STATEMENT OF WORK

INTRODUCTION

Concern for a potential shortage of petroleum-derived fuels has led to a broad study effort within the NASA Office of Aeronautics and Space Technology to review energy trends and to evaluate the possibilities for alternate aircraft fuels. Liquid hydrogen is one candidate among the possible alternate fuels. Assuming that it can be manufactured and distributed at an acceptable price, and especially interesting for long range aircraft; however, there are obvious questions related to airworthiness, safety, flight and ground operations, and economic viability. To provide guidance for technology programs required for the airplane, the NASA OAST is performing studies and design studies in-house for both subsonic and supersonic transport aircraft and is implementing contract studies with the aircraft industry.

The study outlined in this Statement of Work will provide: (1) an evaluation of the feasibility and advantages of utilizing hydrogen fuel in subsonic transport aircraft conceived for introduction in the next ten years; (2) an evaluation of the technology associated with the aircraft.
STATEMENT OF WORK

STUDY OF THE APPLICATION OF HYDROGEN FUEL TO LONG-RANGE SUBSONIC TRANSPORT AIRCRAFT

1.0 INTRODUCTION

Concern for a potential short-supply of petroleum-derived fuels has led to a broad study effort within the NASA Office of Aeronautics and Space Technology to review energy trends and to evaluate the possibilities for alternate aircraft fuels. Liquid hydrogen is one candidate among the possible alternate fuels. Assuming that it can be manufactured and distributed at an acceptable cost, liquid hydrogen is especially interesting for large aircraft; however, there are obvious questions related to airframe design, the propulsion system, structural materials, flight and ground operations, and operating costs. To provide guidance for technology programs required for the airframe, the NASA OAST is performing systems and design studies in-house for both subsonic and supersonic transport aircraft and is implementing contract studies with the aircraft industry.

The study outlined in this Statement of Work will provide: (1) an assessment of the feasibility and advantages of utilizing hydrogen fuel for long-range subsonic transport aircraft conceived for introduction to service in the 1990-1995 time period; (2) an assessment of the problems and technology requirements peculiar to hydrogen-fueled subsonic aircraft; and (3) identification of actions to be taken (theory, laboratory studies, flight research, etc.) in order to accelerate development of the required aircraft technology. Consideration of the technology associated with the
manufacture, ground storage, and ground distribution of hydrogen fuel is outside the scope of this study.

2.0 SCOPE

The contractor shall conduct the necessary engineering investigation, analyses, and design studies to evaluate the utilization of hydrogen fuel in long-range subsonic transport aircraft conceived for introduction to service in the 1990-1995 time period consistent with 3.0, Guidelines, and in accordance with the tasks described in 4.0, Contractor Tasks.

3.0 GUIDELINES

The hydrogen-fueled and reference transport aircraft to be studied shall be consistent with the constraints of the following guidelines:

3.1 Mission Ground Rules

3.1.1 Payloads

An aircraft shall be designed for transport of approximately 250,000 pounds of cargo having an average density of 10 pounds per cubic foot for each of the mission ranges of Section 3.1.2.

An aircraft shall be designed for transport of approximately 400 passengers in combination with realistic airline cargo capacity and passenger accommodations (e.g., galleys and lavatories) for each of the mission ranges of Section 3.1.2.

3.1.2 Range

The mission ranges shall be 3000 and at least 5000 nautical miles.
3.1.3 Speed

The design cruise Mach number shall be selected between the limits of 0.8 to 0.95.

3.2 Design Criteria and Certification

In general, the aircraft studied shall satisfy the requirements for type certification in the transport category under FAR Part 25 and be capable of operating under the pertinent FAA rules.

3.3 Technologies

In addition to the use of a hydrogen-fueled propulsion system, conceptual design advances in technology in other disciplinary areas judged to be available, as well as advantageous, for a 1990-1995 aircraft shall be utilized. It is expected that these will include supercritical aerodynamics; advanced structural concepts and advanced materials, such as filamentary graphite epoxy; active controls for load control, flutter suppression, and relaxed static stability; and advanced secondary systems. The reference aircraft referred to in Section 4 shall utilize the same levels of advanced technologies as the hydrogen-fueled aircraft.

3.4 Environmental Conditions

The goal for the area of the 90 EPNdB noise contour is two square statute miles during approach and takeoff. This noise goal may be obtained through a combination of sound suppression at the engines and nacelles and other design and operational factors. For the passenger-mission aircraft, the interior noise levels shall be within the limits of passenger comfort and shall not exceed the levels existing in current subsonic aircraft.
The goals for engine emissions are as follows: at engine ground idle, carbon monoxide and unburned total hydrocarbons shall not exceed 14 and 2 grams/kg fuel burned, respectively, and at takeoff with full power, oxides of nitrogen shall not exceed 13 grams/kg fuel burned and the Smoke number shall not exceed 25.

3.5 Operations

3.5.1 Runway Length

The aircraft shall be designed to take off and land on an 8000-foot length runway at the gross weights corresponding to the mission ground rules of Section 3.1, for a 90-degree Fahrenheit day at 1000 feet airport altitude.

3.5.2 Terminal-Area Compatibility

Studies have been made for the DOT to predict the Air Traffic Control System required in the 1990's. In an NASA Contract (NASI-12018), a study is being made of means to ensure that the aircraft can be responsive to the advanced form and capability of the future ATC system. The NASA will provide the results of this latter study as they become available. The results of these studies shall be utilized in determining the design features that will make the hydrogen-fueled and reference aircraft compatible with projected future operational procedures and with the ATC system in the terminal area.

3.5.3 Airport Facilities

3.5.3.1 Ground Handling

The aircraft shall be designed so that the equivalent single wheel loads, the turn radii, and passenger and cargo loading and unloading operations and equipment are compatible with domestic and international facilities expected for the 1990-1995 time period.
3.5.3.2 Hydrogen Fuel

The existence at the airport of ground storage and distribution facilities for hydrogen fuel and an adequate supply of fuel shall be assumed.

3.5.4 Safety, Reliability, and Maintenance

Safety, reliability, and maintenance aspects of advances in technology in the areas of aerodynamics, structures and materials, flight controls and avionics, hydrocarbon-fueled propulsion systems, and secondary systems have been assessed in other studies (NASA CR-112088, 112089, 112090, 112091, 112092, 112093, 112242, and 132268). In this study, particular attention shall be given the safety, reliability, and maintenance aspects of the hydrogen-fuel systems and the interactions of the hydrogen-fuel systems with the previously mentioned advanced technologies. No attention shall be given the hydrogen-fuel ground storage and distribution system except for the safety aspects associated with loading and possible unloading of aircraft fuel.

3.6 Direct Operating Cost

The 1967 ATA equations using a labor rate of $5.00, domestic crew cost constant of 160, international crew cost constant of 180, appropriate fuel costs, and a 15-year depreciation period with zero residual value shall be used. Costs will be expressed in January 1, 1973, dollars and distance in nautical miles. Aircraft price levels will be based on a production run of 350 aircraft for each of the four missions.
4.0 CONTRACTOR TASKS

4.1 Introduction

The contractor shall perform studies to define the characteristics of hydrogen-fueled subsonic transport aircraft consistent with 2.0, Scope, and 3.0, Guidelines. If in the course of these studies, the contractor identifies guidelines and tasks in addition to those described herein that would contribute strongly to the value of the studies, he shall bring these to the attention of the Contracting Officer. Throughout the technical studies, the contractor shall perform trade-off studies and analyses necessary to define two conceptual cargo-mission aircraft and two conceptual passenger/cargo-mission aircraft which will operate within the guidelines. The four aircraft shall be designed to satisfy the payloads of Section 3.1.1, the range of Section 3.1.2, and the design cruise Mach number of Section 3.1.3. The contractor shall submit to the Contracting Officer his rationale for selection of the design cruise Mach number.

4.2 Aircraft and Systems Definition

4.2.1 Hydrogen-Fueled Aircraft

The contractor shall define advanced-technology hydrogen-fueled aircraft configurations and systems to meet each of the cargo missions and each of the passenger/cargo missions of Section 3.1 in a safe and economically efficient manner. Conceptual design studies shall be made to the depth necessary to indicate both the technical and economic feasibility of liquid hydrogen-fueled transport aircraft. The contractor shall use ingenuity and innovation in these conceptual design studies. A detailed design of a hydrogen-fueled engine is not expected but rather engineering judgment and experience shall be used to estimate the pertinent engine characteristics. Because of unique features associated with the use of hydrogen fuel, some
aircraft characteristics may tend to conflict with existing Federal Air Regulations and in these instances, changes in regulations that appear to be needed shall be identified and described. At least the following aspects of aircraft and systems shall be evaluated:

(1) Airframe configuration design concepts (including, at least, unconventional arrangements for which the fuel is remotely located from the payload).

(2) Airframe structural design concepts.

(3) LH₂ tankage design concepts.

(4) LH₂ insulation requirements and design concepts.

(5) On-board fuel system (e.g., pumping, pressure and flow regulation).

(6) Unique problems due to LH₂ (e.g., temperature-cycling effects on structural fatigue).

(7) Interaction of aircraft with LH₂ ground storage and handling procedures.

(8) Propulsion system-airframe integration.

(9) Interaction of aircraft with ground-support equipment.

(10) Landing-gear type and integration with airframe (e.g., the possible advantages of utilizing ACLS).

(11) Production and maintenance costs.

(12) Safety (e.g., safety aspects involved with tank-compartment inert purge system during flight and ground service, as well as special fuel system protection that may be required for crash conditions).
(13) Possible feasible changes in hydrogen fuel reserves requirements because of the advanced technologies projected for the 1990-1995 period.

4.2.2 Reference Aircraft

Advanced-technology hydrocarbon-fueled (JP fuel) aircraft capable of performing the four specified missions of Section 3.1 shall be designed to the depth necessary to provide reasonable comparisons with the advanced-technology hydrogen-fueled aircraft.

4.2.3 Design Approval

The design and characteristics of all hydrogen-fueled and reference aircraft, along with the rationale for the selection of these designs, shall be submitted to the Contracting Officer for approval prior to the benefits evaluation.

4.3 Benefits Evaluation

4.3.1 Economics

Economic benefits will be obtained by comparing the direct operating costs of the advanced-technology hydrogen-fueled aircraft with the direct operating costs of advanced-technology hydrocarbon-fueled aircraft designed to perform the same missions. Included in the DOC comparison shall be an evaluation of possible differences in utilization and maintenance between the hydrogen-fueled and hydrocarbon-fueled aircraft. The sensitivity of the direct operating cost to fuel cost and to maintenance cost shall be established for both the advanced-technology hydrogen-fueled aircraft and the advanced-technology hydrocarbon-fueled aircraft.
4.3.2 Environmental

Comparisons shall be made of the noise footprints defined in Section 3.4 for the advanced-technology hydrogen-fueled aircraft with the noise footprints resulting from advanced-technology hydrocarbon-fueled transports designed to perform the same missions. Estimates shall be made of the chemical emissions expected from the advanced-technology hydrogen-fueled aircraft and comparisons made with advanced-technology hydrocarbon-fueled transports designed to perform the same missions.

4.3.3 Energy Consumption

Comparisons shall be made of the energy (in terms of BTU/ton mile or BTU/seat mile) and fuel (in terms of gallons/ton mile or gallons/seat mile) consumed by the advanced-technology hydrogen-fueled aircraft in performance of their design missions with the energy and fuel consumed by advanced-technology hydrocarbon-fueled transports performing the same missions. In addition, the effect of design cruise Mach number on energy and fuel consumption shall be determined for the advanced-technology hydrogen-fueled aircraft.

4.4 Research and Technology Requirements

4.4.1 Problem Area Identification

The contractor shall identify critical or long lead-time technology advances required for hydrogen-fueled transport aircraft.

4.4.2 R&T Program Recommendations

The contractor shall recommend specific research and technology activities including any necessary flight validation required
to resolve the problems associated with hydrogen-fueled transport aircraft as identified in Section 4.4.1. Preliminary cost estimates and schedules for all recommended activities shall be prepared.

4.5 Parametric Evaluation of Passenger Transport Payload

The contractor shall, in addition to the evaluations and comparisons identified in the preceding parts of Section 4.0, evaluate parametrically the effect on the hydrogen-fueled aircraft configuration and R&T requirements of an increase in passenger payload to 600 and to 800 passengers (for each mission range of Section 3.1.2).