NASA CR-121133

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

II - ENGINE PRELIMINARY DESIGN ASSESSMENT

by G. Phillip Sallee

AMERICAN AIRLINES

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS 3-15572

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-121133		

4. Title and Subtitle AN AIRLINE STUDY OF ADVANCED TECHNOLOGY REQUIREMENTS FOR ADVANCED HIGH SPEED COMMERCIAL TRANSPORT ENGINES II - ENGINE PRELIMINARY DESIGN ASSESSMENT	5. Report Date March 1973
	6. Performing Organization Code
7. Author(s) G. Phillip Sallee	8. Performing Organization Report No. None
	10. Work Unit No.
9. Performing Organization Name and Address American Airlines 633 Third Avenue New York, New York 10017	11. Contract or Grant No. NAS 3-15572
	13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Project Manager, Robert J. Antl, V/STOL and Noise Division, NASA Lewis Research Center, Cleveland, Ohio

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 of 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 II study effort and covers the following areas:

a. General review of preliminary engine designs suggested for a future aircraft
b. Presentation of a long range view of airline propulsion system objectives and the research programs in noise, pollution, and design which must be undertaken to achieve the goals presented
c. A review of the impact of propulsion system unreliability and unscheduled maintenance on cost of operation
d. A listing of detailed design requirements for future engines by component
e. A discussion of the reliability and maintainability requirements and guarantees for future engines

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Advanced technology; Airlines; Subsonic aircraft; Turbofan engines; Noise; Emissions; Maintenance	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	76	$3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

The provisions of NASA Policy Directive 2220.4 pertaining to the use of the International System of Units have been waived under the authority of paragraph 5.d. of the Directive.

TABLE OF CONTENTS

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 of 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 II study effort and covers the following areas:

a. General review of preliminary engine designs suggested for a future aircraft by the study contractors. This review includes general observations with respect to the engine design and general recommendations covering the noise and pollution reduction features, the installation concepts and the economic studies presented by the contractors.

b. A suggested plan for propulsion system research is presented based on airline objectives for the 1979 to 1985 time period. The considerations, both environmental and economic, which form the basis for the suggested research programs and their order of priority is presented considering a broad range of potential advanced aircraft types including the ATT.

c. The impact of current propulsion system reliability and the related cost for unscheduled maintenance, including cost of departure delays, is discussed as a guide for advanced engine design.

d. A list of design criteria for commercial engines is presented as an aid to insure that past mistakes in engine design and good commercial practices are reflected in future design.

e. Maintainability objectives for future propulsion systems are discussed with emphasis on the cost of repairing prematurely removed engines and the relationship these costs and labor costs have to aircraft direct operating cost. Emphasis is also placed on mean time between unscheduled removal objectives and removal and replacement times for engines and subsystems.

Page Intentionally Left Blank

INTRODUCTION

This report has been prepared in response to NASA-Lewis Research Center Contract NAS 3-15572 with American Airlines, and reports on the studies undertaken in response to Task II of the contract.

The material contained herein is directed at providing an assessment from an airline point of view of the preliminary propulsion system design concepts provided by NASA for an advanced high speed subsonic transport aircraft with respect to accessibility, maintainability, noise and pollution control. The major component designs and performance objectives of these engines have been reviewed with respect to airline requirements for repairability, tolerance to deterioration and technical risk. In addition to these specific reviews, general design criteria have been developed and reported to assist in the preparation of new designs. These criteria are based on airline experience with engines from a number of manufacturers and are directed at defining the design principles which insure a maintainable engine and installation.

Airlines require high levels of reliability from engines and propulsion subsystems to insure aircraft operating economics meet projections. This report contains a review of current propulsion system reliability and the costs associated with premature removals and aircraft departure delays and cancellations. The gas turbine engine has brought a high degree of reliability, however, propulsion system elements such as starting systems have not produced the levels of reliability necessary for advanced aircraft. Design reliability criteria and premature removal rate objectives have been specified for components of future propulsion systems. Projected cost trade-off criteria are presented as tools to assist the designer in achieving the desired goals.

Finally, this report includes a specific review of the ATT engine contractors final oral reports and provides recommendations for future research efforts.

This report is divided into five sections.

I. Evaluation of Phase II - Assessment of Preliminary Designs

II. Evaluation of Phase III - Assessment of Technology Readiness

III. Propulsion System Reliability and Cost for Unscheduled Maintenance

IV. Design Criteria for Future Transport Engines

V. Reliability and Maintainability Requirements for Subsonic Commercial Aircraft Propulsion Systems

SUMMARY OF TASK I STUDY RESULTS

The airlines under increasing economic and environmental pressures place heavy emphasis on improved engine economics for future propulsion systems. This requirement, as well as the requirement for significant improvements in aircraft noise and pollution levels, present additional challenges to research and technology programs. Advances in areas which will produce lighter and more efficient engines are required to offset expected penalties associated with noise pollution control. Along with these advancements, improvements in engine life, reliability and maintainability are essential to insure improvements in direct operating cost and return on investment. Areas of fundamental research which can be of significant benefit to the airlines are advanced composite materials, advanced engine controls, and improved thrust reverser and engine components, to provide improved performance with respect to deterioration, stall margin and lesser cost. The area of propulsion system integration is expected to provide significant potential for advances in performance, weight and maintainability. The tools available to assess engine economics and the effects that past engine advancements have had on maintenance cost were reviewed extensively in the Task I report. It is essential that the adverse trends be reversed. This reversal can only be achieved by careful attention to these factors in the research and development process. Without fundamental research in long-life, high temperature hot section components and higher pressure rise per stage compressors of fewer blades, the objectives of low noise, low pollution and lesser cost cannot be achieved. The challenges for the future are these broader interpretations of the requirements for advanced research.

SECTION I - EVALUATION OF PHASE II - ADVANCED TRANSPORT TECHNOLOGY ENGINE STUDIES -- ASSESSMENT OF PRELIMINARY DESIGNS

The purpose of this section of the report is to review to the extent possible the preliminary designs of both engines and installations studied for application to an advanced transport with a design cruise speed of Mach No. 0.95 to 0.98. The contractor placed emphasis on reducing engine noise and pollution and on improving engine specific weight and specific fuel consumption. The engine cycle designs selected as the result of the contractors' studies during Task I were finalized and preliminary design drawings were produced for both engines and installations. These drawings were conceptual rather than detailed. The following subsystems were omitted or only partially defined.

a. Accessory drive and gear box
b. Customer bleed air
c. Oil system
d. Electrical system
e. Fuel System
f. Instrumentation
g. Borescoping provisions
h. Rotor balance provisions

The omission of this data suggested that a detailed list of design preferences should be prepared. This material is presented in Section IV of this report.

Engine Design - General

a. Both contractors selected designs which minimized the number of stages and eliminated the inter-turbine frame. The objective of reducing the number of stages required to achieve the design performance is supported. Hopefully the reduction of stages also reduces the cost of maintaining these types of engines.

b. It is not clear from the engine drawings whether various blade elements were designed as individually replaceable pieces, or were constructed in pairs, triples or segments. Recognizing the importance of leakages between gas path parts, it is expected that the latter approach has been used in these designs. This approach is directly contrary to airline needs. The more costly the part, the more seriously the airlines become concerned with the joining of parts. Other design means, such as additional seals to control leakages, should be employed. An example of the worst kind of design would be a single piece first turbine nozzle blade assembly. As a unit, the assembly would cost in the area of $70,000. The replacement of the whole assembly due to burning of a single blade, cracking of a single blade, etc., would be extremely costly to the airlines. Repair of the assembly would require special tooling and present real cost problems in terms of the value of spares required to be on hand.

c. The engine designs for the late 1970 time period drew heavily from current engines or developmental hardware. The engine designs for the 1985 time period considered changes to discs, high pressure compressor, combustor and materials. Both contractors employed piggy-back turbine bearings to reduce engine length and eliminate the inter-turbine frame. Particular attention must be given to minimizing the number of joints and to alignment provisions to ensure good tip clearance control. The ability to assembly and disassemble the engine without damaging seals is essential. Additionally the oil system must be well designed and the use of radioactive isotope impregnated parts should be considered to aid in rapid fault isolation.

d. Both contractors planned to use composite blading. It is suggested that early examination of the large bird ingestion problem is appropriate, both from the standpoint of the realism of current requirements and to develop means to protect the blades from damage.

Installation Design - General

The installation designs for the engines were described only briefly and pod aerodynamics were adequately discussed in only one report. Both installation design concepts were unacceptable as shown, either from the lack of detail or from poor design concept. As a general conclusion, greater emphasis is required in the area of installation design and further wind tunnel work on nacelle-wing or body aerodynamics is essential.

Noise - General

a. The approaches to achieving the NASA goals of: 1) FAR 36 - 10 EPNdB in the late 1970's, 2) FAR 36 - 15 EPNdB in the mid-1980's and 3) FAR 36 - 20 EPNdB in the mid-1980's using aircraft operating procedures were adequately addressed.

b. Contractors' results indicated that the FAR 36 - 10 EPNdB goal was achievable, the FAR 36 - 15 EPNdB goal was achievable at significant penalty and the FAR 36 - 20 EPNdB goal was not achievable even utilizing unrealistic flight procedures.

c. Neither contractor studied an aircraft-engine configuration using current technology engines or their derivatives to provide a basis from which to judge the difficulty of achieving the noise goals, or the relative cost in terms of DOC and ROI with current technology. This is a significant oversight.

d. The contractors did not truly assess the impact of inlet acoustic splitters. Nor was the loading produced by engine stall, the anti-icing bleed required, the accessibility for fan blade maintenance, and the impact of anti-icing the splitters on aircraft takeoff performance considered.

e. The airlines would probably look to operational procedures as the first step towards achieving the specified noise reduction goals. Additional acoustic treatment would be used to achieve the actual goal and every means of avoiding fixed inlet splitters would be examined prior to their acceptance.

f. Noise footprint areas were provided in the contractors' reports. It is suggested that this type of data be more carefully analyzed to determine the benefits of varying the goals at each of the three measuring stations defined in FAR 36. Uniform reduction of land area exposed to high noise levels, until the impact area lies within the airport boundary, should be the overall guide for noise research.

Pollution - General

The final reports of both contractors continue to suggest the use of water injection to meet the NASA emission goal for oxides of nitrogen (NO_x) of 3 pounds of NO_x per thousand pounds of fuel. The airlines believe that meaningful reductions in NO_x emission can be achieved through advanced combustion research. The airlines are unalterably opposed to the use of water injection either for thrust augmentation or for pollution control.

The bases for this position are:

a. The use of water injection in past and current engines has invariably led to marked deterioration of hot section parts life.

b. Engine reliability and aircraft dispatch performance are adversely effected, and

c. The cost of logistically supporting water injection is considerable.

Water injection should be considered only as a last resort. It is recommended that current emission goals be reconsidered, and that the NASA set emission objectives based on forthcoming Environmental Protection Agency

Standards. NASA's objectives should be to insure that the required state-of-the-art is available to meet stated requirements in a technically reasonable and cost/effective manner.

Economics - General

The assessment of economic benefits resulting from advanced technology and the costs associated with meeting the pollution and noise goals are the weakest area of the contractors' reports. In future studies and perhaps as a separate and distinct project, "economics" needs more study. It is the airlines understanding that the Department of Defense is also concerned about ownership and operational costs associated with advanced technology engines.

SUMMARY

The Advanced Transport Technology Propulsion System Studies produced a wealth of insight into the areas of research which require further or new effort to enable the challenges of lower noise and pollution to be met. This report although critical in nature is directed at providing additional insight into airline concerns. The normal goals of better fuel consumption and lighter weight need to be judged in the broader perspective of lower noise, lower pollution and lower system operating costs.

SECTION II: EVALUATION OF PHASE III - ADVANCED TRANSPORT TECHNOLOGY ENGINE STUDIES -- ASSESSMENT OF TECHNOLOGY READINESS

The following recommendations and conclusions are based on the final oral reports presented by the ATT Engine Study Contractors and address the state of the art projected to be required to enable future propulsion systems to meet the pollution, noise, performance and economic goals which must be achieved. The ATT engine study contractors did not present definitive statements as to the timing and research funding required to meet future objectives. Both contractors did provide recommendations concerning the research programs required to meet the NASA objectives for the late 1970 and mid-1985 time periods.

The following suggested research programs have been organized in a fashion to prioritize the research effort in categories of near and long range as judged appropriate from an airline point of view. The organization of the programs are based on a broader range of aircraft types being considered for the same 1975 and beyond time frame, and the combination of tasks in individual research projects to meet more than individual aircraft requirements.

Background

Long Range Plan for Propulsion Systems

Long range plans are of little value beyond the immediate time frame in which they are produced. The organization of data and the interfaces between requirements are, however, valuable in assessing an alternative course of action and project timing.

The airline environment is currently one of heavy economic and social pressures to reduce aircraft noise and pollution. The economic pressures are not expected to change even though airlines are beginning to return to a profitable status, but investments in new facilities and equipment are expected to be at a much slower rate than might otherwise be expected. The investment rate in new facilities and aircraft and the growth rate in cost of labor have far exceeded the growth rate of revenue. These trends must be reversed and effort over a considerable number of years will be required to achieve a proper balance. Effort to standardize fleet mixes, prolong the use of current in-service aircraft through interior re-arrangement/refurbishing are expected to dominate the efforts of airlines. The purchase of new aircraft of existing or under construction types will be slowed until well past the 1975 time period. Noise levels of current aircraft will be addressed by current research programs under FAA and NASA cognizance and a retrofit of noise attenuation devices is possible for the 1975 to 1978 time period. Reconsideration by the airlines of the economics of retiring current aircraft or retrofit may spur additional sales of current wide-body aircraft types beyond those currently planned or on option. The sale of unretrofitted current aircraft to supplemental or foreign carriers is judged to be highly improbable as other industrialized nations have similar serious noise problems and would undoubtedly require similar retrofit of their own carrier aircraft and impose suitable aircraft noise limits for access to national airports.

The combination of economic burdens placed on the airlines could probably defer additional new type aircraft purchase until the 1978 to 1980 time period.

In the 1978 time period there are several aircraft types open for consideration: super-sized wide-body jets of the 747 type, quiet

STOL aircraft and short field conventional aircraft of 727 to DC-10 size (100 to 250 passengers). The environmental pressures against new airport development pose serious difficulty in the development of a STOL transportation system. The airlines already are greatly concerned over the high dollar per mile cost of the 747 so that except in isolated cases, a super 747 does not appear attractive.

The use of existing airports of the 4000 to 5000 feet runway category to take over the short haul transportation function appears attractive for a variety of reasons; reduce large airport congestion, market expansion potential, population re-distribution, etc., particularly in terms of U.S. national long-range needs. Such aircraft must fit into the airport environment without negatively changing the community social, environmental, and economic nature. If this can be successfully accomplished, a STOL transportation system could be developed for the mid-1980 time period.

In long haul transportation a second generation SST is possible. However, the environmental pressures particularly noise, will have serious impact on the profit potential versus investment risk of such a project. SST's must meet the same noise requirements as conventional subsonic aircraft which will be below current FAR 36 requirements. This is an impossible challenge with todays state of the art. The ATT is a logical choice, as is a slightly transonic aircraft with good subsonic and low supersonic Mach number (1.3 to 1.6) capabilities. These aircraft types appear to have a better chance of meeting environmental acceptability criteria than a supersonic transport. A supersonic transport meeting FAR 36 minus 15 EPNdB is a monumental task currently impossible to achieve.

For long range large freighter aircraft and transports, the field of nuclear propulsion becomes attractive in the 1990 and beyond period, particularly in light of the world's dwindling known oil reserves.

In summary, research projects must be structured to fulfill the needs of projected aircraft propulsion systems, permitting as many alternative courses of action as are possible. The emphasis on engine economics with heavy stress on the maintenance labor element associated with engine operation, must not be overlooked. Pollution control is obviously an integral part of advanced research efforts.

Military requirements are expected to provide continued advancements in the field of materials, light weight components and high performance engines. The lack of emphasis on noise, pollution and economics, however, make the use of military developed engines highly unlikely. Considerable re-design of core engine components would undoubtedly be required to meet maintainability, reliability, life and other economic criteria of the airlines. The value of these technology programs, however, will be significant.

Technology Required

Through the 1978 time period, retrofit and short field CTOL seem to dominate the picture in airline advanced planning. The socio-political picture indicates that something must be done to the current narrow-bodied aircraft powerplants to correct the excessive noise produced. During the 1980 to 1985 era, STOL, a second generation SST and transonic type aircraft propulsion systems appear reasonable targets. In the 1990's, probably nuclear propulsion could be the "start" for advanced technology research.

Research Program Elements & Timing

NOISE

A. The noise research programs required for near term aircraft and retrofit are listed below, with 1976 the objective for availability.

1. Fan Noise Research
   - (a) Single stage high speed (1.7 to 1.9 pressure ratio)
   - (b) 2nd Stage low speed, high pressure (1.9 to 2.5) fans
   - (c) Inlet plus fan aero design integration.
2. Jet Noise
   - (a) Low speed jet (700' to 1500'/second)
   - (b) Effects of: turbine swirl, clearance tip speed, nozzle configuration, mixing, suppressors.
3. Operational Procedures --

   Validation of realism and effects of aircraft procedures including effects on psycoacoustic reaction (fear of crash).
4. Psycoacoustics --
   - (a) Relationship of social and economic factors,
   - (b) spectral shaping as an approach to reducing psychological reaction to noise, and
   - (c) Low velocity noise and house vibration/resonance on annoyance.
5. Reverser Noise & Control --

   Relationship to community annoyance.
6. Validation of current slant range noise levels (beyond 3000') to establish baseline footprints of existing aircraft.
7. Inlet shape and variable geometry effects on noise including,
   - (a) Sonic Inlets
   - (b) Retractable Splitters
   - (c) Variable Lip/Suck-in door

8. Advanced load carrying acoustic treatment materials.

B. Long Term Noise Research - Objective, completion by 1980.

1. Fan Noise
   - (a) Low speed low pressure ratio single stage fans (1.1 to 1.3) including variable pitch fan effects.
   - (b) Multi stage fans of very high pressure ratio, 1.9 to 3.0 (for STOL & SST).
2. Jet Noise
   - (a) High Speed Jets (1500'/second to 3000'/second).
   - (b) Low Speed (500' to 700'/second).
3. Combustion Noise - both basic combustor/duct burning and afterburning.
4. Acoustic Materials.
5. Aircraft noise-floor due to flaps and gear extended (STOL).
6. Psychoacoustics.

EMISSIONS

The control of emission is essential.

1. Demonstrate combustors with ATT goals for smoke, carbon monoxide and hydrocarbon emission levels in current high by-pass engines by 1975.
2. Validate effects of water injection on NO_x formation on various engines and demonstrate effects of other emissions by 1974.
3. Demonstrate advanced combustor system for NO_x control on appropriate real engines capable of reducing NO_x by one half by 1975, without water.

4. Dèmonstrate advanced combustion system capable of reaching ATT goals by 1979.
5. Review and investigate dispersion of pollutants from aircraft engines in upper atmosphere -- continuing program.

ECONOMICS OF GAS TURBINE ENGINE/PROPULSION SYSTEMS

Undertake a study effort to establish the cost benefit relationships of various engine design features as a guide to producing economically attractive propulsion systems to offset cost of meeting social requirements.

1. Maintainability criteria and design.
2. Reliability criteria for design.
3. Fuel consumption, purchase cost and maintenance cost relationships and trade-offs.
4. Cost for development, certification and production and minimization (realism of certification testing requirements).
5. Advanced engine diagnostics.

The timing is urgent and such a program should be started forthwith to insure better guidance than the current ATA methods for assessing engine design features.

ADVANCED TURBINES

Objectives for 1976 --

1. Highly loaded high speed turbines (reduced cost of high turbine modules).
2. Highly loaded low speed turbines (reduce cost of low speed fan turbine).

3. Turbine Materials -- improved life, higher temperature, lower cost.
4. Burst Protection.

INTEGRATED NACELLE DESIGN & AERODYNAMICS

Objectives for 1974 --

1. Weight reduction and improved economics.
2. Validate drag and performance of high speed nacelle configurations.
3. Economic utilization of material for acoustic treatment.
4. Maximize maintainability.
5. Improve engine design techniques and reversers.

ADVANCED ENGINE CONTROL & INSTRUMENTATION FOR 1973-74

1. Reliable and accurate instrumentation for operation and diagnosis of engine faults.
2. Engine controls which will provide desire/required power at fixed power lever angle during appropriate flight segment.

ADVANCED COMPRESSORS/FANS (1978)

1. Lower cost -- high stage loading, fewer blades -- for pressure ratios of 20 to 30.
2. Composite Materials.
3. Burst Protection.
4. Low deterioration of performance and stall margins.

SECTION III: PROPULSION SYSTEM RELIABILITY AND COST FOR UNSCHEDULED MAINTENANCE OF TODAYS AIRCRAFT

Introduction

The propulsion system for aircraft represents between 15 and 20 percent of an aircraft's purchase price and 45 to 50 percent of the cost of aircraft maintenance. The material covered in this section of this report addresses historical performance in terms of propulsion system reliability and the cost for unscheduled maintenance. Presented are data concerning the reliability of current propulsion systems as expressed in delays in scheduled aircraft departures with a breakdown of the delays by ATA coded subsystem. The economic impact of these delays is discussed in relationship to the estimated cost and in terms of gross profit per aircraft flight. Lastly the economics of premature removals is discussed with costs information of engine and subsystem premature removals and the importance of accessability and simplification of installation removal tasks.

Departure Reliability

Departure or dispatch reliability is usually quite poor when a new aircraft is introduced into service. Figure 1 shows the trend of Boeing 707 series aircraft dispatch reliability versus years of service. Each new aircraft follows the same trend. The airline concern is directed at the final level achieved. The following table (Table 1) shows 6 months average dispatch reliability performance as of March 1972 for several aircraft and the portion of the unreliability due to the propulsion system.

Figure 1

707/720 DISPATCH RELIABILITY

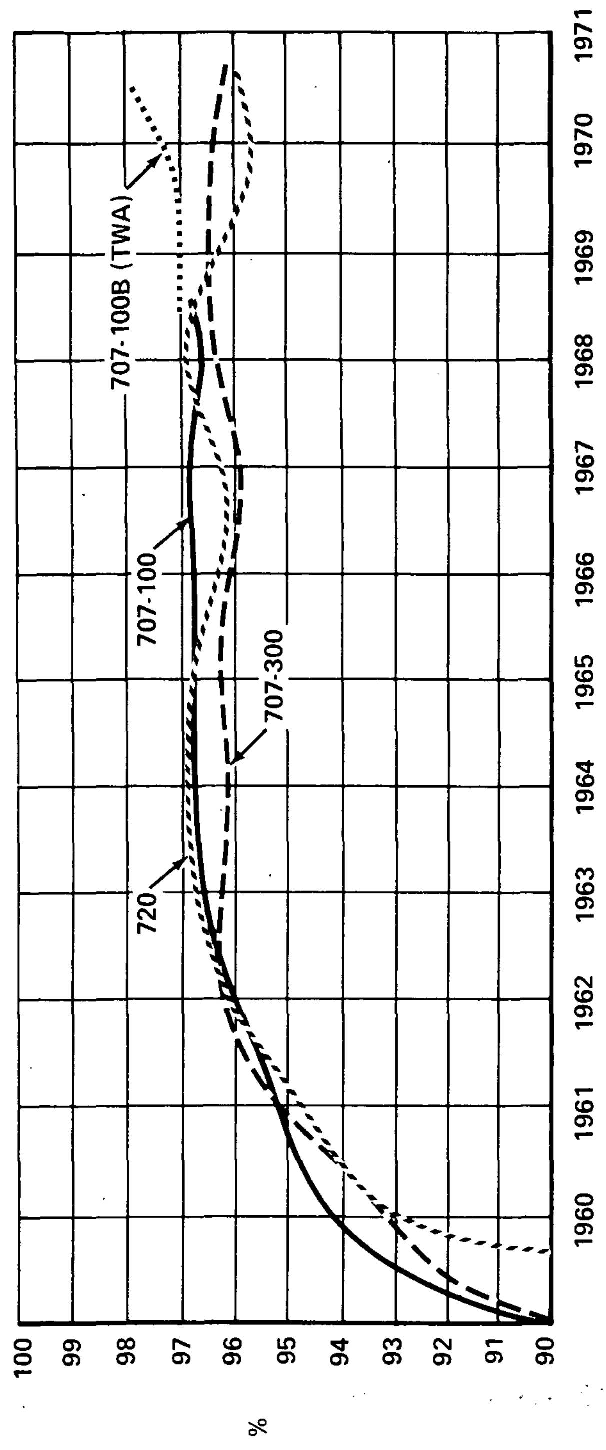

Table I

Aircraft Dispatch Reliability
(6 month average Oct. 1971 thru Mar. 1972)

	B727	B707	B747	DC-10*
Dispatch Reliability	98%	96.5%	93.3%	89.5%
Delays/1000 departure	20	35	67	105
Engine (D/1000 dep.)	5.2	8.7	19.9	21.5
(ATA Code 72-80) Sub-total	(26%)	(24.9%)	(29.8%)	(20.5%)
Total Powerplant (D/1000 dep.) (ATA 72 thru 80 plus 2410,2420, 2612, 2910	6.9	10.9	23.4	Not Avail.
% Total	(34.5%)	(31.1%)	(34.9%)	Not Avail.

*Note - first 6 months of service.

The engine as defined above includes all items of engine subsystems including starter, instrumentation and reverser/nozzle. See Appendix I for ATA coding of engine and subsystems. The second groups called powerplant includes all of the above plus the CSD (ATA Code 2410), Alternator/Generator (ATA Code 2420), fire detection system (ATA Code 2612) and hydraulic pumps (ATA Code 2910). These items are included because they are installed on the engines, subject to the engines environment, and require opening engine cowling for servicing. The design simplicity of removal and installation of these components effects the dispatch delay rates.

The basic engine (ATA Code 72) represents 8 to 10% of the delays caused by the total engine or propulsion system. The large bulk of the delays are caused by engine subsystems with starting, reverser and oil causing the majority. The oil pressure/temperature instrumentation is part of the oil system. Review of Table II which follows will provide the breakdown of delays by ATA code and length of delay.

Table II

Six-Month Delay Summary
October 1971 Through March 1972
(Rate: Delays per 1000 departures)

System	Delay Length (Mins.)	707-Psgr. No.	707-Psgr. Rate	707-Ftr. No.	707-Ftr. Rate	727-023 No.	727-023 Rate	727-223 No.	727-223 Rate	747 No.	747 Rate
72	6-29	6	.104	0	0	5	.085	4	.087	1	.156
	30-59	9	.156	3	.418	7	.119	2	.044	2	.312
Engine	60+	21	.364	9	1.254	15	.254	17	.371	8	1.248
	Total	36	.624	12	1.672	27	.458	23	.502	11	1.716
73	6-29	39	.676	1	.139	24	.407	10	.218	2	.312
Engine Fuel	30-59	13	.226	3	.418	11	.186	3	.065	2	.312
& Control	60+	18	.312	4	.558	10	.170	3	.065	4	.624
	Total	70	1.214	8	1.115	45	.763	16	.348	8	1.248
74	6-29	0	0	0	0	0	0	1	.022	0	0
	30-59	0	0	0	0	12	.203	4	.987	0	0
Ignition	60+	8	.139	3	.418	5	.085	7	.153	4	.624
	Total	8	.139	3	.418	17	.288	12	.262	4	.624
75	6-29	12	.208	2	.279	19	.322	13	.284	4	.624
	30-59	13	.226	2	.279	12	.203	7	.153	5	.780
Air	60+	10	.173	7	.976	21	.356	10	.218	3	.468
	Total	35	.607	11	1.534	52	.881	30	.655	12	1.872
76	6-29	4	.069	0	0	3	.051	5	.109	1	.156
	30-59	1	.017	0	0	4	.068	4	.087	1	.156
Controls	60+	2	.035	1	.139	1	.017	5	.109	1	.156
	Total	7	.121	1	.139	8	.136	14	.305	3	.468
77	6-29	6	.104	3	.418	3	.051	4	.087	3	.468
	30-59	3	.052	0	0	3	.051	0	0	1	.156
Engine Ind.	60+	3	.052	0	0	4	.068	2	.044	0	0
	Total	12	.208	3	.418	10	.170	6	.131	4	.624
78	6-29	69	1.198	5	.697	17	.288	14	.305	7	1.092
	30-59	35	.607	6	.836	9	.153	13	.284	9	1.404
Exhaust	60+	17	.295	3	.418	9	.153	9	.196	18	2.820
	Total	121	2.100	14	1.951	35	.594	36	.785	34	5.316
79	6-29	39	.676	0	0	19	.322	24	.523	6	.936
	30-29	34	.590	5	.697	19	.322	15	.327	7	1.092
Oil	60+	26	.451	6	.836	16	.272	7	.153	5	.780
	Total	99	1.717	11	1.533	54	.916	46	1.003	18	2.808
80	6-29	56	.971	4	.558	36	.610	44	.960	16	2.500
	30-59	35	.607	5	.697	14	.237	7	.153	10	1.560
Starting	60+	20	.347	4	.558	7	.119	7	.153	8	1.248
	Total	111	1.925	13	1.813	57	.966	58	1.266	34	5.308

Table II
(Cont'd)

System	Delay Length (Mins.)	707-Psgr. No.	707-Psgr. Rate	707-Ftr. No.	707-Ftr. Rate	727-023 No.	727-023 Rate	727-223 No.	727-223 Rate	747 No.	747 Rate
2410	6-29	17	.295	1	.139	4	.068	7	.153	0	0
	30-59	3	.052	0	0	7	.119	2	.044	0	0
CSD	60+	0	0	2	.279	1	.017	3	.065	1	.156
	Total	20	.347	3	.418	12	.204	12	.262	1	.156
2420	6-29	27	.468	1	.139	17	.288	5	.109	0	0
	30-59	16	.278	4	.558	3	.051	2	.044	1	.156
Generator	60+	10	.174	2	.279	7	.119	3	.065	2	.312
	Total	53	.920	7	.976	27	.458	10	.218	3	.468
2612	6-29	13	.226	1	.139	7	.119	8	.174	1	.156
	30-59	4	.069	0	0	3	.051	9	.196	0	0
Fire Prot.	60+	2	.035	3	.418	5	.085	13	.284	1	.156
	Total	19	.330	4	.557	15	.254	30	.654	2	.312
2910	6-29	7	.125	0	0	10	.170	8	.174	3	.468
	30-29	8	.139	1	.139	17	.288	8	.174	5	.780
Hyd. Pumps	60+	25	.433	8	1.115	17	.288	19	.414	8	1.248
	Total	40	.697	9	1.254	44	.746	35	.762	16	2.496

The Economics of Aircraft Departure Delays

The ability of commercial aircraft to leave the gate on a scheduled flight on time in the majority of instances has been one of the reasons for the growth of commercial aviation. Individuals planning business trips or trips for personal pleasure do not appreciate having carefully laid plans for meetings with associates or friends cancelled or rescheduled by a long delay or a cancellation of their planned flight. Airlines are sensitive to the fact that reliable performance in completing planned flights and in meeting flight schedules has an effect on their continued business success. In addition to this simple truism the purchase price of an aircraft of the ATT type will be high as is the space the aircraft occupies at the airport. The people who service the aircraft or provide the gate services for aircraft arrival and departures must also be paid. The ability to make a profit requires the efficient utilization of all of these resources. The key feature of all airline planning and scheduling is attempting to achieve the maximum practical utilization of these resources. The ability of the aircraft to arrive and leave the airport in a dependable fashion is a powerful function in this planning. A delayed departure is expensive and efforts are undertaken to avoid them. The cost for a departure delay is associated with the unrecognized utilization of the aircraft, the expense for crew time, passenger service personnel time, baggage service personnel time and snarls, the revenue lost as passengers in a hurry find other means of transportation, (normally a competitor) the cost for passenger assistance, and revised reservations and analysis of why the delays occur. If all of the delay costs are considered, excluding the cost of unrecognized utilization, Table III below represents the estimated cost of a delay. The ATT type aircraft will have at least the same expense per delay as the DC-10 and 747.

Table III

Cost per Delay
(Length of Delay in Minutes)

	0-29	30-59	60 and over
747	$160	$420	$1710
DC-10	140	350	1435
707 (Stretch)	100	280	1315
707	95	270	1230
727 (Stretch)	98	245	1100
727	90	230	950

Note: These cost are representative costs of an average delay variations of $20 or $30 for 0 to 29 minutes and 100 to 400 dollars for 60 minutes and over are possible depending on circumstances.

The cost of delay data given above are made up of four parts: 1) lost passenger revenue, 2) passenger handling costs for lost passenger, 3) operating cost (cost of crew, fuel and oil) and 4) analysis costs. The cost for maintenance effort, parts replaced or aircraft depreciation over unused hours is not included. If for accounting purposes it is assumed that the delayed time loss cannot be recaptured by operating longer another day, the cost for depreciation could be added raising the cost by between $200 and $400 per hour of delay. There is no continuing or return trip revenue loss (subsequent flight legs cancelled or delayed) included in the values covered above and if they were the costs would become very much larger. The average net profit per flight in a very good year would amount to $100 per flight with an aircraft mix similar to American Airlines. The larger the aircraft the larger the profit potential. For the ATT type aircraft an average gross profit per flight of $500 dollars should be projected. The cost of a delay equally projected would be between $2000 and $2500 per one hour delay. It would therefore take several flights with good payloads to recover the cost of a single delay over one hour. Improved reliability is essential for any new aircraft type.

The Economics of Premature Removals

The premature removal of any items of equipment due to failure or unsatisfactory operation prior to the expected maintenance inspection or repair period is equally expensive. In American's accounting system for reliability planned removals are not counted. Engines or components removed from service on a scheduled basis for replacement of life limited parts or upgrade modifications are not considered in the statistics reported below.

The basic causes for the unscheduled removal of engines are categorized below as a percentage of total engines removed.

Table IV

Basic Causes of Unscheduled Removals

Blade failure	17.3%
Bearing failure	13.1
Accessory drive failure	13.2
Cracked frame	11
Cracked casing	7.4
Leaking or cracked fuel or oil line	6.5
Carbon seal wear or failure	5
Performance loss	3.5
Pump wear or failure	3.1
Combustor distress	3
Vane failure	2.5
FOD	2
Imbalance	1

Note: Based on a sample of 2163 unscheduled removals.

Unscheduled engine removals are the most expensive aircraft component removal. The repair of the average prematurely removed low bypass ratio engine is 30,000 to 40,000 dollars. The cost to repair a prematurely removed high bypass ratio engine is expected to average between 100,000 and 120,000 dollars. Cost of repair of other prematurely removed minor components varies from $11 to $200. The repair cost of main engine fuel controls varies from $413 to $2430 as you move to the more expensive engines. Premature removal repair costs of starters vary from $220 to $1305.

The cost of premature removals can be segregated into removal/installation, transportation, repair, and testing. A large factor in the cost of removals is the manhours required for each of the task's set forth above. The installation and removal manpower requirements are influenced by the complexity of the installation and accessibility to the component for removal and replacement. The 2nd largest manhour requirements are associated with engine removal and the effort required to remove aircraft associated hardware (inlets, plumbing, components, etc.) from the engine such that repairs can be accomplished. The Quick Engine Change (QEC) configuration of the engine is a configuration where part of the aircraft installation hardware is installed. Normally this hardware includes instrumentation, fuel system plumbing, electrical and hydraulic systems, reverser/nozzle systems and inlets. Cowling and special position equipment is added later during installation to match the position for installation (inboard, outboard, center, right or left side).

Table V

Maintenance Elapsed Time & Manhours Required to Change an Engine, and to Strip or Rebuild the Quick Engine Change Configuration

Engine/Aircraft Model	Engine Change* Elapsed (Hr.)	Engine Change* Manhours	Q.E.C. Strip Elapsed (Hr.)	Q.E.C. Strip Manhours	Q.E.C. Build Elapsed (Hr.)	Q.E.C. Build Manhours
JT8D/727	8	40	8	12	24	80
JT3D/707	8	30	8	27	32	102
JT9D/747**	8	44	24	100	60	500
CF6/DC-10***	4	31	8	32	16	120

Notes: * Engine change time based on QEC configured engine.
** Accessories mounted on core.
*** Accessories mounted on fan in an Integrated Propulsion System Design.

Table V provides the elapsed time and manhours required for engine change and QEC strip and buildup. The JT9D installation, designed for minimum drag, requires 450 manhours of additional labor per engine change, strip and rebuild over the CF6 installation. The added cost is roughly $2250 per removal in direct labor. Elapsed time is also important and impacts spare engine requirements and aircraft delays and cancellations. These factors are the basis for the airlines insistence on an integrated pod design, outside gearbox (not mounted to the core), and excellent accessibility. In Table VI the demonstrated times to change various components are listed for the 747 pod and DC-10 pod. These times are indicative of what installation complexity or simplicity can do to replacement times and the possibility of delays. While only a few components have been listed there is sufficient indication of the differences to understand airline concern in this area.

Table VI

Power Plant Accessory Replacement Times
Engine/Aircraft

Unit	CF6/DC-10 (Wing) in Minutes	JT9D/747 (Wing) in Minutes
Anti-Ice Shut-Off Valve	6	23
CSD	12	17
AC Generator	39	96
Hydraulic Pump	11	45
H.P. Bleed Control Valve	12	60
Starter	4	45
Bleed Air Precooler	None	60
Oil Tank	19	33
Fuel Control & Pump	45	240
Fuel Flow Transmitter	15	49
Oil Cooler	25	40
Fuel Nozzle	13	105 to 240 (depends on location)
Hot Section B'scope	29	150

Airlines are concerned with small differences because they tend to get multiplied by large numbers.

Unscheduled Maintenance and Delay/Cancellation Costs

Table VII is a summary of 1971 estimated annual costs by ATA subsystem giving the cost per 1000 flying hours of delays, cancellations, pilot reported discrepancies

(PIREPS) and premature removals (P/R). These costs exclude engine costs and are directed at subsystems. These data are part of the management tools utilized to control costs and improve reliability.

Table VII

Estimated Cost for Unscheduled Maintenance,
Delays and Cancellations for 1971
($/1000 aircraft hours)

		727 Stretch	727 Standard	707-123/320-720	747
7310	Fuel Heating	16	27	51	428
7320	Fuel Control	136	375	250	338
7330	Fuel Flow Ind.	250	180	123	505
74	Ignition	282	345	-	245
75	Engine Air	570	361	207	1528
7711	EPR	104	102	67	267
7712	Tachometers	113	90	70	579
7722	EGT	77	95	82	189
7730	Vibration	82	67	44	138
78	Thrust Reverser	483	459	789	2328
7901	Oil leaks/Svcng.	160	107	143	347
7930	Oil Pressure Ind.	205	155	358	581
7931	Oil Quantity Ind.	131	112	47	253
8000	Misc. Starting	78	145	42	549
8011	Starter	215	200	592	1948
8012	Start Valves	672	343	106	224
$/(1000 A/C hr.) Total		2574	3163	2971	10447
or $ per A/C Hour.		2.58/hr.	3.16/hr.	2.97/hr.	10.45/hr.
A/C Total per/hour		$22.27/hr.	$21.22/hr.	$22.56/hr.	$83.44/hr.

(excluding engine premature removal and delay costs)

The importance of this data is the relative increases in costs for simple subsystems with advancing technology aircraft. If the DC-10 does not show marked improvement the airlines will be extremely disappointed. Whatever happens future aircraft must improve on the best that currently exists.

SECTION IV: DESIGN CRITERIA FOR FUTURE TRANSPORT ENGINES

Introduction

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.

It is possible that the annotation of these few principles will be considered redundant, however, experience has shown that each new engine design violates many of the principles set forth herein. The engineering design teams familiar with current and past problems are unfortunately not necessarily involved in the design of future products and mistakes previously overcome at great expense are often repeated.

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)

General Design

The engine as installed shall be designed for modular maintenance.

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.

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.

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.

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.

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.

Labyrinth Seals. Knife-edges of labyringth seals must run against a soft abradable material to maximumize 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.

Support/Handling Points. Ground handling points shall be provided on engine case to facilitate engine buildup and teardown and on all components and assemblies that exceed 44 pounds.

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 fitting which 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 blind assembly and captive fasteners should be used where access is difficult and dropped feasteners difficult to recover.

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.

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 cricital areas.

Engine Rotating and Stationary Parts

1. 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.

2. 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.

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

b. 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.

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

4. 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.

5. 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.

6. 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.

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

8. Provide means of ataching 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.

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

Fan

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

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

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

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

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

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

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

Low Compressor

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

High Compressor

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

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

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

4. 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.

Turbines

1. 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.

2. 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.

3. 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.

4. Replacement and repair of turbine blades are one of the most expensive elements of engine maintenance cost, and blade cracking is a large source of engine premature removals. Considerationof 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 acomplished with the engine installed.

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

Combustor/Fuel Nozzles

1. 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.

2. 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.

3. 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.

4. 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.

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

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

7. 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.

Structural Cases

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

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

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

4. Provide extra material (.020 to .030) in flanges to facilitate repair.

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

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

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

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

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

Bearings

1. 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.

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

3. Sumps must be easily replaceable.

4. 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.

5. 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 are not possible. Special attention should be given to split inner races.

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

Gearbox/Gearbox Drive

1. 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.

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

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

4. Spline repair procedure shall be provided.

Accessories, Plumbing and Wiring

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

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

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

4. Consider ease of replaceability of EGT thermocouples when selecting mounting design and type and location of wiring junction.

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

6. 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.).

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

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

9. Utilize trapped nuts or bolts where necessary to facilitate removal of external units.

10. Consider accessibility when selecting locking devices for nuts and bolts. (Lockwire requires more accessibility than tablocks.)

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

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

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

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

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

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

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

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

19. Provide wrench flats as necessary to facilitate tightening and loosening of gland nuts.

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

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

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

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

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

25. Let design be guided by the requirements for minimum time, minimum complexity and minimum cost.

SECTION V: RELIABILITY AND MAINTAINABILITY REQUIREMENTS FOR SUBSONIC COMMERCIAL AIRCRAFT PROPULSION SYSTEMS

Propulsion System Reliability Objectives

The reliability objectives for future aircraft will be that the total mechanical delays over 15 minutes plus mechanical cancellations and interruptions shall not exceed 2 percent of the scheduled departures during the last 6 months of the second year after introduction into scheduled service. During the last 6 months of the third year of service the total mechanical delays over 15 minutes plus mechanical cancellations and air interruptions should not exceed 1 percent of the scheduled departures. The objective is a dispatch reliability of 98% during the last 6 months of the second year and 99% during the last 6 months of the third year.

Current dispatch reliability performance of the Boeing 727 is 98%. The dispatch reliability of the Boeing 707 has averaged between 96.5 and 97.5% for a long period. The Boeing 747 and DC-10 as of March of 1972 had dispatch reliabilities of 95% with improvements in performance expected.

The powerplant contribution to aircraft mechanical delays, cancellations and air interruptions is not expected to change greatly in the future. Current propulsion systems are responsible for between 30 and 40 percent of disptach delays. In order to achieve the goals stated above the propulsion system for future aircraft must not produce more than 70 delays over 15 minutes per 10,000 departure as a 6 month average during the last 6 months of the second year of service, and not more than 35 delays over 15 minutes per 10,000 departures on average during the last 6 months of the third year.

The cost for delays beyond 1 hour increase rapidly. Additional design goals for delays over 1 hour have been established at no more than 25 delays per 10,000 departures during the last 6 months of the second year of service, and not more than 8 to 10 delays per 10,000 departures during the last 6 months of the third year of service.

The performance of current aircraft propulsion systems in meeting the 1 hour delay objectives based on 1971 data are as follows Boeing 727-21/10,000, Boeing 707 series - 28/10,000 and 747 - 98/10,000. In these delay rates the delays over 1 hour for the constant speed drive, generator, hydraulic pump and fire detection system have been included. The inclusion of these items is based on the rationale that installation and removal of such items is a function of the manner in which the pod is designed. Delay rates versus time for the majority of engine and installation subsystem can be studied by reviewing Table II in Section III. If only normal power plant components are included in the consideration of objectives (and this practice will be followed for the rest of this report) the 1971 annual experience for propulsion delays are 727 - 15/10,000, 707 - 22/10,000 and 747 - 80/10,000 departures. The objectives of 8 to 10/10,000 departures is approached the closest by the 727.

It is obvious that to meet the goals set forth that an allocation of permissible delays within powerplant subsystem must be made. The following table (Table VIII) is such a suggested allocation, and such allocations would be made by the contractors under normal development programs, with adjustments for the actual design. Boeing 727 experience is included in the table to illustrate suggested improvements and where relaxation can be tolerated.

Table VIII

Possible Allocation of Potential Departure Delays
Over 15 Minutes and Over 1 Hour

(Targets 35 delays/10,000 departures over 15 minutes and 8 delays/10,000 departures over 1 hour)

ATA Code	Over 15 min. Target	Over 15 min. B727 Exper.	Over 1 hour Target	Over 1 hour B727 Exper.
72 Engine	13.1	4.8	3.5	3.1
73 Engine Fuel & Control	5.5	5.5	1.4	1.2
74 Ignition	2.1	2.7	0.6	1.2
75 Engine Air	4.1	7.7	0.7	2.9
76 Engine Controlling	0.3	2.2	0.1	0.6
77 Engine Indicating	2.0	1.5	0.3	0.6
78 Exhaust	3.3	6.9	0.6	1.7
79 Oil	2.3	9.6	0.5	2.1
80 Starting	2.3	11.2	0.3	1.3
Total	35.0	52.1	8.0	14.7

Note: Objectives and experience for other pod subsystems are as follows:

ATA Code	Over 15 min. Target	Over 15 min. B727 Exper.	Over 1 hour Target	Over 1 hour B727 Exper.
2410 CSD	2.0	2.3	0.75	0.4
2420 Generator	2.0	3.3	0.75	0.9
2612 Fire Protection	1.0	4.5	0.10	1.8
2910 Hyd. Pumps	5.0	7.5	1.6	3.5

Reliability Requirements for Incorporation in Future Contracts

1. 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.

2. 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.

a/ Proposed "Dispatch Reliability Guarantee"

a.1/ - 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 disptach 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.

a.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%.

a.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)

3. 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

4. Definition of Parameters -

a/ 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.

b/ Mean-time-between-unscheduled-engine removals:

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

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.

5. 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 I. For the purpose of applying these criteria/goals it should be assumed that there will be 20 minutes available on scheduled through flight 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.

Maintainability Objectives for Future Propulsion Systems

Maintenance costs are a function of maintainability and unscheduled removal rates. The times required to isolate a fault, gain access, repair or replace a component and the manpower required are part of maintainability. The manpower and hours required to remove the engine, its quick engine change items and disassemble the engine, and repair and/or replace damaged parts is equally a part of maintainability. The efforts for the future must be on reducing premature removal rates and at reducing the labor and material required in maintenance. Section III of this report addressed the economics of unscheduled maintenance for current systems and Section IV the design criteria which is fundemental to maintainability. This section addresses the goals for future engine premature removal costs, engine and subsystem premature removal rate, and possible requirements for incorporation in future contracts.

An ATT type aircraft would be employed in American Airlines system in much the same manner as the current Boeing 707 series aircraft. The objectives for premature removal rates and costs would be expected to equal or better current performance with costs at least in proportion to the increase in seating capacity.

1. Engine Premature Removal Costs Projection & Goals - Based on current experience the average cost to repair an engine premature removal from an ATT aircraft would be estimated to be between 60,000 and 100,000 dollars. This estimate includes both labor and material. The range of this estimate considers the possible variation in engine maturity, installation configuration and areas of probable distress. The cost per hour for repairing premature removals can vary depending on actual rate achieved. Repair of premature removals is not the total cost of maintenance. To the cost for repair of premature engine removals must be added replacement of life limited parts, upgrade and modifications, and in-service inspection and servicing. The cost per hour projected by the ATA equation for the contractor selected engines would be from $45 to $50 dollars but from American's Task I Report, Figures 10, 11 and 12, the cost would be projected at between $65 and $70 an hour for the near term, 1978, ATT engine. In order to approach the ATA projected level of maintenance cost the premature engine removal rate must be equal or less than 0.2 per 1000 hours. A P.R. rate of .3 to .35 would produce the $65 to $70 per hour maintenance cost level. If aircraft hourly

direct operating costs are anticipated to be in the $2000 an hour range then the difference of 20 dollars per engine hour in engine maintenance cost represents a 3% change in direct operating cost.

2. Unscheduled Removal Rate Goals for ATT Engines and Components - In keeping with the objectives for reduced engine maintenance cost to improve overall aircraft operating economics Table IX presents by ATA code Mean Time Between Unscheduled Removal objectives and Time to Remove and Replace objectives for ATT propulsion system elements.

3. 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.

Table IX

Mean Time Between Unscheduled Removals and Removal and Replacement Time Goals for an ATT Propulsion System

ATA Code	MTBUR*	Remove and Replace Time as Installed
71 - Cowls		
71-10 Engine Nose Cowl	10,000 hrs.	1 hr.
72 - Engine	5,000 hrs.	2 hrs.
73 - Engine Fuel		
73-10 Distribution		
Heater Fuel	40,000 hrs.	45 min. (Max.)
Pump	10,000 hrs.	45 min. (Max.)
Valve	10,000 hrs.	45 min. (Max.)
73-20 Controlling		
Fuel Control	8,000 hrs.	45 min. (Max.)
73-30 Indicating		
Instrumentation	8,000 hrs.	45 min. (Max.)
74 - Ignition		
74-10 Power Supply		
Exciter	10,000 hrs.	20 min.
74-20 Distribution		
Plug	15,000 hrs.	20 min.
75 - Engine Air		
75-10 Engine Anti-Icing		
Valves & Regulators	10,000 hrs.	30 min.
77 - Engine Indicating		
77-10 Power		
Tach. Generator	10,000 hrs.	20 min.
Tach. Indicator	5,000 hrs.	20 min.
EPR Transmitter	5,000 hrs.	20 min.

Table IX (Cont'd)

ATA Code	MTBUR*	Remove and Replace Time as Installed
EPR Indicator	5,000 hrs.	20 min.
77-20 Temperature		
EGT Indicators	5,000 hrs.	20 min.
77-30 Analyzer		
Vibration	5,000 hrs.	30 min.
78 - Exhaust		
78-30 Reverser		
All elements	20,000 hrs.	Same as 72
79 - Engine Oil		
79-10 Storage		
Oil Tank	60,000 hrs.	45 min.
79-20 Distribution		
Oil Cooler	60,000 hrs.	30 min.
79-30 Indicating		
Oil Pressure & Temperature	7,000 hrs.	30 min.
80 - Starting		
80-10 Cranking		
Starter	10,000 hrs.	15 min.
Valve	7,000 hrs.	15 min.

*Mean Time Between Unscheduled Removals.

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.

Specific Engine Maintainability Requirements - 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 functions 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.

Maintainability Elements -

a/ - Predictability - 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/ - Postponeability - 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 occurred, but shall not compromise safe flight as defined by the FAA or aircraft contractor.

c/ - Fault Indication - 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/ - Fault Isolation - 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.

e/ - "AIDS"/"Bite" - 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. Dispatch Inoperative - 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. Predictability - 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 predicatble 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. For such 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 to 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.

General Maintenance Requirements, Guarantees & Design Objectives -

a/ - 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 three dollars per one hundred thousand dollars of the initial price, for the initial ten years of airline operation, and shall be suitably guaranteed.

b/ - Maintenance Manhours - (i) The mean direct manhours required for scheduled major maintenance when necessary, shall not exceed 2000, (ii) 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.

c/ - 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.

d/ - Scheduled Maintenance Programs - (i) 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, (ii) 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, (iii) corrective actions found necessary at other than the 500-hour check shall be achievable within the normal Through and Turnaround Service elapsed times.

e/ - 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.

f/ - Powerplant Assembly Removal - The time required to convert a 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.

CONCLUDING REMARKS

Noise and pollution control must dominate advanced research efforts for the forseeable future. The purpose of such research must be twofold however, to reduce noise and pollution, and to reduce the economic impact of achieving the reductions. Improvements in propulsion system reliability, maintainability and engine installation technology offer areas where economic benefits can be achieved. Advanced research projects must consider total engine economics as a major forcing function for the future. It is apparent that specific fuel consumption and specific weight improvements cannot by themselves produce the economic improvements necessary for a timely introduction of the results of noise and pollution research.

SPECIFICATION[1] FOR MANUFACTURERS' TECHNICAL DATA

SYS/ CHAP	SUB-SYS/ SECTION	TITLE	DEFINITION
72	ENGINE TURBINE/TURBO-PROP		
	-00	General	This topic is intended to cover general information, limits and procedures. In the engine overhaul manual this section would include such subjects as tear down, cleaning, inspection, assembly, testing, etc.
	-10	Reduction Gear & Shaft Section (Turbo-Prop)	The section of the engine which contains the propeller shafts and reduction gears. Includes items such as drives for nose mounted accessories, etc.
	-20	Air Inlet Section	The section of the engine through which the air enters the compressor section. Includes items such as guide vanes, shrouds, cases, etc.
	-30	Compressor Section	The section of the engine in which the air is compressed. Includes items such as cases, vanes, shrouds, rotors, diffusers, etc. Also includes the maintenance and overhaul of stator blades but not the operation of variable stator blades which is covered under Chapter 75 - 30. Does not include compressor bleed system.
	-40	Combustion Section	The section of the engine in which the air and fuel are combined and burned. Includes items such as burner cans, cases, etc.
	-50	Turbine Section	The section of the engine containing the turbines. Includes items such as turbine nozzles, turbine rotors, cases, etc.
	-60	Accessory Drives	The mechanical power take-offs to drive accessories. Includes items such as engine-mounted gear boxes, gears, seals, pumps, etc. Does not include remotely installed gear boxes which are covered in Chapter 83.
	-70	By-pass Section	The section of the engine which by-passes a portion of the normal engine airflow (either ram or compressed air) for the prime purpose of adding to engine thrust or reducing specific fuel consumption.

1 APPENDIX II contains pages 50, 52, 53, 54, 56, 57, 58, & 59 of ATA Specification 100, August 25, 1970

SYS/ CHAP	SUB-SYS/ SECTION	TITLE	DEFINITION
73		ENGINE FUEL AND CONTROL	For turbine engines, those units and components and associated mechanical systems or electrical circuits which furnish or control fuel to the engine beyond the main fuel quick disconnect; and thrust augmentor, fuel flow rate sensing, transmitting and/or indicating units whether the units are before or beyond the quick disconnect. Includes: Coordinator or equivalent, engine driven fuel pump and filter assembly, main and thrust augmentor fuel controls, electronic temperature datum control, temperature datum valve, fuel manifold, fuel nozzles, fuel enrichment system, speed sensitive switch, relay box assembly, solenoid drip valve, burner drain valve, etc. For reciprocating engines, those units and components which deliver metered fuel and air to the engine. The fuel portion includes the carburetor/master control from the inlet side to the discharge nozzle(s), injection pumps, carburetor, injection nozzles and fuel primer. The air portion includes units from the scoop inlet to the vapor vent return, and the impeller chamber.
	-00	General	
	-10	Distribution	That portion of the system from the main quick disconnect to the engine, which distributes fuel to the engine burner section and the thrust augmentor. Includes items such as plumbing, pumps, temperature regulators, valves, filters, manifold, nozzles, etc. Does not include the main or thrust augmentor fuel control.
	-20	Controlling	The main fuel controls which meter fuel to the engine and to the thrust augmentor. Includes items such as levers, cables, pulleys, linkages, etc., which are components of the fuel control units.
	-30	Indicating	That portion of the system which is used to indicate the flow rate, temperature and pressure of the fuel. Includes items such as transmitters, indicators, wiring, etc.

SYS/ CHAP	SUB-SYS/ SECTION	TITLE	DEFINITION
74		IGNITION	Those units and components which generate, control, furnish, or distribute an electrical current to ignite the fuel air mixture in the cylinders of reciprocating engines or in the combustion chambers or thrust augmentors of turbine engines. Includes induction vibrators, magnetos, switches, lead filters, distributors, harnesses, plugs, ignition relays, exciters, and the electrical portion of spark advance.
	-00	General	
	-10	Electrical Power Supply	That portion of the system which generates electrical current for the purpose of igniting the fuel mixture in the combustion chambers and thrust augmentors. Includes items such as magnetos, distributors, booster coils, exciters, transformers, storage capacitors and compositors, etc.
	-20	Distribution	That portion of the system which conducts high or low voltage electricity from the electrical power supply to the spark plugs, or igniters. Includes wiring between magneto and distributor in these systems where they are separate units. Includes items such as ignition harness, high tension leads, coils as used in "low tension" systems, spark plugs, igniters, etc.
	-30	Switching	That portion of the system which provides a means of rendering the electrical power supply inoperative. Includes items such as ignition switches, wiring, connectors, etc.

SYS/ CHAP	SUB-SYS/ SECTION	TITLE	DEFINITION
75		AIR	For turbine engines, those external units and components and integral basic engine parts which go together to conduct air to various portions of the engine and to the extension shaft and torquemeter, assembly, if any. Includes compressor bleed systems used to control flow of air through the engine, cooling air systems and heated air systems for engine anti-icing. Does not include aircraft anti-icing, engine starting systems, nor exhaust supplementary air systems.
	-00	General	
	-10	Engine Anti-Icing	That portion of the system which is used to eliminate and prevent the formation of ice by bleed air in all parts of the engine, excluding power plant cowling which is covered under Chapter 30. Includes items such as valves, plumbing, wiring, regulators, etc. Electrical anti-icing is covered in Chapter 30.
	-20	Accessory Cooling	That portion of the system which is used to ventilate engine compartments and accessories. Includes items such as valves, plumbing, wiring, jet pumps, vortex spoilers, etc.
	-30	Compressor Control	That portion of the system which is used to control the flow of air through the engine. Includes items such as governors, valves, actuators, linkages, etc. Also includes the operation of variable stator blades, but not the maintenance and overhaul, which shall be covered under 72-30.
	-40	Indicating	That portion of the system which is used to indicate temperature, pressure, control positions, etc. of the air systems. Includes items such as transmitters, indicators, wiring, etc.

SYS/ CHAP	SUB-SYS/ SECTION	TITLE	DEFINITION
77		ENGINE INDICATING	Those units, components and associated systems which indicate engine operation. Includes indicators, transmitters, analyzers, etc. For turboprop engines includes phase detectors. Does not include systems or items which are specifically included in other chapters.
	-00	General	
	-10	Power	That portion of the system which directly or indirectly indicates power or thrust. Includes items such as BMEP, pressure-ratio, RPM, etc.
	-20	Temperature	That portion of the system which indicates temperatures in the engine. Includes items such as cylinder head, exhaust (turbine inlet), etc.
	-30	Analyzers	That portion of the system which is used to analyze engine performance or condition by means of instruments or devices such as oscilloscopes, etc. Includes items such as generators, wiring, amplifiers, oscilloscopes, etc.

SYS/ CHAP	SUB-SYS/ SECTION	TITLE	DEFINITION
78		EXHAUST	Those units and components which direct the engine exhaust gases overboard. For turbine engines, includes units external to the basic engine such as thrust reverser and noise suppressor. For reciprocating engines, includes augmentors, stacks, clamps, etc. Excludes exhaust-driven turbines.
	-00	General	
	-10	Collector/ Nozzle	That portion of the system which collects the exhaust gases from the cylinders or turbines and conducts them overboard. Includes items such as collector rings, exhaust and thrust augmentor ducts, variable nozzles, actuators, plumbing, linkages, wiring, position indicators, warning systems, etc. Does not include power recovery turbines, turbo-superchargers, etc., nor noise suppressors or thrust reversers where they are not an integral part of the nozzle system.
	-20	Noise Suppressor	That portion of the system which reduces the noise generated by the exhaust gases. Includes items such as pipes, baffles, shields, actuators, plumbing linkages, wiring, position indicators, warning systems, etc. Use -10 where integral part of nozzle system.
	-30	Thrust Reverser	That portion of the system which is used to change the direction of the exhaust gases for reverse thrust. Includes items such as clamshells, linkages, levers, actuators, plumbing, wiring, indicators, warning systems, etc. Use -10 where integral part of nozzle system.
	-40	Supplementary Air	That portion of the system which varies and controls supplementary air flow to the exhaust system. Includes items such as tertiary air doors, actuators, linkages, springs, plumbing, wiring, position indicators, warning systems, etc.

SYS/ CHAP	SUB-SYS/ SECTION	TITLE	DEFINITION
79	OIL		Those units and components external to the engine concerned with storing and delivering lubricating oil to and from the engine. Covers all units and components from the lubricating oil engine outlet to the inlet, including the inlet and outlet fittings, tank, radiator, by-pass valve, etc., and auxiliary oil systems.
	-00	General	
	-10	Storage	That portion of the system used for storage of oil. Includes items such as tanks, filling systems, internal hoppers, baffles, tank sump and drain, etc. Does not include tanks which are an integral portion of the engine.
	-20	Distribution	That portion of the system which is used to conduct oil from and to the engine. Includes items such as plumbing, valves, temperature regulator, control systems, etc.
	-30	Indicating	That portion of the system which is used to indicate the quantity, temperature and pressure of the oil. Includes items such as transmitters, indicators, wiring, warning systems, etc.

SYS/ CHAP	SUB-SYS/ SECTION	TITLE	DEFINITION
80		STARTING	Those units, components and associated systems used for starting the engine. Includes electrical, inertia air or other starter systems. Does not include ignition systems which are covered in Chapter 74, IGNITION.
	-00	General	
	-10	Cranking	That portion of the system which is used to perform the cranking portion of the starting operation. Includes items such as plumbing, valves, wiring, starters, switches, relays, etc.

DISTRIBUTION LIST

	Copies
National Aeronautics and Space Administration Washington, DC 20546	
Code R, Mr. Roy P. Jackson	1
Code RD-M, Mr. Edwin C. Kilgore	1
Code RD-P, Mr. George W. Cherry	1
Code RD-T, Dr. Seymour C. Himmel	1
Code AAD-2, Dr. J. Ian Dodds	1
Code RG, Mr. Gerald G. Kayten	2
Code RH, Mr. Albert J. Evans	1
Code RA, Mr. William S. Aiken	1
Code RL, Mr. Harry W. Johnson	2
Code RW, Mr. George C. Deutsch	1
Code RE, Mr. Frank J. Sullivan	1
Code RX, Mr. Richard J. Wisniewski	1
Code RJ, Mr. J. J. Kramer	1
National Aeronautics and Space Administration Ames Research Center Moffett Field, CA 94035	
Code D, Dr. Hans M. Mark	1
Code FAV, Mr. Rodney O. Bailey	1
National Aeronautics and Space Administration Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135	
Mr. B. T. Lundin, Director, MS: 3-2	1
Dr. B. Lubarsky, MS: 3-3	1
Mr. M. A. Beheim, MS: 86-1	1
Mr. W. L. Stewart, MS: 501-5	1
Mr. R. W. Schroeder, MS: 501-5	1
Mr. J. H. Povolny, MS: 60-6	1
Mr. E. W. Conrad, MS: 501-4	1
Mr. C. C. Ciepluch, MS: 501-4	1
Mr. D. N. Bowditch, MS: 86-1	1
Mr. R. J. Weber, MS: 86-1	1
Dr. E. J. Rice, MS: 501-5	1
Mr. J. F. Dugan, Jr., MS: 86-1	1
Mr. A. J. Glassman, MS: 77-2	1
Mr. R. R. Secunde, MS: 500-202	1
Mr. R. J. Rulis, MS: 501-2	1
Mr. A. A. Medeiros, MS: 501-4	1
Mr. M. J. Hartman, MS: 5-9	1
Mr. S. S. Manson, MS: 49-1	1
Mr. J. B. Esgar, MS: 60-4	1
Mr. L. W. Schopen, MS: 500-206	1
Mr. L. M. Wenzel, MS: 100-1	1
Mr. A. Ginsberg, MS: 5-3	1
Mr. R. J. Antl, MS: 501-4	18

	Copies
National Aeronautics and Space Administration Flight Research Center P. O. Box 273 Edwards, CA 93523	
Code C, Mr. Lee R. Scherer, Director	1
Code R, Mr. D. A. Deets	1
National Aeronautics and Space Administration Langley Research Center Hampton, VA 23365	
Mr. E. M. Cortright, Director, MS: 106	1
Mr. O. W. Nicks, Deputy Director, MS: 103	1
Dr. J. E. Dubert, Assoc. Director, MS: 103	1
Mr. R. E. Bower, MS: 116	1
Mr. T. A. Toll, MS: 184	1
Mr. W. J. Alford, Jr., MS: 184	6
Air Transport Association of America 1000 Connecticut Avenue, NW Washington, DC 20036	
Mr. Vern W. Ballenger	1
Department of Transportation Federal Aviation Administration Washington, DC 20590	
Code RD-700, Mr. George P. Bates, Jr.	1
Grumman Aerospace Corporation South Oyster Bay Road Bethpage, Long Island, NY 11714	
Mr. Mark H. Siegel, Dept. 391; Plant 30	1
Headquarters United States Air Force Washington, DC 20330	
Lt. Col. Robert H. Blinn, Jr., AFRDQ	1
Department of the Air Force AFML Wright-Patterson Air Force Base, OH 45433	
Bernard Chasman	1

DISTRIBUTION LIST CONTINUED

	Copies
Department of the Air Force AFFDL Wright-Patterson Air Force Base, OH 45433	
Maj. Joseph E. Graetch	1
Lawrence Kummeth	1
Cecil Wallace	1
Secretary of the Air Force/SAFRDD Washington, DC 20330	
Laurence K. Loftin, Jr.	1
Department of the Air Force AFAPL Wright-Patterson Air Force Base, OH 45433	
George E. Thompson	1
Department of the Navy Naval Air Systems Command Washington, DC 20360	
James C. Taylor, Code AIR 530141C	1
Cornell Aeronautical Laboratory, Inc. 4455 Genesee Street Buffalo, NY 14221	
W. O. Breuhaus	1
Trans-World Airlines, Inc. 605 Third Avenue New York, NY 10016	
Edward A. Carroll	1
United Air Lines, Inc. San Francisco International Airport San Francisco, CA 94128	
Richard E. Coykendall	1
United Air Lines, Inc. P. O. Box 66100 Chicago, IL 60666	
Harry G. Lehr	1
American Air Lines, Inc. 633 Third Avenue New York, NY 10017	
M. B. Fannon	20

	Copies
Pan American World Airways, Inc. Pan Am Building New York, NY 10017	
William F. Hibbs	1
Wright-Patterson Air Force Base AFAPL/TBP Wright-Patterson Air Force Base, OH 45433	
L. J. Obery	1
Eastern Air Lines, Inc. Miami International Airport Miami, FL 33148	
James E. McMillen	1
Delta Airlines Atlanta Airport Atlanta, GA 30320	
W. J. Overend	1
Gates Learjet Corporation P. O. Box 1280 Wichita, KS 67201	
Ronald D. Neal	1
National Aeronautics and Space Council Executive Office of the President Washington, DC 20502	
Richard D. Fitzsimmons	1
Department of Transportation Office of Secretary of Transportation Washington, DC 20590	
Lawrence P. Greene, Code TST-22	1
Department of Transportation Joint DOT/NASA Noise Abatement Office Washington, DC 20590	
Louis J. Williams, Code TST-53	1
McDonnell-Douglas Corporation 3855 Lakewood Boulevard Long Beach, CA 90801	
Mr. R. T. Kawai	1

	Copies
North American Rockwell Corporation 430[illegible] Avenue Columbus, OH 43216	
Reid B. Lyford	1
William E. Palmer	1
Bell Aerospace Company Buffalo, NY 14240	
Alan Coles	1
Mr. William M. Magruder Special Consultant to the President White House Washington, DC 20500	1
LTV Aerospace Corporation Vought Missiles and Space Company 3221 North Armistead Avenue Hampton, VA 23366	
Charles W. Pearce	1
Northrop Corporation 1800 Century Park East Century City Los Angeles, CA 90067	
Sidney A. Powers	1
Joint DOT/NASA CARD Implementation Office 400 7th Avenue, SW Washington, DC 20590	
William N. Gardner, Code TST-31	1
Mr. S. M. Nehez Deputy for Development Planning Aeronautics System Division Directorate for General Purpose and Airlift Systems Planning (XRL) Wright-Patterson Air Force Base, OH 45433	1
Department of the Air Force AFSC Wright-Patterson Air Force Base, OH 45433	
Col. Francis J. McNamara	1

	Copies
Lt. Col. Alan M. Edwards Executive Office of the President National Aeronautics and Space Council Washington, DC 20502	1
The Boeing Company Commercial Airplane Group P. O. Box 3707 Seattle, WA 98124	
Mr. G. W. Hanks, Mail Stop 79-57	2
Lockheed-California Company Dept. 74-31 Plant 2, Bldg. 202 P. O. Box 551 Burbank, CA 91503	
T. Sedjwick	1
General Dynamics Corporation Convair Aerospace Division P. O. Box 748 Fort Worth, TX 76101	
A. J. K. Carline	2
Lockheed-Georgia Company 86 South Cobb Drive Marietta, GA 30060	
R. H. Lange, Zone 401, Dept. D/72-79	2
Mr. C. J. Schueler, Chief Aerodynamics Division von Karman Gas Dynamics Facility Arnold Research Organization, Inc. Arnold Air Force Station, TN 37389	1
NASA Scientific and Technical Information Facility P. O. Box 33 College Park, MD 20740	
Attn: NASA Representative	10

(Enclose copy of Document Release Authorization (DRA))

DISTRIBUTION LIST CONTINUED

	Copies
Detroit Diesel Allison P. O. Box 894 Indianapolis, IN 46206 Attn: Mr. D. H. Jacobson	1
General Electric Company Attn: Mr. W. L. Collier Aircraft Engine Group Cincinnati, OH 45215	2
Pratt & Whitney Aircraft Attn: Mr. G. L. Brines 400 Main Street EB 1F-3 East Hartford, CT 06108	2
Rohr Corporation Attn: Mr. S. L. Beggs P. O. Box 878 Chula Vista, CA 92012	1
Procurement Executive Ministry of Defence Attn: Mr. Ray Holl AD/Eng Dr Room 144 St. Giles Court 1-13 St. Giles High Street London WC2H 8LD England	1
Wright-Patterson Air Force Base ASD-XRF/T. Durham Dayton, OH 45433	1