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RICH BURN COMBUSTOR TECHNOLOGY AT PRATT & WHITNEY

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NEAR TERM OBJECTIVES

The stringent NO_X emissions constraints necessary to produce an environmentally acceptable High Speed Civil Transport aircraft dictate the use of advanced combustor concepts that will require substantial technology acquisition and integration to produce a viable configuration. Under their joint HSCT Program Pratt & Whitney and General Electric have agreed to initiate this process through parallel technology acquisition and verification activities with Pratt & Whitney concentrating on rich burn combustor concepts while General Electric focuses their efforts on lean burning methods. The parallel approach permits critical evaluation of both concepts to the depth necessary to make a conclusive selection of the preferred concept after which Pratt & Whitney and General Electric will concentrate on the joint evolution of a single flightworthy and environmentally acceptable combustor based on the selected concept. This downselect between rich and lean burning approach is scheduled to occur late in CY1992 and has led to definition of the near term objectives listed on Figure 1. The intent of this presentation is to demonstrate how these timely objectives will be accomplished in a manner that is also consistent with the initiation of the larger effort that would be required to achieve technical viability of a rich burn combustor for the HSCT.

BY LATE 1992:

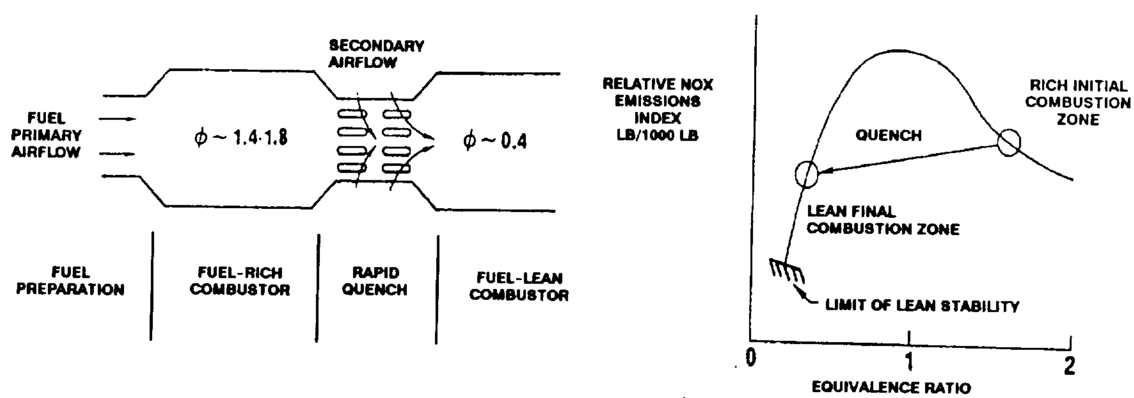
- **VERIFY THE EMISSIONS REDUCTION CAPABILITY OF RICH BURN COMBUSTOR CONCEPTS AT HSCT SUPERSONIC CRUISE CONDITIONS WITH GOAL OF ACHIEVING A CRUISE NO_X EMISSIONS INDEX OF 3 TO 8 GM/KG.**

- **ASSURE THAT THERE ARE NO FUNDAMENTAL LIMITATIONS OR TECHNOLOGY BARRIERS THAT WOULD PRECLUDE SUCCESSFUL EVOLUTION OF A FLIGHTWORTHY COMBUSTOR BASED ON RICH BURN CONCEPTS**

Figure 1

RICH BURN QUICK QUENCH COMBUSTOR

The Rich Burn Quick Quench (RBQQ) or Rich-Quench - Lean (RQL) combustor is the primary rich burn concept. As shown on Figure 2, all of the fuel is consumed initially in a rich combustor zone. This zone is deficient in oxygen - operating at an equivalence ratio in the range of 1.5 to 2.0. The deficiency of oxygen inhibits thermal NO_X production but the ensuing combustion products include incompletely reacted species - particularly carbon monoxide and carbonaceous particulates (smoke). Additional air is introduced into the combustor in the quench section providing the necessary oxygen to complete the combustion process. As shown in the process diagram of Figure 2 the quench air introduction must be effective to minimize NO_X production and the second phase of combustion in the lean zone occurs at temperatures dictated by combustor exit temperatures. Experience with the RBQQ combustor concept is based on potential industrial power generation engine applications which involved cylindrical or can type combustors utilizing heavier fuels from diverse feedstocks and at combustor inlet and discharge temperature levels substantially lower than those anticipated in an HSCT engine at supersonic cruise.



EXPERIENCE BASE

CONTRACTED PROGRAMS ADDRESSING CAN TYPE COMBUSTORS IN INDUSTRIAL ENGINES USING HEAVIER FUELS

Figure 2

RBQQ CRITICAL TECHNOLOGY AREAS

As enumerated in the list of Figure 3 there are five critical technology areas that must be addressed to produce a viable RBQQ combustor for the High Speed Civil Transport engine application. The experience base with experimental versions of this combustor concept is inconsistent with the HSCT application and must be extended and verified in that environment. Operation on aviation fuels and the demand for compact systems in a flight engine require definition of more relevant and aggressive design and sizing criteria. The necessity for a rapid and effective mixing process in the quench zone has been emphasized in the discussion of Figure 2. Sustaining rich oxygen deficient combustion in the rich zone dictates unique thermal/structural constraints on the liner enclosing this zone because cooling air may not be discharged into the gaspath. Fuel/air mixture preparation may have a significant role in optimizing the emissions characteristics of the rich zone because mixture uniformity could minimize smoke formation in this zone and allow more effective management of NO_X formation. Finally the operational flexibility requirements of a flight engine must be considered and is expected to lead to the need for variable geometry air admission components to provide efficient performance over the entire flight envelope.

The remainder of this presentation describes the efforts being conducted at Pratt & Whitney to address these five critical rich burn combustor technology areas. Particular emphasis in place on technology acquisition in preparation for the downselect process and in forming the nucleus of a longer range program.

- RBQQ VERIFICATION AND DESIGN / SIZING CRITERIA
- QUENCH ZONE MIXING
- NONEFFUSIVE COOLED RICH ZONE LINER
- FUEL-AIR MIXTURE PREPARATION
- VARIABLE GEOMETRY AIR ADMISSION

Figure 3

CYLINDRICAL RBQQ COMBUSTOR RIG

The cylindrical Rich Burner Quick Quench Combustor rig will be the major test vehicle used in the near term effort to verify the emissions reduction potential of the rich burn concept, define relevant design criteria and establish the direction for subcomponent refinement. The rig has been designed on the basis of prior experience with experimental rich burn can type combustors for industrial engine application. The inlet air to the rig will be preheated electrically to temperatures as high as 1400°F to simulate supersonic cruise of the HSCT engine and inlet total pressures in excess of 200 psia are attainable. As shown on Figure 4, the air supply system is designed to allow variable flow split between the rich combustion zone and the quench section. Gaseous emissions and particulate concentrations are measured at the combustor exit and at the end of the rich combustion zone. Additional diagnostic instrumentation will include traversing probes to establish mixture uniformity immediately downstream of the quench air admission section, gaspath pressure measurement and heat flux sensors in the wall of the rich and lean combustion zones.

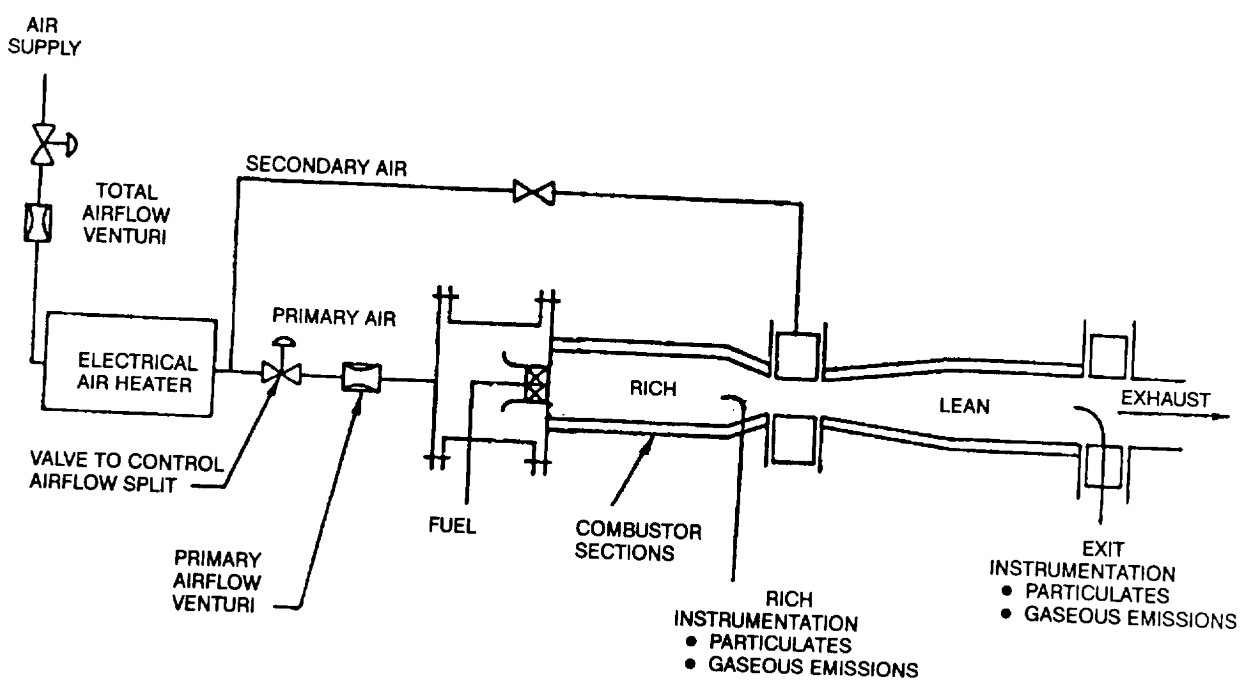


Figure 4

MODULAR RBQQ COMBUSTOR

Figure 5 shows details of the construction of the combustor section proper of the cylindrical RBQQ combustor rig. Emphasis in the design has been on flexibility of the configuration. The basic construction elements are flanged cylindrical and conical pipe sections. The noneffusive cooling requirement is achieved by externally cooling with a water jacket while casting a thick ceramic wall inside the section to permit high gaspath surface temperatures. The cylindrical sections of the rich and lean zone have been fabricated in several lengths and are interchangeable or used in series to vary residence time. The rich zone air admission and fuel injection system are installed in the inlet plenum and may be mounted on or replace the front bulkhead that separates this plenum from the combustion zone proper. The initial configuration of the rig incorporates a quench section with eight canted air inlet slots in a reduced diameter gaspath section. This quench air admission section and its adjacent conical transition pieces may be replaced with alternate components to produce different quench section configurations.

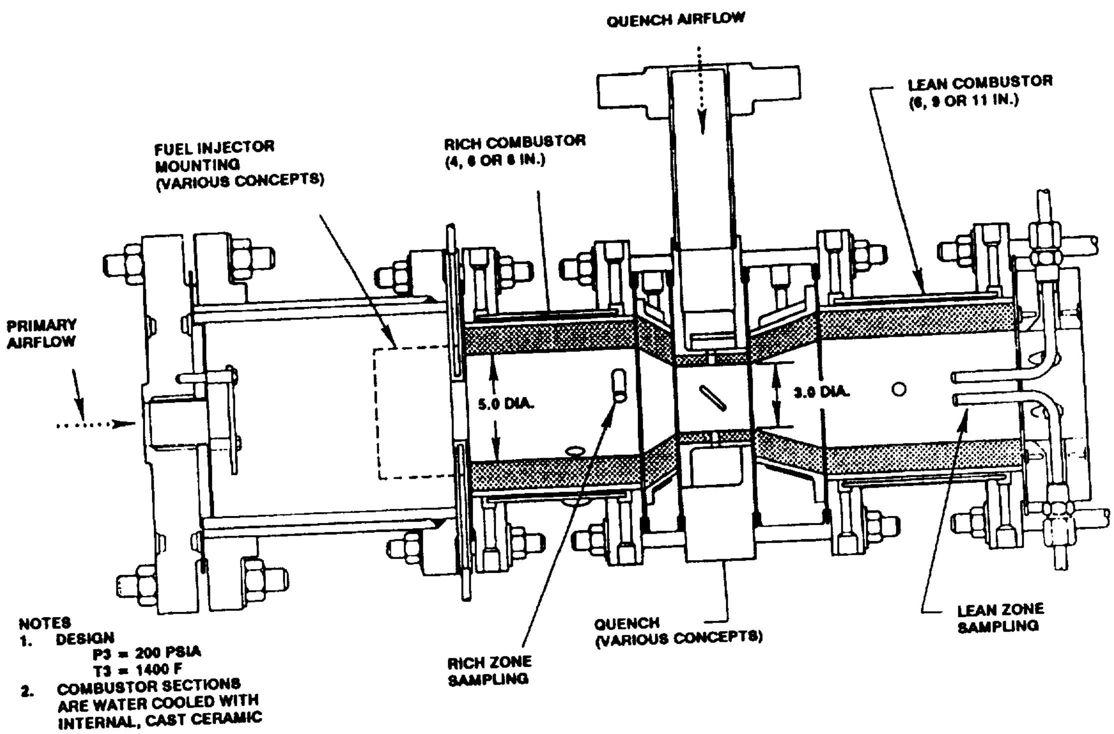


Figure 5

CYLINDRICAL RIG OBJECTIVES

The cylindrical RBQQ combustor rig is being used to accomplish several near term program objectives and to establish the direction for longer range component refinement. The table of Figure 6 lists the objectives of the activity on this rig through CY1992. The test program is being initiated with parametric evaluation of the effect of combustor inlet and operating conditions on the emissions characteristics of the RBQQ combustor concept. These will be used to verify the NO_X reduction capability of the combustor and to generate the data base for trade and optimization studies. Systematic variations of zone airloading and length will be used to optimize residence time effects and to generate corresponding stage sizing criteria. The cylindrical combustor rig will also be used for evaluating the sensitivity of the RBQQ combustor concepts to subcomponent performance. Exploiting the flexibility incorporated in its design several different rich zone fuel/air admission concepts using both single and multi-distributed sources are being designed for evaluation. Similar systematic variations in the configuration of the quench zone are also anticipated.

- VERIFICATION OF NO_X REDUCTION CAPABILITY OF THE RBQQ AT HSCT SUPERSONIC CRUISE CONDITIONS
- GENERATE DATABASE FOR OPTIMIZATION AND SENSITIVITY STUDIES AT HSCT ENGINE CONDITIONS
- GENERATE DESIGN CRITERIA FOR ZONE SIZING AND LOADING, RICH ZONE HEAT LOADS AND LEAKAGE TOLERANCE
- ESTABLISH SENSITIVITY TO SUBCOMPONENT PERFORMANCE
  - FUEL INJECTION AND RICH ZONE MIXTURE PREPARATION
  - QUENCH ZONE MIXING EFFECTIVENESS

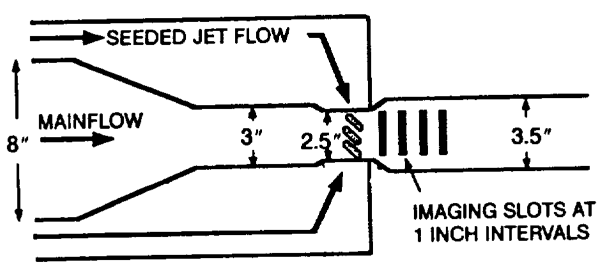
Figure 6

QUENCH ZONE MIXING

The mixing process occurring in the quench zone is critical to the operation of the RBQQ combustor. Rapid and thorough mixing must be achieved to avoid generating excessive NO_X during the quench process. An independent task is being conducted to screen and evaluate mixing concepts for the quench zone and optimize their performance. The experimental approach involves nonintrusive measurement of the flow structure in nonreacting mixing processes. As shown on Figure 7 one of the participating streams is seeded with an oil aerosol and Mie scattering in a laser illuminated plane is measured and processed through planer digital imaging to provide instantaneous distributions of the seed concentration from which the progress of the mixing processes is evaluated quantitatively. An extensive series of cylindrical mixer configurations of the type shown on the figure have been evaluated and led to the definition of an optimum mixer geometry for the previously described cylindrical combustor rig. The quench zone mixing investigation has been subsequently redirected to an apparatus with a rectangular gaspath to explore mixing approaches that will be more compatible with the annular combustor configuration anticipated in the product engine.

OBJECTIVE
EVOLVE CONCEPTS THAT EXPLOIT FLUID DYNAMIC INSTABILITIES AND SCALE EFFECTS TO ACHIEVE RAPID AND COMPLETE MIXING

APPROACH
USE PLANAR DIGITAL IMAGING OF MIE SCATTERING TO QUANTITATIVELY EVALUATE MIXING PROCESSES



TYPICAL IMAGE

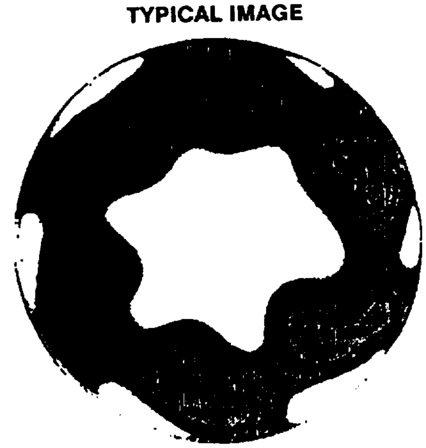


Figure 7

NONEFFUSIVE COOLED LINER

The requirements for a noneffusive cooled liner for the rich zone fo the RBQQ combustor will required a new liner material having thermal and structural properties beyond those of state of the art metallic or monolithic ceramics. The Enabling Propulsion Materials program has been established with the objective of defining and optimizing this material for use in either a rich or lean burning HSCT engine combustor. As shown by the schedule of Figure 8 this program has the milestone of producing a substantiated advanced material liner for verification testing in a demonstrator engine under the High Speed Research program in the 1998 time period.

Pratt & Whitney has also initiated studies of the requirements and constraints on the liner for the rich zone of the RBQQ combustor. As shown on Figure 8, these thermal and structural design studies are directed at three near term program objectives: providing definition of boundary conditions for tl.e Enabling Propulsion Materials program; generating a design base for interim liner constructions for combustor rigs that will be operated under future elements fo the High Speed Research program and in conjunction with the initial output from the Enabling Propulsion Materials program provide technical data to support the combustor concept downselect process in late 1992.

1991-92 OBJECTIVES

- **DEFINE BOUNDARY CONDITIONS FOR ENABLING PROPULSION MATERIALS PROGRAM**
- **DEFINE AN INTERIM RICH ZONE LINER CONSTRUCTION FOR TEST RIGS**
- **PROVIDE TECHNICAL BASIS FOR VIABILITY POSITION FOR THE COMBUSTOR CONCEPT DOWNSELECT IN LATE 1992**

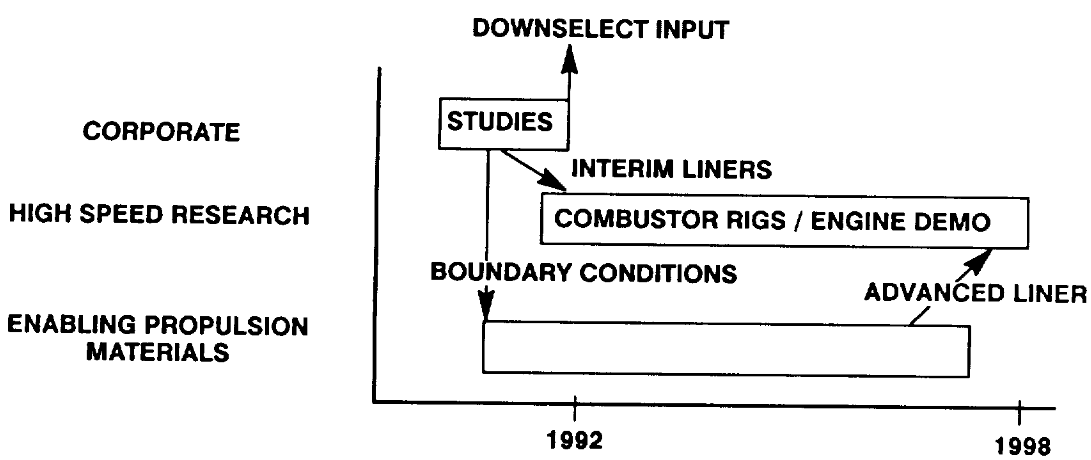


Figure 8

VARIABLE GEOMETRY REQUIREMENTS

The majority of the initial effort on the HSCT combustor concepts will concentrate on the optimization of the configuration and stochiometry to minimize NO_X emissions at the supersonic cruise flight condition. However, acceptable performance, emissions and operability over the remainder of the flight envelope must be assured and variable geometry air admission components are expected to be required to achieve this capability. Figure 9 shows an air control mode for the RBQQ combustor that requires variable air admission on the inlet to the rich combustion zone. The rich zone equivalence ratio schedule of that figure satisfies engine cycle requirements in that the high equivalence ratios conducive to minimum NO_X production is maintained at high fuel air ratios; an equivalence ratio near unity is achieved at ground idle to minimize carbon monoxide and unburned hydrocarbon emissions and adequate lean stability is retained. This equivalence ratio schedule is shown to be achieved with only a moderate variation in rich zone airloading at high fuel air ratios.

While the definition of variable geometry airflow components and their actuation mechanisms would be deferred to a later phase of the High Speed Research program after the combustor downselect, initial evaluation of performance or emissions sensitivities to airflow shifts could be conducted in the cylindrical combustor rig. The airflow shifts would be simulated in sequential tests with interchangeable components sized to represent the extreme areas of the airflow apertures.

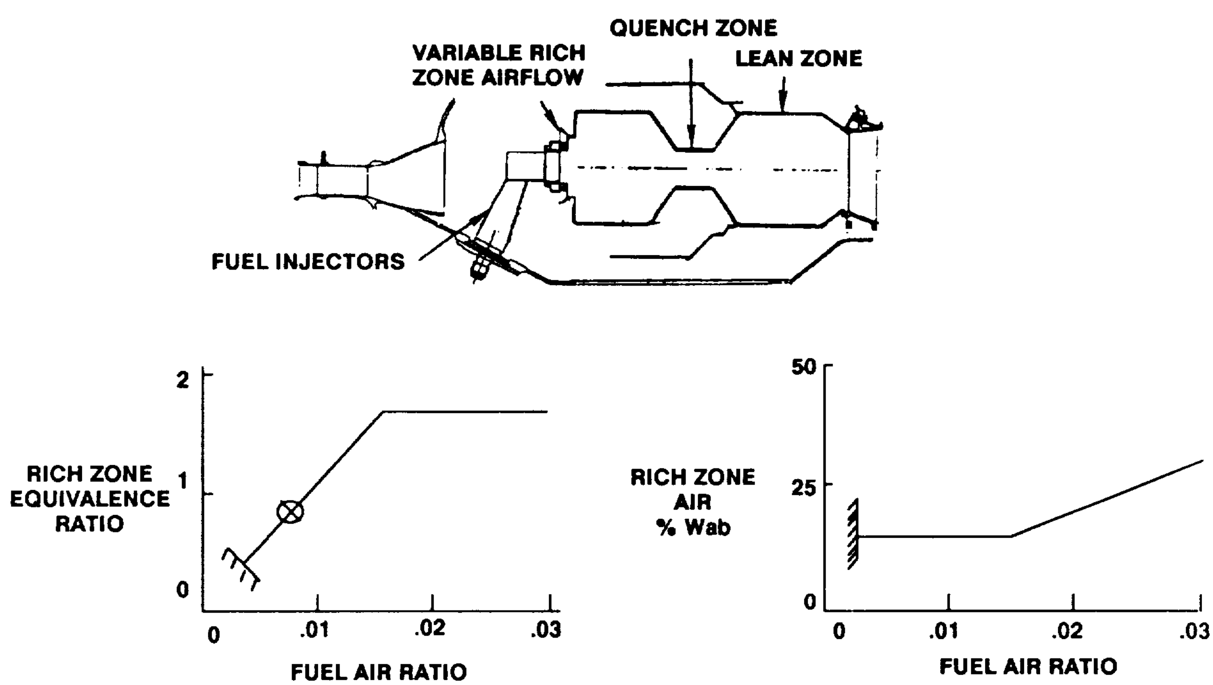


Figure 9

SECTOR COMBUSTOR RIG

While the initial evaluation and technology acquisition on the Rich Burn Quick Quench combustor concept will be conducted on the cylindrical combustor, the HSCT engine combustor is expected to be on annular configuration. To provide an assessment of the RBQQ combustor in a better simulation of an annular combustor geometry a sector combustion rig such as that shown on Figure 10 will be incorporated in the program. The design of this rig and its aerothermal details will be based on the experience derived in the previously described technology acquisition tasks. Zone sizing and rich zone fuel/air admission module configurations will be based on criteria developed from data acquired with the cylindrical combustor rig and the quench air admission system will have been optimized in the rectangular quench zone mixing evolution task. The sector combustor rig is expected to be operational in late 1992 to provide further concept verification prior to the downselect decision.

INITIAL CONFIGURATION FOR EVALUATION IN LATE 1992 BASED ON INPUT FROM THE FUNDAMENTAL TECHNOLOGY TASKS

PROVIDE DEMONSTRATION IN SIMULATED ANNULAR BURNER WITH MULTIPLE FUEL / AIR ADMISSION MODULES

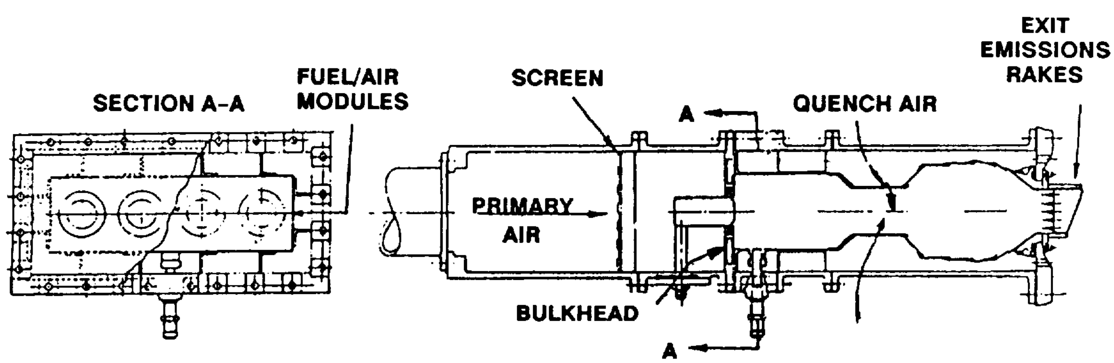


Figure 10

CONCLUSIONS

The near term program to evaluate rich burn combustor concepts for application to the High Speed Civil Transport engine will meet the intended program schedule and objectives. The fundamental technology tasks outlined will provide the necessary substantiation of the Rich Burn Quick Quench combustor concept for the downselect process. These tasks will also establish the direction for additional technology acquisition and combustor component refinement if this concept is selected. The test procedures and experimental apparatus developed and constructed under these initial tasks will be available for subsequent combustor component refinement efforts in the later phases of the High Speed Research program.

- **NEAR TERM TECHNOLOGY ACQUISITION EFFORTS WILL PROVIDE SUBSTANTIATION OF THE POTENTIAL FOR RICH BURN COMBUSTOR CONCEPTS IN THE DOWNSELECT PROCESS.**
- **DIRECTION FOR SUBSEQUENT REFINEMENT OF RICH BURN COMBUSTOR WILL BE ESTABLISHED**
- **TEST PROCEDURES AND APPARATUS FROM NEAR TERM TASKS AVAILABLE FOR SUBSEQUENT COMPONENT REFINEMENT**

Figure 11

Session VII. Emission Reduction

Low NOx Combustor Design
Dr. Hukam Mongia, Allison

PAPER UNAVAILABLE AT TIME OF PUBLICATION

Session VII. Emission Reduction

Low NOx Mixing Research
Professor Scott Samuelson, University of California-Irvine

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This publication is in four volumes and represents the compilation of papers presented at the First Annual High-Speed Research Workshop held in Williamsburg, Virginia, on May 14-16, 1991. This NASA-sponsored workshop provided a national forum for presenting and discussing important technology issues related to the definition of an economically viable, and environmentally compatible High-Speed Civil Transport. The Workshop and this publication are organized into 13 sessions, with Session 1 presenting NASA and Industry overviews of the High-Speed Civil Transport Program. The remaining sessions are developed around the technical components of NASA's Phase I High-Speed Research Program, which addresses the environmental issues of atmospheric emissions, community noise and sonic boom. Because of the criticality of the materials and structures technology area, and the long-term nature of the supporting research requirements, a session was added in this area to capture the ongoing work at NASA Lewis and NASA Langley and within industry.

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