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Development and Logistics Technical Program Plan Engines and Fuel Systems

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINSTRATION
TECHNICAL CENTER
Atlantic City Airport, N.J. 08405

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

EXECUTIVE SUMMARY

INTRODUCTION.

During the past 20 years, much progress has been made to advance commercial and general aviation in concert with advancements in engine technology. Recent demanding requirements for engines consuming less fuel, producing significantly less noise and pollution, and insuring maximum dependability in airline service have brought about rapid development of advanced turbomachinery designs to achieve higher thrust and higher efficiency. The introduction of these newer technology propulsion systems into commercial service must be achieved with an equal or better propulsion safety and reliability than existing capability. The definition of these advanced air-breathing engine system configurations and the desired state-of-the-art advancements, requires research and development efforts of components, materials, and structures techniques applicable to these engines, to be modified as needed to adapt to lessons learned and changing needs.

The National Transportation Safety Board (NTSB) continues to report that a significant number of general aviation accident types are directly or indirectly related to the propulsion system. However, FAA review of the details of these reported incidents indicate that only five percent of the accidents are propulsion oriented, per se. The FAA Technical Center will establish programs designed to understand and reduce the propulsion system related percentage. The FAA Headquarters and Regions will be continually updated on such progress.

This Propulsion Safety Engineering and Development Program Plan has been formulated to accomplish these goals.

OBJECTIVES.

The objective of the Engineering and Development Program Plan for Propulsion Safety is to:

1. Be responsive to FAA Headquarters' and Regions' propulsion related problems in a timely and expert matter.
2. Evaluate upon request of FAA Headquarters and/or Regions, propulsion service difficulties.
3. Contribute solutions to improve propulsion system safety and reliability which will provide a framework for future technology standards.
4. Maintain state-of-the-art knowledge relative to propulsion system technology developments and investigate those areas which show promise of improved propulsion system safety or reliability.
5. Establish expertise in pertinent fields related to propulsion safety.

ISSUES.

The following are areas of investigation that have been identified by FAA Headquarters and/or the Technical Center as requiring R,D,T&E efforts:

1. Aircraft Turbine Engines.
    a. Ingestion Criteria
        1. Birds
        2. Water
        3. Ice
        4. Other

b. New Production In-service Surge Margin Measurement and Definition.

c. Safety Fuels

1. Adaptability to Current and New Engines

2. In-service evaluations

d. Containment capability of propulsion systems.

e. Current engine related in-flight shutdown causes.

f. Maintenance of state-of-the-art technology in propulsion safety and reliability

2. Aircraft Piston Engines.

a. Use of alternate fuels.

b. Air induction system icing problems.

c. Engine related general aviation accidents.

3. Propulsion Function Systems.

a. Effectiveness of power management system.

b. Component redundancy requirements.

TECHNICAL APPROACH.

In this Propulsion Plan, various project tasks have been defined as either near-term or long-term efforts. Near-term tasks are those work tasks which vary in length from one to three years to reach a solution or a product.

Long-term tasks are those efforts which, due to lack of basic data or technical expertise, require more than three years to achieve a satisfactory solution or product. Within each of the identified areas of investigation, those tasks that are considered long-term will be identified as such; all others are considered near-term. Where possible, the

long-term tasks are grouped
together in the latter part of the discussion of each task area.

The approach to accomplish objectives in both near- and long-term tasks will usually be as follows:

1. Utilization of available background data.
2. Development of new data bases.
3. Development of analytical techniques.
4. Validation of analytical techniques.
5. Cost/benefit analysis of data to determine feasibility for consideration as the basis for regulations, standards, criteria, etc.

SCHEDULE.

The overall schedule of the major subdivisions of investigations are depicted in Figure 1. These are expanded in those sections that describe in detail the approach to investigatory solution.

PROGRAM MANAGEMENT.

The management of the Propulsion Safety Program will be performed within the Engine/Fuel Safety Branch, ACT-320. The overall administration, coordination, and technical responsibility for the execution of the RDT&E efforts are accomplished under the direction of ACT-320. Program accountability and responsibility has been assigned to the Program Engineering and Maintenance Service, APM-700, in FAA Headquarters under the Associate Administrator for Development and Logistics, ADL-1. Other major participants within the FAA include, but are not limited to, Office of Aviation

Safety (ASF), Office of Flight Operations (AFO), Office of Airworthiness (AWS), and the Engine Certification Regions.

Certain projects will require expertise, facilities, and/or scheduling which are beyond current FAA Technical Center capabilities. In order to obtain the most cost effective and timely results, participation from activities outside of FAA will be requested. These participants will include, but not be limited to, the following organizations: United States (U.S.) Air Force/Navy/Army, Arnold Engineering Development Center, and National Aeronautics and Space Administration (NASA) Lewis.

An informal communication channel will be established between the NASA, Army, Air Force, and Navy Aircraft Propulsion community to exchange data.

FUNDING REQUIREMENTS.

Total program contract funding requirements are as follows:

FY	1984	1985	1986	1987	1988	1989	1990	1991
TOTAL($000)	575	3010	5155	4425	1325	480	260	80

NOTE* = Actuals

MANPOWER REQUIREMENTS.

The milestones contained within this plan are based on effective utilization of in-house engineers and technicians. This manpower will be adjusted within specific tasks as new critical problems arise. The baseline in-house manpower resources required for the plan are as follows:

FY	1984	1985	1986	1987	1988	1989	1990	1991
MY	21	22	24	24	20	15	15	10

1, INTRODUCTION.

° GAS TURBINE ENGINE TECHNOLOGY GROWTH.

Since the advent of commercial jet transports, numerous types of gas turbine engine have been used and are being considered as power plants for commercial, business, general aviation aircraft, or rotorcraft. Although the basic thermodynamic cycle is the same for all, each engine type has its own particular design and reliability, and/or maintenance requirements. Based on a review and analysis of the National Transportation Safety Board (NTSB) accident reports, Flight Standards Service Difficulty Reports (SDR), technology trends, potential areas that could impact safety are identified.

Current gas turbine engines will continue in service for many years into the future. To maintain and/or improve the performance, reliability, durability, and sizing accelerated mission testing as well as sophisticated analytical supporting programs as a means of effectively controlling unplanned removal and inflight shutdown rates. Newer and more fuel efficient gas turbine engines will continue to be introduced. These engines are expected to employ vastly improved technology such as higher turbine inlet temperature, lower turbine cooling flows, increased bypass ratios, increased power extraction levels, etc. Therefore, airworthiness criteria must be reviewed constantly. Criteria addressing these new requirements should be based upon testing, investigations, evaluations, results, and/or projections, should supply sufficient technical information to support the conclusions in each area.

° GENERAL AVIATION GROWTH.

In the 10-year period (1973-1982), general aviation flying has increased approximately 27 percent in aircraft hours flown and approximately 26 percent in numbers of aircraft flown. During this period, the average number of accidents has decreased approximately two percent and the average number of accidents had decreased approximately 1.5 percent.

For this same period, the average number of fatal accidents has decreased 2.0 percent. NTSB data reports that approximately 24 percent of the most prevalent accident types are related to the propulsion system. The FAA analysis, however, indicates that the engine caused accidents are approximately 7 percent. Even at this low percentage figure, the FAA feels improvement in safety to reduce the number of fatalities and accidents is mandatory. One of the critical, propulsion-system related problems that contributes to these accidents is operation in a diverse environmental conditions. Both the air and the fuel entering the engine are affected and can produce severe operating conditions for the engines. In addition, cooling air and system temperature effects are considered important contributions toward durability problems. High temperature exhaust systems are critical with regard to material strength and integrity.

Based on the above, this plan contains projects to be undertaken to evaluate light aircraft piston engines to establish baseline data for critical environmental conditions along with other factors determined from further analysis. In addition, effort will commence to advance the state-of-the-art with the view toward developing means to minimize the incidence of post-crash fire in general aviation aircraft.

To insure that commercial and general aviation aircraft power plants continue to be reliable and safe, it is necessary to maintain updated regulations and standards methodology. This understanding will produce several worthwhile accomplishments: (1) anticipation of changes where necessary, which will improve the current airworthiness code for future propulsion systems; (2) establish testing requirements that will provide the technical data needed to assess regulatory codes; and (3) evaluate new technology advances where appropriate.

° FUEL SAFETY.

The expanding use of the wide-body or jumbo jet aircraft has increased the concern that exists regarding post-crash fires involving aircraft which transport hundreds of passengers in a single aircraft. Post-crash fires involving these aircraft can be of catastrophic proportions, as was tragically demonstrated at Tenerife in 1977. Aircraft, such as these, dictate that safety fuels (antimisting type or equivalent) must be seriously considered and evaluated. If successfully developed, future commercial airliners incorporating the use of safety fuels can minimize the loss of life, equipment, and property due to the post-crash fire. The propulsion system involvement in these post-crash fires must be clearly defined. The problems associated with the use of antimisting fuels, while addressed in Reference 1, must also be examined and evaluated under this plan to assure that interaction with the propulsion system is considered. Typical areas of concern are the heat transfer on engine materials, including the oil system components; the effects of the fuel on hot section components and on the present engine cycles; and the effects of the fuel one engine performance.

° SYSTEMS FUNCTIONAL RELIABILITY AND INTEGRATION.

Systems integration, with regard to aircraft propulsion systems, relates to the reliability of the total installed systems. These include the fuel system and its components, the engine and its components, and all of the other support systems, functions, and operational equipment needed to make the entire aircraft function as a unit in a safe, reliable, and airworthy manner.

1.1 PROGRAM OBJECTIVES.

The overall objective of this program is provide FAA Headquarters and Regions with independent supporting technical data to assess current service problems and to determine the adequacy of current regulations for future engine certification.

The objectives will be accomplished by close coordination with all pertinent FAA suborganizations. The Federal Aviation Administration (FAA) Technical Center will utilize historical data from various sources. The results of the analysis of such data will lead to an assessment of the Federal Aviation Regulations (FAR) requirements. Sources such as NTSB, FAA's Accident Incident Data System (AIDS), and Service Difficulty Reports (SDR) will be given prime consideration for the construction of this data base. Prime responsibilities for action resulting from analysis of accident data, AIDS, and SDR rests with the lead region. Research and development efforts to support these actions will be accomplished by contract, interagency agreement, or performed in-house (depending on funding, scheduling, and/or on-site technical ability) at the Technical Center's direction.

1.2 PROGRAM TECHNICAL APPROACH.

The tasks delineated within each subprogram element are efforts which develop the technical data base to support an advisory position and/or technical recommendation on the particular element. Portions of the program can be accomplished at the Technical Center or through outside contracts, including interagency agreements (IA) which allow the FAA the expeditious access to, and use of, other agencies' in-house and contractual capabilities.

As a continuing effort, survey of data sources such as NTSB accident reports, Airworthiness Directive, Advisory Circulars, Advance Notices, and Notices of Proposed Rulemaking and their related dockets will be maintained and catalogued. This compendium of information will be analyzed to serve as a data base identifying areas of concern or where technology gaps exists and will be used, in part, to establish individual projects such as are listed in this plan. Continuous coordination of such data with other FAA activities will be mandatory.

1.3 PROGRAM STRUCTURE.

This plan provides for a coordinated FAA engine and fuel systems safety development effort. It is intended to be a living document with flexibility to respond to and/or anticipate the needs of other FAA activities. It has been structured into major categories in order to separate specific interest groups. These categories are as follows: Aircraft Gas Turbine Engine Safety/Reliability, Aircraft Piston Engine Safety/Reliability, and Engine and Fuel Systems Functional Reliability.

Aircraft turbine engine work is subdivided into mechanical reliability, aerodynamic/thermodynamic reliability, and state-of-the-art investigations. The aircraft piston engine effort is broken into the same categories. System functional reliability is common to both the gas turbine and piston engine areas.

1.4 FACILITY CAPABILITIES/REQUIREMENTS.

Within each subprogram area, the facilities necessary to achieve the objectives are described, along with the capabilities of the specific facility. In those areas where it is not practical or cost effective to provide or maintain a specific capability, alternate approaches are addressed.

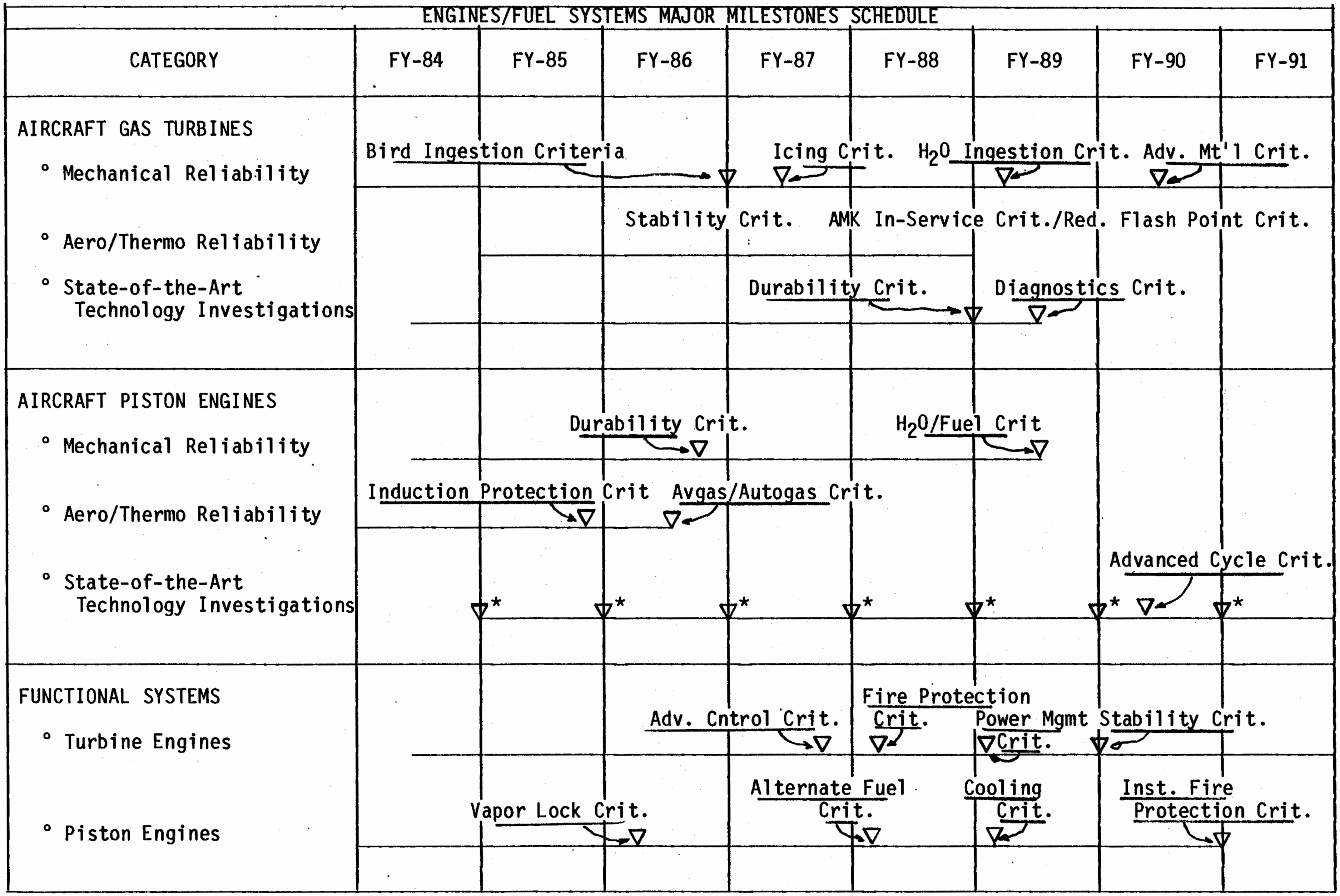
1.5 INTERAGENCY PARTICIPATION.

In order to be cost effective, this program plan is predicated upon maximum utilization of facilities and ongoing/planned development efforts of other government agencies. In support of this effort, the following assumptions are made:

a. Wherever possible, joint programs with common objectives are and will be utilized in order to preclude costly duplication of efforts and facilities.

b. Establishing the technical data base is of prime importance. Efforts will be made through workshops, meetings, etc., to provide visibility and understanding of propulsion problems and to develop approaches to their solution.

FIGURE 1



*Continuous Evaluation of SDR/AIDS events.

2.0 AIRCRAFT TURBINE ENGINES.

Since aircraft gas turbine engines are experiencing a wider appeal for application in various types of aircraft (from large, wide-body multiengine transports to small, business-type aircraft), it has become evident that the FAA needs to expand and further develop its data and technology base. In the mechanical, aerodynamic and thermodynamic reliability, and state-of-the-art technology improvement areas which need to be investigated and evaluated. The data to be collected or obtained as a result of conducting the various tasks will be used to support the solution to aircraft propulsion service problems, support the revision/improvement of regulatory code(s) pertaining to these systems(s), and foster an improved state-of-the-art capability.

2.1 Mechanical Reliability.

The objective of the mechanical reliability efforts are to substantially increase the general knowledge of, and to document reliability. This data can be used to guide improvements to the current and future airworthiness of aircraft gas turbine engines.

2.1.1 Ingestion Criteria.

Using analysis, scaled testing, and/or representative-type engines, investigate and evaluate engine ingestion problems, such as birds, water, ice, or foreign objects. These investigations and evaluations will be guided by the requirements of Federal Aviation Regulation (FAR) Part 33, Foreign

Object Ingestion, Section 33.77, Airworthiness Standards, Aircraft Engines, as the basic criteria for this task.

The technical approach to be employed for bird ingestion and water ingestion criteria development is as follows:

a. Bird Ingestion - A study of bird ingestion by large high bypass ratio turbine engines is being conducted. The prime objective of this investigation is to obtain statistical samples of the numbers, sizes, and types of birds which are ingested into large high bypass ratio turbine engines durng in-service use and what damage, if any, results. This information will be used to determine the effectiveness of the bird ingestion criteria of Title 14 of the FAR, Paragraph 33.77 regarding in-service operations. Further emphasis on this subject is noted in Reference 2.

   Basic data relative to bird strikes on large high bypass ratio engines has been obtained. The long-term technical approach will use selected portions of this near-term result to establish criteria and parameters needed to investigate bird strikes relative to "small" turbofan engines. The bird strike problem, relative to small turbofan engines, is believed to be significantly different than that of the large engines, due to the sensitivity of system operations to changes in aerodynamic characteristics, i.e., reduced core airflow due to blockage or changes to fan airfoil shapes. The ability of the fan to centrifuge birds into the fan air stream together with engine performance changes during uniform and non-uniform water ingestion conditions could be assessed using the same rigs as noted above.

c. Ice Ingestion - One area of turbine engine certification for safe operation in adverse environmental conditions that has not received extensive attention is that of ice crystal ingestion. Current requirements address the ingestion of sheet ice and hailstones, but the knowledge of what impact ice crystal ingestion has on blade perforamnce is lacking. Scaletesting will be conducted to examine these problems.

d. Other Foreign Object Ingestion - There have been numerous instances of tire failure during both the takeoff and landing modes. The ingestion of fragments of these tires has given a random picture of the severity if such occurrences. Research is underway in other program areas to minimize such tire failures but no criteria is forthcoming from the engine standpoint, i.e., is there a critical size or type of fragment that must be controlled or avoided. Scale investigations and analyses will be conducted in this area.

2.1.2 Advanced or Improved Engine Materials.

This effort will be a continuing-type task which will monitor the state-of-the-art progress that is made by government and industry in development of new, advanced materials for aircraft gas turbine engines. The prime purpose of this task will be to catalog their use and application and, where

2. Compressor aerodynamics during transient operation will be investigated, and effects of water ingestion on performance will be evaluated. Dynamic performance of a fan engine during ingestion of water will be determined by computer simulations. Changes in engine performance characteristics versus the nature and extent of control system changes necessary to meet the desired conditions will be considered.

3. Effectiveness of Analytically Modeling Water Ingestion. Fuselage generated engine inlet distortion will be examined by analytical modeling of the aircraft flow characteristics during various flight conditions. A study to determine the proper similitude parameters applicable to scale model data of engine water ingestion phenomena, including water droplet size and water sheeting from aircraft surfaces will be performed. If feasible, a study using a scaled aircraft model in a wind tunnel will be initiated to validate data obtained from the analytical results.

4. Effects on Landing Gear Water Spray on Engine Operation. Landing gear water spray must have no significant adverse effect on engine operation during the taxi, takeoff, or landing phases relative to runway standing water depths. Recent related problems during certification of small jets have been reported. A study will be made of the factors involved in complying with FAR 25.1091. Is it reasonable to have a set of requirements for small business jet airplanes

which comply with FAR 25 and which are separate from the requiremetns of large air carrier airplanes?

5. Full Scale Testing. Service experience to date indicates that current certification requirements for water ingestion do insure safe engine operation under reasonsable rainfall conditions. Periodically, "what if" questions arise which can only be answered by specifically tailored tests. Such tests are typified by full-scale engine test. Such a program involves testing a full-scale engine under sea-level and altitude conditions while an engine is operating at various performance levels and simultaneously ingesting water. Spool down and/or surge characteristics would be of prime concern. Mechanical condition of the engine would be noted through special instrumentation. Such testing results in an exceptionally high expenditure of funds. Therefore, specific objectives and justification are prime requisites, in order that such tailored options be exercised.

Completion of the above full-scale rig evaluation may necessitate full-scale engine testing to verify critical findings. This full-scale engine testing would be confined to specific engine applications which are agreed necessary by the FAA propulsion community.

A long-term technical approach will be used for water ingestion testing. Fan versus core water/air ingestion ratios during uniform and non-uniform water ingestion conditions could be assessed using the same rigs as noted above.

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2.2 Aerodynamic/Thermodynamic Reliability.

2.2.1 Engine Stability.

This task will be undertaken to identify new production in-service surge margin measurements. The effects of deterioration on the surge margin of these engines will be considered.

This effort will be one of considerably long duration and will require its conduct be done utilizing other than in-house facilities. Potential approaches include the use of NASA or DOD aircraft on which "control" engines are mounted. Detrailed testcell and installed performance levels would be identified at the start of the control period. Tracking of the installed performance over incremental time periods and detailed documentation of operating conditions and/or damages incurred would be maintained. Test cell repaet of the baseline performance would be conucted at periods prior to and after engine removal for overhead or repair.

2.2.2 Antimisting Fuels Evaluation.

The major task, with regard to determining the usability of antimisting fuels in current and future aircraft propulsion systems (beyond its flammability characteristics in a crash instance), is its compatibility with these systems and the system components. Feasiblity tests must be conducted to ascertain the general compatibility of the engine(s) to function satisfactorily and safely with a selected safety fuel that may be developed to diminish crash-fire hazards. In addition, the aircraft fuel system and its components (pumps, valves, filters, etc.) must be capable of handling this fuel in all flight regimes and during all operating conditions and evnironments. Engine-mounted fuel system components (fuel control, pumps, filters, pressurizing and dump valves, heat exchangers, etc.) must also be able to handle this fuel without performance degradation or compromising in-flight operation, starting, relite, etc.

Compatibility-type testing will be performed on antimisting fuels which have been screened through initial feasibility tests and which have been deemed as the best currently available. This engine compatibility testing is an integral part of the antimisting fuel program noted in Reference 1, will be evaluated using the selected candidate fuels on flow bench rigs or simulated engine fuel systems. Methods of validating degraded fuel, including the sensitivity of individual engine components to the fuel, will be explored. Flow characteristics and/or visual examination will be used to determine the suitability of the fuel for use in-service.

Full-scale engine feasibility testing will be initiated after the compatibility evaluation has been established. This testing will document potential operational problem areas associated with short-term usage of potential operational problem areas associated with short-term usage of antimisting fuel. The successful completion of this testing will serve as a major milestone to approve the flight test engine for evaluation, as noted in the Reference 1 program plan. There will be continued coordination and integration of all propulsion compatibility efforts related to antimisting fuel.

In-Service Evaluations.

The technical approach used for the fuel system evaluation of AMK is the concern for system and component integrity or reliability in lieu of the effectiveness of antimisting fuel in a crash. The latter was demonstrated in Reference 3 Plan. A prototype degrading system was developed and flight tested under FAA contract No. DTFA03-83-C-00018. Predictive analysis was demonstrated over the period of this contract by actual flight testing on a Convair 880 aircraft.

Data resulting from this contract will be analyzed and optimization determined. Flight testing on this available system will be implemented into a second phase in with approximately 200 hours of accumulated operating time on AMK. Our Technical Center will be used as the base of operation for this flight test. Fuel handling and blending will be accomplished by our on-line personnel.

The flight testing will be accomplished by contracted personnel. Concurrently with the effort selected, NASA aircraft(s) will be configured to accept a typical AMK fuel system and flight tested for approximately 100 hours. it should be noted that this AMK testing will piggy back other basic NASA testing. Results of both these aforementioned tests will be used to support with confidence actual air cargo inflight evaluation.

2.2.3 Reduced Flash Point/Alternate Fuel Compatibility.

The future utilization of reduced flashpoint kerosene, as an aircraft fuel, is becoming more of a possibility due to the energy shortage. The increased volatility of reduced flashpoint kerosene is the most important distinguishing factor from Jet-A to determine their effects on safety. It is necessary to test fuels that have this property carefully defined. One objective of this program plan is to determine experimentally how the physical and flammability properties of reduced flashpoint kerosene compare with those of standard ASTM D-1655 specification Jet-A fuel.

More jet fuel can be made from a barrel of crude oil if one is willing to accept a Jet-A fuel specification which has extended on both the lighter and heavier ends. Extending the lighter end of Jet-A fuel will lower its flash point. A relaxation in the flash point of Jet-A would probably have little, if any, effect on aircraft performance, although components could be affected by lower fuel lubricities. This same lower flashpoint fuel would decrease some safety aspects by an unknown amount in the areas of handling post crash fires and vulnerability to lightning strikes.

Broadening the jet fuel specification on the heavy end will increase the freeze point of the fuel. This does create an increased safety consideration in that the aircraft operator will need to manage his fuel temperatures more closely to prevent fuel freezing. Aircraft performance will probably decrease using fuels with heavier ends with dirtier exhaust fumes.

The aircraft industry is not likely to accept the performance penalities with using jet fuel with increased heavy ends.

2.3 State-of-the-Art Technology Investigations.

2.3.1 Durability.

Improved engine fan-blade fragment containment capability and materials which can better absorb the energy associated with fan-blade fragments will be examined.

This task will also address uncontained engine failures, which include a continuous comprehensive data search and analysis of past uncontained engine failures. With assistance of the regions, classification of incident consequences will be accomplished in order to identify areas of greatest potential improvement. These studies are directed toward commercial aircraft and include only the fixed-wing type for the present with expansion to other categories being a long-term task. These results will be analyzed to determine follow-on efforts.

2.3.2 Evaluation of Future Engine Diagnostic Methods.

Recent advancements in computer technology have brought about more effective use of engine diagnostic systems. These systems, when used in conjunction with current "on-condition maintenance" concepts, should result in optimum engine utilization while further enhancing engine reliability. This project will identify, define, and assess the impact of these future engine diagnostic systems on maintenance philosophy.

2.4 Facility/Capability Requirements.

2.4.1 Ingestion Rig/Facility.

The antimisting fuel wing spillage facility will be modified and expanded upon to provide a capability to conduct bird, water, ice, and other foreign object investigations. Incorporation of a shute injector for bird carcasses and water spray/fog nozzles at the inlet section to the facility are required. Existing engine installation run-up pads at the exit section of the facility will be modified to allow installation of motor driven fan assemblies for bird and other ingestion investigations at the fan station. The use of small turbine engines mounted behind the facility but in the flow stream will allow ice crystal and compressor blockage tests.

The facility offers the capability of investigating the ingestion phenomena while the enigne is at an actual flight condition (with an actual installation inlet, if desired) and with the ingested material in a real life condition.

Hot wire anemometry, high speed photography, laser sheet illumination of selected inlet planes, droplet size and liquid water content instrumentation as well as standard pressure, temperature, and other physical parametric measurements will also be available. Operation of this facility for icing tests, however, will be limited to wintertime operation.

2.4.2 Fuel System Simulator Rig Test.

Representative aircraft/engine type fuel simulation test rigs, which can be used to evaluate engine fuel system problems will be employed in the Engine

Fuel Components Facility to identify critical operation problem areas associated with fuel system component performance and antimisting fuel compatibility. Attention will be given to component operations at fuel temperature extremes.

2.4.3 Full Authority Electronic Control Analyzer.

Computerized analysis of the performance, response, and failure modes of advanced engine fuel controls will also be conducted within the Engine Fuel Component Facility. This will enable operation of these advanced controls under simulated conditions of environment and load.

2.5 Program Schedule and Program Management.

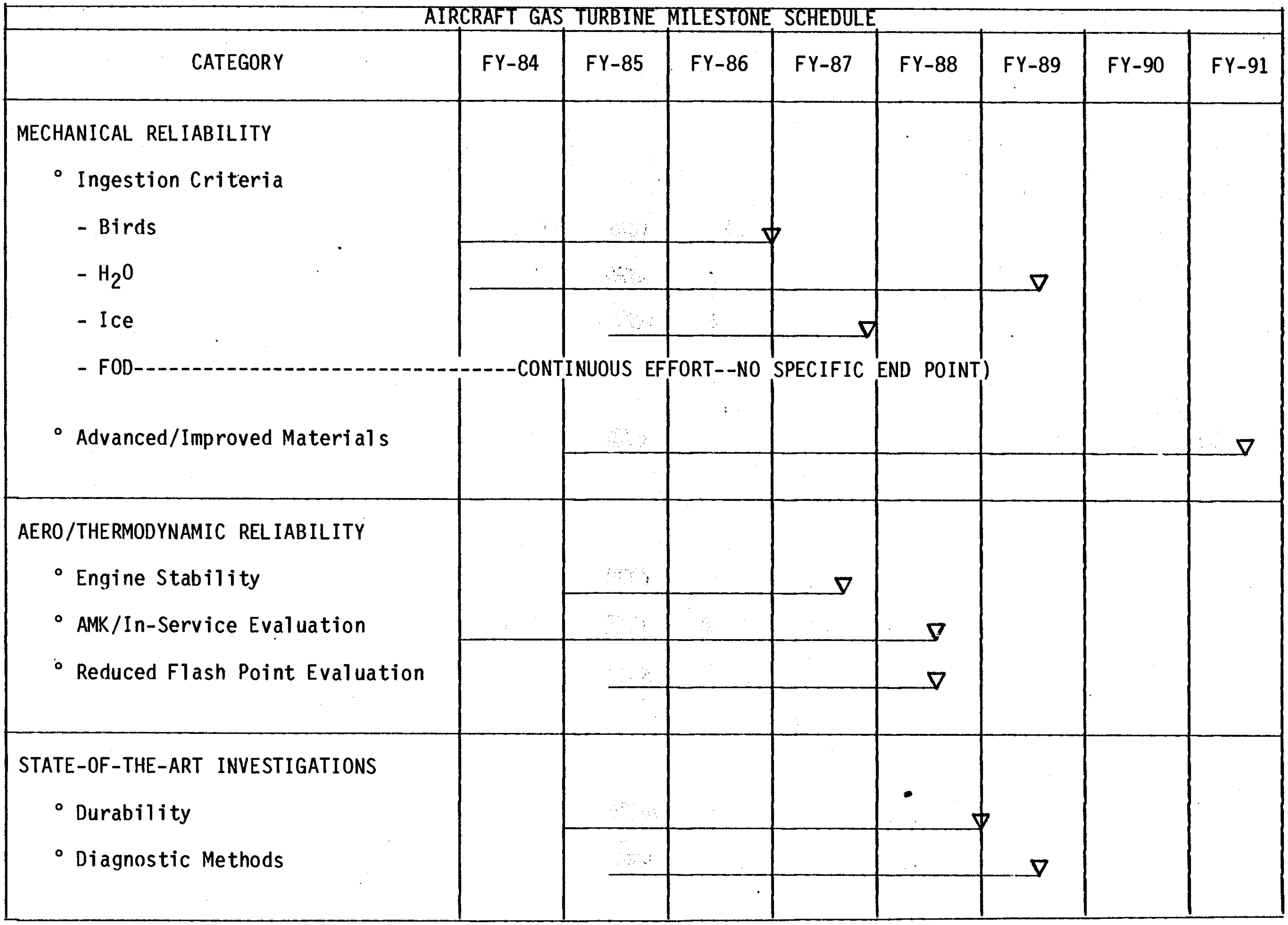
The near-term program schedule for aircraft gas turbine engine reliability is outlined in Figure 2.

2.6 Funding Requirements.

Aircraft gas turbine engine reliability contract funding requirements:

FY	1984	1985	1986	1987	1988	1989	1990	1991
TOTAL ($000)	440	2220	4025	3375	870	140	100	20

FIGURE 2


AIRCRAFT GAS TURBINE MILESTONE SCHEDULE
CATEGORY
FY-84
FY-85
FY-86
FY-87
FY-88
FY-89
FY-90
FY-91
MECHANICAL RELIABILITY
° Ingestion Criteria
- Birds
- H2O
- Ice
- FOD--------------------------------CONTINUOUS EFFORT--NO SPECIFIC END POINT)
° Advanced/Improved Materials
AERO/THERMODYNAMIC RELIABILITY
° Engine Stability
° AMK/In-Service Evaluation
° Reduced Flash Point Evaluation
STATE-OF-THE-ART INVESTIGATIONS
° Durability
° Diagnostic Methods

3.0 AIRCRAFT PISTON ENGINES.

The expanded growth in general aviation flying during the past 10 years has been matched with an annual increase in the number of accident-related fatalities. As stated earlier, although the NTSB reports that approximately 24 percent of the accident types are propulsion system related failures/malfunctions, this percentage is misleading because these propulsion system failures have varied from pilot mismanagement of fuel to actual malfunctions/failures in propulsion functional systems and components (cylinder, valve, rod, line-failures, etc.).

This section defines important aircraft piston engine project tasks to substantially increase general knowledge and document how engine safety and reliability data can be used to improve the current and future airworthiness of this class of engines. A greater understanding of the above (by expanding the current data bank and by additional documentation) will provide a criteria on which to base future engine development and for reasonable modifications to current engines.

At the present time, the most significant items affecting the overall safety, reliability, and airworthiness of light aircraft piston engines deal with mechanical reliability, aerodynamic/thermodynamic reliability, and the state-of-the-art technology. Therefore, separate project areas covering the above items and their impact on airworthiness are presented.

3.1 Mechanical Reliability.

3.1.1 Durability/Material Investigations.

Investigations are necessary to evaluate benefits that can be derived if new materials are incorporated in future piston engine designs. The material changes to be evaluated would be examined from the standpoint of improved safety. All material changes considered and evaluated must also take into consideration the need to be compatible with any and all fuels and oils that could be certified for use in such engine(s).

The operational environment of engines presents another aspect of long-range durability. Investigations of methods that can be applied to improvement in engine cooling characterisitcs and limits can impact such durability as related to type of fuel being utlized.

3.1.2 Fuel System Related Investigations.

In 1983, the National Transportation Safety Board (NTSB) forwarded to the FAA recommendations (A-83-3 through A-83-11) which related to aircraft engine failure or malfunction accidents in United States general aviation aircraft involving water in the fuel as a cause/factor. Using today's techniques, detecting the presence of water in aircraft fuel tanks is extremely difficult, perhaps impossible to prevent; and the pilot/ground personnel are never 100% certain whether it does exist or has been eliminated, regardless of aircraft type. Methods and/or techniques will be explored to give a more simple, positive indication of water in the fuel system.

Analytical and full-scale sea-level aircraft fuel system (for instance, Cessna 150 or 172) testing will be utilized to provide positive validation of proposed methods for simple position indication of water in the fuel, then repeated with known increasing amounts of water added to the aircraft fuel system.

Long term surveillance and evaluation of the technical advances made in the area of aviation fuels as these advances specifically apply to general aviation needs and requirements will be maintained. Through this project, the FAA will maintain an active and on-going program to insure that any attempts to introduce new fuels (additives or alternate fuels) will not result in compromising airworthiness. Alcohol, ethanol/methanol, and/or turbine fuels, such as Jet-A, are typical examples of alternate fuels.

3.2 Aerodynamic/Thermodynamic Reliability.

Projects in this area concern present day piston engine induction system problems associated with carburetor icing, induction system moisture ingestion, and carburetor anti/deicing. Utilizing representative type certificated engines, this investigation will provide the technical data necessary to assess the airworthiness of existing FAR regulations for present off-the-shelf equipment, and state-of-the-art advancement. As a result, criteria for engine certification and operational limitations for safety requirements may be reassessed. Analysis and testing of typical off-the-shelf carburetor ice detector devices has ascertained how ice formation propagates through the carburetor of a typical small piston-type engine. This information will be used as the foundation for future induction system testing.

3.2.1 Induction System Investigations.

These investigations will be accomplished by installing a representative-type carburetor aircraft piston engine in sea-level propeller test installations which have the capability to produce water and icing conditions to simulate actual sea-level/low-altitude conditions. The effects of moisture ingestion, carburetor icing, and anti/deicing requirements will be investigated and evaluated. Advanced ice detectors will be evaluated to determine their effectiveness. Improved methods of detecting carburetor icing will be considered.

Representative engine nacelle configurations will be used. Instrumentation to measure the cooling air pressure differentials, quantities, flow direction, and temperature patterns relative to the engine cylinders will be analyzed. Correlation with actual flight test data can be accomplished in a follow-on effort, if neccessary.

Further expansion of installed engine instrumentation will also provide data to identify critical temperature areas in the nacelle and on the engine. This data will also be used in evaluations and analyses of fire protection requirements.

Bsaed on the approaches described herein, it is advisable for parallel programs to be utilized so that an expanded program data base will be developed. Additional engines may include other carburetor, fuel injection, and/or turbocharged types. Follow-on flight test work may be undertaken if test-stand results indicate that such evaluations and development data are needed.

3.2.2 Fuel Investigations.

Investigations and evaluations of the current fuel situation dictate analytical efforts and experimentation are necessary. Currently, certain light aircraft pilots and owners have requested and received approval for the use of autogas as an alternate fuel for aviation gasoline. It has been determined that the FAA needs to expand its technical knowledge and understanding of the characteristics and properties of the various fuels available in the marketplace. A better understanding of these fuels requires knowldege of correlation factors, similarities and dissimilarities between fuels, critical fuel parameters, differences in additives and other chemical constituents and properties, etc.

3.3 State-of-the-Art Technology Investigations.

3.3.1 Airworthiness Analysis.

Continual review and analysis of all available data relative to accidents, incidents, maintenance, and repair records will be conducted. Computerized analysis of the statistical information resulting from these reviews will be relied upon to categorize the relative importance of each area toward maintenance of airworthiness.

3.3.2 Advanced Cycle Analyses.

Within the continual increase in sophistication of avionics equipment, general aviation aircraft are engaging in more and more areas that require improved performance from the power plant. Likewise, the need for economy of operation is forcing the technology into more exotic regimes. This effort will be comprised almost entirely of analysis of the thermodynamic cycles suitable to achieve these required levels of performance improvement. The investigation of cycles that will allow the safe use of less expensive fuels (kerosene, for instance) and the ramifications of such usage will be under constant analysis and assessment.

3.4 Facility Capabilities/Requirements.

The capability of evaluation of a full general aviation propulsion system is available through the use of several facility components.

Dynamometer Operations - Typically an effort that requires experimentation, is initiated using the test capability of an Eddy Current Dynamometer. In this facility, basic engine operating characteristics and limits can be obtained.

Sea-Level Run-up Stands - As a second step in the experimentation, the propulsion system can be operated in a sea-level run-up stand configured to provide actual airframe fuel system components, but wtih club or clipped propeller to permit reasonable loading.

Flight Simulation - The final step involves the installation of the propulsion system into the pertinent component of the airframe. This can then be mounted in position behind the antimisting fuel wing spillage facility (which then supplies the flight airflow). In this facility, environmental variations are also possible.

3.5 Program Schedule and Program Management.

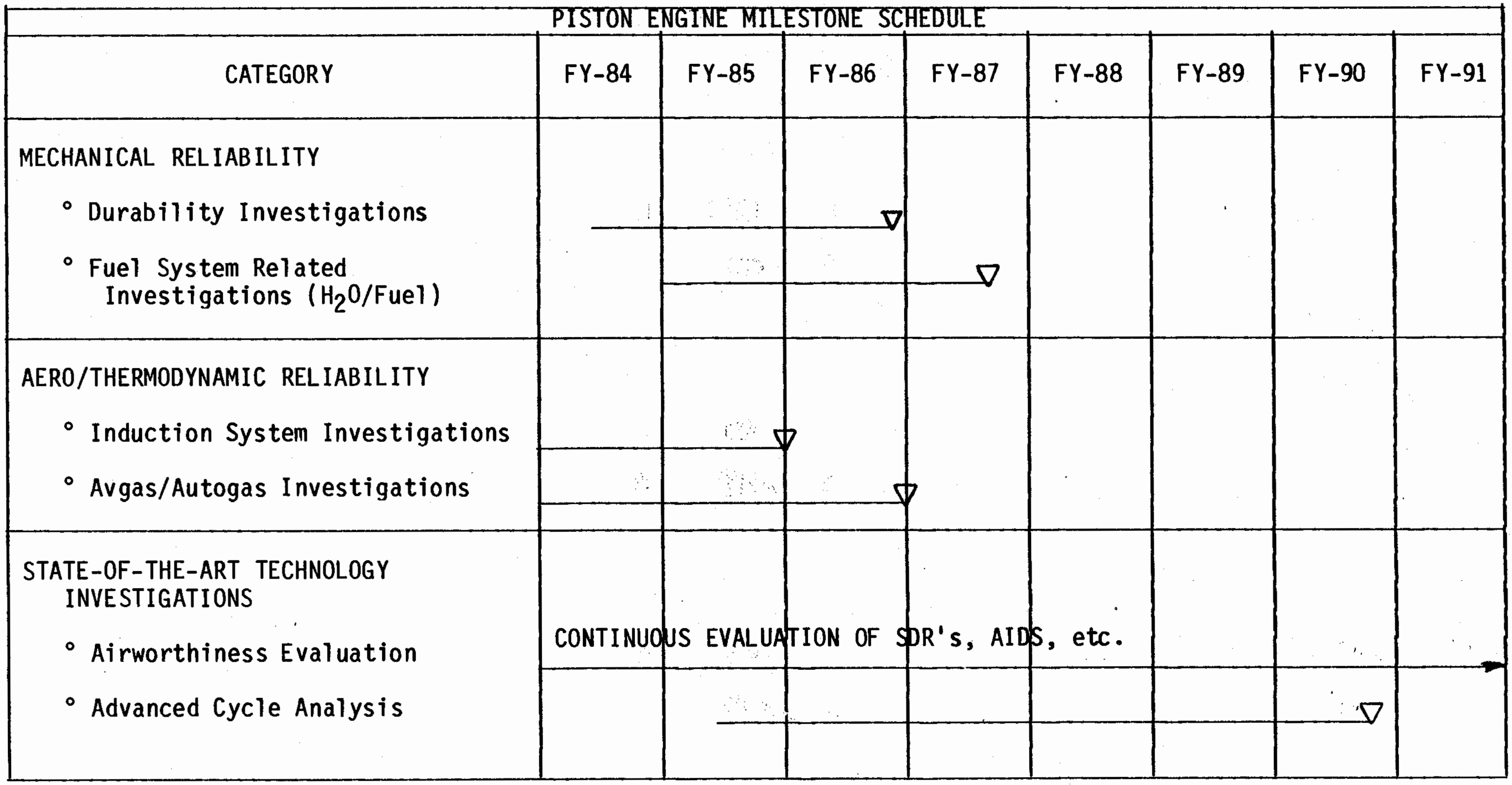
The program schedule for aircraft piston engine safety and reliability is outlined in Figure 3. The program management will be set forth in Section 4.

3.6 Funding Requirements.

Aircraft piston engine safety and reliability program funding requirements are:

FY	1984	1985	1986	1987	1988	1989	1990	1991
TOTAL ($000)	55	300	260	280	375	155	60	40

FIGURE 3


PISTON ENGINE MILESTONE SCHEDULE
CATEGORY
FY-84
FY-85
FY-86
FY-87
FY-88
FY-89
FY-90
FY-91
MECHANICAL RELIABILITY
° Durability Investigations
° Fuel System Related Investigations (H_2O/Fuel)
AERO/THERMODYNAMIC RELIABILITY
° Induction System Investigations
° Avgas/Autogas Investigations
STATE-OF-THE-ART TECHNOLOGY INVESTIGATIONS
° Airworthiness Evaluation
° Advanced Cycle Analysis
CONTINUOUS EVALUATION OF SDR's, AIDS, etc.

4.0 FUNCTIONAL SYSTEMS.

The aircraft/propulsion functional systems have become consistently complex in the last 15 to 20 years. Consequently, validation of their reliability and functional integrity have become more of a technical challenge. These factors have become even more complex because modern aircraft functional systems, particularly propulsion systems, are being designed to incorporate mechanical and electronic features for effective power management. Some of this complexity has come about as a result of airworthiness and flight safety requirements which require redundant and fail-safe features as well as to improve efficiency and economy of operation.

Major areas are advanced fuel system assessment, power management, component redundancy requirements, and installation protection. From the FAA's standpoint, it is necessary to evaluate the degree of complexity that can be permitted without compromising airworthiness and flight safety.

Propulsion functional systems efforts emphasize the interaction of the control system on the overall engine performance and power management systems. Engine diagnostic systems are evaluated relative to their ability to predict critical engine parameter changes.

As with turbine engines of the commercial area, sophistication has developed in the general aviation piston field also. These developments have been generated by the trend toward use of alternative fuels, the drive for improved efficiencies which are forcing more and more airframe streamlining (and the subsequent tightening of engine nacelle areas) and the need for providing additional protection against fire as these developments progress.

4.1 Turbine Engines.

- Advanced Control Systems.

Technology advances in control systems have been primarily pioneered by the engine manufacturers for military aircraft purposes. With the advent of the new, efficient, aircraft such as the B767, B757, and A310, etc., use of this technology is expected to become commonplace. Criteria must be developed by the FAA to assure that safety is maintained when these new technologies are certified for commerical use.

Areas that will be examined include the normal practice of use of the aircraft fuel to dissipate the heat load produced by the electronic controls. The impact of this heat input to the fuel will be analyzed. The beneficial aspects of heat addition to fuels such as the antimisting type will be examined as trade offs considereing that the cyclic cooling systems may cause a loss of misting protection. Also, anticipated long service use of such a fuel cooling system must be examined with respect to potential leaks, and detection or suppression of potential fires.

4.1.2 Power Management Technique Effectivity.

The various manufacturers of turbine engines employ different principles of power management. Such power management techniques are selected to take advantage of specific design features of these different engines and are primarily to effect better efficiency of operation. There are other aspects, however, that have bearing on the degree of safe operation that

FAA must be aware of and fully understand. Control of engine power, for instance, by using low pressure rotor speed as the independent parameter can conceivably be ignoring the stall margin of the high pressure rotor and as such, may be causing operations to be conducted at a marginally safe point for fuel efficiency purposes alone. The initial thrust of these efforts will be to conduct sensitivity analyses on critical parameters. To conduct supporting experimentation, small, high bypass ratio engine will be selected and tested (in a sea-level test cell) to enable comparison of the effectiveness of the different power management systems.

4.1.3 Stability Investigations.

The review of SDR's and monitoring of in service characteristics has revealed that practically all aircraft/engine combinations exhibit unexplained and apparently random instances of compressor stall/surge. The operational conditions at the time of these unexplained instances is often well within the expected operating envelope, where such stall/surge is not expected. Because of these occurrences, in flight shut downs have occurred. The thrust of this effort will be to conduct analyses using existing engine performance and component performance computer decks and evaluate those parameters that could be associated with stall/surge margins. Once in hand, experimentation will be conducted to monitor these parameters in an engine whose characteristics have been well defined The end product is the development of real time sensors or systems that can track the stall/surge margin and give indication when limits are to be exceeded.

This task will systematically analyze engine induced nacelle fires, as noted in SDR and NTSB reports of accidents or incidents. Evaluation of current engine nacelle and fire detection and fire suppression systems shall be included. In conjunction with the study and evaluation of the equipment characteristics, the adequacy of the nacelle fire detection and fire suppression systems performance in flight, relative to false alarm, will be of prime importance. Past records, particularly SDR's, indicate that there are considerable in-flight false-fire warning indications which are caused by faulty systems. These false warnings result in unscheduled engine shut-downs, which present potential safety hazards along with increased aircraft logistics problems. The results of these evaluations, analysis, and later tests will be published in reports to aid in the definition of practical criteria that can be considered for incorporation into FAR airworthiness requirements.

4.1.4 Installation Fire Protection.

Examination of the Service Difficulty Reports reveals a considerable number of instances where unscheduled shutdown of engine, precautionary shutdown, air turn back, or aborted takeoff has occurred as a result of propulsion installation system false warning. These data will be analyzed statistically to separate the most frequent single cause, and whether a relationship exists between other factors such as engine time, number of operational cycles, etc. Based upon this information, experimentation will be collected during these experiments to indicate means of improving the detection schemes.

4.2 Piston Engines.

4.2.1 Vapor Lock Investigations.

Currently, certain low pressure ratio engines are approved by FAA for operation using automotive fuel instead of aviation grad fuel. Automotive fuel, by design, contains considerable more variability than aviation gasoline. The petroleum industry blends automotive fuel to be responsive to both area and climate. Investigations will be made to determine if serious hazards and problems are involved in the substitution of auto gas (also known as motor gasoline) in aircraft piston engines in lieu of aviation gasoline. A survey was made of the current state-of-the-art tehcnology of gasoline to determine what significant differences exist between autogas and 80/87 and/or 100LL aviation gasoline. The following questions will be addressed. Information from this survey forms the basis for investigations addressing the following efforts:

a. How critical is volatility?

b. What are the signficant additive differences?

c. Can the different methods in determining octane rating be correlated?

d. Is there a compatibility problem when autogas is burned and the engine continues to use aviation motor oil?

e. How consistent is the production of auto gas across the country?

f. How critical is the water absorption problem?

g. Is the autogas compatible with aircraft fuel systems/materials?

One of the elemental fuel properties that are seen to vary is the fuel vapor pressure, automotive fuel having a higher vapor pressure than aviation gasoline. Another is that automotive fuel has a higher propensity for water. The FAA needs to expand its technical knowledge and understanding of the characteristics and properties of the various fuel available in the marketplace. Experimentation will baseline engines and aircraft fuel systems using a developed standard fuel and then with incrementally imposed changes of the properties of interest.

It is expected that pressures and requests will be made of the FAA to approve the use of the automotive fuel in aircraft engines of increasing pressure ratio, an action that will aggravate tendencies to malfunction. FAA will maintain an on-going investigation in this area to assure minimal impact airworthiness.

4.2.2 Alternative Fuels

This area of investigations is closely allied with the previous discussions concerning vapor lock, and utilize the analyses done under the section on Advanced Cycles. For some time, there has been interest on the part of the general aviation industry to develop means to be able to use turbine-type fuel. The obvious reason being one of economics. It is also known that there are thermodynamic approaches, such as the use of a stratified charge combustion chamber that will function on turbine (or kerosene) fuels. Investigations will be carried out, mostly under contract, to encourage the full development of such engines. The benefits to the public would, of course, be economics; to the FAA, however, a potential would exist for reduction or elimination of the crash fire instasnce, since use of the antimist additive would then apply to general aviation piston type accidents as well as the commercial turbine cases.

4.2.3 Cooling Investigations.

This area of investigation is also closely aligned with the investigations regarding the use of automotive fuel rather than aviation gasoline. One of the concerns about the use of automotive fuel is that of potentially harmful detonation occurring. Such detonation can be aggravated by improper or poor cooling characteristics. It is the intent of this effort to conduct analyses and experimentation to determine those characteristics of installation cooling that both mitigate and aggravate such undesirable operations as detonation.

4.2.4 Installation Fire Protection.

Current FAA regulations do not require detection or extinguishment requirements for piston engine aircraft, only that such occurrence of engine installation fire be contained in the enigne compartment. That such engine compartment fires have occurred is readily documentable. In a certain number of cases such fires have not always been contained to the engine compartment. The intent of this investigation will be to examine whether reliable, simple, economical, and practical means exist to detect such a power plant caused fire and if so, to evaluate the proper procedures and methods of control and/or extinguishment.

4.3 Program Schedule and Program Management.

The program schedule for propulsion functional systems and components is outlined in Figure 1, Major Milestones. The program management will be set forth in Section 4.

4.4 Funding Requirements.

The propulsion functional systems and component development program funding requirements are:

FY	1984	1985	1986	1987	1988	1989	1990	1991
TOTAL (0000)	80	495	870	750	280	185	100	20

*Actuals

The funding estimates for the purchase and/or lease of major equipment items such as large engines, nacelles, fuel systems, air frames, etc. Funding to purchase or lease such equipment will be requested as future priorities to justify their need.

FIGURE 4

FUNCTIONAL SYSTEMS MILESTONE SCHEDULE								
CATEGORY	FY-84	FY-85	FY-86	FY-87	FY-88	FY-89	FY-90	FY-91
TURBINE ENGINES								
° Advanced Control System				▽				
° Power Management Technique Effectivity						▽		
° Stability Investigations						▽		
° Installation Fire Protection Investigations					▽			
PISTON ENGINES								
° Vapor Lock Investigations			▽					
° Alternative Fuels					▽			
° Installation Cooling Investigations						▽		
° Installation Fire Protection Investigations								▽

FIGURE 5

FUNCTIONAL SYSTEMS MILESTONE SCHEDULE								
CATEGORY	FY-84	FY-85	FY-86	FY-87	FY-88	FY-89	FY-90	FY-91
AIRCRAFT GAS TURBINES								
° Mechanical Reliability	290	510	625	1000	250	130	100	20
° Aero/Thermo Reliability	150	1500	3150	2150	420	---	---	---
° State-of-the-Art Technology Investigations	---	210	250	225	200	10	---	---
AIRCRAFT PISTON ENGINES								
° Mechanical Reliability	10	125	100	30	---	---	---	---
° Aero/Thermo Reliability	30	105	40	---	---	---	---	---
° State-of-the-Art Technology Investigations	15	70	120	275	375	155	60	40
FUNCTIONAL SYSTEMS								
° Turbine Engines	20	305	675	495	160	110	---	---
° Piston Engines	60	190	195	250	120	75	100	20

5.0 PROGRAM COORDINATION.

Program coordination with all participants and elements involved in the planning and execution of this Engineering and Development Program Plan involves identification of both technical and support requirements and personnel, allocation of resources and facilities, initiation and coordination of interagency and international agreements, integration of related efforts with other agency programs, and continuation of dialogue with all civil operating and industrial entities and their representatives to insure that the Program Plan is relevant to current and projected needs. Coordination with industry, NASA, FAA Headquarters, Regions, etc., of program directions, revisions, and results will be a continuing effort.

6.0 REFERENCES.

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4. FAA Engineering and Development Major Program Plan, 1982-1981, May 20, 1982.