Fault Isolation and Correction Effectiveness Goals.)

A design requirement shall be to develop fault isolation and correction procedures and initial maintenance training programs so that the resulting maintenance corrective actions on system faults shall average at least 90% for the last six months of the second year after initial service. This effectiveness shall increase to an average of at least 95% during the last six months of the third year after initial scheduled service.

Scheduled Maintenance Programs -

a/ The design goal shall be to design the propulsion system and establish procedures which permit scheduled maintenance and appropriate remedial actions to be accomplished on the airplane within a maximum of 8 hours elapsed time at minimum intervals of 500 hours.

b/ Scheduled maintenance, other than flight crew "Walkaround" inspection and minor maintenance servicing tasks (such as lubrication checks and fuel sump draining) shall not be required at intervals less than 500 hours. Minor maintenance servicing tasks required at less than 500-hour intervals shall not collectively require more than 1/2 hour elapsed time nor more than 1 manhour to accomplish and at intervals not less than 50 hours.

c/ Corrective actions found necessary at other than the 500-hour check shall be achievable within the normal Through and Turnaround Service elapsed times.

Time Between Overhauls (TBO) - It is desired that minimum reliance be placed on scheduled overhaul. Inspections and tests which verify system/component operability, or which indicate performance degradation, are preferable to the establishment of arbitrary scheduled overhaul times.

In general, a scheduled overhaul time shall only be specified if a component incorporates a detail part which will wear out or deteriorate as a function of time in service. Where the failure or malfunction modes of a component are random with respect to time and/or cause, no scheduled overhaul time shall be established unless the consequences of an undetected malfunction would result in a compromise to safety or excessive repair cost.

If a scheduled TBO is required on any item supplied as a part of the propulsion system package, numerical TBO guarantees for the first and third years of operation shall be established. The numerical values of such goals shall be subject to acceptance and approval by the FAA, aircraft contractor, and its customers. If these values are not met, the contractor shall take whatever action is required to meet these goals.

Powerplant Assembly Removal - The time required to convert a Quick Engine Change (QEC) from either a wing-mounted or tail-mounted configuration shall not exceed 45 minutes.

All items which must be changed to make a wing-mounted or tail-mounted configuration shall be designed for ease of removal and replacement to minimize the time to make a change.

This feature shall be demonstrated and resolved by use of the mock-up.

Engine and QEC mounting provisions shall permit removal or installation of a complete QEC unit in one hour elapsed time with optimum manpower.

The inlet duct retention system shall be consistent with this time limitation.

SECTION II

PERFORMANCE REQUIREMENTS FOR COMMERCIAL TRANSPORT PROPULSION SYSTEMS

The performance characteristics of the system and engine shall be as specified in the system and engine specification. These performance characteristics shall be determined using Jet A kerosene fuel conforming to D1655-65T (ASTM) and commercially available lubricants conforming to MIL-L-23699 in the specification. "The performance characteristics and ratings shall be determined using the actual engine control system specified in the model specification." All fuel consumption performance shall be based on fuel having a lower heating value of 18,400 BTU/lb.

1. OPERATING ENVELOPE

a. Takeoff and Landing Altitude Limits

The propulsion system shall function satisfactorily when installed in an airplane certificated for takeoff and landing at altitudes between -2000 and 15000 feet above sea level.

b. Maximum Operating Altitude

The propulsion system shall be capable of certification to a maximum operating altitude of 50,000 feet. Alternatively, the propulsion system must exceed the expected aircraft operating envelope by at least 5000 feet in altitude.

c. Environmental Conditions

The propulsion system shall be capable of certification for operation in unlimited icing conditions, in any or all conditions that will be encountered during commercial aircraft operation, except for fuel temperature and viscosity conditions beyond the limits noted herein.

It shall be a design objective to maintain ambient air temperatures in the accessory section below 250 degrees Fahrenheit under extreme temperature conditions.

2. FLIGHT MANEUVER FORCES & LOADS

The engine mount structure shall withstand without permanent deformation, the general flight, gust and landing limit loads given on Figure 1. The weight allowed for the engine shall be added to the specified weight allowed for all engine mounted accessories and by the weight of the items specified as making up the powerplant which are engine mounted.

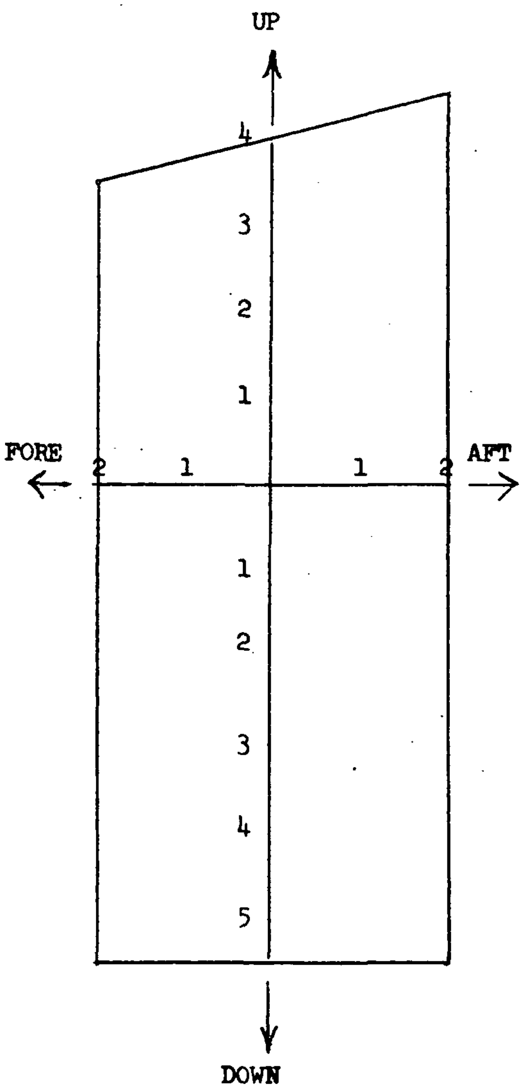
All the loads given in the following paragraphs of this section assume axial forward and reverse thrust.

FIGURE 1

MOUNT ARRANGEMENT LOAD ENVELOPES

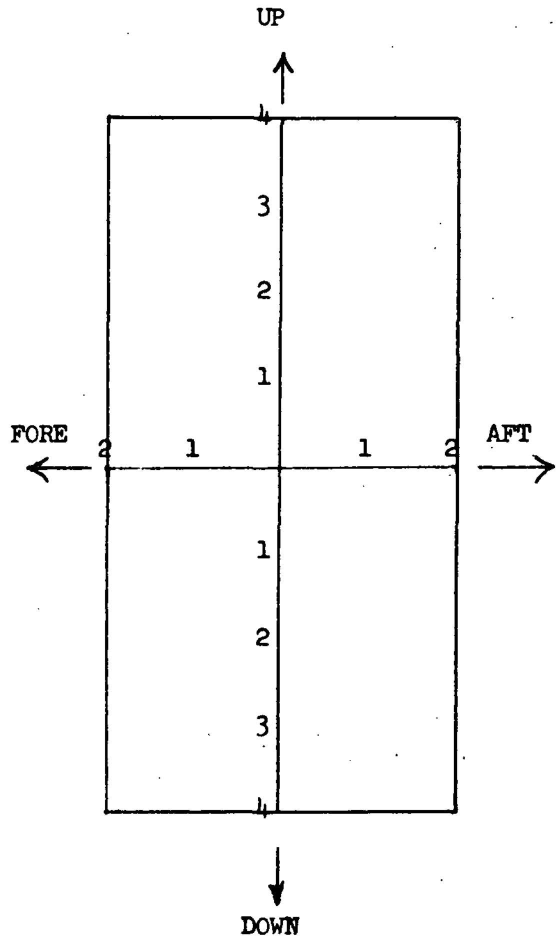
(G)

O TO MAX. FWD. THRUST
SIDE LOAD = ± 1.0G
PITCH PRECESSION ± 0.5 RAD/SEC



GENERAL FLIGHT AND GUST CASES
(LIMIT LOAD)

MAX. REV. TO MAX.FWD. THRUST
SIDE LOAD =± 1.0G



GENERAL LANDING CASES
(LIMIT LOAD)

Load factors and angular velocities are taken at, and about, the center of gravity of the engine and are relative to the engine axes. Dow loads occur during dive pull-out, and fore loads occur during arrested landing.

An ultimate factor of 1.5 is to be applied to each of the limit load cases given in Figure 1 and to the limit load cases given in the paragraph below to obtain the corresponding ultimate load cases. The emergency landing loads are ultimate load cases only.

a. Additional Loads - The engine mounts shall be designed to also withstand the following limit loads:

A side load factor of $\pm$ 2.00 but without other inertia factors with zero to maximum thrust.

A yaw velocity of 1.0 radian per second with maximum reverse to maximum forward thrust, together with a load factor of 1.0 down, $\pm$ 1.0 side and $\pm$ 1.0 fore and aft.

A seizure of any shaft system in 1.0 second together with a load factor of 1.0 down.

b. Emergency Landing Loads - The engine mounts and support structure shall be designed to withstand the following emergency landing loads.

A load factor of 12 forward, together with a downward load factor of 6.

A load factor of 11.6 forward together with a side load factor of $\pm$ 3.1.

A load factor of $\pm$ 5.0 side load acting alone.

Slinging - The slinging points shall be designed to withstand an ultimate vertical load factor of + 4.

c. Special Design Criteria

The engine mounts and the bulkheads to which they attach shall be designed in such a manner that a margin of safety of zero or greater is obtained when the limit thrust or reverse thrust is multiplied by an ultimate factor of 3.00 instead of nominal 1.5 for all conditions. For design purposes all specification thrusts or reverse thrusts shall be multiplied by a factor of 1.20 to obtain limit loads for engine performance growth.

All weights, including trapped fuel and oil used in stress analysis, shall be multiplied by a factor of 1.05 for growth.

The nose cowl shall be designed for actual aerodynamic bursting pressures times a factor of 2.25 ultimate.

All actual gyroscopic moments to be multiplied by a factor of 1.15 to obtain limit loads for growth.

All items of the propulsion system, as installed, attached to or associated with the engine or pneumatic system shall function properly under the loads and environmental conditions of the airplane when operated in commercial service, and in addition shall meet the requirements of MIL-E-5272 as applicable.

All components making up the power plant shall be compatible with deflections and thermal expansion of the engine, engine mounts and other load carrying members.

For crash landings, the package must remain attached to the fuselage under the emergency, inertia loads. Local folding, tearing and crushing are permitted under this load, but the engines must not become detached in such a way that it might be thrown forward or pivot into the occupied portion of the cabin.

d. Fail Safe Provisions

Engine mounts and attaching structure shall be so designed that after the failure of any single element of a dual load path structural member, the remaining element of the failed member will be capable of carrying 67% of ultimate flight or landing loads. It shall also be required that normal engine operation will continue after the failure of any such element of the engine mount support structure including pylon bulkheads. Further, it shall be required that engine whirl will not occur due to these failures in either the normal operating mode or windmilling mode. In addition, single failure of elements, such as structural attachments, latches, hinges, frames, etc., shall not result in loss of nacelle components throughout the flight envelope.

3. AIRCRAFT OPERATING CONDITIONS

All performance data are for NASA Standard Atmosphere.

The package shall function satisfactorily under the following flight conditions:

- Level position (horizontal) and 15 degrees angle of attack with the airplane yawed 15 degrees to either side of the flight path without time limit; and 25 degrees yaw momentarily.
- High-low angle of attack (airplane stall/emergency descent) with the airplane pitched $\pm$ 30 degrees for 15 seconds and $\pm$ 25 degrees without time limit.
- Flight operation under zero "g" flight conditions for 15 seconds.
- Flight operation under negative 1 "g" flight conditions for 10 seconds.

a. Flight Envelope

The engine operating envelope must exceed the expected aircraft envelope by at least 5000 feet in altitude and minus a minimum of 75 knots on the low speed side and plus 50 knots on the high speed side.

b. Ambient Temperature Envelope - (Figure 2)

Takeoff, Landing and Ground Operations, after temperatures soak at extreme conditions.

Minimum Temp ^{o}C	Maximum Temp ^{o}C	Pressure Altitude ^{o}C
-54	50	-2000
-54	50	2500
-54	25	15000

With linear interpolation between tabulated points.

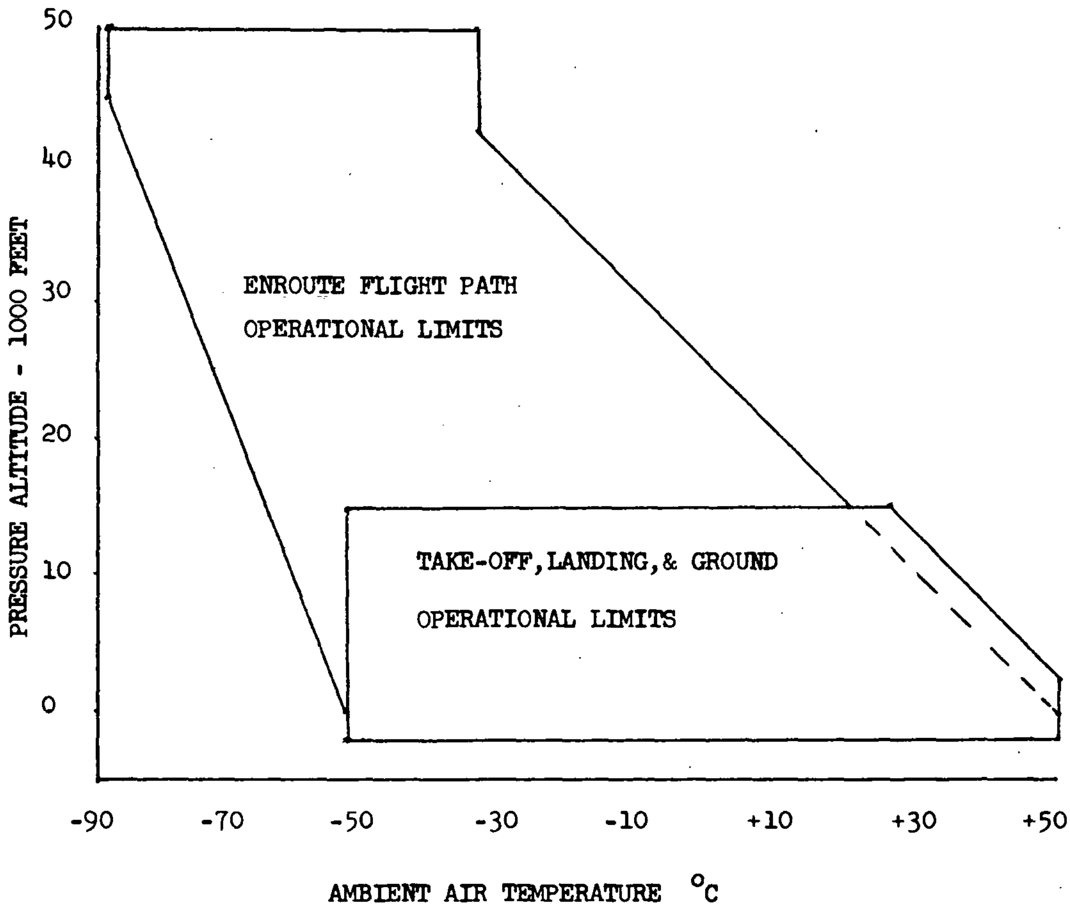
Enroute

Minimum Temp ^{o}C	Maximum Temp ^{o}C	Pressure Altitude ^{o}C
-54	50	-2000
-54	50	S.L.
	-34.5	42450
-88.9	-34.5	45000

With linear interpolation between tabulated points.

FIGURE 2

AMBIENT TEMPERATURE LIMITS



4. INSTALLED PERFORMANCE

The subcontractor shall specify and guarantee the thrust and specific fuel consumption of the installed engines, including pylon effects, under static operating conditions. These guarantees shall include all installation effects such as air bleed, power extraction, inlet loss, nozzle performance, drag, etc. As a minimum five conditions from ground idle to takeoff shall be supplied.

In addition, the subcontractor shall specify and guarantee the inflight thrust and specific fuel consumption of the installed engine at a minimum of 10 flight conditions. The guaranteed performance shall be achievable after 4000 hours of operation without significant engine repair or replacement of parts.

The subcontractor shall establish, and substantiate with the aircraft contractor, procedures for the determination of in-flight net thrust at any engine operating condition. This procedure may be based on the nozzle thrust coefficient method or equivalent of gross thrust determination and will be suitable for the determination of installed engine performance under both steady state and transient operating conditions (both airplane and engine). This mutually established procedure will be the basis for evaluating the installed engine performance in flight and, if necessary, would establish the need for further investigation and correction of any engine deficiency.

The subcontractor's plan for substantiation of installation losses should also be specified.

The thrust and specific fuel consumption of the bare engine, equipped with reference inlet and exhaust hardware, will suffer degradation from a variety of effects, including the following:

(a) All Engine Positions.

   (1) Acoustic treatment

   (2) Bleed air requirements for airframe systems and engine and cowl ice protection.

   (3) Basic inlet duct losses relative to reference hardware.

   (4) Fan discharge losses relative to reference hardware, taking into account maximum tolerances on fan discharge area.

   (5) Nacelle and pylon drag, taking account of cowling discontinuities, deviation from lofted surfaces and air leakage.

   (6) Drag due to leakage through the fan reverser (when stowed in normal flight) into the external air flow over the fan cowling.

   (7) Shaft power extraction for accessory drives.

(b) Additional Losses Associated with a Fuselage Engine Installation

   (1) All losses associated with the inlet boundary layer control system.

   (2) Inlet losses associated with pressure and velocity distribution as well as average levels at the engine inlet face.

5. PRIMARY FUEL

The system shall function satisfactorily throughout its complete operating range for any steady-state and transient operation condition when using primary fuels conforming to and having any of the variations in characteristics permitted in jet kerosene fuel per D1655-65T (ASTM) dated June 1965.

(a) Alternate Fuel - Operation of the system shall also be required using any alternate fuel conforming to the requirements of MIL-T-5624. The operating limits, thrust outputs, and thrust transients specified in the specifications shall not be adversely affected. The effect on performance, when using the specified alternate fuel, shall be specified in the specifications. The use of external adjustments in order to meet this requirement are not allowed.

(b) Fuel Contamination - The engine shall function satisfactorily when using fuel contaminated to the extent specified in Table I.

TABLE I - FUEL CONTAMINANT

CONTAMINANT	PARTICLE SIZE	QUANTITY
Iron oxide Iron oxide	0 - 5 microns 5 - 10 microns	1.0 gm/1,000 gal. 1.0 gm/1,000 gal.
Prepared dirt conforming to A. C. Spark Plug Co. Part No. 1543094, not less than 68 percent SiO_2	Mixture as follows: 0 - 5 microns (39 percent) 5 - 10 microns (18 percent) 10 - 20 microns (16 percent) 20 - 40 microns (18 percent) 40 - 500 microns (9 percent)	6 gm/1,000 gal.
U.S. Standard Staple No. 7 prime cotton linters	As ground in a No. 4 Wiley mill and screened through a 4 mm screene.	0.1 gm/1,000 gal.
Crude naphthenic acid		.03 percent by vol.
Salt water in accordance with salt spray solution per MIL-E-5272		.01 percent by volume entrained

NOTE: The engine and the fuel system shall be designed to operate continuously with fuel contaminated by the iron oxide levels specified above.

1. The number of hours and deterioration of the fuel system running with iron oxide levels up to 14.25 grams per 1,000 gallons 0 - 5 microns and .75 grams per 1,000 gallons 5 - 10 microns shall be demonstrated by test.

2. The fuel system shall be demonstrated to be unaffected by city water contaminated with entrained surfactants in a quantity of .02 percent by volume entrained in the fuel.

6. STARTING AND OPERATION

The complete propulsion system shall perform satisfactorily using the oil(s) specified in the specification under the following conditions:

(a) Start and operate satisfactorily on the ground after a soaking period of 10 hours at a nacelle ambient temperature of 160°F (71.1°C) when supplied with fuel at 135°F (57.2°C) and inlet air at 125°F (51.7°C). Restart and operate satisfactorily on the ground after a soaking period of 15 minutes at a nacelle ambient temperature of 275°F (135°C).

(b) Start and operate satisfactorily on the ground and in flight after a soaking period of 10 hours at an ambient temperature of -65°F. If a MIL-J-5624 fuel other than grade JP-4 is specified, the engine shall also start and operate on the ground and in flight after a soaking period of 10 hours when supplied with air and the specified fuel, all at a temperature corresponding to a fuel viscosity of not less than 12 centistokes.

(c) Start and operate satisfactorily throughout the ambient air temperature ranges shown on Figure 3 throughout the airspeed and altitude operating limits specified when supplied with D1655-64T (ASTM) fuel at (1) that temperature corresponding to a fuel viscosity of 12 centistokes and (2) a maximum fuel inlet temperature not less than 135°F. Fuel temperature above that specified for maximum continuous operation shall be specified for limited durations.

7. STOPPING

Normal stopping of the engine shall be accomplished by provisions which shall permit the use of a single, rapid, pilot-controlled actuation and it shall be possible to stop the engine by this means from any operating condition. If the provisions for normal stopping of the engine include any components other than mechanical, an additional completely redundant emergency system for shutting off all fuel flow shall be provided. No damage to the engine or engine fuel system shall result when shutting off the fuel supply by the foregoing means or by shutting off the fuel supply to the engine inlet from any engine operating conditions, and the limiting component or zone temperatures after shutdown shall not be exceeded.

8. GROUND & FLIGHT IDLE

With the power lever in the ground idle position, the thrust shall not exceed 5 percent of the takeoff (T.O.) thrust available at ISA + 15°C day conditions. The flight idle thrust between Sea Level and the highest operating altitude shall not exceed 10% of T.O. thrust available at Sea Level ISA + 15°C day conditions and shall be shown in the specification performance curves.

9. STABILITY

Under nominally steady-state operation conditions, within the operating limits of the aircraft, thrust fluctuation between ground idle and maximum continuous thrust conditions shall not exceed $\pm$ 1.0 percent of maximum continuous thrust or $\pm$ 5.0 percent of the thrust available at the power lever position and flight condition, whichever is less. During operation above maximum continuous thrust, fluctuations shall not exceed $\pm$ 1.0 percent of the thrust available at that condition.

10. THRUST TRANSIENTS

During the selection of power lever positions in any sequence and at any rate, there shall be no overspeed, over-temperature, combustion instability, or fan/compressor instability. Power lever movements shall be 0.5 seconds or less, and the time required to accomplish 95 percent of the thrust change shall not exceed the values specified below for standard day conditions. Corresponding acceleration times for nonstandard day conditions, changes in altitude and effect of increased air bleed shall be specified in the engine specification. The total time required to accomplish each specified transient and reach stable operation shall not exceed the time specified for 95% of the change in thrust plus 10 seconds. The times specified below shall be achieved while withdrawing bleed air and horsepower load from the accessory gear box specified for normal aircraft operations at 90°F ambient temperature conditions unless otherwise specified.

(a) From flight idle to takeoff thrust available, 5 seconds up to 150 knots indicated airspeed (IAS) at Sea Level.

(b) At 10,000 feet and at or above 125 KIAS, from flight idle to takeoff thrust eight seconds with maximum airbleed combined with maximum HP accessory load.

(c) From flight idle to maximum reverse thrust available, 5 seconds.

(d) From 30 percent takeoff to takeoff thrust available, 3 seconds up to 150 knots IAS, at Sea Level.

(e) From takeoff thrust to maximum reverse thrust available, 6 seconds under all thrust reverser operating conditions at Sea Level.

(f) From maximum reverse thrust to ground idle thrust available, 5 seconds under all thrust reverser operating conditions.

(g) From 35% takeoff thrust to flight idle thrust available, 2 seconds from Sea Level to 10,000 feet at a minimum of 100 knots IAS.

(h) From flight idle to ground idle or ground idle to flight idle, 2 seconds at Sea Level.

11. ENGINE WINDMILLING CAPABILITY

The propulsion system shall be capable of extended windmilling operation, without damage, without excessive loss of lubricating oil, and without affecting capability of air restart and operation, throughout its entire operating envelope. The engine and aircraft accessories shall not be damaged by reverse windmill on the ground. The following information shall be specified in the specification:

(a) The limits of windmilling operation.

(b) The limits of windmilling operation without lubrication.

(c) The oil consumption during windmilling.

12. INLET AIR PRESSURE VARIATION

Engine stall under any condition of operation within the operating envelope shall be considered a flight safety item and shall not be tolerated. The estimated maximum radial and circumferential total pressure distortion limits which can be safely tolerated by the propulsion system shall be specified. The estimated effect on system performance of these distortions shall be specified. The estimated maximum radial and circumferential total pressure distortion limits which can be tolerated without adversely affecting rated system performance shall be specified. These limits shall not include an area bounded by the duct walls and a line spaced therefrom by 1.5 percent of the fan tip diameter. Back pressure effects on the fan shall be included in the process of establishing inlet air pressure distortion limits. The instrument location shall be specified for inlet air pressure distortion determination. Using representative values obtainable from this instrumentation, the method and sample calculations for determination of inlet air pressure distortion shall be specified.

In addition to the requirements stated above, the propulsion system shall be free of stall during transient and steady state operation under static conditions with the inlet distortion produced by a 50 knot crosswind coming from any direction in either steady or gusting conditions.

13. NOISE

The following is the expected guarantee noise level requirement related to Appendix C of FAR 36 and the introductory year of aircraft operation.

Year	Level
1975 to 1978	FAR 36 minus 5 EPNdB
1978 to 1981	FAR 36 minus 8 EPNdB
1981 to 1984	FAR 36 minus 11 EPNdB

The achievement of these levels will require the use of operating procedures to minimize noise. Consideration must be given to the noise level produced by reverse thrust operation on the ground which must not exceed the sideline levels covered by the requirements stated above.

14. POLLUTION CONTROL

While no Federal regulations exist at present, guidelines will undoubtedly come into existence during the projected time period. The objectives planned by the airlines will be to require that all engines developed after 1975 control the emission of oxides of nitrogen* to no more than 25 pounds/1000 pounds of fuel for engines over 20:1 in pressure ratio and 15 pounds/1000 pounds for engines less than 20:1 in pressure ratio. The weight of hydro-carbon plus carbon monoxide (HC + CO) emitted at idle should not exceed 60 pounds/1000 pounds of fuel and a design goal of 40 pounds/1000 pounds of fuel is expected to be achievable. (The emission values specified shall be measured in accordance with SAE ARP 1256.) The emission of smoke shall not be visible at any operating condition.

Provisions for collection and retention of material released from various seal drains will be required.

15. GROWTH

The engine shall have as a minimum, capabilities for the following growth:

Years after initial service	3	6
Takeoff, Climb & Cruise Thrust (% increase)	5	10
Cruise Specific Fuel Consumption (% increase)	0	0
Takeoff Thrust/Engine Weight (% increase)	0	0

The method of achieving the proposed engine growth shall be consistent with the minimum change to the propulsion system possible.

16. SYSTEM OPERATION

Only one instrument or one engine variable shall be used as the primary power setting device throughout the takeoff, climb and landing portion of flight. Fan speed with core speed as alternate are preferable modes. All limitations on EGT shall be specified to the nearest $5^{\circ}C$ or EPR values to the nearest .05 and rpm to the nearest .1%. All oil, hydraulic and fuel pressure limitations shall be established at no less than the closest 5 psig interval, 30 to 35 not 29 to 36. All temperature limitations such as oil, fuel, etc. shall be specified to the nearest $5^{\circ}C$.

*($NO + NO_2$)

SECTION III

DESIGN CRITERIA FOR FUTURE TRANSPORT ENGINES

1. GENERAL

The following material presents design requirements for commercial powerplants. This section is divided by normal engine components from front to rear (fan inlet case to final turbine case). The intent of this material is to provide design guidance as to those features which assist the airlines in long term maintenance and operation of commercial engines. These requirements should not be considered as rigid. Specific situations may dictate a departure from the principles set forth, however, the necessity for such a departure should be well supported.

2. ENGINE COMPONENT DESIGN LIFE

The components of the engine shall have, as a minimum with normal maintenance and repair, the design life capabilities as listed below:

	*SLPI		**TSL	
	Hours	Landings	Hours	Landings
Stationary components Casings, frames, compressor section guide vanes, accessory drive casings, inlet adapters and associated components	10,000	10,000	35,000	35,000
Stationary Components Combustion chamber, turbine nozzle guide vanes, exhaust nozzles and associated components	6,000	6,000	25,000	25,000
Rotating members Fan blades & compressor blades	10,000	10,000	25,000	25,000
Rotating members Turbine blades	6,000	6,000	20,000	20,000
Rotating members Fan discs, compressor discs, spacers, hubs, shafts and associated components	15,000	15,000	30,000	30,000
Rotating members Turbine wheels, spacers, shafts and associated components	15,000	15,000	25,000	25,000

* SLPI - Service Life Per Installation

** TSL - Total Service Life (with inspection/repair)

3. GENERAL DESIGN

The engine as installed shall be designed for modular maintenance.

a. Reference Surfaces

The engine shall have permanent reference points to be used for the purpose of alignment and reference in plating, machining, balancing and engine build up. The reference points serving this function shall not be subject to wear or distortion. The use of close tolerance bolts and bolt holes for maintaining concentricity and alignment is unacceptable.

b. Fretting/Galling Protection.

All bolted disc/disc, disc/shaft, or shaft/shaft attachments must be designed or otherwise protected from fretting and galling. Additionally, all air tubes, clamping devices or other components in contact with compressor discs must have anti-fret protection on both the component and bores.

c. Coatings/Wear Surfaces

Avoid coatings and processes that cannot be applied at overhaul shops. Wear surfaces should be designed to be repairable or replaceable (throw away) parts. Compressor vane platform ledges should be protected with silver, moly spray, and tungsten carbide or equivalent in the proper stages in the progression from forward to rear. Provisions to apply peripheral loading on the vane assemblies in the casings shall be provided to eliminate relative motion.

d. Bolted Assemblies

Bolt holes shall be capable of repair by bushing and sufficient material shall be provided for refurbishing such holes. Dowel bolts shall not be used in rotating assemblies as radial alignment and radial load carrying members - rabbeted joints or snap diameter provisions are required. Avoid use of two-thread series such as 1/4-20 and 1/4-28 on the same part or in the same area. When different threads must be used, use different diameters. Bolt threads should not be exposed to hot air streams.

e. Alignment of Assemblies

Provisions shall be incorporated to facilitate checking the alignment of shaft to shaft connections, squareness of components to their respective shaft. For shaft to shaft connections helical splines are preferred.

f. Labyrinth Seals

Knife-edges of labyrinth seals must run against a soft abradable material to maximize knife-edge life. Stationary seal linings should be easily replaceable, preferably bolted. Backing plates should be designed such that unlimited replacement of abradable material is possible. Nibrazing or EB weld repair of knife-edge seals must be developed. Long lead-ins should be provided on engine parts to prevent damage to knife-edge seals, bearings, etc. during assembly. Reliance on the use of special guide tools by maintenance personnel should be avoided.

g. Support/Handling Points

Ground handling points shall be provided on engine casesto facilitate engine buildup and teardown and on all components and assemblies that exceed 44 pounds.

h. Bolt/Fastener Considerations

In designing and selecting fasteners it is desirable to use quick opening fasteners wherever feasible and to provide ample clearance to permit the use of power tools. The use of integral threads on expensive parts should be avoided. Plugs and fittingswhich require frequent removal should have rugged threads to avoid stripping. The design should insure that washers, gaskets, bolts, etc. do not fall out of position during blindassembly and captive fasteners should be used where access is difficult and dropped fasteners difficult to recover.

i. Maintenance Tools and Operation Considerations

The total engine design should be such that all maintenance actions can be performed in accordance with human engineering standards (Ref. MIL STD 803A). Provide means to manually rotate engine rotors for inspection by borescope or other visual means. Design to prevent personnel injury and damage to engine parts when performing preventive and corrective maintenance. Wherever possible existing tooling and wrenches should be considered. Provide guides to prevent tool disengagement when tool access must be blind. Avoid the use of torque values which exceed those attainable with hand operated torque wrenches with the obvious exceptions of spanner nuts and bearing retainer nuts. Provide clearance for drive sockets and at least 90 degrees movement of wrench handles.

j. O-Ring Installations

Blind o-ring installations must not be "blind," i.e. it must be possible to insure that the o-rings are not cut or gouged during installation. O-ring seals must not be used on internal oil lines or in the combustion section. A redundant o-ring seal installation should be considered in critical areas.

4. ENGINE ROTATING AND STATIONARY PARTS

a. Each major rotating unit such as the fan, compressor and turbine shall be capable of being individually balanced prior to final engine assembly. The requirement to trim balance after assembly is to be minimized.

b. The design of the fan, compressor and turbine cases shall provide containment of damage from rotor blade failures. All possible failure modes of all high rotational speed portions of the engine shall be studied with the objective of eliminating the possibility of catastrophic failure where failed parts penetrate the engine cases. Fail-safe designs shall be incorporated with the objective of eliminating the possibility of catastrophic failure. Particular attention shall be given to the following.

(1) The integrity of turbine, fan, and compressor discs with the objective of having blades fail first under overspeed or overtemperature malfunctions.

(2) The integrity of shafts connecting fan and compressors to turbines such that bearing or lubrication failure shall not cause parting or decoupling of the shaft.

c. Design stator vanes to be individually replaceable insuring that reverse installation or installation in the wrong stage is precluded.

d. Design compressor blades such that installation in the wrong stage or in reverse position is precluded. Moment weighted blades should be used. If shear wire is used for blade locks, use minimum diameter consistent with loading and make wire holes in blades readily accessible.

e. Knife edge seals and seal lands should be inexpensive replaceable parts. Replacement seal lands should have additional material to allow continued use of worn knife edge seals.

f. The design must permit and provide for borescope inspection to the maximum extent possible. Borescope provisions for rotating components should all be located on the same side of the engine below the horizontal centerline and must be free of obstruction for rapid access as installed.

g. Provide centerpunch on turbine blade tip and vane roots at stacking points. This point serves as a reference for dimensioning to facilitate repair.

h. Provide means of attaching fixtures for radial and axial restraint between static and rotating parts for use in assembly and disassembly. Provide generous snap engagement on hubs, spacers and discs.

i. Rotating assemblies should be removable without loading the bearings.

5. <u>FAN</u>

a. Design the nose cone (spinner) and cover to be individually replaced with quick release fasteners.

b. Insure that the nose cone is independent and not a part of fan blade retention.

c. Access to low rotor trim balance weights through the nose cone cover is required.

d. The fan blades should be individually replaceable as installed.

e. Blade retention should be accessible from the forward side.

f. The design should avoid the requirement to remove the entire rotor assembly for blade replacement.

g. All fan maintenance action required including fixturing for axial anti-torque, and radial restraint for removal and replacement of fan hub or entire rotor assembly should be possible from the front of the engine without loading the bearing or removing the turbine.

6. <u>LOW COMPRESSOR</u>

. The design should provide for the removal and replacement of the low compressor assembly without removal of the low turbine or loading the bearings.

7. <u>HIGH COMPRESSOR</u>

a. Variable stator vane system design should insure foolproof attachment of variable stator actuating levels to preclude improper installation of stator vanes.

b. Rod end bushings and seal must be externally replaceable and provisions for larger bushings to account for rod end wear shall be provided.

c. The actuating system elements must be easily replaced, adjusted or repaired with the engine installed.

d. Experience dictates the last stages of the compressor should be designed to permit removal of material from the leading edges of blades and vanes without significantly effecting performance or surge/stall characteristics.

8. TURBINES

a. Nozzle guide vanes should be weld repairable without a requirement to strip coating, if used. Additionally, coating should be such that localized applications can be made for patch repairs. Nozzle guide vane leading and trailing edges should be repairable by installing a new segment employing nibraze or an equivalent process.

b. Turbine cases and components must be designed to be satisfactory with regard to distortion rail wear, repair welding and machining, maintenance of distortion free turbine tip shroud assemblies, and matching of used case halves with new halves in lieu of scrapping entire assemblies.

c. High turbine inlet temperatures require that all components forming the cooling air passage be designed with an absolute minimum of exposure to leaking, clogging, etc. In addition, anticipating that inspection limits on these components will be extremely critical, ease of repair and restoration is mandatory.

d. Replacement and repair of turbine blades are one of the most expensive elements of engine maintenance costs and blade cracking a large source for premature removals. Consideration of blade replacement and repairability are essential during the initial phases of design. It is desirable to design the turbine such that the replacement of first stage turbine blades as well as first stage nozzle vanes can be accomplished with the engine installed.

e. The means to check first turbine blade stretch at hot section inspection should be provided.

9. COMBUSTOR/FUEL NOZZLES

a. Fuel nozzle ferrules must be durable and should be easily replaceable without the need for spot welding. In addition, increased durability of fuel nozzle shrouds is required. Fuel nozzles should be self-cleaning to eliminate carbon buildup and resultant clogging or hot streaks in combustors.

b. Fuel manifold should be external to the case and both manifold and fuel nozzles individually replaceable. Removal and installation of spark ignitors shall require a minimum of time.

c. Historically, myriads of small cooling holes and slots in combustor assemblies will be extremely critical regarding distortion, closure, etc., and such distortion will occur frequently in service. Every effort should be made to produce a configuration not critical in this respect.

d. Combustion section support/sliding areas should be highly wear resistant. Design for repair of wear surfaces by replating or easily replaceable parts. Special attention should be given to swirler cups, combustion liner seals, liner retaining pin bosses and 1st N.G.V. attachment points.

e. Provide for long lead-in on dowels, etc. in vane retaining rings to facilitate reassembly after vane replacement

f. Consider use of trapped nuts, tapped threads, studs, etc. at fuel nozzle attachment pads.

g. Provide for borescope inspection of combustion section. Locate a sufficient number of borescope ports to facilitate inspection of fuel nozzles, combustion liners, and first stage turbine vanes and blades.

10. STRUCTURAL CASES

a. Use weldable materials for static structures and, where possible, avoid materials requiring extensive heat treatment after welding.

b. Design case structures to be weld repairable on "the wing" where possible.

c. Minimize the number of flange bolts where possible to facilitate installation and removal.

d. Provide extra material (.020 to .030) on flanges to facilitate repair.

e. Eliminate areas which will trap metal particles. They should discharge through the scavenge system where they can be collected and monitored.

f. Provide sufficient piloting of plumbing to facilitate blind assembly.

g. Provide additional mounting locations for use when engine must be disassembled for shipment.

h. Minimize size of case weldments to simplify repairability and reduce spare parts requirements.

i. Bypass ducting shall not be part of the engine but rather part of the installation for both non-mixed flow and mixed flow engines.

11. BEARINGS

a. All bearings should have anti-rotation devices to prevent spinning, wear and metal debris development. If bolted, attachment/alignment surfaces must have anti-fret treatment.

b. Bearing balls, rollers, races, and cages should be considered interchangeable where possible.

c. Sumps must be easily replaceable.

d. Provide non-integral bearing and seal supports where feasible. Where integral seal supports are used, design to permit replacement of seal assembly independent of the support structure.

e. Puller grooves should be provided as necessary to permit removal of bearing without loading the bearing. This applies to inner and outer races when other means of removal is not possible. Special attention should be given to split inner races.

f. Avoid use of gear-driven scavenge pumps and "last chance" oil filter screens in the bearing compartments.

12. GEARBOX/GEARBOX DRIVE

a. Gearbox drive shaft gear should have positive retention with anti-fret and gall treatment on both the nut and mating surfaces. Silver is not acceptable.

b. Gearbox drive shaft and gear must be removable as a unit and gear matching should be a simple procedure with no blueing required.

c. Weak link in engine to gearbox drive assembly should be splined center shaft.

d. Spline repair procedure shall be developed.

13. ACCESSORIES, PLUMBING AND WIRING

a. Consider location of plumbing and accessories to provide for ready removal of gearbox.

b. Route external plumbing and wiring to minimize disassembly required for replacement of external components.

c. Locate joints in plumbing and wiring systems near separation planes of basic engine units.

d. Consider ease of replaceability of EGT thermocouples when selecting mounting design and type and location of wiring junctions.

e. Design to permit calibration of exhaust probes without running the engine.

f. Consider combining external components wherever reliability and maintenance cost suggest payback (piggy-back fuel pump-fuel control, integral fuel filter-fuel pump, combined variable stator and main engine controls, etc.)

g. Locate individual components and accessories to permit replacement without prior removal of other units.

h. Quick-disconnect mounting features for all components and accessories shall be used.

i. Utilize trapped nuts or bolts where necessary to facilitiate removal of external units.

j. Consider accessibility when selecting locking devices for nuts and bolts. (Lock-wire requires more accessibility than tablocks.)

k. Provide ready access to borescope locations to provide for use of borescope equipment.

l. Provide ready access to chip collectors, scavenge screens, vibration pick-ups and other engine monitoring systems.

m. Provide access to oil and fuel filters, spark igniters, oil filling provisions, oil level indicating devices, etc.

n. Establish envelopes for removal and/or inspection of oil and fuel filters, spark igniters, chip detectors, scavenge screens, gearbox oil pumps, and critical accessories.

o. Design to permit a check on ignition system continuity without removal of spark igniters.

p. Fuel control wear points should be determined well in advance so field check out and repair procedures can be simplified.

q. Pressure port provisions should be considered in-between controls to determine condition of control without removal.

r. Cockpit engine trim capability shall be provided for use after changing control.

s. Provide wrench flats as necessary to facilitiate tightening and loosening of gland nuts.

t. Slip joints and more wear resistant materials should be used in clamping areas. Replaceable wear strips are preferred.

u. Oil cooler should be designed to facilitate cleaning,inspection and repair.

v. Provide control adjustment features which preclude movement caused by vibration, etc.

w. Provide an external speed trim adjustment on main fuel control.

x. Variable stator bellcrank bearings (if used) must have satisfactory wear characteristics such that wear will not cause calibration drift which could induce stall.

y. Let design be guided by the requirement for minimum time, minimum complexity, and minimum cost.

14. ENGINE VIBRATION

The normal and maximum permissible engine vibration envelope in terms of acceleration (G's) or displacement (mil's) and frequency or frequency ratio from rotor speeds, as applicable to production engines shall be specified. This vibration envelope, shall be provided for idle, cruise, maximum continuous, climb and takeoff power settings and other power settings if vibration peaks occur which exceed those at the basic five settings listed above.

The point(s) of attachment for the accelerometers used to establish the vibration envelopes shall be shown on the engine installation drawing together with detector operational temperature requirements under all conditions of engine operation including thrust reversal, shutdown and soak-back. It shall be demonstrated that the locations chosen for the vibration detectors are suitable for detection of vibrations generated by the failure of any rotor bearing, accessory gear train component(s) or damage beyond operational limits of compressor or turbine rotating or stationary components. The manufacturer shall specify all fundamental frequencies-tip passing, ball passing, etc. -- which are characteristic of a normal engine.

15. CONNECTION IDENTIFICATION

The engine and accessories shall be permanently marked to indicate all connections shown on the installation drawing for instrumentation, and fuel and oil connections. Similar fluid connections located in close proximity to each other shall be made physically non-interchangeable.

16. COVER PLATES

Cover plates for covering all accessory drive openings where the accessory is not mounted for engine shipment shall be supplied with each engine. Suitable provisions for covering or plugging all other connection openings shall be made. Cover plates suitable for flight operation shall be provided on drive pads and connecting points which may not be used.

17. ENGINE ACCESSORY DRIVE

Drives for mounting and driving aircraft accessories shall be specified. The drive splines shall use couplings or muffs and shall be lubricated by engine oil. The engine and drives shall be suitable for simultaneous operation of all the drives when each drive is subjected to the maximum permissible continuous torque rating specified for the individual drive. Drives used for starting shall be capable of withstanding a maximum torque equal to twice the constant torque required for a 30 second starting period beginning at rest and ending at starter cutout speed. Each drive pad shall have QAD mounting of the type appropriate for the accessory to be mounted.

18. ENGINE CONTROL SYSTEM

The engine control system shall include all control units such as fuel control, variable area jet nozzle control, compressor bleed or geometry control, temperature, inlet guide vane control, and any other control units required for proper control of the engine. Provision shall be made in the design of the control to allow ready attachment of remotely actuated devices for all adjustments which may be required in service. The fuel control mounting pad and drive shall conform to commercial design standard; and the drive splines shall be positively lubricated with engine lubricating oil.

a. <u>Objectives for Engine Controls Systems</u>

It should be possible for the pilot to establish a given power setting and have the engine control system maintain that setting regardless of aircraft speed, altitude, or attitude. In addition, the engine control system should be capable of providing sufficient engine fuel to meet all engine design and operation criteria, i.e., start, accelerate, decelerate, and shut down, without incurring unnecessary engine hardware distress or operating malfunction.

To achieve this control, the fuel control system needs several of the following signal inputs:

(1) All Engine Rotor Speeds
(2) Ambient Air Pressure and Temperature
(3) Core Engine Compressor Discharge Pressures
(4) Engine Pressure Ratio
(5) Core Engine Discharge Pressure (Pb)
(6) Core Engine Turbine Inlet or Exhaust Gas Temperature
(7) Power Lever Position Input

The preferred basic signal reference for the control system would be core engine speed modulated by the other parameters to achieve the constant speed requirements at each preselected power lever position.

To achieve the desired accuracy of speed control necessary to permit uniform and symmetrical thrust, maximum fuel economy and maximum engine parts utilization, it is essential engine speeds be controlled accurately and synchronized to within $\pm$ 0.2% between engines and to within $\pm$ 0.2% of the set parameter.

b. <u>Design Requirement</u>

The ideal engine control system should contain the following features:

(1) <u>Central Computer</u>

(a) An automatic thrust rating computer system incorporating the ability to preset, select and maintain a selected number of power control modes (takeoff, maximum climb, maximum cruise as a minimum).

(b) The ability to select, synchronize and maintain all engines to within $\pm$ 0.2% of the selected thrust setting parameter (N1 for large bypass fan engine; EPR or equivalent for pure jet engines) regardless of aircraft speed, altitude or attitude.

(c) The provision/capability to maintain constant aircraft speed as the prime parameter.

(2) <u>Engine Control</u>

In addition to the normal control functions the following should be provided.

(a) The engine control system should have the ability to automatically trim individual engines $\pm$ 5% to achieve the desired power setting. Outside of this range, the system should incorporate a failure warning device to indicate engine control system malfunction.

(b) The engine control system should be designed such that air is easily purged from the system without the use of additional systems or components. The introduction of air into the system should be precluded except as a result of fuel tanks either becoming depleted of fuel or the opening of a fuel supply line.

(c) The engine control system should be packaged as a modular assembly permitting either the changing and checkout of the total system or any specific major module, i.e., pump, fuel control, electronic control package, etc. In addition, any portion of the engine control system shall be readily accessible with the engine cowls open and component or system change times of not more than 1 hour duration shall be easily accomplished.

(d) The engine control system should incorporate a separately manually operated fuel cut-off device or system between the control function and the fuel distribution manifold.

(3) Reliability

Reliability goals for the control system should not be less than 30,000 hours MTBF and 25,000 hours MTBUR. In addition, the reliability of the system should not rely on such items as critical torque settings for electrical connectors, etc.

(4) Self Test

The correct functioning of any portion of the electronic system shall be capable of either being checked out using built-in test equipment or preprogrammed ground support test equipment.

19. ENGINE FUEL SYSTEM

Performance With Assistance from Airplane Boost Pump. The engine fuel system shall supply the required amount of fuel at the required pressures for operation of the engine throughout its complete operating range, including starting with the following conditions at the fuel inlet connection on the engine:

- Fuel Temperature. From a minimum of -65°F (-53.9°C) (when using MIL-T-5624, grade JP-4 fuel) or that temperature corresponding to a fuel viscosity of 12 centistokes (when using other grades of MIL-T-5624 fuel) to a maximum as specified in 3.2.

- Fuel Pressure. From true vapor pressure of the fuel plus 5 psig to 50 psig (relative to the atomosphere), with a vapor/liquid ratio of zero.

Performance With No Assistance from Airplane Boost Pump. The engine fuel system shall supply the required amount of fuel at the required pressures for engine operation from Sea Level up to 30,000 feet altitude, including ground and air starting, under the following conditions:

- Compressor inlet ram pressure ratio varying linearly from 1.15 at Sea Level to 1.70 at 30,000 feet.

- Ambient air temperature.

- Fuel temperature at the fuel inlet connection at a minimum of 40°C.

- Vapor/liquid ratio of fuel at the inlet connection from zero to 0.45.

The pump shall be capable of priming itself when subjected to a dry lift of 1 foot at an inlet pressure of 9 inches of mercury absolute.

Performance Under Conditions of Excessive Fuel Vapor. The engine fuel control system shall have provision for relieving the vapor or air when operating under excessive vapor/liquid ratios.

- Fuel Resistance. The materials and designs used in engine and components shall be satisfactory when tested with TT-S-735, types I and III test fluids when used in any sequence.

- Salt Water Resistance. The functioning of the engine fuel system shall not be adversely affected by the presence of salt water in the fuel to the extent specified.

- Fluid Leakage. There shall be no leakage from any part of the engine except at the drains provided for this purpose. The quantity of leakage from all drains provided shall not exceed 5 cc. per minute.

- Fuel Filters. The filter shall be a part of the engine, and shall be of sufficient capacity to permit a cumulative fuel flow equivalent to a minimum of 10 hours of continuous engine operation at maximum conditions rated sea level thrust with fuel contamination as specified herein without being cleaned and shall be protected against internal icing by means integral with the engine. Main flow filter shall be provided with an integral bypass and provisions for attaching instrumentation to determine when the filter is clogged or is bypassed and an accessible visual impending bypass indication. The filter system shall be described.

- Fuel Flowmeters. The engine shall be equipped with a self-bleeding rate type gravimetric fuel flowmeter calibrated in pounds of fuel per hour and total fuel consumed in pounds suitable for pointer and digital rate flowmeter indicators. Fuel flowmeter installation shall not be affected by icing during normal operation and its end fittings shall be tolerant of misalignment.

- Combustible Fluid Drains. Provisions shall be made if required for automatically clearing the combustion areas of combustible fluids after each false start and for preventing excess combustible fluids from entering the combustion areas after shutdown with the engine in a level position, 15 degrees nose up, and 20 degrees nose down. Provisions shall also be made for clearing all vent areas and other pockets or compartments where combustible fluids may collect during or subsequent to operation of the engine. Any check valves in the system shall be qualified with the engine.

- Fuel Anti-Icing System. A fuel anti-icing system if required shall be incorporated in the fuel system and the limits of operation, such as fuel temperature limit maintained, maximum temperature of fuel, maximum fuel pressure drop across the fuel heater, and temperature and flow rate of the heating medium shall be included in the specifications.

- Fuel Flow. The contractor shall specify maximum and minimum fuel flow at specified ratings and operating conditions.

20. COMPRESSOR AIR BLEED

The engine shall be designed and matched to provide for compressor inside diameter (ID) air extraction. The quality of bleed air specified for aircraft air conditioning and pressurization and aircraft anti-icing use shall be that quantity available over and above the bleed air needed for engine acceleration, engine anti-icing, engine fuel anti-icing and any other engine system requirement. During compressor air extraction, power lever modulation shall not be required to maintain engine stability and limits within the operating envelope of the engine. The engine specification shall specify the quantity, pressure and temperature ratios of air furnished from ground idle to maximum power at all operating altitudes, air inlet temperatures, and flight speeds. The effects upon engine performance when bleeding this air from the engine shall be shown in the specifications. The location of the bleed ports shall be shown in the installation drawing. The maximum flow capability of each bleed air port in percent of total airflow shall be specified.

21. BLEED AIR CONTAMINATION

It shall be the responsibility of the engine manufacturer that the engine generated substances contained in the aircraft air conditioning and pressurization bleed air are within the threshold limit values specified below. Where substances other than those listed below are contributed to the extracted air by engine operation, the engine manufacturer shall list these items in the engine specification with maximum threshold limits. Where any concentrations of those substances occur in combination, or where chemical substances other than those listed are contributed to the extracted air by engine operation the engine manufacturer shall report the substance(s) and the contamination in parts per million. The method of threshold limit determination and sample calculations for a mixture of two or more engine generated substances shall be specified in the model specification. The engine manufacturer shall demonstrate that the specified threshold limits for the following substances and those listed in the engine specification are not exceeded by the analyzing bleed air samples. The engine provided bleed air extraction system shall insure no upstream malfunction of the engine will cause the specified contamination limits to be exceeded.

Substance	Parts Per Million
Carbon Dioxide	5000.0
Carbon Monoxide	20.0
Ethanol	1000.0
Fluorine (as HF)	0.1
Hydrogen Peroxide	1.0

Aviation Fuels	250.0
Methyl Alcohol	200.0
Methyl Bromide	20.0
Nitrogen Oxides	5.0
Oil Breakdown Products (e.g., acrolein, aldehydes)	1.0
Ozone	0.1

The air shall contain a total of not more than 5 mg/cubic meter of submicron particles.

Acceleration Air Bleed - Where overboard ducting of acceleration bleed airflow is necessary, the airflow conditions for which provision must be made shall be specified. The ducting attachment details shall be shown on the installation drawing. Compressor air bleed required for compressor surge protection, which operates continuously during steady-state engine operation in a surge sensitive regime, shall be defined as to the operating envelope involved, and the penalty in specific fuel consumption. Acceleration air bleeds shall be manifolded in the engine and vented through one overboard vent pipe.

Air & Gas Leakage - The location, maximum amount, temperature, and pressure of engine leakage shall be specified in the installation specification. Leakage from engine case flanges or split lines shall be minimized. Such leakage as does occur shall be considered in the heat rejection of the engines and the design of the engine enviornmental cooling system.

22. IGNITION SUBSYSTEM

a. Engine Ignition System

A dual high energy ignition system, capable of continuous duty, shall be designed such that replacement of one element system can be accomplished without disturbing the other.

Either engine start ignition system shall be capable of releasing sufficient energy for all ground and air starting requirements and for inclement weather operations. The continuous ignition feature shall have the ability to reinitiate combustion after a momentary disturbance causing engine flameout without manipulation of the engine power lever, provided the cause of engine flameout has been removed.

b. Power Plant System

The electrical harness from the firewall disconnect fitting to the ignition system unit(s) shall be supplied as part of the power plant package.

The ignition control for each engine shall be integrated with starter and engine fuel shutoff controls for automatic sequencing.

An override position shall be provided to bypass starter and fuel shutoff circuitry.

Both ignition systems may be used simultaneously for starting.

23. ENGINE INDICATING SUBSYSTEM

a. Engine Instrumentation

Performance monitoring and thrust setting parameters shall be displayed separately for each engine.

The design and installation of all engine indicating transmitters and switches shall take into consideration the complete engine vibration spectrum in all modes of operation as well as temperatures to be encountered on the ground, in flight, and after engine shut-down.

Care shall be taken to prevent damage to pressure transducers due to pressure transients.

As a minimum the provisions for indication of the following for the engine shall be installed.

- In reverse indicator light
- Reverser intransit indicator light
- Pressure Ratio Indicator (Pointer and digital readout) (Settable target bug and digital readout if power set parameters)
- Exhaust Gas Temperature Indicator (Pointer and digital readout)
- N_1 Engine Tachometer (Pointer and digital readout) (Settable target bug and digital readout if power set parameters)
- N_2 Engine Tachometer (Pointer and digital readout)
- Fuel Consumption Rate Indicator (Pointer and digital readout)
- Oil quantity indicator
- Oil temperature indicator
- Oil pressure indicator
- Oil low pressure indicator light
- Oil filter bypass warning light
- Fuel filter bypass warning light
- Fuel temperature indicator
- Engine vibration indicator
- Engine breather pressure indicator
- Fuel consumed indicator (digital readout)

The engine indicating equipment to be used in the aircraft and for AIDS shall be tested during propulsion system reliability testing for a minimum of 1500 simulated flight cycles.

An engine vibration monitoring system compatible with requirements of advanced diagnostic techniques shall be installed. A single vertical scale indicator for display of all engine vibration conditions shall be installed in the flight compartment.

The output of the temperature sensing device as a function of temperature and its range of normal operating shall be specified. The accuracy of the signal in relation to the actual temperature measured, and its transient response characteristics, shall be stated. The thermocouples used shall be a multiple emersion type and the relationship between temperatures and output signal shall be in accordance with the applicable calibration of National Bureau of Standards Circular No. 561. Provisions shall be made for periodic ground checks of the functioning and calibration of the temperature sensing system while installed in the engine.

24. ENGINE LUBRICATING SUBSYSTEM

The lubricating system shall adequately lubricate the engine without change in lubricant throughout its operating range. The oil reservoir and cooler shall be furnished as component parts of the engine lubricating system, and shall automatically maintain the oil within temperature limits. However, motoring of the engine is allowed below -40°F to heat the oil prior to starting. All sections of the oil system plumbing shall be approved as fireproof as defined under FAR Part 25.

a. Oil Consumption. If the average oil consumption rate during the certification test is less than one-third of the anticipated value, the specification oil consumption rate shall be adjusted to a value no greater than three times the certification test average.

b. Oil Supply. The engine shall function satisfactorily throughout the operating range of the engine and at any of the flight conditions or attitudes specified, when the oil reservoir contains more than that quantity of oil which is defined as "unusable." The "unusable" oil is that minimum amount needed to provide oil to the engine containing no more than 10 percent, by volume, entrained air. Unless specific deviation is authorized, the "usable" oil shall be a quantity equal to 10 times the maximum hourly oil consumption. An "expansion space" equal to, or greater than, 20 percent of the capacity needed for both "usable" and "unusable" oil shall be provided. In addition, the oil reservoir shall contain remote filling and overflow provisions, and means for remote continuous indication of the "usable" oil level. These provisions shall be described, and the "usable," "unusable," and "expansion space" capacities shall be specified.

c. Internal Oil Leakage. The design of the lubricating system shall be such that oil leakage within the engine shall not cause oil discharge from the engine upon subsequent starting after shutdown, adversely affect oil supply determination, cause contamination of bleed air, or cause residual fires in the engine.

d. Oil Drain & Vents. Provision shall be made for draining the engine of oil while the engine is in a horizontal position, 10 degrees nose up, and 10 degrees nose down. Oil vent system outlets shall be designed to prevent the possibility of outlet icing or oil discharge onto the pod or aircraft. Unless the oil tank drain will drain clear of all power plant components, it shall have provisions for ready attachment of an oil drain hose. Consideration shall be given to the pollution impact both air and water of oil drainage and venting.

e. Indication

Sensors and necessary wiring for oil temperature, pressure and quantity indication system shall be provided.

The oil pressure transmitter shall be vented.

The oil temperature bulb shall be located at the engine oil inlet.

Sensors for oil low pressure warning and oil strainer clogging warning systems shall also be provided.

Magnetic chip detectors, of a design providing a warning signal output shall be installed in all oil drain ports or in locations where the warning signal will be most significant. The electrical characteristics of these chip detectors shall be described in the specifications.

f. External Oil System. The oil tank and oil cooler shall be furnished with the engine, and the following requirements shall apply.

g. Inlet Pressure. The engine lubricating system shall adequately lubricate the engine when oil containing 10 percent aeration, by volume, is supplied to the engine oil inlet at a pressure of 2 inches of mercury absolute.

h. Oil Flow Interruption. The engine shall operate continuously with no detrimental effects during and after a period of 30 seconds in which no oil is supplied to the engine oil inlet.

i. Scavenging System. The scavenging system shall adequately scavenge the engine under ground operating conditions and under all flight conditions specified. Back pressure on the scavenging system shall not exceed 40 psig.

j. Oil Pressure & Temperature. The operating oil pressure and temperature limits and maximum transient oil temperatures shall be specified. The minimum and maximum oil pressures during starting and initial operation at -65°F (-53.9°C) cold weather conditions prior to significant oil temperature increase shall be specified. Minimum and maximum oil pressures during starting and initial operation shall not persist for more than 2.5 minutes.

25. ENGINE STARTING & STARTER SUBSYSTEM

a. Engine Starting. The engine as installed shall consistently make satisfactory ground and air starts. The engine shall be certified for air starting and restarting when supplied with air at the fan inlet at a ram pressure rise consistent with V_2 + 10 knots from Sea Level up to an altitude of 30,000 feet. At fan inlet pressures below those necessary to effect wind-milling air starts, the engine shall be certified with an airborne starter provided. A satisfactory start shall be a complete start and acceleration from initiation of the starting sequence to the appropriate ground or flight idle operating conditions. The engine shall not exceed any operating limit during a satisfactory start. Satisfactory ground starts shall be obtained within 30 seconds on a sea level standard day when using the starter provided.

b. Engine Starting Procedure. The normal starting procedure shall be simple and shall not require critical timing. With the power lever in the ground idle position and after initiation of the starting sequence, the control shall provide for ground and air starting and satisfactory acceleration to stabilize ground idle operation conditions. During all starting, simultaneous operation or actuation of switches or levers or combinations thereof shall not be required. Consideration shall be given to a completely automatic engine starting system.

Ground starting shall be possible using any of the following air sources:

- APU system
- Operating engine
- Existing ground air source

c. Starter System Design. Each engine shall be equipped with a pneumatic starter system consisting of a low pressure air turbine starter, and a starter shut-off valve, piping and wiring. The valve shall be installed between the pylon and the starter.

The starter air valve shall incorporate manual override provisions operable without opening the cowl. Starters may incorporate automatic cutout switches if required. The starter drive pad spline will be oil mist lubricated. Other accessory drive pads will have pressure lubricated splines. The design of the starter shall provide containment of damage from failure due to overspeed.

Start valve position indication will be provided in the flight compartment. This may be accomplished by a pressure or mechanical sensing system. The sensing portion of the indication system shall be included as well as all necessary lines, wiring etc. required.

The starter valve shall incorporate adequate means to prevent valve malfunction due to bleed air contamination or freezing of accumulated moisture.

A starter Quick Attach-Detach (QAD) shall be provided.

The starter oil sump shall contain sufficient oil to require infrequent servicing, and shall be independent of all other oil systems in the power plant. Exhaust from the pneumatic starter shall be expelled within the cowling.

There shall be no magnesium used in the starter.

The starter design shall be an integral part of the aircraft pneumatic system and shall be designed with the objective of providing a fully satisfactory start after extended use (4000 to 5000 starts).

The engine starting system shall be designed to permit re-engagement while the engine is rotating at maximum inflight windmilling speed in the normal direction. The engagement of the starter when the engine high rotor is windmilling in the reverse direction shall be possible without damaging the engine or starter if such is found necessary.

26. ENGINE ELECTRICAL SUBSYSTEM

a. Electrical Power

In the event of loss of externally supplied electrical power to the engine, the engine shall operate safely at all engine speeds at or above ground idle and throughout the complete thrust range. Any thrust limitations caused by loss of externally supplied electrical power shall be specified.

. External Electrical Power. Where externally supplied electrical power is required, the following shall apply:

.. The electrical power requirements of the engine shall be specified in the specifications.

.. Electrical equipment shall operate with power defined in MIL-STD-704.

b. Electrical & Electronic Interference

No electrical and electronic components shall cause interference beyond limits specified in MIL-STD-826A, Method 1001. These components shall not be susceptible to interference generated by other electrical and electronic sources within the limits specified in MIL-STD-826A, Method 1001. Short duration transients and impulse interferences will not be considered as interference if their duration is less than 3 seconds and they do not occur more than twice per flight. In addition, anti-icing, fuel de-icing, and temperature sensing thermocouples systems are specifically exempted either because of the short duration of operation of their actuating mechanics or the low energy level generated. Ignition components used only during engine starting may deviate from the limits of 20 db. Also, equipment which has a maximum interference duration of 1 second and has a maximum recurrence rate of once in each 3 minutes may deviate from the limits by 20 db.

c. Explosion-Proof

All electrical components shall be explosion-proof in order not to ignite any explosive mixture surrounding the equipment.

d. Connectors & Cable

As a minimum, at a temperature of -40°F, it shall be possible to connect or disconnect electrical connectors and to flex electrical conductors, as necessary for routine maintenance, without damage to these items.

SECTION IV

DESIGN REQUIREMENTS FOR POWERPLANT PACKAGE

The aerodynamic configuration and installation interface requirements of the power plant package shall be established by coordination and mutual agreement between the propulsion system contractor and aircraft contractor. These agreements shall be documented in specification form and shall be made available to the airline(s).

1. POWER PLANT

The engine, engine mounted accessories, and nacelle structure shall be detachable as a demountable power plant unit, without impairing the adjustment of the power plant control rigging.

2. POWER PLANT ASSEMBLIES

The time for removal and replacement of any demountable power plant (QEC) shall be less than two hours.

The build-up time from a neutral power plant (QEC) configuration to that required for wing or aft positions shall be less than two hours.

The inlet duct retention system (wing engines) shall permit removal or installation of the duct in 30 minutes elapsed time.

Flexible mounts and/or acoustic damping shall be installed if found to be essential during testing.

The installation shall be designed to incorporate the use of plain bearings, simple machine elements and standard parts to the fullest extent practicable.

Parts and components of the Package that will require periodic maintenance, inspection and/or replacement, shall be designed to be quickly replaceable and/or accessible without requiring disturbance of other components or systems on the engine or on the airplane.

Access to engine adjustment and inspection points (including boroscope holes) shall be provided without the necessity of removal of any components other than cowling and fairings. Where this requirement cannot be met, means for ready removal of the adjacent equipment shall be provided.

Plumbing and electrical connections at locations expected to be frequently disturbed by service and maintenance operations shall be designed to minimize the possibility of misconnections.

Holding fixtures, hoisting points, etc. will be incorporated on various components after an analysis based on size, shape, weight and location dictates that such features are required.

Provisions shall be made for remote adjustments of all units which require adjustment for engine trimming with the engine operating.

3. TRANSPORTABILITY

The QEC shall have hard points incorporated in the structural components to allow it to be hoisted and to be secured to a shipping fixture to insure transportability without damage.

4. THE NEUTRAL QEC shall not exceed 96 inches in width, or shall be quickly reduceable to this width by removal of components, to permit unrestricted truck shipment.

5. CERTIFICATION

The Package shall be built to the requirements of Federal Aviation Regulation Part 25, including Amendments to the extent that Part 25 and the Amendments apply to turbofan powered transport aircraft, and also including such revisions in force up to the time of certification of the aircraft and any special regulations that the FAA may deem necessary.

6. NACELLE STRUCTURE

a. General

Composites, corrosion resistant steel, aluminum, and titanium shall be used as dictated by structural, temperature, and fire resistant requirements.

b. Cowling

The cowling shall consist of a removable inlet nose cowl and hinged removable side cowl panels to enclose the engine and accessory section. Quick release latches shall be provided to facilitate opening and removal of the panels. Latch closure shall be readily verified by a visual inspection. Retention devices, with positive stowing means, shall be incorporated to support the cowling in the open position. Cowling panels shall be designed to withstand duct failure or retained relief devices shall be provided.

c. Nose Cowl

The nose cowl shall consist of the engine air-inlet duct, an aerodynamic leading edge section, and external fairing and support structure all mounted to the front face of the engine. The engine inlet shall be designed for thermal anti-icing. One bulkhead aft of the anti-ice area shall be sealed to control discharge of the cowl anti-icing air. The nose cowl duct shall provide unidirectional airflow into the primary and secondary engine inlets under all operating conditions.

d. Fan Case and Reverser Access Cowl

The fan case and reverser access cowl comprises the area immediately aft of the nose cowl and forward of the fan reverser. This cowling assembly shall contain access doors for maintenance of the fan reverser actuation mechanism and engine and aircraft accessories.

These doors shall be hinged at the top. A hold-open device shall be installed on each door in a manner to provide adequate access to the reverser controls for all normal maintenance and servicing operations. Hinge and latch design shall permit ready opening and removing of access doors.

e. Aft Cowl

The aft cowl encloses and forms a continuous fairing over that portion of the engine from the fan case cowl to the fan exhaust nozzle and consists of left hand and right hand cowling. The aft cowls for each engine shall be designed for attachment to and support from the pylon apron. The cowlings shall latch together at the bottom centerline. Adequate seals, and faired surfaces between the engine access doors, and the pylon apron shall be maintained. This cowling shall be quickly removable for routine maintenance. The aft cowl shall be an integrated assembly of the cowl reverser and nozzle.

f. Main Engine Doors

The main engine doors shall provide access to all parts of the engine and accessories not located beneath the fan cowl that may need inspection, maintenance or servicing. The doors shall enclose and form a continuous fairing over that portion of the engine section between the fan exit plane and the aft cowl. The two doors shall be supported and hinged from a pylon apron and latched together in the bottom quadrant of the nacelle. Seals and faired surfaces shall be maintained between the fan reverser and aft cowling, and between the access doors and the apron.

The main access doors shall be designed with minimum circumferential stiffening in order to maintain adequate clearances with a minimum nacelle cross section. A minimum number of latches and hinges shall be provided consistent with allowable deflections and leakage limits. Material used for the upper portions of the doors shall serve as a fire barrier to protect the pylon and wing surfaces.

g. Access Provisions

Small, quick-opening hinged doors shall be provided within the large access doors as required for adjustment, inspection and servicing of the engine, CSD, generator, starter and other engine-mounted accessories. Hinging arrangement shall be such that the external airstream will tend to blow the doors closed in flight wherever practicable.

A quick-opening access door shall be provided in each of the lower main engine pod doors for access to the starter valve manual control for manually overriding the starter in the event of a valve failure. The access door shall be large enough and located so that the starter control valve can be reached with a gloved hand.

A spring-loaded door, which swings inward, shall be installed near the bottom of the nacelle in the accessory compartment. The door shall be of sufficient size to allow insertion of standard ground fire extinguishing equipment. The location shall not permit the accumulation and subsequent drainage of fuel or oil from the nacelle area onto personnel who will be opening the door. Appropriate marking shall be noted on the door or doors.

Adequate means shall be provided to seal the gaps between adjacent panels to reduce accessory section airflow leakage during all conditions of engine thermal expansion and excursions of the flexible engine mounting system. Flexibility to accommodate normal manufacturing tolerances and QEC (Quick Engine Change) requirements.

Field repair of sheet metal parts and replacement of seals and wear surfaces shall be given strong consideration in the design.

7. MOUNTING

Each propulsion package shall be attached to the airframe by fittings at the engine forward and aft support locations. The support fittings shall be designed to allow for thermal expansion of the engine and shall permit removal and installation of the engine with standard tools. The airplane structure will incorporate provisions for the attachment and use of hoisting equipment for installation and removal of the engine as required. The mounting system shall not preclude removal and installation of the fan and fan case in the shortest possible period of elapsed time.

Each package mounting system shall consist of that portion of the mount on the QEC up to the pylon disconnect plus the parts used for attachment. The engine attach bolts and mating fittings shall be designed to minimize the effects of mismatch during engine installation. The engine mount components shall be fabricated of high-strength, high temperature alloys. Materials for mating parts shall be such as to prevent galling of contacting surfaces. Margins for all high-strength bolts shall be such that substitution of an AN bolt will not result in failure under design loads. Adequate stress margins shall be incorporated in the design of all main components.

The mounting design in addition to providing for differential thermal expansion between engine and support structure shall provide for engine thrust and weight growth, crashworthiness, and component interchangeability.

Mount attachments and engine hoisting points shall be accessible without removing Package components.

8. FLIGHT MANEUVER FORCES AND LOADS

The engine and its support points shall withstand without permanent deformation, the general flight, gust and landing limit loads for the engine given on Figure 1. The calculated weight of the engine shall be increased by the specified weight allowed for all engine mounted accessories and by the weight of all the items of the power plant which are engine mounted.

All the loads given in the following paragraphs of this section assume axial forward and reverse thrust.

Load factors and angular velocities are taken at, and about the center of gravity of the engine, and are relative to the engine axes.

An ultimate factor of 1.5 is to be applied to each of the limit load cases and to the limit load cases given in a. below to obtain the corresponding ultimate load cases. The emergency landing loads given in b. are ultimate load cases only.

a. Additional Loads - The engine mounts shall be designed to also withstand the following load limits:

    1. A side load factor of $\pm$ 1.33 but without other inertia factors with zero to maximum thrust.

    2. A yaw velocity of 1.0 radian per second with maximum reverse to maximum forward thrust, together with a load factor of 1.0 down, $\pm$ 1.0 side and $\pm$ 1.0 fore and aft.

    3. A seizure of any shaft system in 1.0 second together with a load factor of 1.0 down.

b. Emergency Landing Loads - The engines shall be designed to withstand the following emergency landing loads.

    1. A load factor of 12 forward, together with a downward load factor of 6.

    2. A load factor of 11.6 forward together with a side load factor of $\pm$ 3.1.

c. Slinging - The slinging points shall be designed to withstand an ultimate vertical load of +4.

9. GROUND SUPPORT ATTACHMENTS

Mounting provisions shall be provided on the engine for support of a QEC engine on ground equipment. The location and dimensions shall be shown on the installation drawing(s).

10. AUXILIARY SUPPORT POINTS

Provisions for supporting the engine as installed during various stages of disassembly for repair or replacement of components shall be provided, e.g. auxiliary support points such that replacement or repair of the combustor can be accomplished on the wing.

11. REVERSER-NOZZLE SYSTEMS

a. Exhaust Nozzles

Nozzle shall be made of corrosion resistant alloys. The exhaust nozzles shall be designed to easily accommodate modest changes in exit areas by trimming, tabbing or extending the exit cone.

b. Noise Suppression Treatment

The exhaust and thrust reverser systems shall be acoustically treated to provide an appropriate portion of the overall, installed engine noise suppression requirement including suppression of the noise in reverse thrust.

c. Thrust Reverser System

(1) The reverser system may be two positional, without modulation except by adjustment of the engine thrust setting.

(2) The system shall be designed to minimize thrust loss and/or specific fuel consumption increase with the reversers in the forward thrust position and shall not cause engine surge, flameout, overspeed, or engine operating condition outside the engine limits while in any position from fully stowed to fully deployed.

(3) Actuation time for the reverser system shall not exceed 2.0 seconds in either direction.

(4) As installed on the airplane,the thrust reverser system must provide the maximum deceleration force to the airplane taking into account changes to the airplane drag due to reverser operation. In addition the reverser operation must not cause serious deterioration of airplane control.

(5) The reverser effectiveness should be as a minimum 40% of engines gross thrust at sea level static conditions.

(6) The reverse effectiveness performance must be maintained at speeds from 120 knots down to 60 knots at maximum continuous power. From 60 knots to static condition the reverser will be left deployed to supply as much additional braking impulse as possible. The contractor will specify the levels of reverse effectiveness and power achievable over this lower speed range without causing flame-out or damage to the engine.

(7) Blockers will be required in the reverser system to limit exhaust air impingement on the ground for the wing mounted installation and on the control surfaces for the aft mounted installation. The blocking or redirectional devices must be easily removable and replaceable for QEC buildup of either wing or tail mounted pods.

(8) Normal operation of the thrust reverser system for ground braking shall not result in significant loss of aircraft directional control.

(9) The reverser system shall be so constructed that if accidentally deployed at maximum cruise speed or if already deployed and speed is increased to the maximum design dive speed, no serious damage shall occur, after which it shall be capable of being stowed when speed is reduced to 200 knots.

(10) The system shall be designed such that no single failure shall result in unintentional operation of the system.

(11) Thrust reverser system position indication shall be provided. The system shall provide a signal to energize a light when in reverse and a similar and separate signal showing the reverser is not stowed or in transit. All light(s) shall be out when the reverser system is stowed and latched in the forward thrust position.

(12) Means shall be provided to secure the reverser and spoiler in the stowed position, both by use of mechanical latches and by over-centering of the actuating linkages. The latches shall not be affected by failure (false signal, etc.) of the hydraulic or pneumatic selector valves or their operation mechanisms.

(13) A means shall also be provided for securing the reverser system in a fixed position for safety of ground personnel during maintenance.

(14) Means shall be provided for securing an inoperative reverser in the stowed position while airplane is on the ground to permit dispatch with the reverser inoperative. Means shall be provided for inspection of the "stowed" position of the latches and over-center linkages. The latch inspection means shall be readily visible.

(15) The system shall be designed so that, in the event of loss of motive force, the reverser will:

- While in the reverse position - remain in reverse position.
- While in the forward thrust position - remain in that position.

(16) The system shall be designed with maximum freedom from asymmetric operation. Where failure can cause asymmetric conditions, the system (including engine mounts) shall be designed to accommodate the resultant loads.

(17) An interlock shall be provided in the reverser control system to limit application of thrust to approximately reverse idle until the reverser is in the reverse position.

(18) Ground functional check provisions shall permit operation of reverser without engine operation.

d. Reverser System Control

(1) The system on each engine shall be completely independent of the system on other engines for normal operation.

(2) The system shall be directly controlled by the engine power lever. The motive power for operation of the system shall be independent of the airplane hydraulic and/or pneumatic systems. Actuation of the system shall not be dependent upon application of the engine power.

(3) The system must be designed to provide maximum simplicity. For proper operation every effort shall be made to avoid the need for sequencing mechanisms in the control system.

(4) All components required for actuation of the reverser system, e.g., actuators, valves and accumulators, shall be supplied by a single contractor whether or not installed in the nacelle. This does not apply to piping and support bracketry for components installed in the airframe.

(5) The system shall include the incorporation of feed-back of position into the control system, which will prevent inadvertent movement of the engine power lever beyond the minimum reverse thrust position unless the reverser buckets are in the reverse thrust position. In addition, if while in reverse thrust the buckets can inadvertently open to forward thrust position, this feedback system or "throttle" interlock shall return the engine thrust level to idle detent thrust.

12. ENGINE HEAT REJECTION & ACCESSORY COOLING

a. Engine Heat Rejection

An engine heat rejection and cooling requirements report, which indicates cooling requirements, heat rejection rates, and corresponding skin temperatures for various engine components and stations of the engine, cooling airflow and pressure distribution requirements, and any additional data necessary to define the complete installed cooling requirements, shall be prepared for various engine operating conditions, accessory pad loadings, and compressor air bleed conditions throughout the complete flight operating envelope.

b. Engine Component Limiting Temperatures

Engine components mounted on the engine shall not exceed their allowable temperatures when surrounded by still air under the following conditions:

1. Continuous operation with ambient air at the maximum stagnation temperature.

2. Flight shutdown from the most adverse condition and continued soaking with ambient air at the maximum stagnation temperature.

3. Ground shutdown with ambient air at the maximum hot day conditions.

c. Oil Flow & Heat Rejection

The performance of oil systems and associated cooling provisions and cooling requirements, including sample calculations of the oil system heat balance, shall be furnished in the specifications. The oil flow and heat rejection data and vent airflow based upon the maximum limiting zone temperatures of (2) above shall be furnished. If an oil to air heat exchanger is required, the airflow and pressure drop shall be specified. A complete oil system heat balance shall be presented for the maximum limiting zone temperature conditions and with 59°F (15.0°C), 135°F (57.2°C), and maximum oil cooler cooling medium temperatures. When liquid-to-liquid type oil coolers such as fuel-oil coolers are used, heat balance data will be based on 59°F (15.0°C), 135°F (57.2°C), and maximum fuel temperatures at the fuel inlet connection on the engine. The instrumentation requirements and sensor locations for evaluation of the oil system performance shall be provided.

d. Accessory Cooling

The nacelle cooling and ventilating system shall automatically provide the required cooling airflow for the engine, aircraft accessories and for the nacelle structure.

The design of the installation shall provide an operating environment compatible with the engine and accessories employed. Ambient temperatures shall be automatically maintained at a level consistent with the shortest possible accessory cool down time for maintenance, and accessory longevity and minimum fire hazard. Charring of lines, decomposition or hydraulic fluid, burning of paint, etc., shall not occur.

Fan air may be used for ventilation and cooling system.

The effect on the fire extinguishing system should be considered in sizing and locating the discharge points. A ventilation air shutoff valve, operated by the fire extinguisher control, may be necessary.

e. Indicating

The Package shall include switches and wiring for the purpose of indicating cowl anti-ice valve position (full open and full closed).

A nacelle overheat detection system may be required.

13. POWER PLANT CONTROL SYSTEM

The engine controls in the Package shall consist of power (throttle) controls and engine fuel shutoff controls from quick disconnect points on each pylon to the corresponding control attachments on the engine. The controls shall be mechanically operated, and shall include a combination two way rigged cable and/or mechanical linkage. Both end attach points shall be easily accessible and swiftly disconnectable.

Mechanical linkages shall be arranged to provide compensation for expansion due to temperature and for inertia effects. They shall be balanced, if necessary, to insure that the control remains stationary when subjected to takeoff acceleration or flight maneuver forces.

Simple means for setting the engine control to match the cockpit control shall be provided at or near the quick-disconnect point on the engine.

The power plant control system shall be compatible with the vibration environment and shall include checking natural frequencies of control system components, providing adequate fatigue strength, and minimizing play at non-preloaded rotating joints through use of close-tolerance bolts in reamed holes.

Push-pull controls in the engine section shall not be used unless absolutely required for design simplicity.

The effects of temperature and corrosion shall be minimized through the selection of adequate lubricants, seals, and bearing materials.

The possibility of jamming shall be minimized by adequate structure clearances on rotating or translating parts.

Cantilever-mounted pulleys and rod ends shall incorporate safety washers to guard against improperly installed bearings.

All cables used throughout the Package shall have:

- Swaged-end fittings.
- Be proof tested.
- Be accessible for inspection, maintenance, and replacement.
- All cables shall be protected against fouling, chafing, and corrosion and have individually replaceable cable grommets and fireseals.
- Engine control cables shall be a minimum of 1/16 inch stainless steel in diameter with 3/32 inch preferred.
- Control cables shall incorporate provision for rigging and adjustment and be arranged to prevent cross connections.
- Sufficient adjustment to permit replacement with pre-manufactured and stock cables shall be provided.

All control pulleys shall be not less than 38 (thirty-eight) times the diameter of the cable and shall be of metal.

Pulleys or bellcranks shall be used at all points where cables change direction more than one and a half degrees.

All control bearings used shall be suitable for the environment and of low friction type. Ball bearings shall be prepacked with the appropriate grease and dust sealed. Teflon bearings shall not be used.

All control rods and linkages shall utilize typical thread end fittings wherever possible with standard hold location, and shall be hermetically sealed or treated internally to prevent corrosion.

Rigging shall be designed so that the engine or engine fuel control may be removed without loss of rigging adjustment in the airframe cable system. Rigged positions indicators shall be used whenever practicable.

Provisions for rigging pins shall be made when their misuse will not create a hazard, and shall be in the "Fuel-Off" position.

a. Engine Fuel Shutoff Control

The engine fuel shutoff control system shall consist of a mechanism which transmits motion from a pylon mounted shaft or crank to the engine mounted fuel control.

The engine fuel shutoff levers in the cockpit will control the engine fuel shutoff function. Each shutoff control will be independent of the other controls.

The two way cable system from the cockpit will terminate at a cable drum in the pylon where the shaft protrudes through the firewall into the engine nacelle.

b. Emergency Shutdown

Actuation of the fire control handle for each engine shall accomplish an emergency shutdown.

14. POWER PLANT FUEL SUBSYSTEM

a. General

The entire engine fuel system downstream of the engine inlet connection, including the fuel flowmeter transmitter, will be integral with the engine.

The fuel piping upstream of the engine pump inlet (including maintenance shutoff valve) and vapor eductor system, if required, fuel pressure and temperature indication systems, and fuel drain system shall be included in the Package.

b. Nacelle Fuel System

(1) General

The fuel system components shall be designed structurally and from a fuel resistant standpoint to use, alternately or in any combination, JP-4 per MIL-T-5624G, revised November 4, 1965, kerosene per D1655-65T (ASTM) dated June, 1965 and 115/130 aviation gasoline. The use of aviation gasoline is not planned, but inadvertent exposure of components to aviation gasoline shall not cause any damage.

(2) Flow Control

It shall be possible to stop the flow of fuel to any engine with one valve, controlled by either the engine fire switch or a lever lock switch. The fuel shutoff valve installation shall provide protection for the valve in case of structural damage to the engine, nacelle or strut. Fuel control valve motors shall be sealed.

(3) Indicating

- Fuel Pressure Transmitter. A fuel pressure transmitter, conforming to the applicable requirements of MIL-T-26638, connected to or installed directly on a suitable engine port, without the use of shock mounts, shall be included. The transmitter shall provide accurate indication of fuel pressure throughout the entire operating range of the engine.

- Valve Position Indication. Fuel valve position indication shall be provided for the fuel valves and fuel jettison systems. The indicator lights shall light when the valve switches are actuated to reposition the valves, Each light shall remain lighted until respective valve has attained a position corresponding to that selected at the control switch. The signal source shall be taken directly from the applicable valve.

- Fuel Filter Differential Pressure Indication. A differential pressure indicating system to show filter bypass shall be installed at the fuel filter of each engine to indicate abnormal pressure differential across the filter. Provisions for the warning light system indicating abnormal pressure differential shall be installed.

- Fuel Temperature Indication. Fuel temperature sensing instrumentation and connecting lines shall be installed at each engine fuel heater outlet.

(4) Fuel Heater

An engine fuel heater installation may be an integral part of each engine. Electrical control wiring shall be installed. If appropriate, heater operation indication (valve position or equivalent) shall be provided.

(5) Fuel Line and Hoses

The main fuel supply line shall connect to the pylon with a 4-bolt flange or equivalent attachment with adequate access provided for the bolts. If flexible fuel hose is required between the fuel pump inlet and the engine fuel inlet, it shall perform satisfactorily and shall not collapse at standard sea level conditions, when the minimum fuel pressure that can occur during any normal or failure condition is applied. All fuel hoses, piping and components shall be fire-resistant per FAR Part 25.

If required, a fuel/air vapor removal (educator) system shall be installed to protect the engine driven fuel pump from vapor cavitation. The system will remove air or vapor from the pylon piping high point during starting and suction feed operation. The system shall use fuel from the first engine fuel pumping stage as the pumping energy source.

c. Drainage System

A drain collection system shall be supplied. The requirement for overboard venting of drains shall be carefully controlled.

The engine combustion chamber drain shall be vented overboard.

Accessory drive seal drains carrying unlike fluids may be grouped together except as stated above. Where practical, drains for "zero" leakage components (e.g., fuel and oil pressure transmitters) should be grouped separately from those for which leakage is more likely.

All drain-can exits shall be designed so that drainage will not run on the nacelle surface or re-enter the nacelle while on the ground or in flight. Exits shall be of a configuration resulting in the minimum drag practicable and shall be located in a negative pressure area.

The drain-cans and all flammable fluid carrying drain lines shall be corrosion-resistant steel or fire proof hose.

All lines shall drain without trapping.

The first segment of seal drains from accessories shall be flexible to facilitate accessory removal.

Condensation drain holes shall be provided for trapped structural areas. Such trapped areas should be interconnected where possible within the structure and the number of required overboard drain holes held to a minimum.

All fluid drains shall be a minimum of 3/8" size.

Differential pressure across the lower cowling shall be outward to assist drainage of fluids in the pod and to prevent re-entry of these fluids farther aft.

All accessory drive seal drains and overflow drains (excluding engine breathers) shall be collected in one or more containers within the nacelle. Provisions shall be incorporated for manual draining of collected fluids on the ground at intervals of 50 hours.

15. ANTI-ICING

The propulsion system with all anti-icing protection systems operating shall meet the requirements specified by applicable Federal Aviation Administration Regulations.

a. Engine Anti-Icing

The type of anti-icing system shall be described in the specifications. Unless continuous anti-icing is provided, operation of the anti-icing system shall be accomplished either automatically or manually as specified in the specifications. If automatic actuation is provided, a manual override shall be included and a signal for airframe indication of system operation shall be provided. The requirements specified herein shall be met within 15 seconds after initiation of anti-icing operation when initiation is made 15 seconds after start of ice formation. An ice detector shall be provided. The type of signal required for actuation of the anti-icing system shall be specified. Continuous operation of the anti-icing system shall not damage the engine. If failure of the anti-icing occurs, it shall remain in or revert to the anti-icing mode.

Anti-icing air or gas shall be provided at the front of the engine for anti-icing the inlet. Details of the connections shall be shown in the installation drawing. If compressor bleed air is used for this purpose, it shall be considered part of the quantity specified for engine purposes, and be available over and above that required for aircraft use.

b. Generator Cooling Air Inlet Anti-Icing

Generator cooling air inlets shall be anti-iced if the aircraft contractor determines that the location on the nacelles is such that ice protection is required.

c. Engine Inlet Ice Protection

A cowl anti-icing system shall be provided in accordance with the requirements of FAR Part 25.

Each engine inlet shall be provided with a hot air anti-icing system which shall utilize bleed air from the engine compressor.

The anti-iced portion of the cowling shall be constructed and sealed to withstand continuous anti-icing for the purpose of dispatching into known icing conditions with a failed cowl anti-ice valve fixed open.

The quantity of bleed air used for inlet ice protection shall be minimized and shall be applied in such a manner that maximum utilization is made of the energy available in the bleed air.

This system shall maintain the leading edges of the nose cowl free of ice.

The forward areas of the engine nose cowl shall be anti-iced with engine bleed air to the extent necessary to limit the runback to acceptable limits during intermittent maximum icing conditions and shall provide 100% evaporation of the water catch which can run back into the engine during maximum continuous icing conditions. The amount of permissible runback during the intermittent maximum icing condition shall be established by the engine manufacturer in coordination with the aircraft contractor.

The cowl anti-ice valve shall have provisions for position indicating (to flight compartment) and for manual override at the engine. The Package shall include associated wiring.

The PT_2 probe shall be thermally anti-iced.

Engine bleed air shall be used if practical.

16. PNEUMATIC SYSTEM

The primary source of pneumatic power for air conditioning, cabin pressurization, cowl and airfoil ice protection shall be either low or high pressure engine bleed air.

The pneumatic installations shall be self-contained within the pod with support and provisions for thermal expansion provided. All the ducting in the fire zones shall be fire proof. Fire seals shall be provided at all points where penetration of fire walls occurs. Duct wall temperatures shall be less than 550°F or shall be insulated to prevent fire.

"Janitrol"-type duct connectors shall be used. The bleed port connections shall be of the bolted flange type.

Flexibility at the engine and pylon mating points shall be provided to accommodate normal manufacturing tolerances and QEC (Quick Engine Change) requirements.

a. Pressure Regulation

A pressure regulator valve shall be installed in the supply manifold from each engine system. In addition, a valve shall be installed downstream of each engine high pressure bleed port to provide switching between high and low pressure bleed. Components and ducting shall be designed or means shall be incorporated to provide excessive pressure protection in case of an open valve failure.

b. Temperature Regulation

A bleed air pre-cooler and temperature control system will be installed (if required) in the pylon pneumatic system to automatically limit the temperature of the bleed air supply for air conditioning and wing ice protection. The bleed air pre-cooler shall not be mounted on the engine and shall be designed for a minimum of at least 10% over capacity to allow for inservice repair.

Engine fan bleed air shall be utilized as the cooling medium with a modulating valve located within the Package.

c. Flow Limiters

Flow limiters shall be installed, at or near each engine bleed port, to minimize the flow of engine compressor bleed air subsequent to the loss of manifold integrity.

17. HYDRAULIC SUBSYSTEM

At least one 3000 psi variable displacement hydraulic pump shall be installed on each engine with all necessary lines and fittings required. The hydraulic system shall be designed for Skydrol 500 fire-resistant hydraulic fluid.

a. Lines and Fittings

The use of hoses shall be minimal. Where hoses are used, flexible hoses of stainless steel construction with Teflon lining or flexible hoses shown to be better, shall be utilized and shall be fire resistant.

Packing, seals and gaskets shall be ethylene-propylene material or equivalent and be compatible with the fluid specified.

Seamless and corrosion resistant steel tubing shall be used with flared-type fittings.

Line support material shall be such as not to deteriorate when impregnated with Skydrol 500 fluid or shrink in their environmental temperature.

The number of connections shall be held to a minimum. Universal-type fittings shall not be used.

All critical pipes shall be jig fabricated.

Pipes shall be marked with AN or MS coding; direction of flow, part number, and purpose of line shall be indicated.

These markings shall be compatible with environment.

The power plant package shall include suction, pressure and pump case drain lines from the pylon interface to the pumps. A disconnect shall be included in the suction line at the interface. Check valves shall be included in the pressure and case drain lines at the interface. Piping from different systems shall be separated as much as possible.

Clearance for use of wrenches and other similar maintenance tools shall be provided.

Line support shall be designed to minimize tube wear.

b. Pumps

Each of the engine driven pumps shall incorporate an outlet blocking feature.

Engine driven pumps shall have a positively lubricated, wet spline drive using gearbox lubricating fluid and the pumps shall be Quick Attach-Detach (QAD) mounted.

The pump environment (temperature) shall be controlled so that the maximum temperature of the fluid shall not exceed 225°F in the hydraulic system during engine operation and after shut-down. If a heat shield and/or cooling air is required, it shall be provided.

Hydraulic fluid temperature shall be controlled to 180°F maximum under normal operating conditions.

It shall be possible to replace a pump within 20 minutes including opening and closing access panels.

Each pump shall have a capacity of approximately TBD* gallons per minute and a discharge pressure ripple less than ± 150 psi.

As a design objective, the discharge pressure ripple shall be ± 100 psi.

c. Filters

Pressure line type filters shall be installed in each pump case drain line. Filters shall be non-bypass type and incorporate disposable filter elements and dependable contamination indicators. Filter elements shall be removable without fluid loss except for the fluid in the filter bowl.

d. Instrumentation

One sensor and associated wiring for each main hydraulic system shall be installed for the purpose of indicating a condition of over-temperature. The sensor shall be located between the pump outlet and the pressure check valve.

One sensor and associated wiring for each hydraulic system shall be installed for the purpose of indicating a condition of low hydraulic pressure. The sensor shall be located between the pump outlet and the pressure check valve.

e. Valves

All hydraulic system electric control valves shall be motor operated except the anti-skid valves, the pump depressurization valves and certain flight control boost package valves.

*To Be Determined by the aircraft contractor.

f. Shutoff Valves

Firewall shutoff valves shall be installed in each engine-driven hydraulic pump suction line.

The valves shall be automatically closed when the fire shutoff handles are operated.

g. Control Valves

As a design objective, when dual valves are required, an attempt shall be made to mechanically connect valves together rather than using tandem type valves.

h. Engine-Driven Pump Pressure Control Valves

Electrically-operated spool type valves to unload each engine-driven variable displacement pump shall be installed.

18. ELECTRICAL HARNESS

Package wiring shall be routed as open harness and shall be terminated at the firewall at which location it shall mate with receptacles installed on the pylon structure. Open wiring shall be routed to minimize the possibility of a broken wire contacting control cables actuating rods, fluid lines or tanks containing fluids. The wire harness shall be installed in a manner that will permit installation or removal of other components from the engine. The harness shall be routed in a manner that will permit the same harness to be used on both left and right hand mounted engines. High-temperature wire shall be used. Resistance type temperature bulb wiring shall be installed in a manner that will minimize indicator errors caused by ground return currents. Ground terminal connections for these circuits shall not be shared with other systems.

Where wiring goes through cutouts in structure, a hard insulating material grommet or equivalent shall be used.

Wire clamping shall be provided at terminating ends to avoid breakage.

Where wire ducts are used, a suitable means shall be provided to prevent accumulation of fluids.

Engine wire for high temperature areas and fire detector (392 degrees Fahrenheit or higher), shall be to MIL-W-25038 or its equivalent.

No wire size smaller than 18 gauge shall be used.

The aircraft contractor shall be responsible for the design of all electrical circuits within the engine section. The aircraft contractor shall provide a composite circuit diagram specifying each wire number and plug pin connection. This diagram will show isolation required.

Unused engine wiring connectors, where provided for engine interchangeability, shall terminate in dummy receptacles in each engine section.

Wiring shall be isolated to the maximum degree possible and shall be routed at higher elevations than fluid-carrying lines.

19. GENERATOR DRIVE AND ALTERNATOR SUBSYSTEM

Constant speed drive unit(s) shall be provided and installed on each engine by means of QAD. This unit shall be compatible with the alternator requirements and the engine. It shall use the same type oil as the engine and shall be installed such that removal of the alternator to remove the CSD shall not be necessary.

a. Drive Unit Oil System. An oil system be installed on each engine to provide fluid for operation, lubrication and cooling of the constant speed drive unit. The drive unit oil system shall be completely independent of the engine oil system. The oil temperature shall be automatically controlled. CSD oil return filter elements are to be of minimum pore size that is compatible with CSD oil and shall have a witness feature. Means shall be provided to service the CSD oil system without opening the engine cowling and a visual oil level indicator shall be provided.

b. Drive Unit Malfunction Detection. Each constant speed drive unit shall have a malfunction detector system consisting of an oil temperature and an oil pressure warning indication. CSD temperature gauges, which will provide the temperature differential between the oil inlet and oil outlet, shall be installed. Means shall be installed in the sumps to permit a ground check for metal particles. In addition, means shall be provided to mount a vibration accelerometer type pickup on the CSD.

c. Drive Unit Disconnect. Each constant speed drive unit shall be equipped with a mechanical shaft disconnect. Disconnect shall be controlled by an electrical signal from the control cabin. Re-engagement shall be accomplished only by a manual operation at the drive.

d. Wiring. All CSD and CSD instrumentation wiring shall terminate in a single connector on the CSD and at the pylon disconnect.

e. Alternator. The alternator to be fitted on the engine shall be defined in the interface by the aircraft manufacturer. Suitable units shall be provided for the propulsion system mockup and system testing. The alternator shall be QAD mounted.

Access shall be provided to facilitate quick attachment and detachment of the generators.

Air inlet and outlet ducting of fireproof construction shall be provided to meet generator cooling requirements.

The generator output and field wiring shall be installed between the generator and the firewall connections, and must be isolated from each other and from other miscellaneous engine wiring.

20. FIRE PROTECTION

a. Fire Shield Attachment

Provisions shall be made on the engine for a convenient attachment of fireproof shields. In establishing the location consideration of auto ignition of combustible fluids sprayed against the engine casings shall be considered.

b. Flammable Fluid Systems

All exterior lines and components which convey flammable fluid shall be fire resistant (5 minutes at 2,000^{o}F (1,093.3^{o}C), except that the lubricating oil system components shall be fireproof (15 minutes at 2,000^{o}F (1,093.3^{o}C)).

c. Firewalls

Corrosion resistant steel or titanium alloy firewalls shall be provided to isolate each nacelle from the strut. Material used for the upper portions of the engine cowling shall serve as a fire barrier to protect the strut and wing surfaces. Special consideration shall be given to firewall design to assure adequate fatigue life. Where titanium is used, coatings shall be provided to protect against corrosive attack from cleaning fluids, skydrol, etc.

Materials which have long after-glow characteristics shall not be used in critical fire zones. Engine surfaces forward of the firewall shall be controlled by means within the engine to temperatures less than 550^{o}F.

d. Isolation Provisions

All fluid-carrying lines and wiring shall enter the nacelle through suitable fittings at the firewalls. The holes for lines passing through the firewall shall be sealed. All fluid carrying lines in a fire zone shall be corrosion resistant steel or fire resistant hose. Electrical wiring shall be isolated from and as a design objective located at elevations higher than fluid carrying lines or should be shrouded and drained.

e. Fire Detectors

Each engine shall be fitted with a dual, ruggedized and shrouded fire detector system. Means shall be provided to test the fire detector systems in flight and identify an inoperative circuit. The type of fire and overheat detection system installations shall be subject to review by the aircraft contractor and airlines, and shall meet FAR 25. An electrical signal shall be transmitted. Sensing elements shall be installed so that maximum replacement time for any one element is one hour. Where different length sensing elements are to be used, the minimum difference in length is one foot. Sensing element routing shall be such that maximum protection is provided to prevent damage during routine maintenance, cowling operation and engine component removal. A minimum of 3/16 inch clearance between the sensing elements and adjacent structure shall be provided. The engine fire detection installation shall be a "loop" system. Every effort shall be made to provide a system capable of detecting a combustor burn through.

f. Fire Extinguishing

A fire extinguishing system shall be installed to supply fire extinguishing agent to each nacelle accessory section. Release of the extinguishing agent shall be by switches located adjacent to the fire shutoff switches. Consideration shall be given to the use of nitrogen as a fire extinguishing agent.

g. Fire Protection Control

Necessary wiring for a fire protection control switch shall be provided as appropriate for the engine. The switch shall accomplish the following functions:

- Close fuel shutoff valve.
- Close engine driven hydraulic pump supply shutoff valves.
- De-excite generator and disconnect generator from electrical system.
- Arm the engine fire extinguishing system.
- Close engine bleed air shutoff valves.

The delivery of the extinguishing agent shall be controlled separately and provisions for this system shall be installed as required.

SECTION V

TESTING

1. ENGINE LOW CYCLE THERMAL FATIGUE TESTS

An engine shall complete 1000 cycles of the low cycle thermal fatigue test prior to initiation of the FAA certification testing. At least the maximum allowable imbalances specified for the engine rotating components and assemblies shall be incorporated prior to the engine buildup. A calibration and recalibration run at the start and completion of the initial 1000 cycles shall be performed. Prior to the engine calibration, the power control fuel schedule shall be preset to obtain fast starts, fast restarts, and rapid accelerations to provide starting temperatures, acceleration temperatures, and temperatures at least at the rated maximum values. Deceleration fuel schedules shall be preset to provide maximum thermal shock. The customer air bleed shall be set to provide maximum permissible bleed airflow. The accessory and power takeoff pads shall be loaded to provide accessory rated loads. The transient data shall be obtained to assure that the present preset values are established as specified above. Post test balancing of compressor and turbine assemblies shall be accomplished after engine teardown, prior to cleaning the assemblies, and after cleaning the assemblies. The results of pre-test and post test balancing shall be compared in the final report.

A minimum of 100 starts preceded by at least a two hour shutdown shall be accomplished at regular intervals throughout the test. In addition, 120 false starts shall be accomplished.

Following completion of the FAA certification test, an engine or engines, as required, to the parts standard of the FAA certification engine shall be subjected to additional cycle testing. These cycles should be accumulated such that the test engine or engines remain 3000 cycles ahead of inservice engines.

2. PROPULSION SYSTEM COMPATIBILITY AND RELIABILITY TEST

The contractor shall conduct a reliability test created to demonstrate satisfactory fatigue life, durability, reliability, stability, and mechanical integrity of the propulsion system.

The reliability test shall be designed to simulate a fore-shortened flight profile such that maximum thermal gradients shall be imposed on engine components. Concentration of the testing is to be accomplished at critical speeds and where high stress is apparent. Operation of all engine systems (such as anti-icing, customer air bleed, inner stage air bleed, hydraulic system, electrical system, performance indication system, etc.) shall be demonstrated throughout the test. Speed relationships between rotors shall be changed on multiple rotor engines by selecting customer air bleed, anti-icing air bleed, extracting accessory power, etc., and combinations thereof.

The duration of the test shall be specified by the contractor but shall as a minimum exceed 1000 cycles, prior to FAA certification testing. This systems testing shall be continued using an engine(s) to the parts standard of the FAA certification test engine with the intent of remaining 3000 flight cycles ahead of the high time in service engines.

3. PROPULSION SYSTEM ALTITUDE TESTS

An engine shall be subjected to altitude tests which shall consist of operation and air starting checks at several selected thrust conditions around the operating limits envelopes specified for the engine in the model specification, except that portions of these tests may be accomplished on separate engines. The points covered on these envelopes shall include, insofar as possible, the entire ambient temperature range and the altitude rating points. The test points selected shall be the minimum necessary to demonstrate the engine operating and air starting (hot starts and cold starts) envelope(s). Loading of the accessory drives and bleed extraction will be required during these tests. The continuous duty ignition system shall be in operation, with rated input voltage, at all times after a normal start sequence has been completed.

The altitude tests shall be accomplished using the primary and alternate fuels. The engine shall be calibrated prior to and after testing. The test points shall be as specified in the specification. Operation at each point shall be limited to the duration required to establish the performance characteristics of the engine at that condition. Each test point shall be conducted with compressor bleed airflow as required for both engine and aircraft. The tests need not be run in the order listed. Maximum runs shall be made using all thrust augmentation, if applicable. When special emergency features are provided in the control, these features shall be tested during the test schedule. Operation shall be conducted to obtain the following data:

- Steady State Operation - A sufficient number of engine thrust settings shall be selected for each specified altitude test condition to establish the engine operating and performance characteristics.

- Transient Operation - The transient performance specified shall be demonstrated and reported.

- Air Starts - Within the engine air starting envelope a normal air start demonstration and a relight after an engine flameout shall be accomplished to demonstrate the air starting envelope without continuous ignition system in operation. The continuous ignition system shall be demonstrated at the same points and utilizing the same flameout technique. With the continuous ignition system in operation, the engine shall demonstrate that it will reignite and return to stable operation without any manipulation of the engine power lever.

Sufficient data shall be corrected by a method suitable to the aircraft contractor to determine compliance with the altitude ratings and validity of the altitude performance curves in the specifications. Comparison of observed test data and performance obtained during the test to the specified performance shall be made by application of suitable correction factors specified for the engine in its specification.

4. INLET DISTORTION

An engine, to essentially the same parts list as the certification engine, shall be tested to establish conformance with the inlet distortion requirements.

5. OIL FLOW INTERRUPTION TESTS

An engine, to essentially the same parts list as the certification engine, shall be operated at maximum continuous rated thrust for 30 seconds in which only air is supplied to the inlet of the oil pump. The engine shall operate without damage during this period and 30 minutes thereafter.

6. ANTI-ICING TEST

An engine, to essentially the same parts list as the certification engine, shall be subject to anti-icing tests to demonstrate compliance with FAR requirements.

7. ATMOSPHERIC WATER INGESTION TESTS

An engine, to essentially the same parts list as the certification test engine, shall demonstrate at sea level static conditions, compliance with the water ingestion requirements by operating satisfactorily under conditions of ground idle to maximum thrust with data recorded for at least 2, 3.5, and 5 percent of the total airflow weight in the form of water (liquid and vapor). Resulting data shall be reported. Following the water ingestion test, the engine shall be disassembled sufficiently for inspection to establish that adequate clearances were maintained and that no damaging rub or detrimental rubbing occurred during the test. Also, the gas-flow path parts shall be examined for any damage resulting from the test.

8. SAND INGESTION TEST

An engine, to essentially the same parts list as the certification test engine, shall be calibrated and subjected to a 10 hour run at maximum cruise thrust, with sand introduced into the engine inlet. The 10 hour run at maximum cruise rating shall include at least one deceleration to ground idle and acceleration to takeoff rating each hour (throttle movements within one-half second) or until the operation results in a stall. During the first hour of the test, ten 1-minute operations of the anti-icing systems and other bleed outlets from the engine shall be performed. The engine shall be recalibrated following the 10-hour run, and then disassembled as necessary for inspection to determine the extent of sand erosion and the degree to which sand has entered bearing and other critical areas.

9. LOW AND HIGH TEMPERATURE STARTING & ACCELERATION TESTS

An engine shall be subjected to low and high temperature tests to demonstrate compliance with starting and acceleration requirements.

All data required shall be recorded during each start. Starting and operating capabilities shall be accomplished with maximum torque loading applied to accessories installed on the accessory drive pads, and with an air bleed setting capable of providing maximum customer air bleed.

The test will be considered successful when four successive starts have been satisfactorily accomplished within the time limits specified and the engine has demonstrated ability to accelerate to maximum continuous thrust.

CONCLUDING REMARKS

The purpose of this report has been to set forth in one place all of the many requirements that may be placed on future subsonic commercial propulsion systems. In addition to these requirements and objectives all engines must meet the applicable requirements set forth in Federal Aircraft Regulations. The requirements presented have been developed from previous experience and from the results of the studies undertaken in Task I and Task II of this effort. Several of the requirements are therefore new and likely to be controversial. One such requirement is that the performance of the engine should be guaranteed over the first four thousand hours of operation. This requirement is based on airline experience with the deterioration in specific fuel consumption performance versus time and the belief that with adequate research, design techniques can be developed which will permit the recovery of this performance at reasonable cost. The requirements set forth for reliability, maintainability, advanced control systems, component design lives, fire detection and suppression fall into the same category. The fundamental objective of this report is to stimulate communication between researchers, manufacturers and users as a means of improving the state-of-the-art of propulsion system technology.

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